A DETECTION OF BRIGHT FEATURES IN THE MICROWAVE BACKGROUND

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ABSTRACT

We report the characterization of bright, compact features in the cosmic microwave background radiation (CMBR) detected during the 1992 June and 1994 June balloon flights of the Medium-Scale Anisotropy Measurement. Spectral flux density is determined at 5.7, 9.3, and 16.5 cm$^{-1}$. No viable counterparts are found in source catalogs at 5 GHz or at 100 µm. The measured spectrum is consistent with a temperature fluctuation in the CMBR. The existence of such features is consistent with adiabatic fluctuation models of anisotropy in the CMBR.

Subject headings: cosmic microwave background — cosmology: observations

1. INTRODUCTION

Recent observations of the cosmic microwave background radiation (CMBR) have found statistically significant anisotropy at 0.5 angular scales (see White, Scott, & Silk 1994, and references therein). In earlier Letters (Cheng et al. 1994, hereafter Paper I; Cheng et al. 1996, hereafter Paper II), we reported on observations of CMBR anisotropy that included two particularly bright features. The presence of bright, unresolved sources suggested the possibility of foreground point-source contamination, or of non-Gaussian fluctuations in the CMBR. Here we present our analysis of these features and a discussion of other work studying their properties.

2. INSTRUMENT AND OBSERVATIONS

The Medium-Scale Anisotropy Measurement (MSAM) instrument has been described in detail elsewhere (Fixsen et al. 1996); only the most relevant features are given here. MSAM is a balloon-borne off-axis Cassegrain telescope with a nutating secondary mirror and a four-band bolometric radiometer. The detectors have center frequencies of 5.7, 9.3, 16.5, and 22.6 cm$^{-1}$ each with ~1.5 cm$^{-1}$ bandwidth. The beam size of the telescope is 28 FWHM, roughly independent of frequency. The secondary executes a horizontal four-position square-wave chop (i.e., center, left, center, right) with an amplitude of ±40' on the sky. The telescope is pointed using a combination of torque motors and reaction wheels referenced to a gyroscope. The absolute sky location is determined by star camera observation.

The data discussed here were collected during two flights of the MSAM instrument from Palestine, Texas: the first on 1992 June 5 (MSAM1-92) and the second on 1994 June 2 (MSAM1-94). These observations have been described in Papers I and II and are only summarized here. In each flight, the antenna patterns for all four bands were measured by rastering over Jupiter. We determine the location of the antenna pattern within the star camera's field of view to within 2 (postflight) by simultaneously observing Jupiter in the star camera and the main telescope. Gyroscope drift increases our absolute pointing uncertainty to ±2.5. We calibrate our spectral flux density measurements using the measured surface temperatures (Griffin et al. 1986) together with Jupiter's apparent diameter at the epoch of flight (Hagen & Boksenberg 1991; Donat & Boksenberg 1993). The calibration has a 10% overall uncertainty, with relative calibration errors of up to 4% between bands (see Griffin et al. 1986).

The CMBR observations were made at roughly constant declination δ ≈ 82°, with the central beam covering right ascensions 14h4'–16h9' and 17h2'–20h3' during the MSAM1-92 flight. This corresponds to ~6.6 deg$^2$ of sky coverage. The goal of the MSAM1-94 flight was to observe the identical field that MSAM1-92 had. This was nearly achieved, with an average declination difference of ~10'. The coverage in right ascension was somewhat less, extending from 15°0–17°0 and from 17°3–20°0. Except for § 5, all results reported here are based on the MSAM1-92 observations.

3. DATA ANALYSIS

The initial data reduction used in this analysis has been reported in Papers I and II; only the salient features are reviewed here. Note that this paper is based on the reanalyzed version of the MSAM1-92 data including the full instrument covariance matrix (Inman et al. 1997). Two nearly statistically independent demodulations are formed from the data. The single-difference demodulation subtracts the right beam from the left beam and ignores the central beam data, while the double-difference demodulation subtracts the average of the left + right beams from the central beam. The single-difference demodulation has an antisymmetric two-lobe response pattern, while the double-difference demodulation has a symmetric three-lobe pattern. The data are binned by position and angular orientation of the demodulated antenna pattern on the sky. To remove instrumental drift, a slowly varying function of time is fit simultaneously with the bins. The bin size is 0.12 in position and 10° in angular orientation.

3.1. Foreground Dust Subtraction

Foreground emission from interstellar dust is the dominant confusion source for CMBR observations at our frequency bands (Weiss 1980; Bennett et al. 1992). We estimate and subtract the contribution of foreground interstellar...
dust emission using the 22.6 cm$^{-1}$ band, assuming a dust spectrum of $\nu^\beta B_\nu(T_D = 20$ K), with nominal $\beta = 1.5$. In making this correction, we assume that the 22.6 cm$^{-1}$ band is an uncontaminated monitor of dust. The field of sky we report on can be roughly divided into a lower dust portion and a higher dust portion, with the brighter dust emission occurring at right ascensions $\alpha \geq 19^h$.0.

To test for systematic sensitivity to details of the dust model, we varied the spectral index of the model, $\beta$, from 1.3 to 2.0. In the low-dust portion of the field, the dust subtraction is a small correction, and the results are relatively insensitive over the range of spectral index tested. In the high-dust portion, however, there is some dependence on $\beta$ in the 9.3 cm$^{-1}$ band. As will be discussed, detections in this portion of the flight are confused as a result of uncertainty in the foreground dust model.

### 3.2. Search for Unresolved Features

After subtracting the estimated dust contamination, we search the remaining three frequency bands for unresolved features using an $F$ statistic to measure significance. Each band is searched independently, and then the source lists are compared. Since the telescope is scanned at roughly constant declination, we parameterize the location of the features as a function only of right ascension and constrain the central declination of the feature to follow a slow linear function of right ascension.

We begin by calculating the raw $\chi^2$ of the data in each band,

$$\chi^2 = \sum_{ij} (t_i - O_j)V_{ij}^{-1}(t_j - O_j),$$

where $t_i$ are the binned data with associated noise covariance $V_{ij}$, and the sum is over both demodulations as well as bins. $O_i$ is one of four arbitrary offset parameters corresponding to the two demodulations and two portions of the flight, appropriate to datum $i$. Then, as a function of right ascension $\alpha$, we find the flux density $S(\alpha)$ that minimizes

$$\chi^2(\alpha) = \sum_{ij} \left[ (t_i - O_j - S(\alpha)B(\alpha))V_{ij}^{-1}\right. \left. (t_j - O_j - S(\alpha)B(\alpha)) \right],$$

where $B(\alpha)$ is the value of the beam map (single or double difference, as appropriate) centered on observation point $i$, evaluated at right ascension $\alpha$. The significance of the fitted flux density is determined by forming the statistic, $F = (\chi^2_0 - \chi^2)/\chi^2/N$ where $N$ is the number of degrees of freedom remaining in the data after fitting out the source. This statistic should be distributed according to an $F$ distribution with 1 and $N$ degrees of freedom (Martin 1971), which allows us to calculate the cumulative probability $P(F)$ of drawing a value greater than or equal to $F$ if the null hypothesis—that the actual value $S(\alpha) = 0$—were true. Values of $F \gg 1$ are highly unlikely under the null hypothesis and correspond to significant detections of compact features in the data. Figure 1 shows $F(\alpha)$ and $P(F)$ for each of the three frequency bands, calculated here assuming a dust spectral index $\beta = 1.5$.

Since we are plotting the cumulative probability of the null hypothesis being true, lower values of $P(F)$ correspond to more significant detections. We have multiple-lobe beam patterns, so a bright unresolved feature will alias to several values of right ascension separated by the 40$'$ beam throw. Thus, the clusters of peaks near 15$^h$ and 19$^h$ do not correspond to multiple features, but rather the aliasing of a single feature into the side beams.

We build a list of candidate unresolved features for each band by iteratively searching for and subtracting the most significant feature, defined here as the maximum value of $F(\alpha)$. After each feature is subtracted, $S(\alpha)$ and $F(\alpha)$ are reevaluated to help suppress the aliasing in right ascension. We continue this procedure until $F_{\text{max}} \leq 11$, corresponding to $P(F) > 10^{-3}$. This process was repeated for four values of the dust spectral index $\beta$: 1.3, 1.5, 1.7, and 2.0, the results of which are listed in Table 1. Up to three candidate features were identified this way for the 5.7 and 9.3 cm$^{-1}$ bands. No features were found at 16.5 cm$^{-1}$ that satisfy the $P(F) < 10^{-3}$ requirement for any of the values of $\beta$ tested.

As can be seen in Table 1, the detections in the low-dust region, near 15$^h$, are fairly insensitive to the dust model spectral index, $\beta$. The situation is more complicated in the high-dust region around 19$^h$. At 5.7 cm$^{-1}$, the detection at 19$^h$29 is stable, while a third feature appears at 19$^h$92 for the larger values of $\beta$. Results at 9.3 cm$^{-1}$ are even less clear; for low values of $\beta$ (corresponding to a larger dust-model subtraction), a negative-flux feature appears near 18$^h$77; at $\beta = 2$ this is replaced by two positive-flux features that approximately correspond to the two features seen at 5.7 cm$^{-1}$ at high $\beta$. While it is likely that some part of the signal seen in this region is due to CMBR anisotropy, our limited knowledge about the submillimeter spectrum of interstellar dust makes it impossible to unambiguously identify compact features here. We will therefore concentrate on the detection near 15$^h$ in what follows.

### 3.3. Spatial Extent

To determine the spatial extent of the feature, we fit the data to a Gaussian-shaped surface brightness model, $I_\nu e^{-((\alpha - \alpha_0)^2 + \beta^2)/(2\sigma^2)}$, with the central brightness $I_\nu$, right ascen-
sion $\alpha$, and width $\sigma = \theta_{\text{FWHM}}/[2(2\ln2)^{1/2}]$ as free parameters. The fits are performed using the Levenberg-Marquardt method (Press et al. 1992). The total flux density of the feature is related to the central brightness by $S_r = 2\pi\sigma^2 I_s$.

The fits near $15^h$ indicate a somewhat resolved feature in both the 5.7 and 9.3 cm$^{-1}$ bands, with $\theta_{\text{FWHM}} \approx 35^\circ$. The results of these fits are given in Table 2. There are substantial correlations between $\theta_{\text{FWHM}}$ and $I_s$, so these are also listed. From $I_s$, we can also infer an equivalent peak variance. These are also listed in Table 2. From we can also infer an equivalent peak variance. These are also listed in Table 2.

4. SPECTRAL MODELS FOR FEATURE

We now compare the measured spectrum of the feature with four simple models for astrophysical sources: CMBR anisotropy, free-free emission with $I_s \propto \nu^{-0.8}$, and cold dust emission with $I_s \propto \nu^{2.1}$, synchrotron emission with $I_s \propto \nu^{-0.8}$, and cold dust emission with $I_s \propto \nu^{2.1} \times [B_\nu(4.8 \text{ K}) - B_4(T_{\text{CMBR}})]$. The last of these is motivated by the possible detection of a cold dust contribution to the Galactic spectrum observed by the COBE/FIRAS experiment (Wright et al. 1991; Reach et al. 1995). Each of the models is fit to the values listed in Table 2, the results of which are displayed in Figure 2. The $\chi^2$ for the spectral fits are 0.2/2, 2.3/2, 1.1/2, and 37/2 for the CMBR, free-free, synchrotron, and cold dust models, respectively. The relative calibration uncertainty is small compared to the statistical uncertainties and is not included in the $\chi^2$ values.

The feature is in agreement with the CMBR model and significantly discrepant with a cold dust spectrum. From these data alone, either free-free or synchrotron emission gives an acceptable fit and could explain the detection. This would, however, require implausibly large amplitudes for emission at lower frequencies. For example, the best-fit free-free spectrum, extrapolated to 40 GHz ($Q$ band), implies an antenna temperature of 3.4 mK for the feature; measurements made at Saskatoon of the same field strongly rule out such bright signals (Netterfield et al. 1997). The limits on synchrotron emission are even stronger, since the extrapolated temperatures are roughly 3 times greater. Recent meas-

| TABLE 1 |
| Candidate Unresolved Features |
| --- |
| DUST SPECTRAL INDEX | BAND 1 (5.7 cm$^{-1}$) | BAND 2 (9.3 cm$^{-1}$) |
| | R.A.$^a$ | $F$ | $P(F)$ | $S_r$ | R.A.$^a$ | $F$ | $P(F)$ | $S_r$ |
| (hr) | (Jy) | (l) | (Jy) | (Jy) | (hr) | (Jy) | (l) | (Jy) |
| 1.3 ………. | 14.97 | 67 | $1.8 \times 10^{-15}$ | $+5.6 \pm 0.7$ | 19.29 | 25 | $5.9 \times 10^{-7}$ | $+5.3 \pm 1.1$ |
| 1.5 ………. | 14.97 | 65 | $3.4 \times 10^{-15}$ | $+5.6 \pm 0.6$ | 19.29 | 26 | $3.5 \times 10^{-7}$ | $+5.2 \pm 1.0$ |
| 1.7 ………. | 14.97 | 64 | $6.7 \times 10^{-15}$ | $+5.5 \pm 0.6$ | 19.29 | 27 | $2.6 \times 10^{-7}$ | $+5.1 \pm 1.0$ |
| 2.0 ………. | 14.97 | 62 | $1.6 \times 10^{-14}$ | $+5.5 \pm 0.6$ | 19.29 | 27 | $2.4 \times 10^{-7}$ | $+4.9 \pm 0.9$ |

* J1992.5 coordinates.

34. Limits at 16.5 cm$^{-1}$

While there are no bright features detected at 16.5 cm$^{-1}$, we can find limits for the corresponding feature found at lower frequencies. We fit using our extended model, fixing $\alpha = 14^h95$ and $\theta_{\text{FWHM}} = 35^\circ$. The results are consistent with zero flux, and upper bounds can be inferred from the variance. These are also listed in Table 2.

4. SPECTRAL MODELS FOR FEATURE

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| TABLE 2 |
| Fit Results at 15$^h$ |
| Parameter | Fit Result | Correlations |
| --- | --- | --- |
| $\alpha$ | $14^h96 \pm 00^2$ | $\theta_{\text{FWHM}}$ |
| $\theta_{\text{FWHM}}$ | $36^\circ \pm 8^\circ$ | $-0.35$ |
| $I_{5.7}$ | $161 \pm 24 \text{kJy sr}^{-1}$ | $0.21$ $-0.68$ |

| 9.3 cm$^{-1}$ ($\chi^2 = 585/627$) |
| $\alpha$ | $14^h95 \pm 00^3$ | $\theta_{\text{FWHM}}$ |
| $\theta_{\text{FWHM}}$ | $34^\circ \pm 13^\circ$ | $-0.31$ |
| $I_{9.3}$ | $142 \pm 40 \text{kJy sr}^{-1}$ | $0.20$ $-0.73$ |

| 16.5 cm$^{-1}$ ($\chi^2 = 533/629$) |
| $I_{16.5}$ | $+4 \pm 90 \text{kJy sr}^{-1}$ | $\ldots$ $\ldots$ |

Note.—Errors shown are statistical. The pointing uncertainty adds an additional 00/2 error.

Fig. 2.—Measured spectra for the feature at $14^h95$. Horizontal bars show the effective width of each band. Superimposed are the best-fit curves for a CMBR anisotropy spectrum (solid), free-free (dashed), synchrotron emission (dot-dashed), and cold dust (triple-dot-dashed).
measurements of Hα emission in this part of the sky imply the free-free contribution to the MSAM1 signal at 5.7 cm$^{-1}$ is less than 500 Jy sr$^{-1}$ rms (Simonetti, Topasna, & Dennison 1996), several orders of magnitude smaller than the signal we report.

5. SEARCHES FOR COUNTERPARTS

5.1. Catalog Searches

We consider the possibility that the detection corresponds to a compact radio (or infrared) point source. Note that the power-law models corresponding to free-free and synchrotron also can be interpreted as flat-spectrum or steep-spectrum radio spectra, respectively, typical of extragalactic radio sources. No counterpart for the feature was found within one beamwidth of the feature location in the 5 GHz S5 Polar Cap Survey (Kihur et al. 1981). The best-fit flat spectrum predicts 5 GHz flux greater than 3 Jy, while the best-fit steep spectrum predicts flux greater than 40 Jy. The S5 survey is estimated to be complete at 5 GHz down to 250 mJy, providing a strong limit on any flat- or steep-spectrum radio counterpart to the detection.

A similar search was performed with the IRAS 100 μm Faint Source Catalog (Moshir et al. 1992). One object was found within one beamwidth of the feature: IRAS source F15048 + 8205, located at 15°03' + 81.89', with S$_n = 1.4$ Jy at 100 μm. This is consistent with the average IRAS FSC source density of ~ 4 deg$^{-2}$. The contribution of this source to the MSAM signal is expected to be negligible based on the 1.25 mm to 100 μm flux ratio, (3.1 ± 0.5) × 10$^{-3}$, determined from a complete sample of IRAS galaxies, together with a relatively flat ν$^3$ spectrum locally around 1.25 mm (Franceschini & Andreani 1995). The greatest contribution is at 16.5 cm$^{-1}$, where it is estimated to be ~ 50 mJy. The contribution at 9.3 cm$^{-1}$ is a factor of 5 smaller than this, while at 5.7 cm$^{-1}$ it is a factor of 30 smaller. These estimates are reinforced with direct observations at 90 GHz of known IRAS sources in the vicinity of the 15h feature, none of which show significant flux density above the rms noise of 25–50 mJy (Chernin & Scott 1995).

5.2. MSAM1-94

In 1994, we flew the MSAM instrument a second time to observe the same field as the 1992 flight. While the sky overlap between MSAM1-94 and MSAM1-92 was not perfect, it was sufficient to permit an overall comparison of the measurements (Inman et al. 1997). We have repeated the fits of § 3.3 on the MSAM1-94 data to see if the bright feature is present. Near 15h, there is a corresponding hot spot at $\alpha = 14^h28^m 53^s 00.03$ with $\theta_{FWHM} = 38^s 12'; I_{S,7} = 106 \pm 32$ Jy sr$^{-1}$, and $I_{S,3} = 71 \pm 62$ Jy sr$^{-1}$ (statistical errors only). The somewhat different flux densities in MSAM1-94 are consistent with the pointing differences between the two flights.

5.3. Other Observations

Since the initial report of these detections in Paper I, a number of groups have searched one or more of these regions for corresponding sources at different wavelengths and/or resolutions. Of particular note is the search reported by Church et al. (1995) using the Caltech Submillimeter Observatory on Mauna Kea. This search, which made a deep map of the sky around the 15h feature at 4.7 cm$^{-1}$ using a 1.7 beam, places an upper limit on any point source in that field of $S_{4.7} < 1$ Jy.

Another observation of this field has recently been reported by Netterfield et al. (1997). These observations were made from the ground at Saskatoon, Saskatchewan, Canada, in the Q band (36–46 GHz, 1.2–1.5 cm$^{-1}$) at 0.5 resolution. A portion of them were designed to reproduce, as closely as possible, the MSAM observations. A three-lobe beam, similar to the MSAM double-difference demodulation, was synthesized (the single-difference demodulation is not usable from the ground because of atmospheric noise). Although having somewhat less statistical weight than the MSAM observations, the Saskatoon results correlate well with MSAM, including the bright feature near 15h right ascension.

6. SIMULATIONS

The presence of bright, compact features in the MSAM1-92 data was unexpected. In Paper I, we questioned whether CMBR fluctuations obeying Gaussian statistics could produce such features. To address this issue, we have performed a detailed Monte Carlo simulation of the MSAM observations.

The approach used is similar to that outlined in § 4.3 of Paper I. We generate numerical realizations of the observations, including contributions from instrument noise and CMBR temperature anisotropies, assuming the anisotropy is a Gaussian random field described by a two-point correlation function, $C(\theta)$. In Paper I, we set limits on the overall amplitude of $\Delta T/T = [C(0)]^{1/2}$ by using the likelihood ratio statistic $\lambda$; here we use those upper and lower bounds to generate realizations which are then searched according to the procedure of § 3.2 for unresolved features. Unlike Paper I, here we simulate both demodulations simultaneously, using $\theta_{0} = 0.4$. We thus determine the distribution of $n$, the number of unresolved features with $P(F) \leq 10^{-3}$, corresponding to the range of $\Delta T/T$ fluctuations found in the data. Our confirmed number of sources is $n = 1$; however, based on details of foreground dust, the number of features could be as high as $n = 5$ (see Table 1). For $\Delta T/T = 1 \times 10^{-5}$, we find the cumulative probability $P(n \geq 1) = 0.60$, $P(n \geq 3) = 0.04$, while for $\Delta T/T = 3 \times 10^{-5}$, $P(n \geq 1) = 0.99$, $P(n \geq 3) = 0.69$. From this we conclude that bright, compact features such as those observed are, in fact, consistent with our assumption of Gaussian statistics.

We have also studied the distribution of $n$ using a more physically motivated correlation function, calculated for "standard" flat cold dark matter (CDM) with $\Omega = 1$, $\Omega_b = 0.05$, $\Lambda = 0$, $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$, and no reionization (Sugiyama 1995). Using this model, normalized to the COBE/DMR detection $Q_{rms-ps} = 20 \mu K$ (Gorski et al. 1994), we find reasonable probabilities for the observed $n$: $P(n \geq 1) = 0.79$, $P(n \geq 3) = 0.15$. Thus, the detections are consistent with adiabatic fluctuation models such as CDM. Similar results have also been reported for a more generic study of 0.5 resolution CMBR maps (Kogut, Hinshaw, & Bennett 1995).

7. CONCLUSIONS

The feature detected near 15h is best described as a temperature anisotropy in the CMBR. While we were initially...
surprised to find bright, compact features in the data, we now understand that these are consistent with our assumption of Gaussian fluctuations. Although our catalog searches were all null, we find the most compelling argument that the feature is not a true point source comes from the direct search by Church et al. (1995). Finally, the morphological agreement reported by the Saskatoon experiment, consistent with a CMBR anisotropy spectrum spanning three octaves in frequency from the \( Q \) band (1.2 cm\(^{-1}\)) to the MSAM 9.3 cm\(^{-1}\) band, leaves little room for alternate explanations of the detection. Given the agreement with a CMBR temperature anisotropy spectrum, together with the implausibility of other explanations, we conclude that the feature is cosmological in origin.

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REFERENCES

Bennett, C. L., et al. 1992, ApJ, 396, L7
Cheng, E. S., et al. 1994, ApJ, 422, L37 (Paper I)
---. 1996, ApJ, 456, L71 (Paper II)
Chernin, L. M., & Scott, D. 1995, A&A, 296, 609
Church, S. E., Mauskopf, P. D., Ade, P. A. R., Devlin, M. J., Holzapfel, W. L., Wilbanks, T. M., & Lange, A. E. 1995, ApJ, 440, L33
Donat, W., III, & Boksenberg, A. 1993, The Astronomical Almanac for the Year 1994 (Washington and London: GPO and HMSO)
Fixsen, D. J., et al. 1996, ApJ, 470, 63
Franceschini, A., & Andreani, P. 1995, ApJ, 440, L5
Görliski, K. M., et al. 1994, ApJ, 430, L89
Griffin, M. J., Ade, P. A. R., Orton, G. S., Robson, E. I., Gear, W. K., Nolt, I. G., & Radostitz, J. V. 1986, Icarus, 65, 244
Hagen, J. B., & Boksenberg, A. 1991, The Astronomical Almanac for the Year 1992 (Washington and London: GPO and HMSO)
Inman, C. A., et al. 1997, ApJ, 478, L1

Kogut, A., Hinshaw, G., & Bennett, C. L. 1995, ApJ, 441, L5
Kühn, H., et al. 1981, AJ, 86, 854
Martin, B. R. 1971, Statistics for Physicists (London: Academic)
Moshir, M., et al. 1992, Explanatory Supplement to the IRAS Faint Source Survey (2d ed.; Pasadena: JPL)
Netterfield, C. B., Devlin, M. J., Jarosik, N., Page, L., & Wollack, E. J. 1997, ApJ, 474, 47
Press, W. H., Teukolsky, S. A., Vetterling, W. T., & Flannery, B. P. 1992, Numerical Recipes in FORTRAN: The Art of Scientific Computing (2d ed.; Cambridge: Cambridge Univ. Press)
Reach, W. T., et al. 1995, ApJ, 451, 188
Simonettii, J. H., Topasna, G. A., & Dennison, B. 1996, BAAS, 188, 12.01
Sugiyama, N. 1995, ApJS, 100, 281
Weiss, R. 1980, ARA&A, 18, 489
White, M., Scott, D., & Silk, J. 1994, ARA&A, 32, 319
Wright, E. L., et al. 1991, ApJ, 381, 200