July 6 2014

[redacted]

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NASA Headquarters
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REQUEST FOR CORRECTION(S) (RFC) Under NASA's Information Quality Guidelines

As an affected person, I am submitting a Request for Correction (RFC) under Section 515 of P.L. 106-553 and the National Aeronautics and Space Administration (NASA) Guidelines for Ensuring the Quality of Information.

THE INFORMATION THAT IS INVOLVED: The information at issue is contained in the second version of an obituary (obit2) for my late husband, Dr. William K. Rose (WKR); both were written by Dr. Virginia Trimble (VT), a former colleague. The obituary has two formats: one with an Appendix and another without but which incorporates the Appendix by reference, namely, "(see appendix)".

(a) Format1: Obit2 With An Appendix

From the end of 2011 until at least early February 2013, a membership organization, the American Astronomical Society (AAS) had a web page for obit2 which included the full text of obit2, an Appendix, a "Note" by the Editor of the Bulletin of the AAS (BAAS) – also the Executive Officer of the AAS -- and a link to WKR's 1992 letter to Dr. SB, science historian and former colleague. ATT 1 and/or http://aas.org/obituaries/william-k-rose-1935-2010 Last visited: July 3 2014

WKR's 1992 letter included "Figure 2," a block diagram of the system used for his physics Ph.D. research project in radio astronomy completed at the U.S. Naval Research Laboratory in 1962. [Please note the original AAS term for WKR's 1992 letter was "Reference" – not "External Link()."] ATT 2

The AAS has distributed obit2 around the globe from its own web sites for over two years. [Please note there is still a link to WKR's 1992 letter at the very bottom of the AAS web page for obit2 but, since at least 2/5/13, the letter "could not be found" on their website.] ATT 3

(b) Obituary Without An Appendix

As part of a program going back more than twenty years, the AAS has provided well over 500 obituaries (including obit2) to the Smithsonian Astrophysical Observatory (SAO)/"NASA Astrophysics Data System" ("NASA ADS" or "ADS.") It is not clear why the NASA ADS web pages for obit2 do not include the Appendix, the "Note from the Editor of the BAAS" or the "External Link()" to WKR's 1992 letter. NASA ADS also has distributed obit2 around the globe for over two years.

[Please also note that since at least February 2013, the link from obit2 on the NASA ADS web sites to the "Publisher's Article" (i.e. obit2 on the AAS website) has brought up a message that obit2 "could not be found.."] ATT 4

NASA ADS currently uses three formats for obit2 – the "Classic" format and two "Labs/Integrated Search" formats. [Please note that different search engines bring up different formats of obit2 on the NASA ADS web sites for "William K Rose" or "William Kenneth Rose" (e.g. a last check on 7/3/14 with Google Search showed a Labs format with a prominent NASA logo on the top right of obit2 ATT 5 whereas an AOL Search brought up the "classic" format without any NASA logo.]

HISTORY OF PRIOR ATTEMPTS TO CORRECT THE INFORMATION AT ISSUE

By e-mail, dated 2/20/2012, to the then-AAS President, I rebutted what arguably was the most serious error in the Appendix and requested "(s)ome way for me to add comments and corrections" or "(s)ome type of peer-review process":

> "(VT)wrote in paragraph 1 of the second obituary that (WKR) "observed…diffuse centimeter emission (see appendix). Yet in the Appendix itself, she appears to have raised doubt about what his equipment actually could have measured. The only stated reason for that doubt seems to be the issue of ground radiation -- an issue familiar to (WKR) and probably to everyone who worked with radio telescopes. In my own study of this matter, I read that the radiometer equation does not depend directly on antenna characteristics. Not surprisingly, not everyone agrees that a horn-shaped antenna would have been required to measure the 3K cosmic background radiation."

By e-mail to the same person, dated 4/4/12, I asked if anyone had come forward (after obit2 was posted online) with any evidence of misconduct by WKR. That question has not been answered to date.

By e-mail dated 4/6/12, the Executive Officer of the AAS stated that obit2 was the "final version of record." He did not address any of the substantive issues raised in my 2/20/12 rebuttal, supra.

On 5/15/12, I tried to correct obit2 on the NASA ADS web site but the corrections were in effect erased after I submitted them. When I objected, NASA ADS advised me that "SAO/NASA Astrophysics Data System…cannot alter or remove content without (the) explicit approval" of the AAS. " (e-mail, 5/21/12)

On 5/22/12, I looked for the administrator of NASA Grant # NNX09AB39G (printed at the bottom of the NASA ADS Home Page) and eventually was referred to the NASA Shared Services Center (NSSC) Help Desk. The NSSC staffer who opened the first Help Desk cases wrote, in part, that I was "upset because the (ADS) has information on (WKR) (his obituary) [*sic*] which has some incorrect information in it."

By e-mail dated 9/9/12 (sent 9/10/12) to the Staff Attorney for NASA NSSC I included the full text of my 2/20/12 rebuttal. I again urged the Staff Attorney to take obit2 offline on privacy grounds but suggested that NASA could play a role in resolving the issues in dispute:

> "Obviously, I would like to see AAS agree to change the wording in the Appendix - but who knows how long that could take. Maybe you or someone else from NASA could help with that also. In the meantime, however, I again urge you to do whatever you can to obtain compliance from the AAS and ADS so that all copies of the obituary and related material are removed from the Internet promptly pending further attempts to agree on the wording of the obituary."

By e-mail dated 9/12/12, to the next (now also former) President of the AAS, I offered to "prepare a list of misleading and/or unsubstantiated statements in the Appendix and see what we can agree on." I never received a response .

In six months of correspondence with NASA NSSC (May 2012 - November 2012) -- which included a FOIA Request followed by a FOIA Appeal – no one advised me that I could file a Request for Correction (RFC) with regard to obit2 under NASA's Information Quality Guidelines.

EFFECTS OF ERRORS

Obit2 creates the wrong impression about WKR and harms his reputation for excellence and integrity without due process of law.

The delay in resolving these issues adds to the original delay (due to WKR's prolonged disability, illness and death) in seeking a publisher for WKR's last manuscript (a fourth textbook) .

The dispute has harmed me as well since VT states in obit2 that I intended to look for a publisher for the manuscript but I am reluctant to do so until these matters are resolved. [Please note there are only a few publishers in the world of graduate-level astrophysics textbooks.]

There also has been a series of unusual and disturbing events in the past year, for example:

(a) Since at least July 2013, Google Books has shown the following snippet online for Astrophysics (WKR's first published textbook) which reads:

> "User Review - Flag as inappropriate. EINSTEIN NEILS B. MECANICA CUANTICA. PROYECTO GENOCIDIO, NARCOTRAFICO DE PRESIDENTES, DENUNCIA…"

Google also put the rest of the same "User Review" online for both Astrophysics and Advanced Stellar Astrophysics (WKR's third and last published textbook) -- even though (a) the "User Review" is not an actual review of either book and (b) I reported a "policy violation" numerous times (using Google's "Flag as inappropriate" link) and wrote to the FTC twice. (my e-mails, 7/24/13, 8/5/13) ATT 6

(b) In February 2014, I received two "spam" e-mails (purporting to come from two large U.S. law firms) with the following threats:

> 2/4/14: "…If the property is not timely vacated we will have to apply sanctions against you."
>
> 2/20/14: "…The premises you are currently occupying are to be vacated within the following two weeks. If you refuse to relocate (within two weeks) a forcible detainer lawsuit may be initiated to evict you and take your possessions." ATT 7

(c) On 3/14/14, more than 3000 screenshots and a very large number of web clips were effectively lost during what started as a routine update of the operating system of my iPad2. The web clips ('bookmarks' which were organized in folders and saved directly to the iPad Home Screen) have not been retrieved to date and a sample of screenshots could not be retrieved in a usable format. [Please note the iPad2 had been backed up daily to iCloud and there were several backups last fall to iTunes. Please note also that most of the missing material was collected between February 2012 (when I purchased the iPad2) and February 2014 and was related to the numerous issues raised in this case -- scientific, administrative and legal.]

REASON FOR THE RFC\

The proposed corrections are justified (necessary) because two NASA-sponsored organizations, NASA ADS and the AAS -- which meet OMB standards for "federal agency web sites" -- continue the online distribution of obit2 even though it does not meet "basic" Agency standards for information quality and obituaries are not listed as "Exempted NASA Information" (see NASA IQG/Ls C.3)

THE REQUEST FOR CORRECTION(S) (RFC)

I have restricted the focus of the RFC to two of NASA's "basic" standards of information quality: objectivity/accuracy (Section 1) and objectivity/bias (Section 2).

Each topic addressed has four (4) parts arranged in a mini-table: (a) the specific issue(s), (b) rebuttal, (c) references and (d) proposed corrections.

[Please note that the abbreviations para1, para2 etc. in the References column point to the corresponding paragraphs in obit2 or in its Appendix (on the AAS website.) Similarly, the initials in the Rebuttal column correspond to names in the Appendix and/or in the adjacent References column. The Attachments in support of my RFC are identified in the text of the RFC or in the References column.]

SECTION 1: OBJECTIVITY/ACCURACY

OBSERVED

Issue	Rebuttal	References	Proposed Correction
VT states in obit2 that WKR "observed … diffuse centimeter emission (see appendix)" but then implies in the Appendix that it would have been impossible for him to have done so.	It does not make much sense to assert that WKR made an observation and then conjecture that it would have been impossible for him to have done so.	Obit2, para1 Obit2, Appendix, para3	Please remove the phrase "(see appendix)" from para1 on all copies of obit2 on NASA ADS and AAS servers. Please link all NASA ADS and AAS copies of obit2 to this RFC..

MARYLAND POINT

In para3 of the Appendix, VT implies that WKR's maser-receiver was in fact installed on NRL's former 84-ft radio telescope in Maryland Point in "March 1962" during "testing." [*We may reasonably assume that VT used the term "antenna" to refer to this __single__ paraboloid radio telescope.*] (please see "Antenna Shape," infra)	VT referred to WKR's 1992 letter in para1, sec. (c) of the Appendix and evidently realized that his maser-receiver may __not__ have been installed on that radio telescope during "testing" in March 1962. [Please note that this is consistent with a 1962 NRL Observatory Report which states WKR's maser-receiver was "installed" on the radio telescope at Maryland Point in "June 1962."]	Obit2, Appendix, para3 Obit2, Appendix, para1, sec. (c) __The Astronomical Journal__ Vol. 66, No. 9 November 1962 Observatory Reports – U. S. Naval Research Laboratory - Programs (1961 - 1962), p. 678 ATT 8	Please remove para3 from all copies of the Appendix on AAS Servers.

ANTENNA SHAPE

Also in para3 of the Appendix, VT implies that the "antenna" used by WKR was not the same shape as the "antenna(s)" used by P&W and JVW.	(a) In WKR's thesis, the block diagram of his maser-receiver system ("Figure 2") shows two small horn antennas used with the 84-ft reflector: a "feed horn" and a "sky horn." (b) Also in his thesis, WKR wrote that he used "small horns" for calibration (testing) of the receiver: (c) Photographs of the antennas used by P&W and JVW show they were variations of horn antennas. Thus, it turns out that the antennas used by P&W, JVW and WKR were all variations of horn antennas. [Please see a diagram of the standard microwave (feed) horn antenna reportedly used at NRL during this period.] (d) That said, the radiometer/noise equation used by radio astronomers implies that antenna characteristics (such a shape) do not determine the "minimum detectable signal" that can be detected and measured by a particular receiver (i.e. a receiver's sensitivity.) (Please see the next table, "Ground Emissions")	WKR Ph.D. thesis, Measurements of the Linear Polarization of Discrete Radio Sources By Use of a 9.4 cm Maser, section VI, p. 19 and "Figure 2" P.J.E.P. et al, Finding the Big Bang , ibid, p. 160 (P&W Holmdel/horn-reflector antenna) ATT 9 P.J.E.P. et al, Finding the Big Bang, ibid, p. 282, (please see JVW, infra) ATT 10 William T. Slayton, NRL Report 4433: Design and Calibration of Microwave Antenna Gain Standards, 1954, p. 1, Fig. 1 ATT 11	Please remove para3 from all copies of the Appendix to obit2 on AAS servers.

GROUND EMISSION

Also in para3 of the Appendix, VT implies that the "antenna" used by WKR did not "exclude as much (ground emission) as possible."	What VT wrote amounts to a caveat. She does not present or offer evidence that ground emission per se made detection of the cosmic background radiation by WKR's maser-receiver system impossible. The radiometer/ noise equation which the co-authors of FBB included in their definition of "receivers" implies that receiver characteristics (such as bandwidth, $\Delta\upsilon$) -- not antenna characteristics (such as shape) -- determine ΔT which corresponds to the "minimum detectable signal" a particular receiver can be expected to detect and measure: $\Delta T = \frac{C_1 T_s}{\Delta t \Delta \upsilon}$ [Please note that C1 refers to a particular "switching" technique, Δt refers to the average time it takes to make a measurement and Ts (undefined in the definition) ordinarily refers to the total "noise" (Tsys, in ° K) generated by various parts of the overall system -- and includes "ground emission," sometimes called ground "noise."]	Obit2, Appendix, para3 P.J.E.P. et al, Finding the Big Bang supra, Glossary, "receivers," p. 526 ATT 12	Please remove para3 from all copies of the Appendix to obit2 on AAS servers.

DETECTION: "SENSITIVITY"

In para2 of the Appendix, VT wrote that it "seems" like the 9.4 cm maser-receiver used by WKR was sensitive enough to detect "diffuse emission."	The "sensitivity" figures VT assumed were "appropriate" for WKR's maser-receiver (0.1° K - 0.2° K) correspond to its so-called "r.m.s. output fluctuations values" (r.m.s. values) -- although VT did not identify them as such. Referring to WKR's maser-receiver, the 1961 NRL Observatory Report stated "(i)t is expected that (the) minimum detectable signal will be about 0.03° K" -- way below the current generally accepted value of the cosmic background radiation (2.73° K.) WKR's best measured sensitivity (r.m.s.) value (0.013° K) -- reported in NRL's 1962 Observatory Report as well as in his 1963 Ph.D. thesis -- and his reported "typical" sensitivity of his maser-receiver system (≅ 0.02° K) was considerably more sensitive than implied by VT.	The Astronomical Journal Vol. 66, No. 9 November 1961 Observatory Reports -- U. S. Naval Research Radio Astronomy Branch, Instrumentation (1960 - 1961), p. 486 ATT 13 The Astronomical Journal , 1962, supra (ATT 8)	Please change "The answers seem to be no, and yes" to "The answers to both scientific questions are yes." [Please see "Detection: 'Significance'" infra]

DETECTION: "SIGNIFICANCE"

Also in para2 of the Appendix, VT implies that the 9.4 cm maser-receiver system used by WKR was not sensitive enough to detect significant * diffuse emission." *[From the context, we may assume that VT uses the term "significant" to refer to statistical significance -- i.e. whether the maser-receiver was sensitive enough to make a reliable detection of the signal of interest.]*	(a) According to the National Radio Astronomy Observatory (NRAO), the minimum detectable astronomical signal needs to be only five times the sensitivity (r.m.s.) value of the system. (b) The Haystack formula for "sure" detection of the signal of interest multiplies the sensitivity (r.m.s.) value of the maser-receiver system (which is also its one-sigma value) by 10. Thus the product of either 5 x 0.2° K or 10 x 0.2° K implies that WKR's maser-receiver would have measured down reliably even below 2.73° K (the accepted value of the cosmic background radiation.) In his 1995 book 3K RBP gave three key reasons for the success of P&W's research. The first factor he listed was the "sensitivity of (P&W's) receiver " -- which was "more than ten times the statistical error in a single measurement." (emphasis added) This implies that P&W's "3.5 K signal" was more than ten times the r.m.s. (one sigma) value of their receiver.	Obit2, Appendix, para2 http://newsoffice.mit.edu/2012/explained-sigma-0209 or ATT 14 Last visited: July 6 2014 http://www.cv.nrao.edu/course/astr534/Radiometers.html page 6 of 16 (the paragraph after equation (3E3)) Last visited: July 6 2014 or ATT 15 http://www.haystack.edu/edu/undergrad/materials/tut6.html#6 Section 6.3.2, para3 or ATT 16 Last visited: July 6 2014 RBP 3K:The Cosmic Microwave Background Radiation Cambridge, England: Cambridge University Press, 1995, p. 48 ATT 17	Please change "The answers seem to be no, and yes" to "The answers to both scientific questions are yes." [Please see "Detection: 'Sensitivity'" supra]

RUMORS

In para1 of the Appendix, VT states she was "aware of rumors…for decades":	VT puts quotation marks around the rumors but does not support them with any references or written statements.	Obit2, Appendix, para1	Please remove the phrases "request from RA" and "nothing seen or reported" from the list of rumors -- or even all of the rumors (as I requested in my 11/12/11 e-mail to VT).]
(a). "request from RA"	RBP wrote in his 1995 book that RA and his colleagues looked in the "mid-1950s" -- not in 1962 -- for radio astronomers to help test their theories about how our universe began (emphasis added).	RBP, 3K supra, p.44, 3rd footnote ATT 17	
(b) (Referring to whether WKR had "looked" for the cosmic background radiation, VT wrote) "nothing (was) seen or reported." (emphasis added)	The corresponding phrase in obit1 was simply "(n)othing reported from this." [Please note that the obit1 wording is consistent with VT's 10/13/11 e-mail -- that she had asked "several senior radio astronomers" about this matter in 1994 and they reportedly "were pretty sure he had looked but not put anything in print, positive or negative."	VT, e-mail, 10/13/11	

JVW

In para2 of the Appendix, VT states that JVW made certain claims in FBB, pp. 280 -288, about a "field effect transistor receiver," "FET(s)" (i.e. field effect transistors) and "Dicke switching radiometers."	JVW did not make those claims in the pages cited and did not mention WKR at all. VT trivialized WKR's scientific/technological accomplishments by suggesting that what he did as a graduate student was not that difficult. [Please note that she also failed to mention the overall impact of masers on radio astronomy and on the space program.]	Obit2, Appendix, para2 P.J.E.P. et al, Finding the Big Bang supra, pp.280 - 288 (Section 4.10.1) JVW "The CMB - how to observe and not see" ATT 18	Please remove the sentence about JVW in para2 from all copies of the Appendix on AAS servers.

"THEY"

Also in para2 of the Appendix, VT wrote that JP (PJEP) – one of the three co-authors of FBB -- "informally confirmed" that "they were not aware of WKR's effort." (emphasis added)	In the "References" section of FBB (2009), the three co-authors list two references which specifically mention WKR in this regard -- including one reference from 2006 by VT about the cosmic background radiation which put WKR on a short list of "major players in these quarter-final games."	Obit2, Appendix, para2 FBB, supra, p. 556 (VT) ATT 19	Please remove the sentence about JP (PJEP) and "they" in para2 from all copies of the Appendix on AAS servers.

SECTION 2: OBJECTIVITY/BIAS

AAS

VT or the AAS removed her tribute to WKR (in the last paragraph of obit1) from obit2 . The tribute stated that WKR "definitely was" a "distinguished scientist." (emphasis added)	[Please note that WKR's Department's online notice refers to him as a "distinguished scientist."]	Obit2, last paragraph Obit1, last paragraph	Please restore the phrase "Rose definitely was" at the very end of obit2 on all NASA ADS and AAS servers.
VT omitted the fact from obit2 that WKR retired "Professor Emeritus."	I pointed out that omission from obit1. (my e-mail, 10/12/11) [Please note that the BAAS Editor's "Note" addressed the issue but his "Note" never was added to the NASA ADS web page for obit2 -- which has been the page most likely to be at or near the top of the regular search results for WKR.]	Obit1 Obit2 BAAS Editor's "Note" following the Appendix on the AAS web site	Please add the title "Professor Emeritus" to the first paragraph of obit2 on all NASA ADS and AAS servers.
VT characterized WKR's last published textbook, Advanced Stellar Astrophysics, as an "advanced undergraduate textbook" In that same "Note" supra, the BAAS Editor stated that Advanced Stellar Astrophysics "is marketed by the publisher as a graduate level textbook" (emphasis added)	VT and the BAAS Editor failed to acknowledge the publisher's judgment that Advanced Stellar Astrophysics is a "graduate-level textbook."	WKR, Advanced Stellar Astrophysics Cambridge, England: Cambridge University Press, 1999, back cover ATT 20	Please add the following footnote to obit2 on all NASA ADS and AAS servers: "Please note, that in the judgment of the Cambridge University Press, Advanced Stellar Astrophysics is a "graduate-level textbook."

NASA

For over two years, NASA has allowed NASA ADS and NASA ADS Labs/ Integrated Search to display the agency's insignia logo directly on the obit2 web page without any disclaimer.	The display of the NASA logo directly on obit2 implies that obit2 is an "official product" of NASA and even that the opinions in the Appendix represent the '"official position" or "view" of the Agency (NASA's terms) [Please note that I objected to the display of the NASA logo on obit2 in two e-mails to the NASA NSSC Staff Attorney in 2012.]	See ATT 4, supra My e-mails to the NSSC Staff Attorney , 9/9/12 (sent 9/10/12) and 10/22/12.	Please add a disclaimer to the NASA ADS "Classic" format and to all formats of NASA ADS "Labs/Integrated Search" web pages for obit 2.

CONCLUSION

It is still unclear how an almost-twenty-year-old-letter which VT apparently referred to as an "important…item" in obit1 (10/6/11) became a burning issue two months later presumably requiring its own dedicated Appendix. The AAS has disseminated an obit2 format with the Appendix for over two years. NASA ADS has disseminated an obit2 format without the Appendix, also for over two years -- but the NASA ADS format incorporates the Appendix by reference and used to link to the obit2 webpage with the Appendix on the AAS web site.

VT implied in the Appendix that it would have been impossible for WKR to detect the cosmic background radiation with the 84-ft reflector "antenna" she assumed he was using without any other antenna(s) during "testing" of his maser-receiver system.

My own study of the AAS format for obit2 (with the Appendix) found several unwarranted assumptions and even assumptions which are self-contradictory. Other assumptions are not consistent with the radio astronomy literature (including VT's own 2006 article on this subject) and some claims are misstated. That said, VT does not present or offer evidence that it would have been impossible for WKR's maser-receiver system to make the measurements he referred to in his 1992 letter. Indeed, the sensitivity VT assumed was "appropriate" for that system was more than enough for certain detection of signals with the generally accepted value of the cosmic background radiation -- and of even smaller or fainter signals.

Putting aside for the moment the questions of how and when VT and the AAS obtained copies of WKR's 1992 letter, VT's discussion of that letter, in my view, is neither objective nor unbiased. NASA, regrettably, has allowed the world-wide dissemination for over two years of a substantially flawed obituary for WKR without any disclaimer -- even though NASA ADS and the AAS were recipients of NASA and/or other federal grants during this period which made both organizations subject to information privacy/security and information quality standards as de facto "federal agency web sites."

Please do no hesitate to contact me if you have any questions. My preferred method of contact is e-mail.

Sincerely,

Sheila T Rose

Sheila T. Rose (Mrs. William K. Rose)

List of Attachments and Attachments

[redacted]

[redacted]

LIST OF ATTACHMENTS

ATT 1	Recent web pages for obit2 on the AAS web site (6/24/14)
ATT 2	Obit2 web pages on the AAS web site originally used the term "Reference()" for WKR's 1992 letter (1/17/12)
ATT 3	Recent message on AAS web site that WKR's 1992 letter "could not be found" (6/24/14)
ATT 4	Current message that obit2 "could not be found" on the AAS web site (by clicking the "Publisher's Article" link on the obit2 webpage on the NASA ADS web site) (7/3/14)
ATT 5	Current obit2 web page with a prominent NASA logo which was retrieved by a regular search engine from a NASA ADS web site (7/3/14)
ATT 6	Part of the Google Books' "User Review" at issue for Advanced Stellar Astrophysics (7/3/14)
ATT 7	"Spam" e-mail threatening a loss of "possessions" (2/10/14)
ATT 8	U.S. NRL Observatory Report in the 1962 Astronomical Journal which refers to the "installation" of WKR's maser-receiver system on their then-owned 84-ft Maryland Point radio telescope in "June 1962"
ATT 9	Photo of P&W's well-recognized horn-reflector antenna in FBB
ATT 10	Photo of JVW's horn antenna in FBB
ATT 11	Diagram of the U.S. NRL's standard microwave (gain) horn antenna used with their 50-ft and 84-ft reflector antennas
ATT 12	The radiometer equation included in the FBB Glossary definition of "receivers"
ATT 13	U.S. NRL Observatory Report in the 1961 Astronomical Journal which stated the "minimum detectable signal" for WKR's system was expected to be 0.03° K
ATT 14	A 'bell-curve' with an explanation of "sigma"
ATT 15	The NRAO formula for certain detection of radio astronomical signal(s) of interest
ATT 16	The Haystack formula for "sure detection" of radio astronomical signal(s) of interest
ATT 17	RBP credits P&W's receiver sensitivity as a key factor in their success
ATT 18	RBP states that RA and his colleagues looked for radio astronomy support in the "mid-1950s"
ATT 19	JVW's pages in FBB which VT cites in para2 of the Appendix
ATT 20	Page from the "References" section of FBB in which the co-authors of the book listed VT's 2006 article which mentions WKR with regard to the cosmic background radiation.
ATT 21	Cambridge University Press described WKR's Advanced Stellar Astrophysics as a "graduate level textbook"

AMERICAN ASTRONOMICAL SOCIETY
ADVOCATES FOR SCIENCE SINCE 1899

William K. Rose (1935 - 2010)

William Rose died on Thursday the 30th of September 2010.

Stellar astrophysicist William Kenneth Rose died near his home in Potomac, Maryland, on September 30, 2010, after an extended illness. Rose was the son of pharmacist Kenneth William Rose and Shirley Near Rose and was born in Ossining, New York, on August 10, 1935. He received an AB from Columbia College in 1957 and a PhD in physics from Columbia University in 1963, with a thesis on "measurements of linear polarization in discrete radio sources using a 9.4 cm maser," under the direction of Charles H. Townes. Rose played a major role in designing and constructing the maser and used it at a radio telescope at Maryland Point that belonged to the Naval Research Lab. He observed Jupiter and Saturn and a number of extra-solar-system sources, and also diffuse centimeter emission (see appendix). The thesis was not published in an archival journal, but can be found under Library of Congress code QB 475.R67.

While in graduate School, Bill married Sheila Tuchman, whose primary scientific interests were biological. None of their three children chose to be scientists, but two are CPAs. Bill moved successfully through the academic hurdles from a research position at Princeton (1963-67), where a collaboration with Nick Woolf and Martin Schwarzchild on the infrared spectra of giant stars became one of his most-cited papers, to assistant and associate professorships at MIT (1967-71), and then associate and full professorships at the University of Maryland (1971 to retirement in 2005). His most innovative work was probably that on nova explosions arising from degenerate ignition of hydrogen accreted on white dwarfs in close binary systems, published in 1968. The same idea occurred to others at about the same time, and Bill did not, perhaps, get quite his fair share of the credit.

I first met Sheila and Bill in summer 1969 at the Stony Brook summer school on stellar evolution (not published until 1972). He lectured on the nature of nova explosions and on nuclear burning in thin shells in stars and the instabilities in each. Almost equally memorable, when the Roses had to depart a few days before the end of the school, they left behind a perfectly magnificent cake for the students to share at the closing party. During the first year that I was a visiting assistant professor at the University of Maryland, Bill and I team-taught the very first of the astronomy program's courses designed to fulfill a new, junior-level breadth requirement. It was called "The Inconstant Universe." I did cosmology and he did high-energy astrophysics.

We were also two of the three authors of a short paper called "A low mass primary for Cygnus X-1?" It pointed out that, if the primary of HDE 226868 was a low-mass, hot, short-lived helium star (on which each of us had published previous papers) then the solution of the radial velocity orbit, which came only from the lines of the OB primary, could yield a companion mass small enough for the X-ray emitting component to be a neutron star rather than a black hole. Such a system would be intrinsically much fainter than one with an OB supergiant primary, and so must be much closer to us than a supergiant plus black hole system. Our prediction resulted in two serious observers rushing to telescopes to look for interstellar absorption features in the optical spectrum of HDE 226868. They found lines with the velocity signatures of two spiral arms, thus placing the system at a large distance, giving it high luminosity and large mass. It was and is a black hole. The paper had the distinction of being the only one either of us ever wrote that was accepted and typeset before the postcard arrived by seamail to announce its receipt.

Bill Rose lent his expertise to a wide range of topics, including models of X-ray and radio sources, magnetic fields, pulsar radiation mechanisms, formation of stars and black holes, and nucleosynthesis. Another much-cited paper, with Beatrice M. Tinsley, had a pun for its title: "Late stages of stellar evolution in the light of elliptical galaxies." The point was that the gE optical and IR emission is dominated by evolved stars, so that one can learn a good deal about the giants from integrated spectra and colors (and must get the stellar population right to understand the galaxies).

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Rose was a member of the International Astronomical Union and its Commission (34) on interstellar matter, though curiously not of 35, stellar constitution. He was also part of the American Astronomical Society, AAUP, and the Washington and New York Academies of Science. The Maryland astronomy program was, in its day, a very collegial one. It was Frank Kerr, one of the two founding members, who proposed both Bill Rose and me for membership in the Cosmos Club as persons distinguished in science.

Appendix: H.K. Rose and the cosmic microwave background

For decades I have been aware of rumors in the astronomical community that included various combinations of the words "Maryland Point," "search for background radiation," "request from Ralph Alpher," and "nothing seen or reported." The process of collecting material for this obituary confirmed (a) that Rose was a research physicist at NRL 1961-63 (in his CV), (b) that his wife remembers being at Maryland Point with him at some time in the early 1960s, and (c) most important, that Rose wrote in 1992 to then-University-of-Maryland historian of science Stephen Brush about "a measurement of the 3K cosmic background radiation in March 1962," made while testing his maser and its integration with an NRL heterodyne receiver for use on the 84-foot radio telescope at Maryland Point. Rose sent a copy of the letter to Michael A'Hearn, who was then the astronomy department chair, and the current astronomy chair, Stuart Vogel, found the letter, which forms the end of this appendix. It confirms that the data were never published, even in the thesis.

A 2009 book, *Finding the Big Bang*, by P.J.E. Peebles, L.A. Page, Jr., and R.B. Partridge discusses at least six marginal detections, near misses, and upper limits for the CMB, but not Rose at Maryland Point, and Peebles has informally confirmed that they were not aware of Rose's effort. The scientific questions are, of course, did he detect significant diffuse emission, or, at least, could he have? The answers seem to be no, and yes. Rose's letter indicates sensitivity of 0.1 - 0.2 K at 9.4 cm, appropriate to the maser-heterodyne amplifier. Jasper Wall (pp. 280-288 of Peebles et al.) has said they could have done equally well with their field effect transitor receiver, and so could anybody else with an FET and a Dicke switching radiometer. But the searcher had to know that there was something to look for (Rose did apparently; Hall did not).

And, as pointed out by Andy Harris of the current Maryland radio astronomy group, it was essential to have an antenna that excluded as much as possible of emission from the ground. Hall did; Rose did not; and, of course, Penzias and Wilson did.

Note from the Editor of the BAAS

It has come to the attention of the Editor that William K. Rose formally retired from the University of Maryland as an Emeritus professor in February of 2007. He left formal teaching duties in 2005. One of the textbooks he wrote, Advanced Stellar Astrophysics, is marketed by the publisher as a graduate-level textbook.

Affiliations: Univ. of Maryland

Obituary Written By: Virginia Trimble (University of California, Irvine and Las Cumbres Observatory)

BAAS: BAAS, 2011, 43, 042

DOI: 10.3847/BAASOBIT2011042

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William Rose's 1992 letter about his 1962 measurement of the cosmic background radiation

ATT 2

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Written By: Virginia Trimble (University of California, Irvine and Las Cumbres Observatory)

References:

William Rose's 1992 letter about his 1962 measurement of the cosmic background radiation

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Obituary: William K. Rose (1935-2010)

Trimble, Virginia

Bulletin of the American Astronomical Society, Vol. 43, id.040

Stellar astrophysicist William Kenneth Rose died near his home in Potomac, Maryland, on September 30, 2010, after an extended illness. Rose was the son of pharmacist Kenneth William Rose and Shirley Near Rose and was born in Ossining, New York, on August 10, 1935. He received an AB from Columbia College in 1957 and a PhD in physics from Columbia University in 1963, with a thesis on "measurements of linear polarization in discrete radio sources using a 9.4 cm maser," under the direction of Charles H. Townes. Rose played a major role in designing and constructing the maser and used it at a radio telescope at Maryland Point that belonged to the Naval Research Lab. He observed Jupiter and Saturn and a number of extra-solar-system sources, and also diffuse centimeter emission (see appendix). The thesis was not published in an archival journal, but can be found under Library of Congress code QB 475.R67.

While in graduate School, Bill married Sheila Tuchman, whose primary scientific interests were biological. None of their three children chose to be scientists, but two are CPAs. Bill moved successfully through the academic hurdles) from a research position at Princeton (1963-67), where a collaboration with Nick Woolf and Martin Schwarzchild on the infrared spectra of giant stars became one of his most-cited papers, to assistant and associate professorships at MIT (1967-71), and then associate and full professorships at the University of Maryland (1971 to retirement in 2005). His most innovative work was probably that on nova explosions arising from degenerate ignition of hydrogen accreted on white dwarfs in close binary systems, published in 1968. The same idea occurred to others at about the same time, and Bill did not, perhaps, get quite his fair share of the credit.

I first met Sheila and Bill in summer 1969 at the Stony Brook summer school on stellar evolution (not published until 1972). He lectured on the nature of nova explosions and on nuclear burning in thin shells in stars and the instabilities in each. Almost equally memorable, when the Roses had to depart a few days before the end of the school, they left behind a perfectly magnificent cake for the students to share at the closing party. During the first year that I was a visiting assistant professor at the University of Maryland, Bill and I team-taught the very first of the astronomy program's courses designed to fulfill a new, junior-level breadth requirement. It was called "The Inconstant Universe." I did cosmology and be did high-energy astrophysics.

We were also two of the three authors of a short paper called "A low mass primary for Cygnus X-1?" It pointed out that, if the primary of HDE 226868 was a low-mass, hot, short-lived helium star (on which each of us had published previous papers) then the solution of the radial velocity orbit, which came only from the lines of the OB primary, could yield a companion mass small enough for the X-ray emitting component to be a neutron star rather than a black hole. Such a system would be intrinsically much fainter than one with an OB supergiant primary, and so must be much closer to us than a supergiant plus black hole system. Our prediction resulted in two serious observers rushing to telescopes to look for interstellar absorption features in the optical spectrum of HDE 226868. They found lines with the velocity signatures of two spiral arms, thus placing the system at a large distance, giving it high luminosity and large mass. It was and is a black hole. The paper had the distinction of being the only one either of us ever wrote that was accepted and typeset before the postcard arrived by seamail to announce its receipt.

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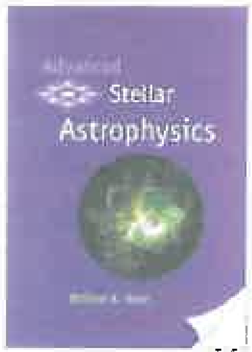

William Kenneth Rose
Cambridge University Press, Apr 16, 1998 - Science
480 pages

1 Review

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February 20, 2014 at 7:38 PM

Eviction letter,

Enclosed you will find a copy of the vacate notice
which was served on you and your family.

We regret the necessity of this type of action,
however, it becomes necessary in these circumstances.
The premises you are currently occupying are
to be vacated within the following two weeks.

If you refuse to relocate within the specified period of time,
a forcible detainer lawsuit may be initiated
to evict you and take your possessions.

Court representative,
CHAPMAN Atkinson

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Court representative,
CHAPMAN Atkinson

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of brightness and polarization, and one group devoted to radar astronomy, principally lunar range measurements. Observational work is carried on at the main station of the Laboratory and at Maryland Point Observatory on the north shore of the Potomac River in Charles County, Maryland. The principal observational instruments are an 84-ft equatorial reflector useful to wavelengths of 10 cm, located at Maryland Point, and two solid-surface reflectors at the main laboratory, one a 50-ft alt-azimuth reflector useful to wavelengths less than 2 cm, and the other a 10-ft equatorial reflector useful at wavelengths as short as 4 mm.

During the past year several changes have taken place in the personnel named in previous reports. C. M. Bowden resigned to enter a teaching post at University of Richmond, and C. R. Grant and F. Wrigley transferred to Goddard Space Flight Center of NASA. The Branch was joined by B. L. Gary from University of Michigan, by S. Knowles from the Naval Observatory, by D. L. Hammond from Sound Division, NRL, and by Dr. J. P. Hollinger from George Washington University.

During the summer of 1962 C. C. McBride of Massachusetts Institute of Technology was a student trainee. Dr. W. V. T. Rusch of University of Southern California was a visitor under an NSF grant.

In March 1962 C. J. Grebenkemper died after a long illness. Prior to his recent association with radio astronomy, he had done pioneering work in low temperature physics.

The Branch was visited by a considerable number of radio astronomers. Among those from abroad were N. W. Broten and R. D. Harrison (Canada), E. J. Blum and J. L. Steinberg (France), H. D. Davies and R. C. Jennison (England), T. Krishnan and J. P. Wild (Australia), and G. Schwachheim (Brazil).

PROGRAMS

Further observations have been made by Mayer, McCullough, and Sloanaker with the 50-ft reflector to investigate the polarization of the radiation from the strongest discrete sources at wavelengths of 3.15, 3.47, and 9.4 cm. The measurements were made using rotating, linearly polarized, horn feed-antennas at the focus of the reflector, which permitted only linearly polarized components of the radiation to be distinguished.

At 3.15 cm, strong, linearly polarized components were observed for Cygnus A, Centaurus A, and the Crab Nebula. The measurements show partial linear polarization of about 8% at a position angle of approximately 143 deg for Cygnus A, about 13% at 144 deg position angle for Centaurus A, and substantiate the value of about 7% linear polarization for the Crab Nebula at 143 deg position angle as determined from previous measurements with the 50-ft reflector. In addition, several other sources were investigated at 3.15 cm which showed no measurable polarization, and the quality of the observations for these sources set upper limits for the fraction of linear polarization at about ½% for Cassiopeia A, and 1% for the Orion Nebula, the Omega Nebula, Virgo A and Sagittarius A, and of about 3% for the planet Venus.

The observations at 9.4-cm wavelength substantiate previous measurements at wavelengths near 10 cm of a linearly polarized component of 3 to 4% of the total radiation from the Crab Nebula, and confirm the earlier negative results with an upper limit of roughly 1% for linear polarization for both Cassiopeia A and Cygnus A. An upper limit of 1% was put on the degree of polarization of Virgo A but Centaurus A gave a result of 7.5% at 127° at this wavelength.

A solid-state maser amplifier at 9.4-cm wavelength designed by W. K. Rose of the Columbia University Radiation Laboratory and NRL, followed by a superheterodyne radiometer designed by J. M. Bologna and Rose was installed on the 84-ft reflector in June 1962. The maser is operated at a bandwidth of about 18 Mc and a gain of about 20 dB. The if bandwidth of the radiometer is 20 Mc. The equivalent noise temperature of the system is about 95°K, including an estimated 25°K background noise picked up by the antenna. The rms output fluctuation is 0.013°K with a 7-sec receiver integration time.

The primary observational program planned for this equipment is the search for linearly polarized components of the radiation from discrete, extragalactic sources, using a rotating, plane-polarized, horn feed-antenna. In addition, observations of Jupiter, Saturn, and possibly other planets are planned. The first observations with this instrument by Rose, Bologna, and Sloanaker have indicated that the sources Hercules A and 3C433 both are about 10% linearly polarized, and that the radiation from Jupiter at 9.4 cm is roughly 15 to 30% polarized.

The series of observations of the 3.15-cm radiation from Venus which were begun early in March 1961 by Mayer, McCullough, and Sloanaker using the 50-ft reflector were continued through August 1961. The observations were spread over a considerable range of phase angle of solar illumination of from about 118 deg before the inferior conjunction of April 11th to about 54 deg after conjunction, and were made primarily for the purpose of more accurately defining the dependence of the average radio brightness over the disk on the phase angle, which had been inferred from earlier 3.15-cm observations using the 50-ft reflector. The measurements were

AJ Vol 67, Number 9
Nov. 1962 — No. 1304 USNRL
Reports of observatories,

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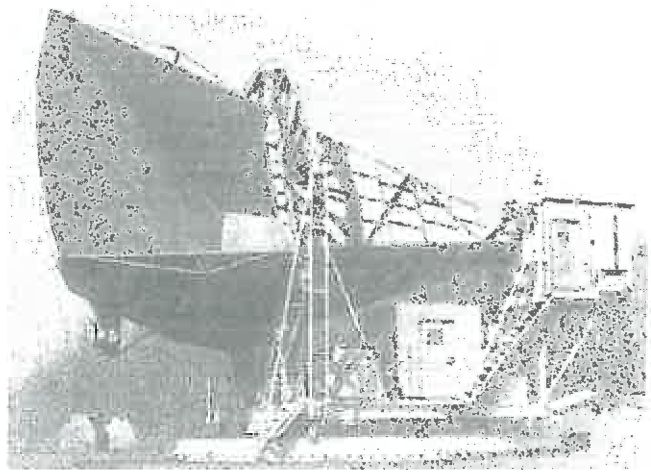

Fig. 4.12. The 20-ft horn-reflector with its parabolic reflector on the left and cab on the right. Since the cab does not tilt, almost any kind of receiver can be conveniently put at the focus of this antenna (apex of the horn). It is clear that the horn shields the receiver from the ground, especially when it is looking up.

built the large (20-ft aperture) horn-reflector pictured in Figure 4.12, to be used with a TWM to receive the weak signals from Echo (Crawford, Hogg and Hunt 1961).

Figure 4.13 shows a polar diagram of the gain of a smaller horn-reflector antenna compared with the gain of a theoretical isotropic (uniform response) antenna. If we put an isotropic antenna on a field with the 300-K ground down below and zero degree sky up above, we expect it to pick up 150 K; half of its response comes from the ground. The response of the horn-reflector is more than 35 dB (a factor of about 3000) less responsive to the ground than the isotropic antenna. So one would expect less than a tenth of a kelvin for the ground pickup from the horn-reflector.

In December of 1962 I went on a recruiting trip to Bell Labs. Of the groups I was interviewed by, I was most interested in the Radio Research Lab at Crawford Hill. I met Arno Penzias there and he showed me his OH experiment and the 20-ft horn-reflector. At that time, he had been there a year and a half. We had much more time to talk a week later at the winter American Astronomical Society meeting, where I gave a talk. He was clearly trying to get me to join him at Crawford Hill. Setting up and carrying out
trying to get me to join him at Crawford Hill. Setting up and carrying out
an observing program with the horn-reflector was certainly a job better done by two people than by one.

We were very different people and, as it turned out, had complementary skills. We made a good team for that job. Arno was as garrulous as I was

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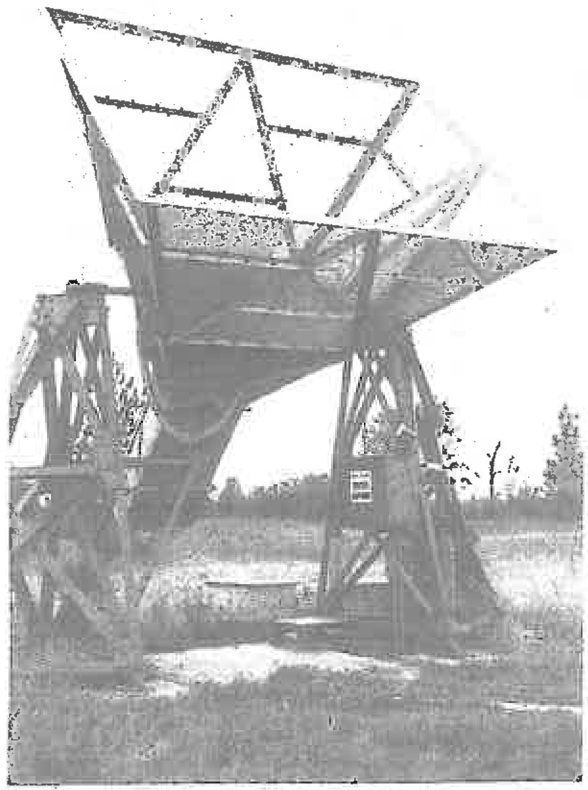

Fig. 4.32. The pyramidal horn antenna, aperture 3.7 by 2.8 m, used at 320 MHz for my galactic background temperature measurements.

a craftsman, a perfectionist, and a delight, whose stories, unrepeatable and certainly unprintable, enlivened many of my days and nights in the little frozen cabin at Richmond Hill, while adding a certain breadth to my graduate education. More supervisor trouble ensued when in the course of transporting a frequency generator to the cabin (they weighed about 150 kg in those days), I settled the old radio astronomy station wagon axle-deep into the Observatory grounds in soft spring mud.

The cold load was a real challenge. Nobody really knew how to proceed, and the one I fashioned was the best technical achievement of my MSc. It did work well, and I was confident of its noise temperature – but note that it was a liquid nitrogen cold load, at about 80 K. This was close to the mean galactic brightness temperatures; but of course a long way away from CMBR values.

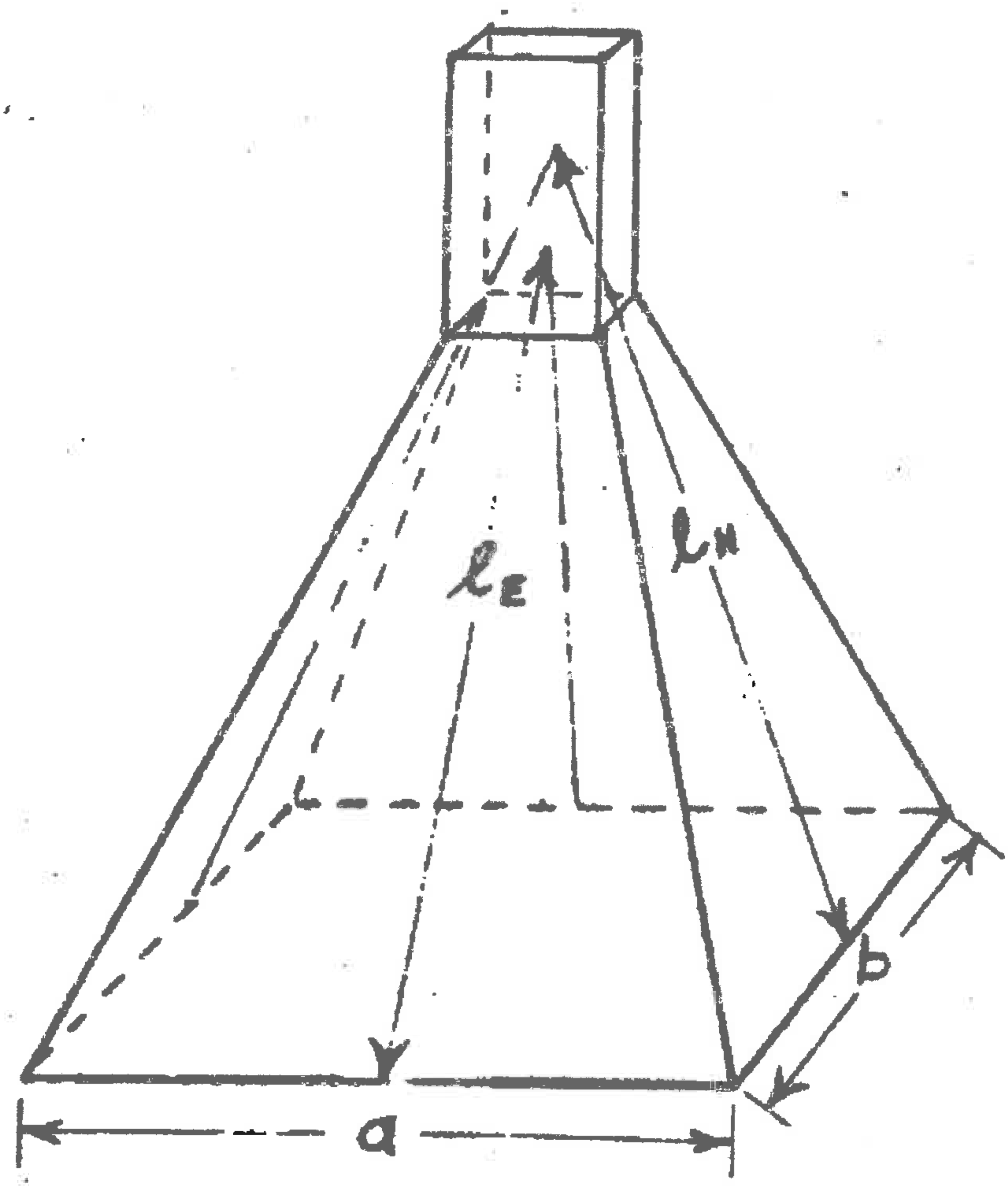

Fig. 1 - Physical dimensions for calculating the gain

ATT 12

This relation expresses radiation energy density or flux in terms of the Rayleigh–Jeans temperature.

reality Our interpretation is on page 6.

receivers In CMBR studies, devices that convert incoming electromagnetic radiation into an electronic signal. The term can refer to coherent or bolometric (incoherent) systems. The Dicke radiometer shown on page 45 employed a coherent detector; *see* mixer. Optical elements include horns, sometimes with lenses, or other antennas, to shepherd radiation into waveguides and then through amplification and frequency filtering. The minimum detectable incoming temperature change that can be measured in a time interval Δt is

$$\Delta T = \frac{C_1 T_s}{\sqrt{\Delta t \Delta \nu}}, \tag{G.3}$$

where $\Delta\nu$ is the bandwidth of the receiver and the constant C_1 is a number of order unity that depends on the switching scheme. Roll and Wilkinson (1967) reported a system temperature of $T_s \sim 3000\,\mathrm{K}$; Penzias and Wilson (1965a) had a system temperature of 18 K. In bolometric systems there is no mixer and most of the optics are cryogenic. *See* bolometer, feed, HEMT.

recombination epoch In this book, the transition at redshift $z = 1100$ from plasma to almost entirely neutral atomic hydrogen and helium. The term is unambiguous but perhaps irrational because in the standard model the baryons have been ionized from creation to recombination. *See* decoupling.

redshift Wavelength shift that may be caused by relative motion, the expansion of the universe or a time-variable gravitational potential. *See* cosmological redshift, noncosmological redshift, Doppler effect.

redshift–magnitude relation A cosmological test: the relation between cosmological redshifts and apparent magnitudes of extragalactic objects that have close to the same absolute magnitude.

Rees–Sciama effect Perturbation to the CMBR by the time-variable gravitational potential of a growing nonlinear mass concentration.

relict radiation Early name for the CMBR; its origin is recalled by Sunyaev (p. 112).

right ascension Component of position in the sky measured as an angle along the celestial equator.

Robertson–Walker line element Geometry of a homogeneous and isotropic world model expressed as

$$\mathrm{d}s^2 = \mathrm{d}t^2 - a(t)^2 \left[\frac{\mathrm{d}r^2}{1 - r^2 R^{-2}} + r^2 \left(\mathrm{d}\theta^2 + \sin^2\theta \mathrm{d}\phi^2 \right) \right]. \tag{G.4}$$

An observer at fixed coordinate position keeps proper or world time t, θ and ϕ are polar coordinates measured by an observer at $r = 0$, r is a radial coordinate, and the expansion parameter $a(t)$ appears in equations (2.3) and (G.1). The physical radius of curvature of a space section at fixed t is $a(t)|R|$. If $R^{-2} > 0$, space is curved in the fashion of the balloon analogy on page 10 and is said to be closed. The circumference c of a circle of physical radius x drawn in this space section is $c < 2\pi x$. If R^{-2} is negative space is curved, so that $c > 2\pi x$, and is said to be open. The tests in Section 5.4 indicate R^{-2} is close to zero, meaning space at fixed t has close to Euclidean geometry (though spacetime is curved). Since the Robertson–Walker form opaque film over the pinhole. However, we were able to ascertain that some limb brightening exists, that the sunspot-active regions produce at least a fourth of the total emission but cover less than three per cent of the disk area and that x ray emission extends to at least 40 000 km above the photospheric limb.

The second camera was flown 21 June 1961 from which pictures were obtained in three wavelength bands between 10 and 100 A. While these have not yet been analyzed in detail it may be said that the results appear consistent with previous measurements. Limb brightening is definitely present and the emission extends to somewhat greater altitude than could be measured on the first picture.

Future plans for solar x-ray photography include development of an image intensifier for use with pinhole cameras, high resolution x-ray telescopes probably utilizing total reflection at grazing incidence and introduction of a third degree of pointing control in order to eliminate smearing of images.

The solar x-ray spectroscopy program is still in the development stage. The planned experiments call for use of crystal spectrographs with Geiger counter and photomultiplier detectors. Some preliminary work has been done on long spacing organic crystals which indicates that these may be employed along with gypsum to cover the range from 5 to 100 A. Two rocket experiments for photography and spectroscopy are planned for September 1962.

S-17 Satellite Experiment. The Upper Air Physics Branch is also participating in the instrumentation of S-17 (reported by R. Tousey above). Experiments are being designed to

(a) scan the solar disk in 8–20 and 44–80 A x rays so as to observe the growth and decay of active centers of x-ray emission;

(b) monitor the eclipsed sun for x-ray emission which might occur at high altitudes following surge prominences or the development of type IV emission regions; and,

(c) monitor the sun for short-lived x-ray bursts which might accompany type III radio noise bursts.

Rocket Astronomy Program. Two rockets equipped with telescope-photometer combinations sensitive in the far ultraviolet were flown. It was again established that no nebular glow of intensity, $I > 3\times10^{-5}$ erg/cm² sec/ster was observable in the bands 1200-

Lyman-α glow was viewed through an atomic hydrogen scattering cell in which atomic H was alternately generated and permitted to decay during successive periods throughout flight, showed that the night Lyman-α glow contains not less than 80% radiation scatterable by atomic hydrogen at rest relative to the earth. The radiation not scattered out of the scattering chamber showed no marked intensity variation with view direction. It is concluded that most if not all the night Lyman-α glow is caused by atomic hydrogen in the earth's exosphere.

TALBOT A. CHUBB, *Branch Head*

RADIO ASTRONOMY BRANCH

PERSONNEL

Robert H. Bruton of the Radar Astronomy Section resigned during the year. The Radio Sources Section was joined by Robert A. Mennella, formerly of the Radar Division of NRL, and by William K. Rose of Columbia University. Summer student trainees Ernest Hildner of the University of Colorado, Boulder, and Michael P. Weinreb of Brandeis University, Waltham, Massachusetts returned during the summer of 1961.

INSTRUMENTATION

The design and development of a 9.4-cm. solid-state maser for astronomical observations have been continued by W. K. Rose, who is a graduate student of Professor C. H. Townes at Columbia University. Bologna and Rose are incorporating the maser into a radiometer system for installation on either the 50-ft or the 84-ft antenna during the coming year. The maser bandwidth is about 20 Mc with a gain of 20 db, and the equivalent noise temperature of the system should be about 75° K. It is expected that the minimum detectable signal will be about 0.03° K, with a 1-sec integration time constant, which is an improvement by a factor of 6 over the 9.4-cm radiometer presently in use.

Also in cooperation with Columbia University, a 21-cm maser was tested on the 84-ft antenna for a time during 1960. Designed by Arno Penzias, a graduate student at Columbia, the maser was intended to feature a wide tuning range. Although the tuning properties were satisfactory, the inclusion of

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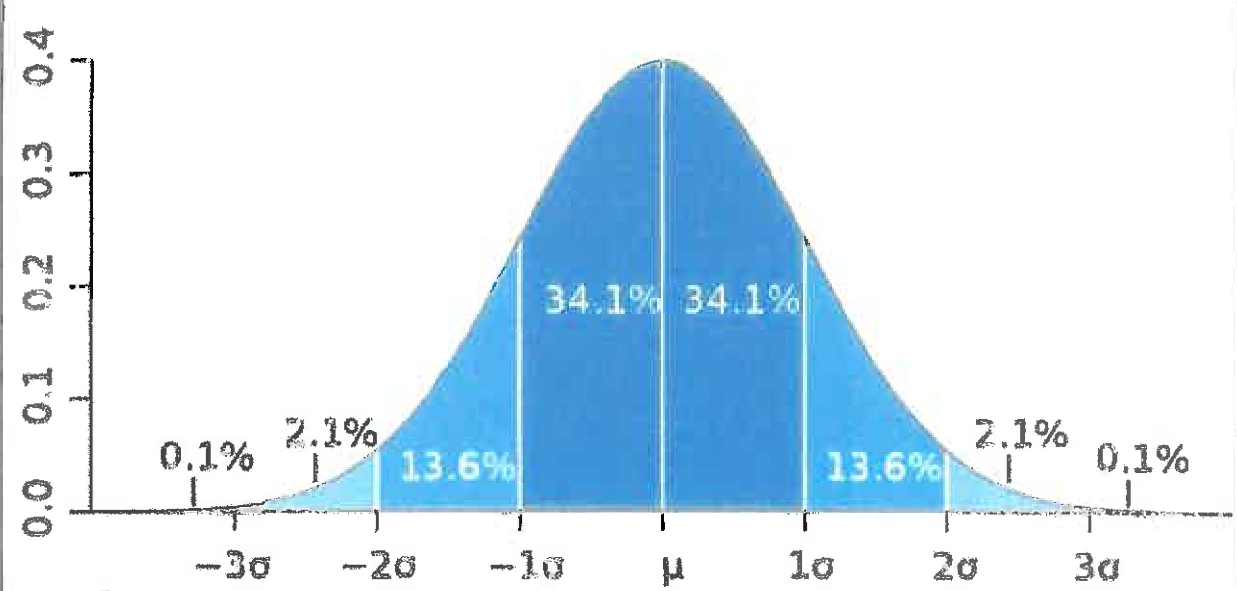


On this chart of a 'normal' distribution, showing the classic 'bell curve' shape, the mean (or average) is the vertical line at the center, and the vertical lines to either side represent intervals of one, two and three sigma. The percentage of data points that would lie within each segment of that distribution are shown.

ATT 15

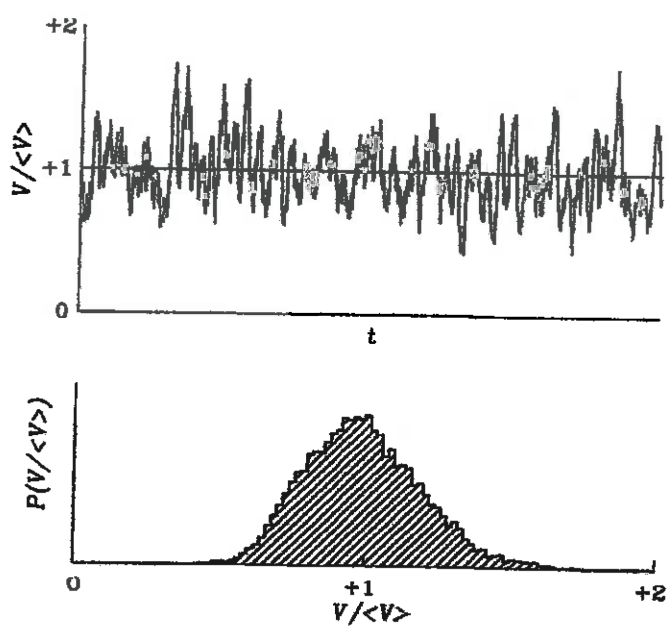
Integration greatly reduces the receiver output fluctuations. In the time interval τ there are $N = 2\Delta\nu_{RF}\tau$ independent samples of the total noise power T_{sys}, each of which has an rms error $\sigma_T \approx 2^{1/2}T_{sys}$. The rms error in the average of $N \gg 1$ independent samples is reduced by the factor $\sqrt{N}$, so the rms receiver output fluctuation σ_T is only

$$\sigma_T = \frac{2^{1/2}T_{sys}}{N^{1/2}} .$$

In terms of bandwidth $\Delta\nu_{RF}$ and integration time τ,

$$\sigma_T \approx \frac{T_{sys}}{\sqrt{\Delta\nu_{RF}\tau}} \qquad (3E3)$$

after smoothing. The central limit theorem of statistics implies that heavily smoothed ($\Delta\nu_{RF}\tau \gg 1$) output voltages also have a nearly Gaussian amplitude distribution. This important equation is called the *ideal radiometer equation* for a total-power receiver. The weakest detectable signals ΔT only have to be several (typically five) times the output rms σ_T given by the radiometer equation, not several times the total system noise T_{sys}. The product $\Delta\nu_{RF}\tau$ may be quite large in practice (10^8 is not unusual), so signals as faint as $\Delta T \sim 5 \times 10^{-4} T_{sys}$ would be detectable. The two figures below illustrate the effects of smoothing the detector output by taking running means of lengths $N = 50$ and $N = 200$ samples.



The smoothed output voltage from the integrator varies on time scale τ with small amplitude

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The factor of 2 in the denominator is because radio astronomers usually define the flux density as that present in both wave polarizations, but a receiver is sensitive to only one polarization. Radio telescopes use linear or circular polarization depending on the type of observations being made, and with two LNAs and two receivers, one can detect two orthogonal polarizations simultaneously. In order to detect and measure signals that are a very small fraction of the power passing through the receiver, signal averaging or *integration* is used. If the receiver gain were perfectly stable, our ability to measure small changes in signal is given by the noise equation in the previous section. There DT is the one-sigma measurement noise.

If the receiver bandwidth is 1 MHz and T_{sys} = 100 K, for example, then we can measure down to 0.013 K in one minute. For a sure detection, we need to see a change of 10 sigma or about 0.1 K change. The receiver gain in practice is seldom exactly constant, and the additional spillover noise and atmospheric noise may also be changing, so it will be difficult at this level to distinguish a real signal from a change in gain or atmospheric noise. There are several solutions to this problem, depending on the type of observing, all of which rely on some way of forming a reference. If we are making spectral-line measurements, the reference is often just adjacent frequencies. If we scan the frequency or simultaneously divide the spectrum into many frequency channels, then the gain or atmospheric noise changes will be largely common to all frequencies and will cancel with baseline subtraction in the final spectrum. In making measurements of broadband or *continuum* radio emission, we usually use a synchronous detection technique known as *Dicke* switching after its inventor Robert Dicke. An example of Dicke switching is the use of a switch to toggle the input of the LNA between two antenna outputs that provide adjacent beams in the sky. If we switch fast enough in this case and take the difference between the power of the two outputs synchronously with the antenna switch, then receiver gain changes will largely cancel. Furthermore, if the two antenna beams are close together on the sky, then changes in the atmospheric noise will tend to be common to both beams and will also cancel. Since we are taking a difference and spending half the time looking at the reference, the DT given above will have to be doubled.

Another powerful technique for extracting weak signals from noise is correlation. The radio telescope in this case has two or more receivers either connected to the same antenna, or, more often, two or more separate antennas. The signal voltages are multiplied together before averaging instead of multiplying the signal voltage by itself to obtain the power. With separated antennas, the correlation output combines the antenna patterns as an interferometer, which generates lobes on the sky that are separated in angle by the wavelength divided by the projected baseline between the antennas. Correlation techniques are common in radio astronomy, and they are becoming popular also in communications. Correlation is used, for example, to detect and demodulate spread-spectrum signals as in code-division multiple-access (CDMA) digital cellular telephones.

6.3.3 An analog-to-digital converter (ADC)

Since all the final processing of a radiometer output is done with a computer, we need to convert analog voltages from the detector to numbers that can be processed in software. A very accurate and effective ADC is a voltage-to-frequency converter followed by a counter. This ADC provides integrated power with as many bits as are needed to represent the count over the integration interval. If reading the output of the counter at perfectly

Fig. 2.2 A. A. Penzias (left) and R. W. Wilson standing in front of the horn antenna with which they detected and measured the CBR as 'excess noise' (see Appendix A here).

'Excess noise' from the sky, of intensity equivalent to 3.5 K at their wavelength of 7.35 cm, remained after all other systematic offsets had been subtracted.

What saved this work from joining the list of 'missed opportunities' was (1) the sensitivity of the receiver (the 3.5 K signal was more than ten times the statistical error in a single measurement); (2) the great care and persistence of Penzias and Wilson, who devoted months to excluding non-cosmic explanations for the 'excess noise'; and finally (3) the fateful telephone call of 1964, to which we now turn.

2.5 'Well boys, we've been scooped!'

Less than an hour's drive from Bell Labs, Robert Dicke and his Princeton colleagues were busy in 1964 reinventing the Hot Big Bang, and designing a sensitive receiver to detect the thermal background left by it. They were apparently unaware of *all* of the theoretical and observational work described above. Indeed, Dicke's motivation for a Hot Big Bang was not to build up elements heavier than hydrogen, but to destroy them. Dicke argued that a closed (recollapsing) Big Bang model might 'bounce' at the end of its collapse and then reexpand – an oscillating model, as shown in fig. 2.3. An infinitely oscillating model defines away a 'beginning,' and hence has the same philosophical tidiness as the Steady State Theory. A potential flaw in such a model is the production of heavy elements (e.g., C, N, O, Fe) in stars in each cycle – after many cycles would the Universe not be full of heavy elements? To cleanse the Universe, a high temperature state is needed at each bounce to photo-disintegrate the complex nuclei. Dicke and his colleague Jim Peebles worked out the necessary temperature, and estimated its present value about 10^{10} yrs after the most recent bounce, obtaining $T_0 \approx 10$ K. They also inde-

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Moreover, it was clear to Gamow and his group that a Hot Big Bang would leave the Universe with a calculable, non-zero temperature. In several of the papers and reviews referred to above, $T(t)$ is plotted, and it is easy to read off the present value, T_0 (typically about 10 K). On several occasions, members of this group made specific predictions of the present 'background temperature,' the phrase employed by Alpher and Herman (1949). In that paper, Alpher and Herman give $T_0 = 5$ K, and that figure appears in other papers as well.*

At first glance, it is astonishing that Alpher and Herman came within a factor of two of the presently accepted value of T_0. However, if one relies on the Hot Big Bang to produce 20–50% ^{4}He by mass, one finds T_0 about a few kelvin, independent of most cosmological details. What is more astonishing is that this discussion of a mean 'background temperature [of] ... the order of 5 K' should have dropped out of scientific sight for nearly twenty years. Why did this happen? Big Bang models remained in vogue, but Gamow's original hope of making *all* heavy elements in a Hot Big Bang was weakened by Fermi and Turkevich and by the pivotal paper of Burbidge, Burbidge, Fowler and Hoyle (1957), which showed convincingly how most heavy elements were built up in stellar interiors. Even the recognition that most elements – C, O, Fe and so on – are made in stars, however, did not entirely submerge the Hot Big Bang model. For instance, in a detailed 1965 review, Zel'dovich, a leading Soviet cosmologist, considered the Hot Big Bang model in detail. In that same year, Hoyle and Tayler noted that the large abundance of ^{4}He relative to still heavier elements was more naturally explained by a combination of Big Bang synthesis of the light nuclei like ^{4}He plus stellar nucleosynthesis than by stellar synthesis alone. In other words, a Hot Big Bang *is* needed to explain the observed abundance of some elements, especially those with atomic mass ≤ 4.

Nevertheless, most physicists and astronomers ignored the predictions of the Hot Big Bang model, perhaps because they seemed to be mere features in a 'dream of zealots.' Both the work of Gamow, Alpher and Herman and reasons for its apparent disappearance have been treated by others interested in the early history of the CBR (see Weinberg, 1972† and 1977; a more informal treatment given by Ferris, 1977; and Alpher and Herman, 1988, among others). To these analyses and to my remarks above, I would like to add a more speculative coda. It is absolutely clear that Alpher and Herman predicted a non-zero 'background temperature' for the present Universe. What is missing in these papers is the recognition that a Universe with non-zero temperature must even now be filled with more-or-less isotropic, thermal, radiation that could be detected, and indeed *had* been detected, as we will soon see. No one took up the challenge of observing the predicted background radiation.‡

* In his 1952 book (and elsewhere) Gamow quotes a much higher figure (50 K in his book) because he carelessly assumed that the expansion of the Universe remained radiation-dominated up to the present, so that $T \propto t^{-1/2}$. Thus, while he and his colleagues correctly derived eqn. (1.28), Gamow (unlike Alpher and Herman) incorrectly extrapolated that relation to the present, deriving a value for T_0 about ten times too large.

† Weinberg, in *Gravitation and Cosmology* (1972, p. 510), suggests as an explanation that, after predicting $T_0 = 5$ K, Alpher and Herman '... went on to express doubts as to whether this radiation would have survived until the present.' I believe Weinberg's argument misses the point; Alpher and Herman were discussing cosmic *rays* at this point, not the thermal cosmic background.

‡ Alpher and Herman have kindly informed me that they and their colleague, James Follin, did indeed explore the possibility of radio astronomical measurements, but were told by the observers that the technology of the day (the mid-1950s) would not permit them; this point may be dealt with further in a book that Alpher and Herman have in preparation.

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I later switched research areas from cosmology to galaxies, especially individual spiral galaxies. My research in the past 25 years has included detailed studies of spiral tracers in the grand-design spiral M81 and detailed multi-wavelength studies of galaxy pairs involved in grazing, prograde encounters (with Debra and Bruce Elmegreen). Our HST image of NGC 2207/IC 2163, part of the latter study, has appeared everywhere in the national news media, including the front page of *The New York Times* as well as scholarly journals (Elmegreen *et al.* 2006).

4.10 Measuring the CMBR energy spectrum

4.10.1 Jasper V. Wall: The CMB – how to observe and not see

Jasper Wall served as Director of the Royal Greenwich Observatory and of the Isaac Newton Group of Telescopes, La Palma. He is now Visiting Professor, University of Oxford, and Adjunct Professor, University of British Columbia.

In 1965 Donald Chu, Allan Yen and I made extensive sky brightness measurements at 320 and 707 MHz. Comparison told us that something was wrong with the zero point, wrong by the same few degrees at each antenna and at each frequency. Here is the story.

Engineering was in my blood, via father and grandfather. I grew up in the Ottawa Valley, in a happy and stimulating household in which the mantra was "This works so well we must take it apart to see why." Clocks, toasters, cars, plumbing, house electrics, lawn mowers, washing machines, hi-fi; nothing was safe from my Dad and his two young sons. Inevitably it was off to do Engineering at Queen's University, from where I graduated in 1963. But well before 1963 I had found the conventional branches of engineering to be less interesting than I had wished. I headed off into Engineering Physics, great training for applied research postgrad studies. But in what? I had spent a couple of summers at the National Research Council in Ottawa, working in the radio astronomy group. It seemed to me at the time that astronomy was perhaps of passing interest and might offer decent engineering challenges. The astronomy got me in the end, but the engineering background paid rich dividends at various times in my later professional life. The immediate challenge was radio astronomy instrumentation, which I set out to do in a Master's degree program in the Department of Electrical Engineering at the University of Toronto, starting autumn 1963.

My joint supervisors were Donald MacRae, Professor and Head of the Department of Astronomy, and the brilliant and enigmatic J. L. (Allan) Yen, Professor of Electrical Engineering, theorist, instrumentalist, expert on Toronto Chinese cuisine (chopsticks were an early part of my graduate education) and a man who required almost no sleep. I saw both my supervisors but rarely, and then only when I was in trouble with them, this more frequently than was comfortable. I learned through the standard apprenticeship system, the senior grad students mentoring the new student intake. I learned most from Ernie Seaquist, who was well into his PhD program in the Astronomy Department. He was patient and generous to me with time precious for his own extensive radio astronomy program, and by example he taught me far more than just radio astronomy.

My project was to measure absolute temperatures of the galactic background at 320 MHz, using the pyramidal horn already installed at the David Dunlap Observatory (DDO), Richmond Hill, 19 miles north of Toronto. The horn itself (Figure 4.32) was in relatively good shape, needing some cleaning to remove certain avian deposits of the sort that Penzias and Wilson (1965a) encountered in their researches. The challenge as I mapped it out was (a) to build a reasonably low-noise amplifier and Dicke-switching receiver and (b) to design and build a reference cold load for the switching system, one with absolute temperature known to specified accuracy. The measurements were then simple drift scans, with the horn turned to the north celestial pole at periodic intervals for a reference level. This level would be calibrated by replacing the horn input with the reference cold load input. There were impedance-matching subtleties involved, as long-serving radio astronomers will recognize.

First task – to build a new receiver at 320 MHz. Field effect transistors, FETs, had just become available, actually working at this high a frequency! Low noise as well! But they cost real money, all of $34 each. In a rare interview with Allan, I got the money and the transistor. Next day I blew it up. (In retrospect I begin to understand the supervisor problem.) I managed to extract funds for a second one, and, after walking around it for an afternoon, made a decision on how to handle it which helped me the rest of my life. It's just another transistor! Handle with ordinary care – otherwise I couldn't see how I would get anywhere. It worked. I applied the lesson later when dealing with original astronomical plates. Treat them as you treat glass, with respect, but without awe. More tense and more "careful" ≡ greater risk and less research.

The second FET ran throughout the project. The new receiver was built with help of George Watson, a solitary soul working out at Richmond Hill:

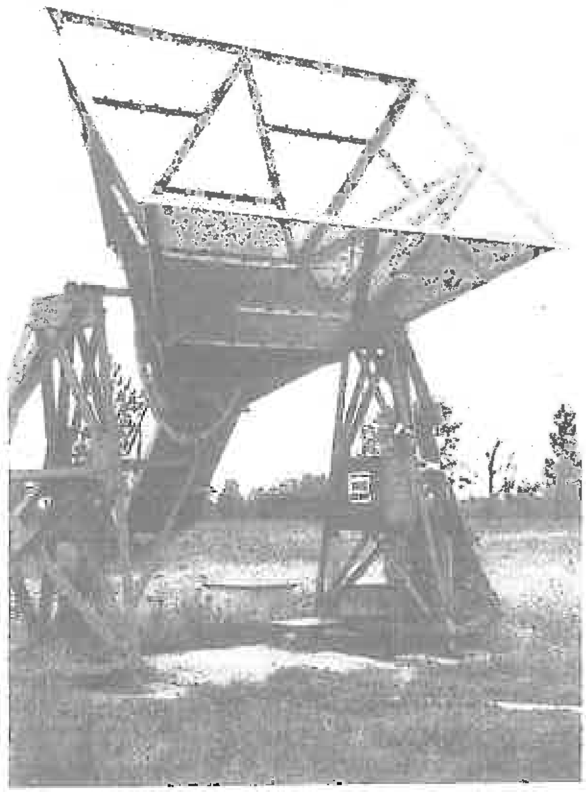

Fig. 4.32. The pyramidal horn antenna, aperture 3.7 by 2.8 m, used at 320 MHz for my galactic background temperature measurements.

a craftsman, a perfectionist, and a delight, whose stories, unrepeatable and certainly unprintable, enlivened many of my days and nights in the little frozen cabin at Richmond Hill, while adding a certain breadth to my graduate education. More supervisor trouble ensued when in the course of transporting a frequency generator to the cabin (they weighed about 150 kg in those days), I settled the old radio astronomy station wagon axle-deep into the Observatory grounds in soft spring mud.

The cold load was a real challenge. Nobody really knew how to proceed, and the one I fashioned was the best technical achievement of my MSc. It did work well, and I was confident of its noise temperature – but note that it was a liquid nitrogen cold load, at about 80 K. This was close to the mean galactic brightness temperatures; but of course a long way away from CMBR values.

I heard/read of the CMBR as my observations progressed. Reaction (a): nothing to do with me; I'm a galactic (semi-) astronomer, working at too low a frequency and too high a mean brightness. Reaction (b), with minimal cosmic consciousness and from a radio astronomy point of view: surprise, Ryle was right after all – but a singular beginning? Steady state was conceptually much easier to handle.

And following this two minutes of deep thought, back to reality – the horn antenna had half-power beamwidths of 19.0° × 22.5°. Absolute temperature mapping requires correction for the response in side- and back lobes, of course. Thus I built a scaled version of the horn, complete with supporting structure, smaller by a factor of 9 and operating at 2.88 GHz. I mounted this on the antenna range turntable on the roof of the Electrical Engineering building, with a distant horn-reflector plus S-band generator to provide the signal. The main-beam and first side-lobe patterns agreed remarkably well with the main-beam measurements of the main horn using drift scans of the Sun, a point source (only 30 arcmin in size!) to the fat beam of the horn. The side and back lobes enabled me to estimate the spillover radiation.

There were many delays, including my MSc course load and stormy winter weather. Measurements began in February 1965 and continued to June; I covered the hottest part of the sky but by June (Figure 4.33), interference

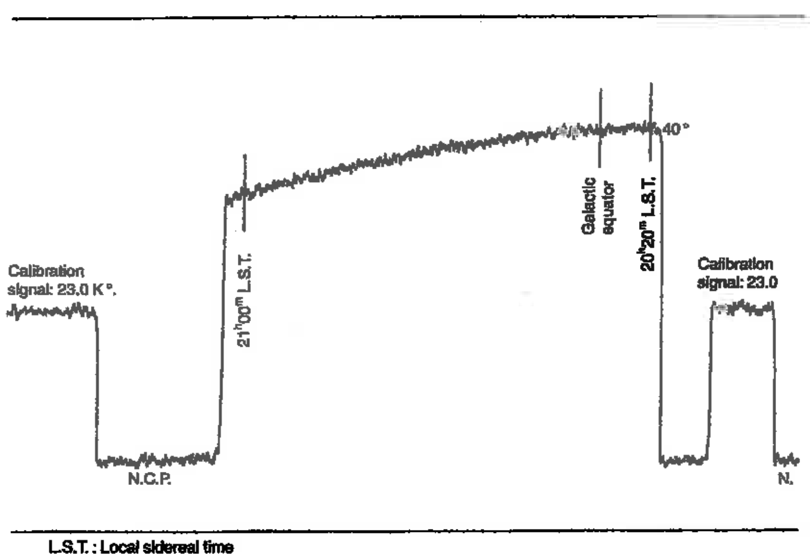

Fig. 4.33. A chunk of drift scan, this one at declination $\delta = 40°$ complete with periodic visits to the North Celestial Pole and calibration-signal injections.

from the USAF Buffalo base essentially halted the observations. I could not finish the cold (galactic anticenter) parts, another sore point between me and supervisors. My MSc thesis, complete with the iterative calculations to remove side- and back-lobe responses, was completed in October 1965. In parallel Donald Chu ran a sister set of measurements at 707 MHz, using a 2.5-m precision horn-reflector at the Algonquin Radio Observatory of the National Research Council of Canada. The techniques he used followed mine precisely, including construction of a scaled model of the horn-reflector. His measurements and mine were to be used to calibrate in absolute terms higher-resolution galactic plane surveys at DDO with a new 10-m paraboloid reflector (for which I did commissioning and feed design.) These together with polarization measurements which Ernie Seaquist was working on were to provide comprehensive data on the Milky Way emission. This grander scheme never happened.

In November I set off for Australia, where I had been offered a scholarship at the Australian National University to do a PhD in a collaborative radio-optical program between Mount Stromlo Observatory and the Australian National Radio Astronomy Observatory at Parkes. John Bolton was to be my supervisor. My seduction by astronomy was complete. Engineering cropped up later in my life in building CCD systems, commissioning telescopes etc.; but it was astronomy now where my commitment lay.

Donald Chu, finishing the same patch of sky I had done, likewise left for different things, a proper job in his case with the then largest computer company.

In the excitement of starting a new life in a country where snow drifts across the telescopes were no longer a problem, the brightness temperature measurements were temporarily laid aside.

The rest of the story has a certain inevitability about it. Donald Chu had made some tentative comparisons of his data with mine; he found unsatisfactory answers. We knew roughly what the emission spectrum of the galactic background was – this synchrotron emission continuum from long-blown supernovae had a brightness spectral index of about −0.5 to −0.7 (Yates and Wielebinski 1967). Comparison of the 320- and 707-MHz results at independent map points by Donald and myself yielded a spectral index of −0.3, far too flat. Trying to reach indices in the "recognized" range meant zero-point errors outside our estimates. In 1965 we had left it at this: we had both moved on.

In 1967 or 1968, as cosmological consciousness dawned, I realized what had happened. Subtracting 3 K from both of our sets of measurements yielded spectral indices in agreement with the "known" results (Figure 4.34).

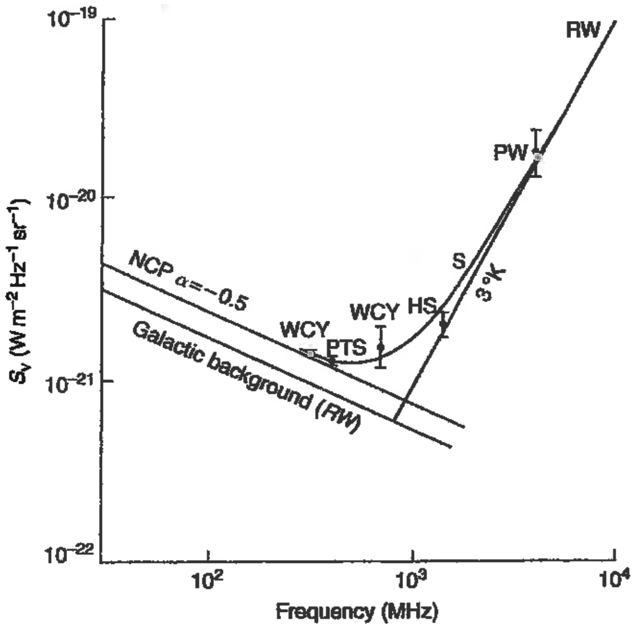

Fig. 4.34. The surface brightness measurements, circa 1969, from Wall, Chu and Yen (1970). PTS: Pauliny–Toth and Shakeshaft (1962); PW: Penzias and Wilson (1965a); HS: Howell and Shakeshaft (1966); RW: Roll and Wilkinson (1966); WCY: Wall, Chu and Yen (1970). ©1970 CSIRO Publishing.

I collected the data together, redigitized it, and finally wrote up the experiments (Wall, Chu and Yen 1970). There was no great urgency at this stage.

In retrospect a dedicated CMBR measurement would have been simple. We had only to cover the colder parts of the sky, put our two sets of measurements together with a prior on the galactic emission spectral index, and a measurement of the excess radiation was there. We were a bit late in the time frame – but if we had got on with it in the first years of our MSc degrees rather than spending them wading through forgotten courses on plasma physics, the result would have been waiting for us.

The most astonishing aspect to me in hindsight was just how easy it would have been to make the measurement successfully, using the horns we already had, and a financial outlay of almost nothing.

I blame VLBI (partially). If Allan Yen had not become preoccupied with this (Broten *et al.* 1967) I know his razor-sharp mind would have seen the possibility; he read everything and was on top of everything. I know that excess radiation was in his mind – although he never mentioned CMBR or excess radiation to me, his annoyance when I had been unable to finish measuring colder parts of the sky convinced me of this. This too came in retrospect.

The CMBR subsequently played little part in my career of observational cosmology. I stuck to AGNs and their spatial distribution, together with schemes of (unified) beaming models. Most of this was with radio-selected samples. There were perhaps just three points of contact:

(i) In carrying out the (1984 version) deepest survey at 5 GHz with the VLA, Ed Fomalont, Ken Kellermann and I put limits on CMBR fluctuations in the range of an arcminute and a bit less (Fomalont, Kellerman and Wall 1984). These were the best upper limits at the time; but they were far from real detections at these angular scales, as we now know. Perhaps our main contribution was to determine how to minimize cross-talk between the antennas, a help to subsequent experiments. Even so, the VLA for all its power was never the instrument for CMBR fluctuations.

(ii) The standard model has the CMBR dipole, 1 part in 1000, explained as the Earth moving at $370\,\mathrm{km\,s^{-1}}$ relative to the rest frame, with apparent temperature brighter in the direction of motion. The predicted motion should be visible in the number counts of distant objects, their combined surface brightness enhanced in the direction of motion of the Earth. There are serious difficulties in looking for this dipole in discrete objects: how distant, how to select, how to perform widescale calibration; what to do about obscuration, how to get beyond the cluster-dominated epoch. A uniform all-sky survey of radio sources offers hope, however, as Ellis and Baldwin (1984) pointed out. After completion of the superb NRAO VLA Sky Survey (NVSS; Condon *et al.* 1998), that hope could be really entertained. It took much work to understand the systematics of the survey, and much work to remove the nearby objects from it – but in the end Chris Blake and I succeeded in observing the dipole (Blake and Wall 2002), agreeing in magnitude and direction with Earth motion as implied by the CMBR (Figure 4.35). This remains the only detection of the velocity dipole in discrete galaxies, objects formed long after the epoch at redshift $z \sim 1100$ corresponding to the last scattering surface from which we see the CMBR. The mean redshift of our radio galaxies is about unity. The universe is therefore showing large-scale homogeneity at this epoch, and further analyses coupled with new deep and wide sky surveys can refine this result. Although few doubt the interpretation of the dipole in the CMBR, the detection in real

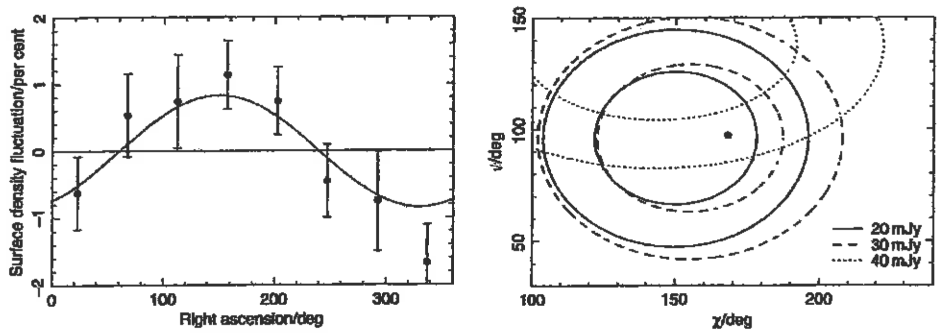

Fig. 4.35. Left: measured amplitudes of the deviation from mean surface density for NVSS sources, as a function of right ascension. (Note that the direction of the CMBR dipole lies – accidentally – close to the Celestial Equator.) The predicted amplitude is shown as the solid line. Right: error circles (1σ, 2σ) representing the direction of the NVSS dipole for samples selected at different flux-density levels. The point denotes the direction of the CMBR dipole.

objects represents one of the tests the CMBR needs to pass if it is truly a relic of the big bang (Ellis 2002).

(iii) With superb results from WMAP (Bennett *et al.* 2003), and with the Planck mission on the horizon, we would like some reassurance that the fluctuations we see in the CMBR are not contaminated by extreme inverted-spectrum populations of radio-millimeter sources. To this end, with Rick Perley, Robert Laing, Joe Silk, and Angela Taylor, I recently proposed a 43-GHz VLA survey of some 2 square degrees of the northern sky to search for such a population. This is the highest frequency search for extragalactic radio sources – and it found very few (Wall *et al.* 2006). We conclude that at small angular scales and the high frequencies of the measurements of the power spectrum of the angular fluctuations of the CMBR, there is little to fear from discrete radio source contamination.

I offer some conclusions.

(i) The CMBR was there all the time in our 1965 data; and we could have done the measurements earlier with specific attention to detecting it as a part of our absolute flux measurements. It would have come in somewhere between 3 K and 5 K at a guess. I think it's a stretch to say that we would have believed it on its own; our frequencies were a little low. But had there had been contact with cosmologists such as between Penzias and Wilson (1965a) and Dicke *et al.* (1965), then it might have been different. Too if my cosmic consciousness had not dawned so slowly, it might have been different.

(ii) I cannot have any regrets. My MSc project was superb for starting research in observational astronomy. How better to learn everything about the basics of radio astronomy? Every aspect in the process was revealed to me in glaring detail, all the pitfalls, noise, bandwidth, line-loss, mismatch, spillover, ground radiation, antenna patterns, conversion of antenna temperature to brightness temperature.... It was baptism by fire, and I did love it, I think. It is next to impossible for a student nowadays to learn about instrumentation in depth at any wavelength, and I grudge a big vote of thanks to my supervisors Donald MacRae and Allan Yen for so comprehensively dropping me into it.

(iii) It is possible to observe and not see. After all, Donald Chu and I were only a couple of engineers playing around with horn antennas...

4.10.2 John R. Shakeshaft: Early CMBR observations at the Mullard Radio Astronomy Observatory

John Shakeshaft is an Emeritus Fellow at St Catharine's College, Cambridge. He served for many years as Editor of Monthly Notices of the Royal Astronomical Society.

At the time of publication of the Penzias and Wilson (1965a) paper, I was a member of staff in the Radio Astronomy Group of the Cavendish Laboratory, the physics department of the University of Cambridge, having been an undergraduate and graduate student at Cambridge, the latter under the inspiring supervision of Martin Ryle. I had had an interest in cosmology and measurements of cosmic radio radiation for over ten years. Indeed my first published scientific paper, in 1954, had the title *The Isotropic Component of Cosmic Radio-Frequency Radiation,* although I advise readers not to bother to search it out. At that date, low-noise receivers for the microwave range had not yet been developed, so interest was concentrated at lower frequencies. Westerhout and Oort (1951) had shown that the survey of galactic radiation at 100 MHz (or Mc/sec as we called it) by Bolton and Westfold (1951) could be explained by assuming that most of the radiation came from "radio stars" distributed through the Galaxy in the same way as the common Population II stars of types G and K, although it was necessary to add in an isotropic component besides. They suggested three possible explanations for this extra component but found none to be satisfactory. Subsequent to

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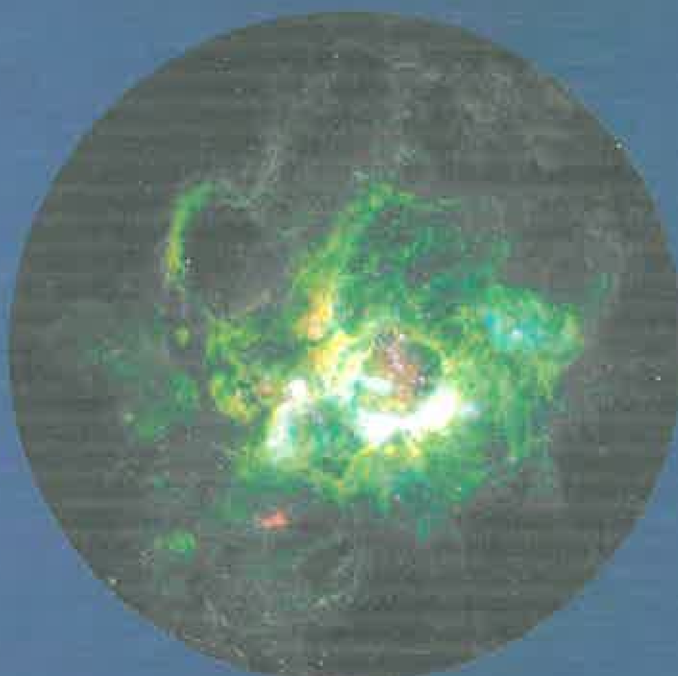
Advanced Stellar Astrophysics



William K. Rose

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Courtesy of Hui Yang, the Space Telescope Science Institute and NASA.**

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