The Discovery of the Radio Source Sagittarius A (Sgr A)

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Abstract. The discovery of Sagittarius A, a discrete radio source associated with the nucleus of the Milky Way, was made by Piddington and Minnett (1951) at 1210 MHz. McGee and Bolton (1954), however, brought to the attention of the astronomical world the association of Sgr A with the Galactic Nucleus. The paper was published in *Nature* and many well known astronomers (Baade, Oort, van de Hulst, Pawsey, Mills, Kerr, and Shain) were involved in the events leading to publication. We summarize the preparation of this paper, re-examining some details published by Morton (1985). In addition we summarize the significance of five publications from CSIRO, Sydney, Australia, in the period 1951 to 1954.

1. Introduction

In contrast to the discovery of the early strong radio sources such as Taurus A, Virgo A, Cygnus A, Centaurus A and Cassiopeia A, the story of the discovery of the radio source Sagittarius A at the center of the Milky Way is not well known. Bolton, Stanley and Slee (1949) suggested optical identifications of Taurus A (the Crab nebula), Virgo A (M87) and Centaurus A (NGC 5128) in a famous but brief (about 600 words) paper in *Nature*. Sea interferometers in Australia and New Zealand had been used at 100 MHz to determine the positions. The positional accuracy was $10'$, a substantial improvement over the 5- $10°$ errors in the earlier sea interferometer results of Bolton (1948), who describes the first six radio sources observed at Dover Heights (Sydney) with the original sea interferometer consisting of a two element 100 MHz Yagi antenna (a photo can be seen in Bolton, 1982, Figure 1).

An example of the existing misconceptions concerning Sgr A can be found in David H. Levy's biography (*The Man Who Sold the Milky Way: A Biography of Bart Bok*, 1993):

"By 1955 radio telescopes were peering into the center of the galaxy and finding deuterium, or heavy hydrogen, at the 91.6 cm wavelength. In the same year Americans R. X. McGee and J. G. Bolton found a bright radio source known as Sagittarius A and proposed, somewhat prematurely, that it could be the actual center of the galaxy."

Of course, deuterium (the DI line) has never been detected by radio astronomers despite repeated searches, and the Australian (McGee) and Englishman (Bolton) never changed their citizenships!

In this paper we summarize the early CSIRO (Australia, "Commonwealth Scientific and Industrial Research Organization") observations in the period 1951 to 1955 made by the Division of Radiophysics in Sydney, New South Wales. We discuss the discovery paper by Piddington and Minnett (1951) of the source Sgr A, and detail the circumstances of the 1954 *Nature* paper by McGee and Bolton. We re-examine some details concerning this publication as discussed by Morton (1985).

A short summary of the discovery of Sgr A has been given by Burke (1964). Slee (1994), in the J. G. Bolton memorial volume, also has described his role in the 80-foot antenna Galactic center survey.

Prior to about 1950, optical observations of stellar kinematics gave a description of the Milky Way as a disk galaxy of radius 8-10 kpc whose center was inferred to be in the direction of Scorpius-Sagittarius. Prior to the radio observations the difficulty in determining the Galactic center position was due to the extinction arising from interstellar dust.

Most of the early papers use the terminology "the Galactic center source". The first reference to Sagittarius A that we have found is by Kraus and Ko (1954), a report on the 250 MHz all sky image made at Ohio State and discussed at the June 1954 American Astronomical Society Meeting in Ann Arbor, Michigan. Also in 1955, Priester used the term *Sgr A* in a paper discussing the possibility that Sgr A is an HII region at a distance of 3 kpc. By 1958-59, the name *Sgr A* was in common usage (eg. Westerhout, 1958 and Drake, 1959).

2. Pre-1950 Observations

In Jansky's 20.5 MHz data of 1932 (Jansky 1935 and Sullivan 1978), made with a resolution of 24° x 35°, a prominent concentration of the Galactic background in the direction of the Galactic center is obvious; Jansky's data do not quite extend to the southern declination of the Galactic center, however. Reber's initial all-sky radio images at 160 MHz (beamwidth, $12^\circ\!.5$, 1944) and 480 MHz (beamwidth 4°, 1948) show prominent concentrations in Sagittarius (RA 17^h56^m, Dec -25°, 1950 coordinates).

3. Piddington and Minnett (1951)

Jack Piddington and Harry Minnett observed at the high frequencies (in 1951) of 1210 and 3000 MHz. They initially used a 10 foot and later an 18 by 16 foot prime focus antenna located at Potts Hill Reservoir in Sydney, shown in Figure 1. This aerial had been used earlier for solar work at 200, 600 and 1200 MHz (Lehany and Yabsley, 1949). At 1210 MHz the noise temperature was 3400K, about 100 times modern values, and the beamwidth was $2^\circ\!.8$.

Piddington and Minnett(1951) describe a ".....new, and remarkably powerful, discrete source" at 1210 MHz, the "Sagittarius-Scorpius" source (the position was close to the border of the two constellations). These authors identify this new source with the center of the galaxy:

"An interesting feature....... is that it lies close to the Galactic plane and very close.... to the plane defined by the maximum level of radio emission. It also lies very close to the centre of the Galaxy and to the maximum of Galactic radiation...... the significance of the position may be considerable. If the source were relatively close to the Sun, it could lie in any direction with equal probability. If, on the other hand, it were at a distance from the Sun which was a considerable fraction of the Galactic diameter, it would be more likely to lie in a direction close to the plane of the galaxy."

Piddington and Minnett then discuss the luminosity of the Sagittarius - Scorpius source assuming a distance of 10 kpc, as well as the presence of a flat radio spectrum between 100 and 1210 MHz. An analogy is drawn with the flat spectrum of Taurus A and the suggestion is made that the source might be an optically thin thermal gas; however, the authors are already aware of the problem of this interpretation in those "pre-synchrotron emission" days.

In a footnote to his book on the history of Australian radio astronomy, Robertson (1992) has given credit to Piddington and Minnett for the discovery of the Galactic nucleus; the main text in the Robertson book is concerned with the McGee and Bolton (1954) paper, however.

4. Mills (1952)

In a fascinating paper in 1952, Mills describes an all sky survey made at 101 MHz with a three element, phase-switched interferometer. The spacings were 270m (lobe spacing $40'$) and 60m ($3°$ lobe); seventy-seven sources were in this catalog. Mills identifies two classes of sources: class I, concentrated to the Galactic plane and class II, the sources randomly distributed over the sky. In addition Mills shows that the extended radio Galactic background cannot be the integrated output of the class I sources. In addition, "....it might be said that there is a suggestion, but no definite evidence, that some of the class II sources are extragalactic." This paper also includes a log N - log S (number counts as a function of source flux density) analysis for both types of sources.

Source 17 - 2 B is undoubtedly Sgr A; the position is a few degrees displaced, probably due to the large primary beam of the single elements of the interferometer ($24°$ x $14°$). Mills makes no mention of a possible identification with the Galactic center. The vastly different flux densities between the shortest spacing (3000 Jy) and the longest (300 Jy) suggested an angular size of $35'$. In addition, the flat radio spectrum between 101 MHz and 1210 MHz is discussed, suggesting a "thermally emitting thin gas." However, the much larger flux density at 18 MHz (57,000 Jy) observed by Shain and Higgins (1954) indicates that the spectrum may be more complex and thermal emission must "be discounted."

5. Bolton et al. 1954a

Bolton, Westfold, Stanley and Slee (1954a) subsequently investigated the radio sky looking for large sources, sizes $> 1°$ at 110 MHz. The primary instrument was a two element sea interferometer with variable azimuth spacings of 12 to 60m. An intense source ("L") near the Galactic center with a large angular size (12° x 2°) was detected. In addition, the 72- foot reflector, the prototype of the final 80-foot reflector, was used to study the source at 160 MHz (see Figure 7 in Bolton, 1982). The position ".... is close to the accepted position of the Galactic centre. .... There is an extended physical object at the centre of the galaxy, which is an unusually intense source of radio noise."

6. Bolton et al. 1954b

Bolton, Stanley and Slee (1954b) used a sea interferometer to image the declination range +50° to -50° with an approximate lobe separation of 1°. The structural elements of the 9-Yagi array were used to build a 12-Yagi array on an azimuth mounting at the cliff edge at Dover Heights on Defence Department property (see the cover of the Proceedings of the Astronomical Society of Australia, Vol. 4, No. 4, 1982). As Slee (1994) has pointed out, the rusty remains of the frame work of the azimuth mounting are all that are to be found in the mid 1990s. The survey was made in 1951-52 and was the final, most sensitive sea-interferometer survey. The positions had a precision of $\sim$0.5° in right ascension and $\sim$1° in declination. The final source list had 122 sources down to a limiting flux density of 40 Jy. Source "68" is Sgr A (although Bolton et al place it in Scorpius!).

For the Dover Heights scene in the mid- 1950s , see the photo (Figure 1c) published by Slee, 1994. In July 1995, Goss photographed this scene; only the rusty remains of the rusting radar turntable remains. A small brass plaque commemorating the 40th anniversary of the first paper on the optical identifications published by Bolton, Stanley and Slee (1949) (see Slee 1994) is mounted nearby on a concrete slab at ground level.

7. The 80-foot Telescope - McGee and Bolton 1954

John Bolton has described his efforts and those of his colleagues to dig a hole in the sandy soil on top of the cliff at Dover Heights, Sydney, to construct first a 72-foot diameter paraboloid to observe at 160 MHz, and later an extension to 80 feet, concreted and surfaced with chicken wire, to operate at 400 MHz (Bolton 1982). During the preparation of the 400 MHz receiving equipment, Bolton was transferred to the Rain Physics group of the Radiophysics Laboratory in mid 1953. He was to spend a year there before taking up an appointment to establish radio astronomy at the California Institute of Technology. Thus Dick McGee, a newcomer to experimental radio astronomy, was left to make a sky survey between declinations -17° and -49° ably assisted by Gordon Stanley and Bruce Slee. The survey and its analysis were completed towards the end of January, 1954. The 80-foot antenna is shown in Figure 2 (see also Bolton, 1982, Figure 11). McGee is shown in this photo from 1953. Another view of this telescope can be found as Plate 1 in McGee et al (1955). A construction photo, with has modern parallels with the construction of the Leighton mm telescopes, is shown in Figure 10 in Bolton (1982).

Don Morton (1985) has told the story of the 400 MHz Sgr A source (detected in this survey) including Baade's excitement over the map: "Frankly I jumped out of my chair the moment I saw what it meant..." Henk van de Hulst writes: "...The position agrees quite well with the best we can do on the basis of the 21 cm observations.". Jan Oort's letter replying to Baade concludes "...I have been excited by Pawsey's diagram..." However some of the details in the account could not be remembered by McGee even when Morton showed him two strongly written letters from John Bolton in 1985. They portray Dr. Joe Pawsey in a rather poor light. In an effort to set the record straight, McGee recently has obtained from the Australian Archives his own observing log, his analysis log, the reductions and maps and, most importantly, his publications file of the *Nature* paper "Probable Observation of the Galactic Nucleus at 400 Mc/s."

His version of the events and how the paper received its title follow. Late one evening in late 1953 or early 1954 the radio astronomy group leader, Joe Pawsey, called into the Dover Heights field station just as McGee was completing the 400 MHz contour map in pencil. He was immediately excited by the prominent appearance of the Sgr A source and asked McGee to redraw the map in Galactic coordinates so that he could send a copy to Walter Baade at the Palomar Observatory. Baade had discovered what he described as the nucleus of the Andromeda (M31) galaxy and in fact had suggested to John Bolton as early as 1951 that a radio search ought to be made for the nucleus of our own galaxy.

On 22 February 1954 Pawsey sent a memorandum to:

"Mr. J. G. Bolton, Mr. R. X. McGee. The attached is Baade's reply to my letter telling him of the source at the galactic centre. What do you think about a note to *Nature* or *Observatory* outlining the various wavelength surveys? The subject is of wide interest, signed J. L. Pawsey, Assistant Chief of Division."

The Baade letter of 16 February 1954 is quoted extensively by Morton (1985). In addition to his excitement (see above), Baade concludes:

"It is very improbable that the coincidence between inferred and observed position of the nucleus is accidental."

Morton also has quoted in detail the letter of Henk van de Hulst (he was in Pasadena in 1954) to Pawsey as well as Jan Oort's reply to Baade concerning the location of the Galactic nucleus.

McGee wrote a letter for *Nature* entitled "The Galactic Nucleus." Pawsey looked over the first draft, changed the title to "Radio Observation of the Galactic Nucleus" and reduced the text by nearly 40 per cent. It was suggested to John Bolton (by McGee) that he should be listed as senior author, but he pointed out that he was no longer involved and eventually compromised to accept second authorship. He was far too busy rainmaking to contribute in any way to the writeup. On 29 March the draft went to be refereed by the famous publications committee of the Radiophysics Laboratory with Frank J. Kerr as chairman. The committee did not take the optimistic view of the leading astronomers mentioned above. To give some examples of the caution they displayed:

Kerr:
"In view of the uncertainty as to whether this is the nucleus, or a source near, or in the direction of the nucleus, the wording wants to be carefully phrased..."

The paper was passed to B. Y. Mills for perusal.

Mills:
"The results should obviously be published quickly as they are important. However the general tone of the paper seems far too dogmatic-even the title! And positive identification with the Galactic nucleus is impossible at present..." An interesting comment which perhaps indicates the state of the art at that time: Mills: "In view of the importance of deciding whether Pop II systems emit radio waves it seems important that a definite identification with the nucleus should not be claimed. (there is also the possibility that the position is a pure fluke - see Haddock APJ Jan 1954.)" (This paper, by Haddock, Mayer, and Sloanaker, appears in the March 1954 Astrophysical Journal.)

On reading through a draft of the current paper in April, 1996, B. Y. Mills, commenting on his views expressed above, writes:

"After several months spent at Caltech (in late 1953 - early 1954) I no longer looked on eminent astronomers as minor deities and I would certainly have taken Baade's reaction with a grain of salt... Also I had been impressed by the observations at NRL (Haddock et al.) which showed a number of sources along the galactic plane, including Sgr A, and I had discussed them at length with Fred Haddock. Why no comment from Baade then? He certainly knew of them. Perhaps the NRL emphasis on emission nebulae [*comment by Goss and McGee: there was, of course, the possibility that Sgr A could have been an HII region along the line of sight to the Galactic center*] made the difference. ...Both Baade and Minkowski in 1954 still believed that the source of galactic radio emission was a type of Pop II star (Baade later told me [*ie Mills*] that he only changed his mind after my failure to detect emission from globular clusters with the Cross in 1955) and galactic nuclei were then believed to be concentrated Pop II systems - AGNs were unheard of. I must have seen the connection and Baade's enthusiasm for the identification could have been the result of suddenly realising that it fitted nicely with his overall view, a view that I did not share. Re-reading a few articles has convinced me that most radio astronomers regarded the determination of a reliable distance as essential for a definite identification and this did not happen until the later H-line observations. In my PASP review of 1959 (Mills, 1959) I wrote : 'For some time it has been known that a strong radio source exists very close to the direction of the galactic centre... and there has been much speculation whether this source, Sagittarius A, might represent emission from the nucleus. As a result of 21 cm line observations by Rougoor and Oort (1959) it now appears very probable that this is so; at least their observations show conclusively that the source must be located in the central regions of the Galaxy. '"

The detailed reader on the publications committee was C. A. Shain who suggested that the title should be "Observations of the Region of the Galactic Nucleus at 400 Mc/s" together with several pages of quite helpful criticisms. Quoting one general remark:

Shain: "The title and the statement towards the end of page 2 indicate that you are making a definite claim that the 'hump' on your contours is the galactic nucleus and, if only by inference, that the position of this 'hump' is the best available determination of the nucleus."

McGee incorporated most of the committee's suggestions into the text which went back to Mills and finally Kerr for further comments and, after a required change by R. N. Bracewell on the contours, final acceptance. The extraordinary interest of senior members of the Radiophysics Laboratory in papers for publication can surely only be gratefully commended. Nevertheless McGee's confidence in claiming observation of the Galactic nucleus was severely shaken.

On 14 April, McGee took the paper to Pawsey for his final approval. Pawsey immediately changed the title back to "Observation of the Galactic Nucleus at 400 Mc/s". McGee suggested that the word "Possible" before "observation..." might be appropriate in view of the committee's attitude. But Pawsey, buoyed up by the support from Baade, van de Hulst and Oort, compromised with "Probable etc." Thus it appears that John Bolton's recall of these events as related to Don Morton was not accurate. Certainly the watered-down title cannot be blamed on Pawsey. The *Nature* paper appeared in the May 22, 1954 issue; the acknowledgements mention Westfold, Stanley, Slee, and Baade. A full account of the Galactic center survey was presented by McGee, Slee and Stanley (1955).

As C. M. Wade has pointed out to us, the general acceptance of Sgr A as the Galactic nucleus was still a controversial point of lunch time conversation at Radiophysics in the period 1957 - 1959. Only later does it appear that the astronomical community accepted the association of Sgr A with the Galactic center with no reservations. (See the above comments by Mills and also a critical discussion by Mills, 1956, who suggests that, based on the lack of spherical symmetry in the non-thermal radio source, the radio emission cannot be related to the spherically symmetric Pop II system of stars in the Galaxy.) In his classic textbook of 1960 (apparently updated in September 1958), I.S. Shklovsky suggests :

".... let us say that today we can consider it definitely established that Sagittarius A is indeed the Galactic radio nucleus."

John Bolton attended the 1955 IAU General Assembly in Dublin and proposed that, in view of the findings on Sgr A, the Galactic coordinate system should be revised. However, the new system was mainly based on 21-cm hydrogen line surveys at Leiden and Sydney. This system was introduced in a series of five papers in 1960 by Blaauw et al. Nevertheless Blaauw, Gum, Pawsey and Westerhout write in 1960 ("The New I.A.U. System of Galactic Coordinates"):

"We shall.......assume that Sagittarius A is located at the galactic centre."

In the final paper in this series by Oort and Rougoor ("The Position of the Galactic Centre," 1960), they conclude:

"The position of Sagittarius A has been discussed.... This position agrees so precisely with the direction of the galactic centre..... that this by itself makes it almost certain that Sgr A is situated at the centre of our Galaxy."

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References

Blaauw, A. ,Gum, C.S. ,Pawsey, J.L. ,and Westerhout, G. 1960, MNRAS,121,123

Bolton, J.G. 1948, Nature, 162, 141

Bolton, J.G. ,Stanley, G.J. ,and Slee, O.B. 1949, Nature, 164, 101

Bolton, J.G. ,Stanley, G.J. ,and Slee, O.B. 1954b, Aust.J.Phys. ,7, 110

Bolton, J.G. ,Westfold, K.C. ,Stanley, G.J. ,and Slee, O.B. 1954a,Aust.J.Phys. 7, 96

Bolton, J.G. ,1982, Proc. Atron. Soc. Aust. ,4,349

Burke, B.F. 1965, Annual Rev. AA, 3, 275

Drake, F. D. 1959, AJ, 64, 329

Haddock, F.T., Mayer, C.H. , and Sloanaker, R.M. 1954, ApJ, 119, 456

Jansky, K.G. 1935, Proc. IRE , 23, 1158

Kraus, J.D. and Ko, H.C. 1954, Sky and Telescope, 14, 22

Lehany, F.T. and Yabsley, D.E. 1949, Aust. J. Sci. Res. ,A2, 48

Levy, D.H. 1993 ,*The Man Who Sold the Milky Way: A Biography of Bart Bok*, Univer. of Arizona Press

McGee, R.X. and Bolton , J.G. 1954, Nature, 173, 985

McGee, R.X. , Slee, O.B. and Stanley ,G.J. 1955, Aust. J. Phys., 8, 347

Mills, B.Y. 1952, Aust. J. Sci. Res., A5, 266

Mills, B.Y. 1956, Obs. ,76, 65

Mills, B.Y.,1959, PASP, 71, 267

Morton, D.C. 1985, Aust.Physicist, 22, 218

Oort, J.H. and Rougoor, G.W. 1960, MNRAS, 121, 171

Piddington, J.H. and Minnett, H.C. 1951, Aust. J. Sci. Res. ,A4, 495

Priester, W. 1955, Zeit. f. Astro.,38,73

Reber, G. 1944, ApJ, 100, 279

Reber, G. 1948, Proc. IRE ,36, 1215

Robertson, P. 1992, *Beyond Southern Skies- Radio Astronomy and the Parkes Telescope*, Cambridge Univer. Press

Shain, C.A. and Higgins, C.S. 1954, Aust. J. Phys., 7, 130

Shklovsky, I.S. 1960, "Cosmic Radio Waves", Harvard Univer. Press

Slee, O.B. 1984, Aust. J. Phys., 47, 517

Sullivan, W.T. III, 1978, Sky and Telescope, 56, 101

Westerhout, G. 1958, BAN, 14, 215

9. Figure captions

Figure 1-left. One of the antennae used by Piddington and Minnett(1951). It was an 18 x 16 foot paraboloid. The observing site was at the Potts Hill Reservoir field station some 20 km south west of Sydney. Photograph provided by W.N. Christiansen. The first detection of Sgr A was made with this antenna.

Figure 2-below. The north aspect of Dover Heights in 1953. The 80-foot paraboloid - the hole in the ground antenna - occupies the foreground. This was a transit telescope that was pointed in declination by tilting the mast. The front end of the 400 MHz receiver was mounted immediately above the dipoles and reflector feed. R. X. McGee is holding one of the mast guy ropes. South and North Sydney Heads can be seen in the central background. Today this site is a sports field in Rodney Reserve. This radio telescope was used for the observations described by McGee and Bolton in their 1954 *Nature* paper.