The Discovery of Sgr A

W.M. Goss 1, Robert L. Brown1,2, and K.Y. Lo1
1 National Radio Astronomy Observatory
2 National Astronomy and Ionospheric Center

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The galactic center compact radio source Sgr A* was discovered on 13 and 15 February 1974 by Bruce Balick and Robert L. Brown using the Green Bank 35 km radio link interferometer (Balick & Brown 1974). We discuss other observations of this source in the years 1965-1985. Early VLBI observations are described. The name Sgr A* was first used by Robert L. Brown (1982) and has become the accepted name for the compact source at the center of the Milky Way.

1 Introduction

The discovery of Sagittarius A as a radio source coincident with the center of the galaxy has been discussed by Goss & McGee (1996). Almost 20 years after the recognition that the center of the galaxy could be associated with Sgr A by Piddington & Minnett (1951) and McGee & Bolton (1954), Sgr A was discovered in February 1974 by Bruce Balick and Robert L. Brown in Green Bank, West Virginia. This discovery is certainly one of the more important galactic radio astronomy discoveries of the 1970’s and has had wide ramifications during the last 30 years. As an example, the recognition that the radio source Sgr A is the dim radio source associated with a black hole has represented a fundamental advance in our understanding of the nuclei of galaxies.

The participants in the complex story of the discovery of Sgr A are numerous: B. Clark, D. Hogg, G. Miley, B. Turner, C. Heiles, R. Ekers, D. Lynden-Bell, D. Downes, A. Martin, B. Balick, R. Brown, M. Goss, K.Y. Lo, U. Schwarz, D. Rogstad and others. (Most of these are still active astronomers.) We present a short history of the discovery process (section 2) and provide some details on the naming of Sgr A in section 3. In section 4, we provide a short summary of the determinations of the secular parallax of Sgr A. Goss (2003) has also presented a summary of the discovery of Sgr A. The process of discovery of Sgr A was the result of the application of a matched filter in angular resolution to the properties of Sgr A; of course, the construction of this filter can only be understood with an a posteriori knowledge of the properties of Sgr A.

2 The years 1965-1985

In 1966, Clark & Hogg (1966) used the newly completed 2 element Green Bank interferometer at 11 cm to investigate the small scale structure of a number of radio sources at 11 cm with a resolution of 10\(^{10}\). The source Sgr A was found to have a compact feature with a flux density of 0.5 f.u. (Jy); with this resolution the confusion from Sgr A West is a dominant effect. But these observers were “close” to the discovery of Sgr A. We now know that a resolution of 30\(^{10}\) is required at this frequency.
The key observation that led to the discovery of the compact source at the center of the galaxy was an observation by Miley, Turner, Balick, & Heiles (1970). With a baseline of 35 km at 11 cm, these authors discovered a compact source in the H II region W51 with a $T_{\text{b}} > 10^5$ K. The 42 foot telescope, located at the time of the Miley et al. observations at Huntersville, West Virginia, is shown in Fig. 1. Note the limited tracking capability of this antenna. Although this brightness component in W51 has not been confirmed, the result did set off a string of circumstances that led to the discovery of Sgr A only four years later.

The theoretical framework for the search for evidence of the presence of a compact object at the galactic center was provided by Lynden-Bell (1969) and Lynden-Bell & Rees (1971), who made the analogy between quasars and the high energy phenomena at the center of the Milky Way: the latter authors propose four tests for the possible detection of a massive object at the center of the galaxy. The second test is: “Very Long baseline interferometry may soon be possible with ...as weak as 0.5 f.u. to diameters of $10^{-3}$”. If so it may be possible to determine the size of any central black hole that may be in our galaxy. However H II may render the central source opaque with a greater angular size.”

In the course of 1970 (January and May), Ekers & Lynden-Bell (1971) used the newly constructed 40m antenna at the Owens Valley Radio Observatory (Caltech) along with one of the original 90 foot antennas to look for the signature of a black hole in the galactic center. At 6 cm the resolution was $\delta^0$ by $18^0$. Ekers & Lynden-Bell detected fine scale structure in the Sgr A West H II region. “Although stimulated by the black hole idea our observations are thus more simply explained in terms of young stars and giant H II regions.” Again if the resolution had been a factor of about two more favorable, Sgr A would have been detected. (Goss has pointed out in several lectures in Australia that Ron Ekers has mispelled his name in the acknowledgements to the Ekers & Lynden-Bell paper!) Ekers & Lynden-Bell also performed one of the five interferometer searches for radio recombination lines; they used the 90 foot antenna interferometer at 6 cm. They searched for broad recombination lines from Sgr A (Ekers, private communication); the negative result was not reported in the Ekers & Lynden-Bell paper. This test had also been suggested by Lynden-Bell & Rees (see above) to search for the existence of a massive object at the galactic center.

The discovery of Sgr A did occur on 13 and 15 February 1974 by Bruce Balick and one of us (R.L. Brown) using the Green Bank interferometer with an 45 foot antenna at the Huntersville West Virginia site at a distance of about 35 km. This site was the same as the one used in the earlier Miley et al. (1970) observations of W51 but an improved antenna was now used. This antenna at the Huntersville site is shown in Fig.2; the antenna had a wider range of sky coverage and was operated at the dual frequencies of 11 and 3.7 cm. This interferometer was constructed to serve as a prototype of the Very Large Array which was under construction at the time. The publication of “Intense Sub-arcsecond Structure in the Galactic Center” was published in December, 1974 (Balick & Brown 1974). The resolution at 11 and 3.7 cm was $0^\circ7^\text{m}$ and $0^\circ3^\text{m}$, respectively. With this resolution and uv coverage (the three simultaneous baselines from the Green Bank 3 element interferometer and the single antenna at Huntersville), the extended confusion from the Sgr A West (flux density of 25 Jy and size $40^\text{s}$) complex was resolved out. Balick & Brown write: “The unusual structure of the sub-arcsecond structure and its positional coincidence with the inner 1-pc core of the galactic nucleus strongly suggests that this structure is physically associated with the galactic center (in fact, defines the galactic center).” These authors compare the compact source with energetic nuclei of other galaxies and even suggest that variations in the radio flux density might be observed.

Bob Brown has unearthed a number of fascinating letters from Bruce Balick written during the analysis period from mid March 1974 to 2 May 1974. No copies of Bob’s letters to Bruce were saved. There are no dates on Bruce’s letters. In these letters, Bruce gives in some detail his analysis of the data and their possible interpretations. A number of possible models for the observed visibilities are proposed. Reading
these letters today, we are impressed with the meticulous attention to detail in the interpretation of this
difficult observation.

Here are a few amusing quotes from the letters with an emphasis on a fear (in retrospect somewhat
unfounded) of competition. The time frame is toward the end of the period March-May 1974. Bruce
writes: “Here are a few thoughts on the 45 foot Sgr A observations. Fred Lo re-analysed some of his VLB
observations of Sgr A based on a new position I gave him and found 0.3 f.u. at 6 cm [see later for a
description of this October 1973 observation. The detection was only 2-3]. I think his baseline was
Green Bank–Haystack [in fact, Maryland Point]. We’d better publish fast if we want to beat him into print.
I haven’t heard from Goss or Downes. Could you call Dave Hogg [then Green Bank site director] and ask
if he’s heard anything?”.

The following letter expresses some apprehension about IR competition: “Dave Rank and I [at the
University of California at Santa Cruz] are going to try to detect these sources in the IR. Please keep the
positions kind of quiet, cause Becklin and co. can wipe us out if they want to. So can Rieke. Your faithful
collaborator...”

In 1975, Ekers, Goss, Schwarz, Downes, & Rogstad (1975) combined Westerbork (WSRT) data with
Owens Valley Radio Observatory data at 6 cm and made a 2-dimensional image of Sgr A with a resolution
of $6'' 18''$. The image was called the WORST image - the Westerbork Owens Valley Radio Synthesis
Telescope. In fact the beam shape looked like a sausage - “worst” in Dutch. Sgr A was just visible at
the longest spacings of the interferometer and Sgr A East, the non-thermal source that may be a luminous
supernova remnant, was clearly detected as well as hints of the mini-spiral structure of Sgr A West, a H II
region associated with the center of the Milky Way.

The first VLBI attempt to detect a compact source at the center of the Milky Way was carried out by
K.Y. Lo and collaborators in October, 1973. The observation is described by Lo (1974) in his MIT Phd
thesis of August 1974: “Interstellar Microwave Radiation and Early Stellar Evolution”. Lo was following
up on the Miley et al. W51 observation of 1970, to try to confirm the detection of compact structure in HII
regions, beyond what had been expected theoretically. The observations were at 6 cm between the Green
Bank 140 foot (see above) and the Naval Research Laboratory 85 foot Maryland Point radio telescope. The
GB-MP baseline is mainly E-W with a length of 228 km. A source with a diameter less than 26 mas (EW)
would be unresolved and detectable down to a flux density of 0.1 Jy. As we now know, the size of
Sgr A at 6 cm is broadened by interstellar scattering to an EW by NS size of 51 27 mas (Lo et al.
1998; Davies, Walsh & Booth 1974). The orientation of the baseline was therefore quite unfavorable for a
detection. So, while there were hints of a signal in the visibility amplitude, the detection was not definitive.
If the baseline had been oriented in a roughly N-S direction, the source would have been detected.

For one of us (Goss), an amusing and somewhat embarrassing episode occurred in the years 1972-1974.
On 2 June 1972, D.Downes and Goss (both working at the Max Planck Institute for Radio Astronomy in
Bonn, Germany) submitted proposal D43 to NRAO for an observation of the galactic center with the Green
Bank 35 km radio link interferometer. The proposal was sent to D.Heeschen, D.Hogg and W.E.Howard.
We have been able to reconstruct all these events based on the extensive paper archive preserved (in 2003)
by Dennis Downes from these pre-email days. The proposal included two positions in Sgr A and three
in Sgr B2. A few key sentences from the proposal follow: “In view of the increasing interest in highly
collapsed nuclear objects as probable sources of the energy in QSO’s and radio galaxies, it is of paramount
importance to pursue investigations of compact structure in Sgr A. Although the center of the galaxy is
relatively quiescent, it is so close that we can observe details on a much finer linear scale than is possible
in external galaxies, even with VLB techniques. We regard this project as an experiment which may be
a useful guide to future observations by the VLA.... These observations might be used in future programs
to investigate short-term variability in the galactic center.” Although these ideas were relevant, Goss and
Downes were not able to come to the US in 1973-1974 due to problems obtaining travel funds. Also initial
observations with the 45 foot telescope were somewhat delayed from late 1972 to mid 1973. Early in
1973, Goss had moved to the Netherlands in a visiting position at the University of Groningen to work on
WSRT projects. In addition, Downes was quite busy with early observations with the 100 m Effelsberg
telescope. With these pressures, the urgency to complete the Downes-Goss proposal with the Green Bank interferometer decreased. D. Hogg had been in continual contact with Downes and Goss about scheduling. As shown above, Balick and Brown had an earlier NRAO proposal to observe small scale structure (W51 type components) in H II regions and Sgr A and Sgr B2 were included. Dave Hogg became aware of the proposal conflict in early 1974 and wrote Downes a letter on 15 February 1974 (note the precise discovery date) proposing several ways to resolve this conflict. However, Goss and Downes seemed to have lost interest at this point. Of course, the significant result is that Balick and Brown did discover Sgr A in early 1974 - in fact on 13 and 15 February.

The first successful VLBI detection of Sgr A was made the following year (19 May 1975) by Lo et al. (1975) using the OVRO 40 m and the NASA Goldstone 64-m Mars antenna at 3.7 cm. K.Y. Lo had become a postdoctoral fellow at OVRO after his MIT thesis, but he was interested in following up on the tantalizing hints of detection of Sgr A* on the GB-MP experiment at 6 cm in 1973. It is interesting to recall that after some persuasion by Lo, the observation of Sgr A* was added to the program of his colleagues R. Schilizzi and M. Cohen to study compact symmetric double radio sources. From the California baseline, the inferred size was 20 mas.

At an URSI meeting in Boulder, probably in January 1976, after Lo had reported the detection of Sgr A* at 3.7 cm on the OVRO-Mars baseline, Don Backer asked the interesting probing question of how one can be sure that Sgr A was not a background compact radio source. Interestingly enough, as indicated below, Don Backer answered his own question some years later when he and Dick Sramek detected the secular parallax of Sgr A due to the rotation of the Sun about the Galactic Center.

In the period 10 June 1974 to 10 September 1975, Sgr A was observed with the early MERLIN array at 0.408, 0.96 and 1.66 GHz with baselines of 24 and 127 km. The detections at the latter two frequencies suggested the angular size scales as \( \lambda^{2} \), originating in a turbulent electron distribution along the line of sight (Davies, Walsh & Booth 1974). A number of groups worked on the subsequent VLBI observations of Sgr A* (Kellermann et al. 1977, Lo et al. 1977, Lo et al. 1981, Lo et al. 1985, & Lo et al. 1993). In the 1985 publication of Lo et al., this group determined for the first time that the scattering size of Sgr A* at 3.6 cm was asymmetrical with an axial ratio of 0:55, and at 1.35 cm the limit to the angular size was 20 AU or 2.5 mas.

The Green Bank 35 km interferometer was used to determine that the radio spectrum of Sgr A (Brown, Lo & Johnston 1978) is inverted. Brown & Lo (1982) carried out a ground breaking investigation of the variability of Sgr A at 11 and 3.7 cm over a time interval of 3 years with 25 epochs (Brown & Lo 1982); time variations were detected over all time scales from days to years. This ground breaking project became the basis for future detailed VLA studies of the various scales in the time variations of Sgr A (Zhao et al. 2001).

### 3 The naming of Sgr A

As far as we can ascertain, the only credit attributed to the naming of Sgr A by Brown (1982) is in the Annual Reviews article by Melia & Falcke (2001). The first attempt at a convenient name of the galactic center compact source is by Reynolds & McKee (1980) in a paper entitled: “The Compact Radio Source at the Galactic Center”. This publication presents a model of relativistic outflows, with either a spherical or jet geometry. The fact that the luminosity is 100 times greater than a pulsar but much less than other galactic nuclei was a puzzle. Reynolds & McKee suggest the name GCCRS – the galactic center compact radio source. This name has not survived.

Brown & Lo (1982) discuss the variability of Sgr A (see above) : “Throughout this paper we use the name Sgr A to refer only and specially to the compact radio source. When necessary, we distinguish this from the more extended radio structure at the galactic center.”

In 1982, Backer & Sramek (1982) presented the initial results of the secular motions of Sgr A using the Green Bank radio link interferometer. The motions were found to be consistent with an object at rest in
the center of the Milky Way. Backer & Sramek propose the name: Sgr A\((cn)\) from “compact non-thermal” object in the galactic center. Again this name has had no staying power.

Eight years after the discovery, one of us (Brown) invented the name Sgr A to distinguish the compact source from the other components in the galactic center and to emphasize the unique nature of this source. Brown (1982) proposed a model of Sgr A consisting of twin precessing jets with a period of 2300 years. The model has not stood the test of time but the name immediately was accepted. As an example, the VLBI results discussed by Lo et al. (1985) uses the name Sgr A; the review article by Lo (1987) also uses this nomenclature.

Bob Brown provides the following rationale for the name: “Scratching on a yellow pad one morning I tried a lot of possible names. When I began thinking of the radio source as the “exciting source” for the cluster of H\(\text{II}\) regions seen in the VLA maps, the name Sgr A occurred to me by analogy brought to mind by my Phd dissertation, which is in atomic physics and where the nomenclature for excited state atoms is He, or Fe etc.”

4 The motions of Sgr A

The physical association of Sgr A with the mass centroid of the nuclear region of the Milky Way remained circumstantial until the observation of the secular motion of Sgr A by Backer & Sramek, noted above, was made in 1982 with the Green Bank radio link interferometer. Even in 1983, Martin Rees wrote to Robert L. Brown to report that at the IAU symposium held in June 1983 in Groningen (Netherlands, IAU Symposium No 106) that Jan Oort was worried that the lack of formaldehyde absorption toward Sgr A could have implied that the radio source is located nearer than the true galactic center.

Such concerns were again soundly put to rest based on two companion papers, which were published in the Astrophysical Journal issue of 20 October 1999 (Backer & Sramek 1999; Reid et al. 1999), that summarize the VLA and VLBA determinations of the motions of Sgr A. Don Backer has pointed out to us that the initial Green Bank 35 km radio link interferometer observation of the 1970’s was inspired by a lunch time conversation with Rick Fisher in about 1975 (see the acknowledgement in Backer & Sramek 1999). The secular parallax due to the motion of the Sun around the center of the galaxy, of course, establishes that Sgr A is in the galactic center, but more importantly can be used to set a lower limit on the mass of the black hole of a few thousand M\(\odot\). In addition, a number of constraints on galactic rotation constants can be determined. The long range goal of the VLBA program (Reid et al 1999) is the determination of a parallax distance to the galactic center.

5 Summary

The observations of the last 30 years have provided a wealth of information about the source Sgr A and the environs of the black hole at the center of the Milky Way. Many puzzles remain. We can only imagine the contents of a possible conference on the center of the galaxy that might be held at the time of the 60th celebration of the discovery of Sgr A in 2034. In March 2004, The National Radio Astronomy Observatory will host a conference in Green Bank, West Virginia, to honor the discovery of Sgr A exactly 30 years previously and to discuss recent results on this fascinating radio and X-ray source.

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engendered the enthusiasm that initiated the fascination of Goss, Ekers and Schwarz in the 1970’s for galactic center research.

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Fig. 1 The 42 Foot antenna. The initial location of this antenna was at Spencer's Ridge - 11 km NE of the Green Bank interferometer. The operation was at 11 cm. Basart et al. 1968 and Basart et al. 1970 describe initial observations with a two element interferometer consisting of this antenna combined with one of the 85 Foot antennas at Green Bank. The sky coverage was limited to declinations from 0° to +66° and hour angles within 2h 40m 15s of the meridian. For the observations of W51 described by Miley et al. 1970, the antenna had moved to the Huntersville site - 35 km to the SW of Green Bank. These observations were a partial inspiration for the Sgr A* observations of 1974. Later the 42 Foot antenna was replaced by the fully steerable antenna shown in Fig.2 at the Huntersville site. Fomalont (2000) summarizes the development of the Green Bank radio link interferometer in the years 1966 to 1978.
The discovery of Sgr A was made in February, 1974 by Bruce Balick and Robert L. Brown using this instrument (Balick & Brown 1974). The dual frequency instrument operated at 11 and 3.7 cm and was used as a prototype for the VLA in the planning stages during the early 1970’s (see Fomalont 2000). The 45 Foot telescope was the fourth element of the interferometer; correlations were performed with all three of the 85 Foot antennas at Green Bank. This smaller antenna is now at the Green Bank site and has had an illustrious career as a component of the tracking stations for the HALCA VLBI spacecraft. The two antennas for telemetry are pointing to the Green Bank site to the northeast; the local oscillator signal was transmitted by a two way link at 1.3GHz while the 18GHz link was used for telemetry and IF transmission. During the summer there was no clear line of sight to the main interferometer site due to leaves in intervening trees. A passive reflector was used on a hill behind the main site to overcome this problem. Much of the development work for the radio link was done by N.G.V. Sarma who was on a sabbatical from the Tata Institute for Fundamental Research (Ooty) in India.