DIFFERENTIAL RADIO ASTRONOMY OF GALACTIC OBJECTS

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INTRODUCTION

In contrast to the very distant quasars and galaxies used for geodetic studies discussed so far, pulsars, radio stars, and other galactic continuum objects have large transverse motions from proper motion, parallax, and orbital effects which can be measured with recently developed microwave interferometers. We (the author in collaboration with R. A. Sramek of the National Radio Astronomy Observatory (NRAO)) established a program in 1974 designed to measure these motions with the 35-km interferometer in Green Bank, West Virginia, at an observing wavelength of 11.1 cm. Our first results (1976, AJ, 81, 430) demonstrated the sensitivity of this instrument to the proper motions of pulsars: Motions of $0\overset{''}{.}05\ yr^{-1}$ were detectable for these faint objects with several observing sessions spaced over 1½ years. We will discuss our differential astrometry technique and present an improved proper motion and a parallax limit for pulsar 1929 + 10 and a limit on the space velocity of the enigmatic object in SgrA.

TECHNIQUE

Most of you are familiar with the 35-km, radio-link interferometer developed by the NRAO and currently operated by the U.S. Naval Observatory (USNO). Three baselines, each with dual polarization, are formed between a remote 45-foot (13.7-meter) telescope and the local 85-foot (25.9-meter) telescopes in Green Bank. Six simultaneous interferometers are thus recorded providing necessary sensitivity and extremely useful redundancy. A small amount of tropospheric phase noise is also eliminated. We observe a sequence of reference (A) – program object – reference (B) – program object – etc., with references located on nearly opposite sides of the program object. A weighted average of reference data will yield the equivalent data of a pseudo-reference source as close as possible to the program object. In principle, three references could be observed and the pseudo-reference placed coincident with the program object to remove phase fluctuations which vary linearly over the object/reference region of the sky. However, the sky density of catalogued compact objects, instrumental sensitivity, and temporal variations of the phase fluctuations conspire to limit our observations to two reference sources.

The online phase residuals from Green Bank were first corrected for known errors in baseline, clock, atmosphere, and source position in Charlottesville, and then averaged to form an amplitude and phase for each baseline and polarization for each 5 to 10 minute scan. These data were taken to Berkeley for further analysis containing the following steps:

(1) position update for errors ascertained after initiating a standard reduction procedure in Charlottesville;

(2) integration over polarization channels and three successive hour-angle scans to obtain unambiguous phase estimates on the faint program object;

(3) removal of lobe ambiguities;

(4) linear interpolation in time of the reference phases to the time of object observations and subtraction of weighted sum of these interpolated values from the object phases;

(5) fitting of the above "first difference" phase for each baseline on each day and each epoch to a pseudo-position offset. The pseudo-position offsets for any program object may be modeled by

$$\underset{\sim}{\Delta S}_{pp} = \underset{\sim}{\Delta S}_{o} + \underset{\sim}{\mu} T + \underset{\sim}{\pi}(T) + \text{orbital effects } (T)$$

where $\underset{\sim}{\Delta S}_{o}$ is a constant and T is the interval of time from initiation of observations. Source structure effects may also enter the model.

1929 + 10 RESULTS

An example of the effectiveness of this technique is demonstrated in figure 1 for the pulsar 1929 + 10. The pseudo-position offsets in milliarc seconds are shown during 1974 to 1976 for position axes (x, y) rotated 40° from the (α, δ) axes to coincide with the normal axes of the measurement errors. This results from our 4-hour observation providing limited UV coverage in pa −50°. The results for each day and baseline are given separately. The agreement of the Y-offset measurements with a proper motion of 0.″08/yr is excellent. This corresponds to a transverse velocity component of 40 km/s at a distance of 100 pc. The sine wave in figure 1 is the parallactic shift for an object at a distance of 50 pc – clearly 1929 + 10 is not closer than 50 pc.

In figure 2, we compare absolute positions for 1929 + 10 from our program and from timing measurements which effectively employ an interferometer with a baseline of 1 AU but which has a delay resolution of only 10 to 1000 μsec. The right ascension measurements are in excellent agreement. Our declination disagrees slightly with the timing measurements which disagree with each other in μ^{δ}.

SgrA

In 1975, we began observing the compact object in our galactic center, SgrA. If this enigmatic object is at rest in the gravitational barycenter of our galaxy, then observations of SgrA with respect

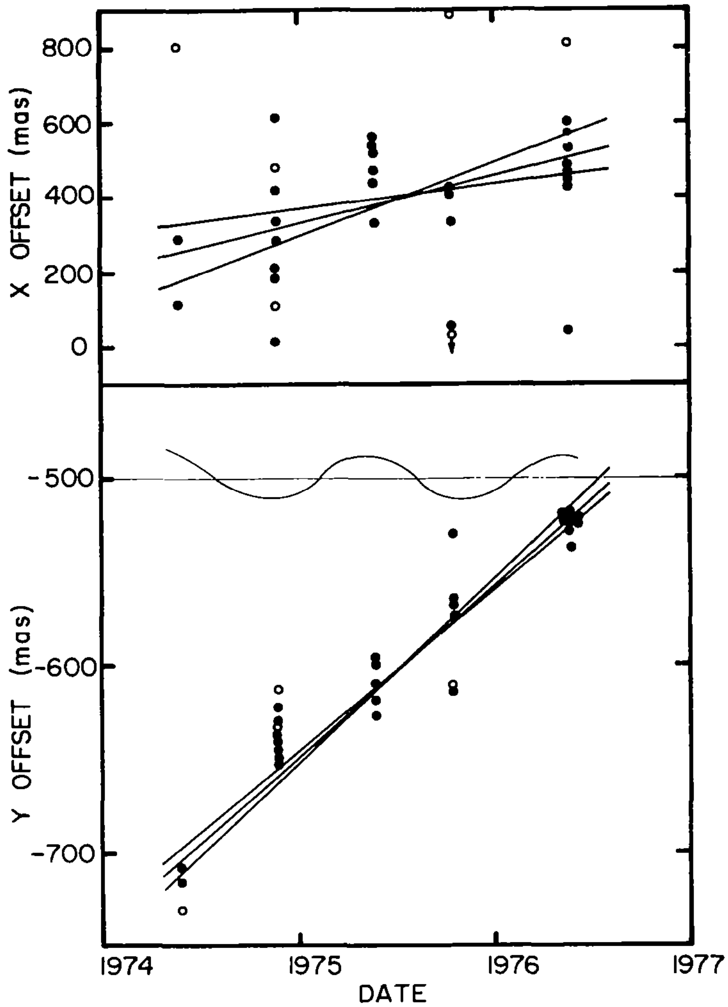

Figure 1. Pseudoposition offsets along axes at position angle of 40° showing proper motion of pulsar 1929 + 10. Offsets are given in milliarc seconds. The sinusoid in the lower section is the expected offset from trigonometric parallax at a distance of 50 pc. Open circles designate data with large errors.

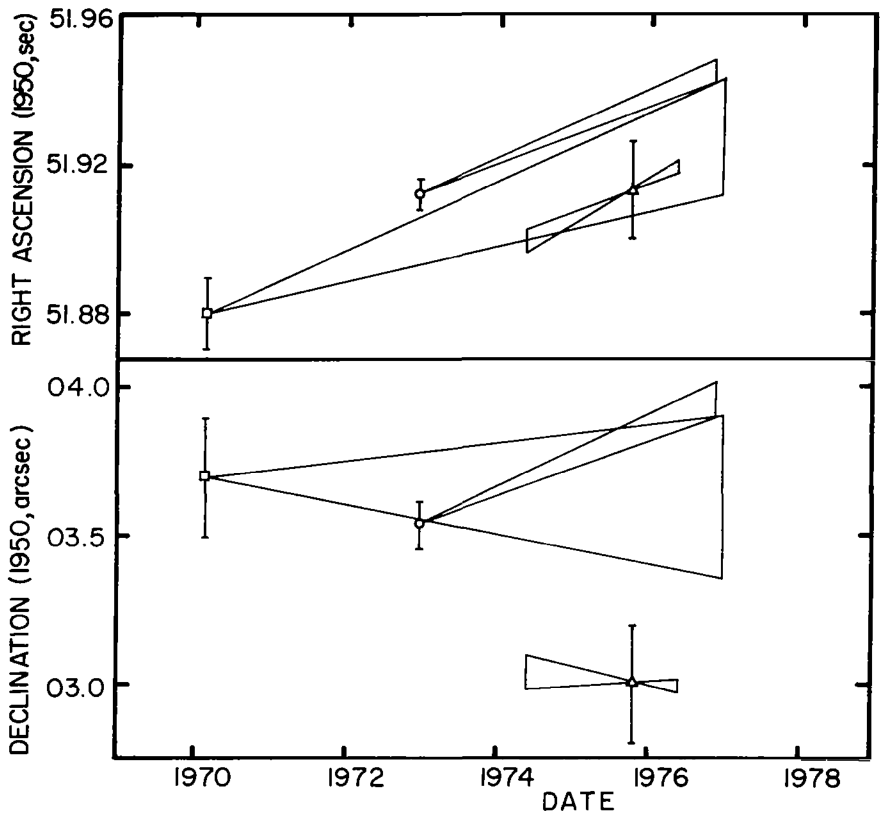

Figure 2. Absolute position and proper motion of 1929 + 10 from our interferometer measurements (Δ), and from timing measurements (□ = Helfand et al. 1979, Ap. J., in press; ○ = Gullahorn and Rankin 1978, A. J., 83, 1219). The right ascension is 19h29m; the declination is 10°53′.

to an extragalactic frame would directly measure the rotation rate of the galaxy. It is likely, however, that SgrA is not at rest – the infrared studies of Lacy and Townes indicate a dynamical center not coincident with this radio object and velocities of order 300 km s^{-1}. In this case, we would remove an assumed galactic rotation rate from a SgrA measurement and hope to learn more about the nature of this object.

Figure 3 shows, unfortunately, that measurements with the 35-km instrument using reference sources 2° and 3° away can only place an upper limit of $\mu_y \leq 0''.01$ yr^{-1} (in 2 years) at a position angle roughly parallel to the galactic plane. The galactic rotation rate is $0''.005$ yr^{-1} in this plane. The limit corresponds to a transverse velocity limit of 1000 km s^{-1} at 10 kpc – moderately interesting, but we would like to do 10 times better.

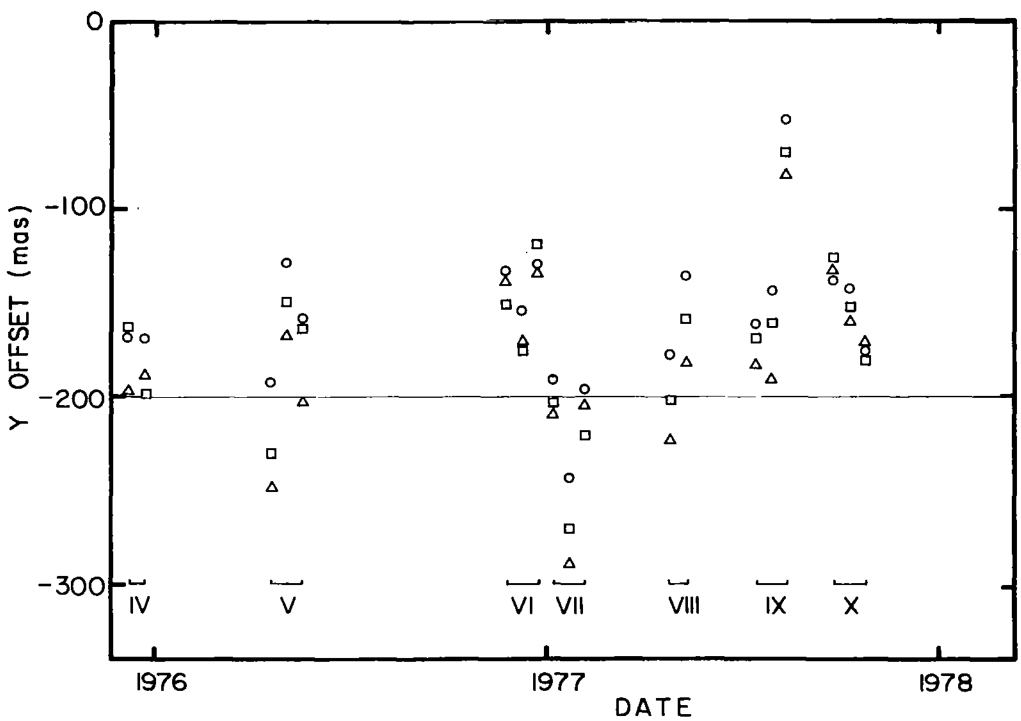

Figure 3. Pseudoposition offsets along an axis nearly parallel to the galactic plane for SgrA. Systematic differences between offsets from the three baselines (○ = 14, □ = 34, Δ = 24) probably result from confusion in the vicinity of SgrA. The measurements were taken at epochs IV through X.

We seem to be affected by structure which causes a 0."030 shift of the 14 baseline offset relative to 24. Tests indicate the shift is not consistent with a first difference lobe error. The shift may well result from structure of, or confusion near, SgrA.* Estimates of interstellar scattering for SgrA would predict an apparent size of 0."300 at 11.1 cm λ.

We note that the sun passes near SgrA in December. Estimates of the differential deflection predicted by general relativity give 0."025 – a factor which must be removed before combining these data for formal proper motion limits.

I should emphasize that figure 3 contains pseudo-position offsets for every day of every epoch independent of the often variable weather in Green Bank. This plot then gives an indication of the reliability for absolute astrometry at declinations of –30° (sec z $\gtrsim$ 3).

*This shift has been identified as the result of comparing Y offsets on slightly different frames of reference for the three baselines. An improved analysis of these observations will be presented elsewhere (Backer and Sramek, 1980, in preparation).

Closer reference sources, a longer time base and, of course, a more southerly site are required to make further progress on this object.

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