Memo to: Craig Walker, VLBA Designers and Pulsar Astrometers

From: Carl Gwinn, Center for Astrophysics

VLB ARRAY MEMO No. 361

Subject: Pulsar Astrometry and Ionospheric Corrections

I would like to contribute to the present discussion of pulsar astrometry with the VLBA (VLBA memos 343, 357). My comments are based on my PhD thesis which describes measurement of the parallaxes of two pulsars with VLBI (Taylor et al. 1983; Gwinn 1984). The research was carried out by Joe Taylor, Joel Weisberg and Lloyd Rawley, in addition to me.

I agree with Don Backer that L-band observations are optimal for pulsar astrometry. As he also states, a large antenna, such as Arecibo or the VLA, will be necessary in addition to the VLBA. This is the case not only because pulsars are weak, but also to make weak, nearby sources available as phase references. Systematic errors make it important to find references as close to the pulsars as possible.

Ionospheric corrections are particularly important for astrometric observations at L-band. The ionospheric free electron column density at zenith (known as the Total Electron Content or TEC) may vary from 5×10^{16} m^{-2} at night to 5×10^{17} m^{-2} by day, representing from 4 to 40 turns of phase at L-band. It is also subject to fluctuations of up to a few percent on timescales of an hour or less (Hagfors 1976, Hinder and Ryle 1971, and references therein).

Several methods have been used for such corrections. They determine the ionospheric path length along the line of sight either from the fringes themselves, from independent ionospheric measurements, or from a priori models.

Dual frequency S/X band observations have been very successful for correcting astrometric observations of quasars (Herring 1984). Pulsars are too weak at X-band to make these practical; L/S band observations would work. The S/X correction might be extrapolated to the pulsar from a nearby quasar, with the help of other ionospheric data. Other data is necessary because the path lengths over each station and an assumed zenith angle dependence (mapping function) are necessary to extrapolate the correction, while the S/X observation yields only the difference in ionospheric path lengths.

Another method using the fringes themselves to determine the correction uses the fact that phase and group delays are affected with opposite sign. This method is limited by the SNR and the systematic errors of the group delays. Norbert Bartel has described these two techniques in his VLBA memo.

Independent ionospheric information from satellite doppler (Campbell and Lohmar 1982), satellite Faraday rotation (Gwinn 1984) and ionosonde measurements (Hinder and Ryle 1971) have been used to make ionospheric corrections for radio interferometry. Satellite doppler observations measure the differences in ionospheric path length among a number of lines of sight. Multiple stations and an assumed mapping function yield absolute thicknesses. Faraday rotation data yields the ionospheric path length along a single line of sight; the technique is insensitive to the the free electron density at very high altitudes. Ionosondes yield data on the ionosphere up to the level of maximum free electron density, from which the TEC can be estimated with a claimed accuracies of up to 20%.

These measurements are then extrapolated to the line of sight from the radio telescope to the source. Typically, this is done in a framework in which the ionosphere is assumed to consist of a thin layer localized at mean ionospheric altitude, whose TEC varies only with geomagnetic latitude and solar time. The ionospheric path length for a particular line of sight is thus the product of the TEC at the point under the intersection of the line of sight with ionospheric altitude (the subionospheric point) and a factor for the slant of the line of sight there. The geometry is shown in Figure 1.

A critical question is the accuracy with which this extrapolation can be made. Klobuchar and Johanson (1977) have studied the question by correlation of Faraday rotation data along different lines of sight. They observed that the day-to-day variation of TEC around its monthly average diurnal pattern is 25%, and correlated these variations between stations. They conclude that the correlation falls linearly with increasing separation of subionospheric points, falling to 0.87 when they are separated by 1200 km in longitude or 800 km in latitude. With some additional assumptions (Gwinn 1984), this represents to an accuracy of about ±13%. Much of the 25% variation is accumulated during a couple of disturbed days per month; the correlation is poorest at such times as well.

An algorithm for estimation of the TEC has been given by Klobuchar (1975). He estimates an accuracy of about ±50%, obtained by roughly calculating the monthly average TEC.

I used Faraday rotation data for my thesis measurements. The data were obtained from the World Data Center in Boulder, CO. Our observations were made with the Arecibo 300 m, Green Bank 43 m, and Owens Valley 40 m telescopes. Since Arecibo is a transit instrument, we observed along a restricted number of lines of sight, corresponding to limited ranges of subionospheric points. These lay close to those of satellite Faraday rotation antennas, as shown in figure 2. A still-incomplete comparison of data between observations indicates that the accuracy of the ionospheric correction is equal to or greater than that estimated on the basis of Klobuchar and Johanson's results, possibly due to a combination of selection effects.

As a cautionary note, corrections based on independent ionospheric information are unlikely to decrease residuals of a single observing session significantly, since they do not remove short-term ionospheric variations. They do remove the ionosphere's diurnal variation, which would otherwise be absorbed into other parameters (Campbell and Lohmar 1982).

In conclusion, independent means of measuring ionospheric thickness can provide needed information for pulsar astrometry. Satellite doppler and Faraday rotation measurements are the most promising techniques. Ionospheric scientists should be interested in cooperating with further studies; VLBI would be another diagnostic for them.

I welcome further questions.

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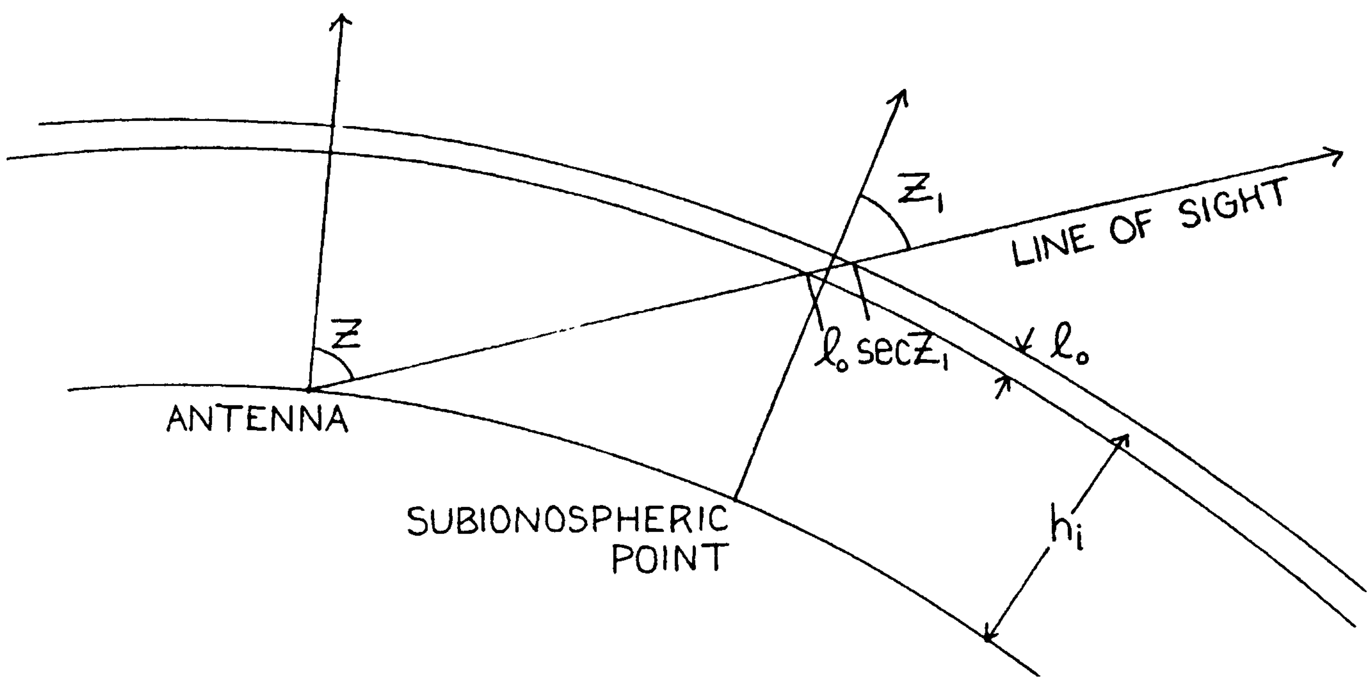

Fig. 1
Typical ionospheric framework geometry.

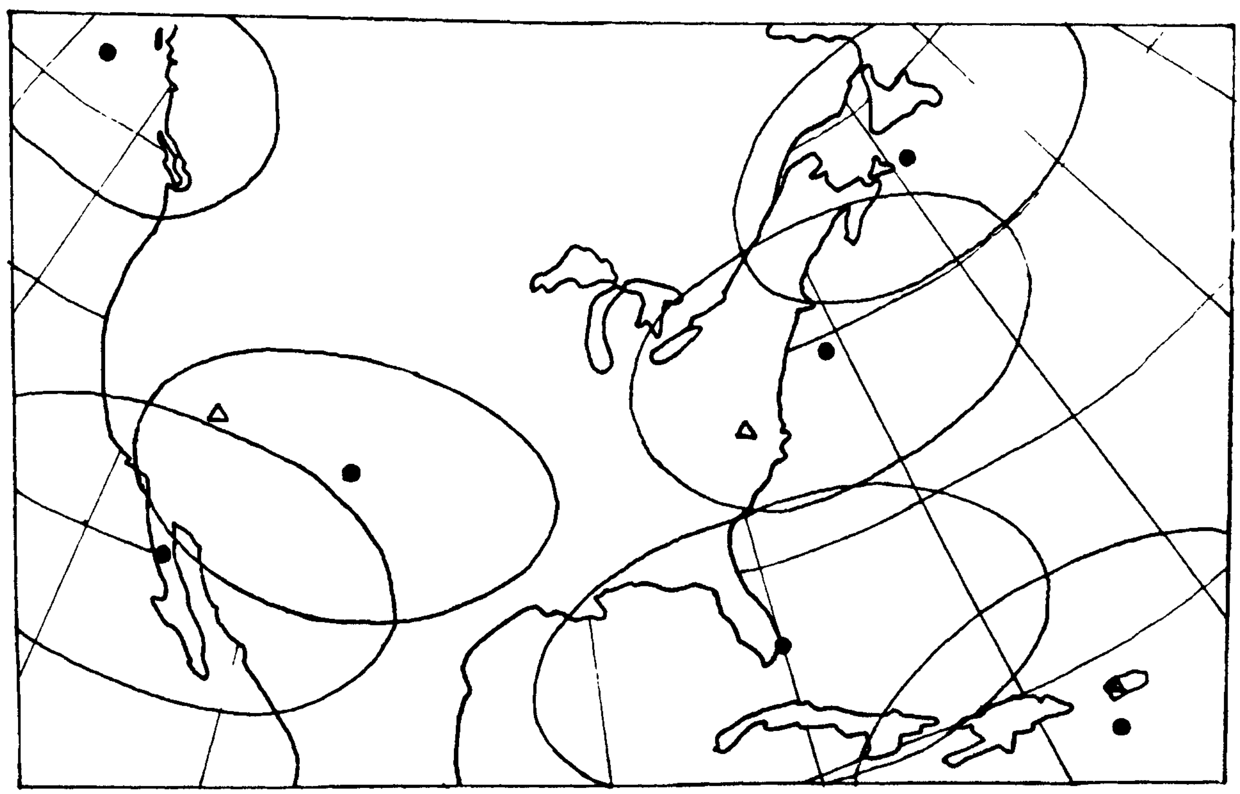

Fig. 2
Subionospheric points of satellite Faraday rotation antennas near the continental U. S. (black circles). On the ellipses, the correlation of TEC with that at the antennas is expected to be 0.87. The open triangles show telescope subionospheric points for my thesis observations.