VLB ARRAY MEMO No. 449

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To: VLBA

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Subject: Proposed Pulsar Support Modes

Introduction

Various VLBA memos discuss pulsar observations with special emphasis on astrometry. See the following:

Memo	Series	Author	Title
351	main	Backer	Pulsar VLBI Specifications
361	main	Gwinn	Pulsar Astrometry-Ionospheric Corr.
367	main	Bartel	Pulsar Dedispersion Mode
380	main	Shapiro	Pulsar Astrometry-Iono. Correct.

The need for dedispersion and ionospheric correction is clear.

Proposed observing pulsar astrometry observing mode:

# Video bands	32*	(16 USB + 16 LSB pairs)
Video bandwidth	1[+]	MHz
# bits/sample	2	
# tracks/pass	32	
Record speed	135	IPS
Data rate	128	Mbits/sec

*When sensitivity is not of prime importance only 16 USB would be used

[+] 2 MHz will be used for increased sensitivity when dispersion is not a problem

With DM = 100 pc cm^{-3}

Sweep time (=pulse smearing) over 1 MHz at 1.4 GHz = 300 usec

Detection sensitivity (SNR $\sim$ 6) $\sim$ 5 mJ (without pulse gate enhancement)

$\sim$ 1 mJ (with pulse gate enhancement)

assuming VLA (or Bonn) to 1 VLBA element ($T_s \sim 30^{o}K$, efficiency $\sim$ 60%, t = 300 sec)

Comments:

a) Dedispersion

With each individual band only 1 MHz wide gating should provide adequate dedispersion for L-band observations. The phase of the pulsar gate should be set individually for each frequency channel. (Dedispersion of 1.5 ms pulsar, 1937+21 is a difficult case but even in this case the SNR will be within about $\sqrt{2}$ of optimum).

b) Ionospheric Correction

The VLBA has sufficient bandwidth at L-band to provide an ionospheric correction using the data itself. To make an approximate evaluation of the performance consider the following frequency sequence:

1300.99 MHz
1305.99 MHz
1320.99 MHz
1350.99 MHz
1405.99 MHz
1445.99 MHz
1470.99 MHz
1480.99 MHz

1619.99 MHz
1624.99 MHz
1639.99 MHz
1669.99 MHz
1724.99 MHz
1764.99 MHz
1789.99 MHz
1799.99 MHz

This sequence provides 2 minimum redundancy sub-arrays each with spanned bandwidth of 180 MHz and ambiguity of 200 nanoseconds. With an SNR of 20^{+} (within each sub-array) the group delay can be measured with one sigma error of 110 picoseconds for each sub-array and the difference between the group delays for each sub-array can be used to estimate the ionospheric path and to develop an observable which is completely free from ionospheric effects with one sigma error of 410 picoseconds.

+Can be achieved with pulsar of 4% duty cycle and average flux of 5 mJ.

Interstellar scintillation (ISS) will increase error owing to incomplete sampling during any single 300s integration. Extra signal in one channel may not compensate for loss in another. The characteristic bandwidth (Bs) and time scale (te) for ISS are given on accompanying plots. However a more robust frequency sequence might be used to reduce ambiguities.

For observations using the VLA as one element the subarray could only span 48 MHz bandwidths although the separation of the sub-arrays could remain at about 320 MHz and still be within the constraints of the VLA frequency coverage. In this case the error in the ionspheric free delay would be increased from 410 ps to 1.5 ns. (1 ns delay precision corresponds to 20 millisec on a 3000 Km baseline - and with time averaging of many scan positions could be measured to a few milliarseconds.)

Another technique which can be used to reduce the effect of the ionosphere is to use phase reference mapping. In this technique a nearby calibration source (with the sensitivity of the VLBA at L-band it should always be possible to find a calibrator (50 mJ) within one degree of the object being studied) is used as a phase reference thereby reducing VLBI to conventional interferometry. Errors in the a priori values of baselines, UT1, calibration source position, ionosphere etc., measured using S/X calibrations are reduced to a small fraction of a fringe for decimeter level errors in a priori and a one degree (0.017 radian) separation between source and calibrator. Because many scans are coherently integrated the technique has high sensitivity as well as high astrometric accuracy.

c) Correlator Support

Minimum requirements

1) Pulsar gating capability with separately programmable gating function+ for each baseband channel.

Gating with precision better than one microsecond and with pulse periods from 100 microseconds to 100 seconds. (The gating could be accomplished in the DPS with some loss of generality - the ability to suport multiple gating functions on each frequency channel without reducing the number of frequency channels).

Other requirements

1) Ability to support the Erickson method (by multiple pass processing if necessary) which requires software to allow processing at harmonics of the pulsar frequency and the instantaneous pulse-spacing delay.

2) Ability to suport multiple gates (by multiple pass processing if necessaray) to be able to measure the interferometric amplitude and phase across the pulse profile.

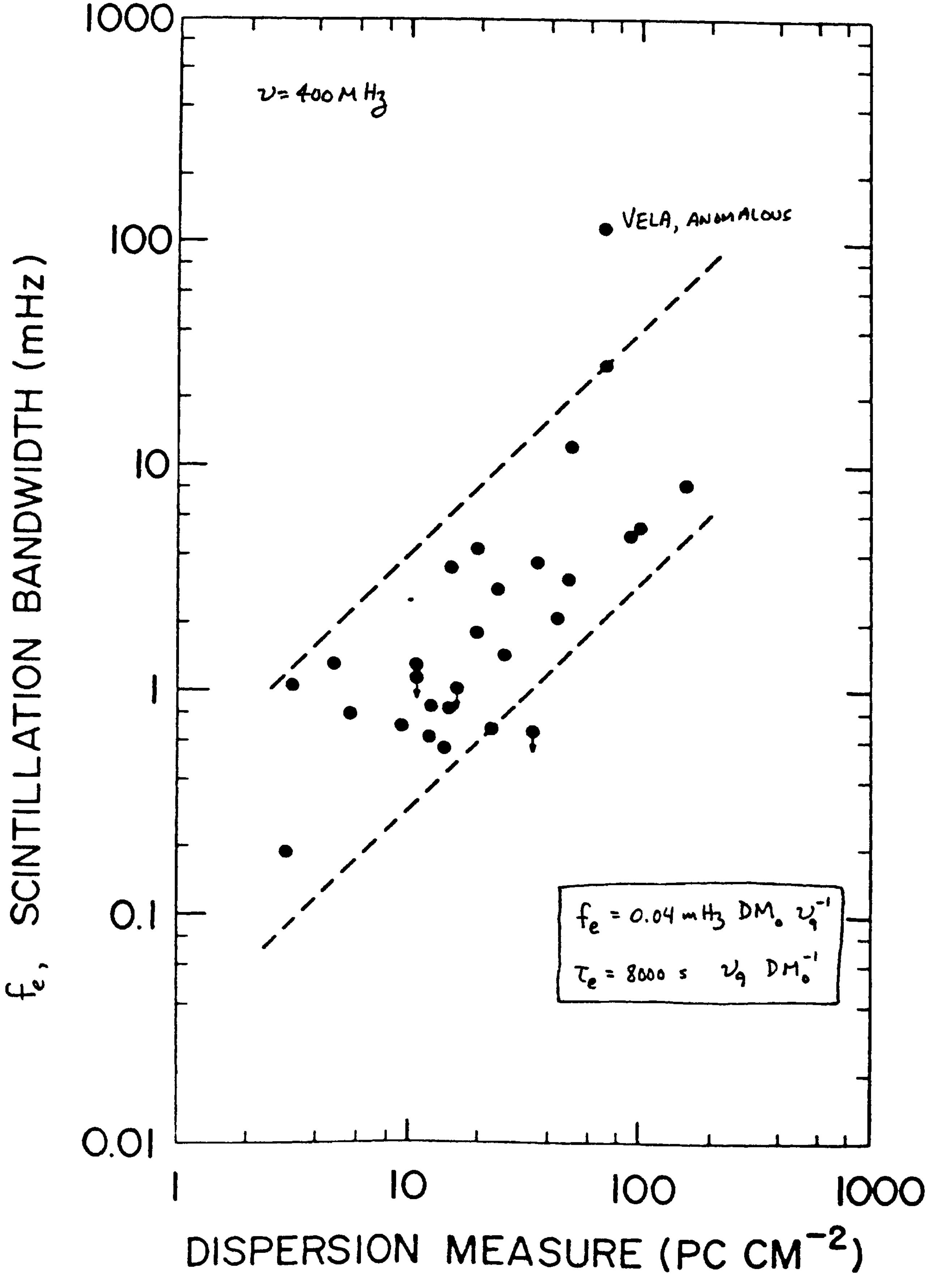
+simple gate function with one phase and duty cycle is not quite sufficient as some pulsars have multiple pulses. A more general gating function with at least three separately programmable phases and three separately programmable duty cycles is needed.

Additional Comment:

GPS

The possibility of GPS calibration (IIS Memo 380) needs to be carefully evaluated as a means of <u>continuously</u> calibrating ionosphere for VLBA observations which cannot be made with very wide or dual band systems. With a constellation of satellites observations may provide quite good (1-10%) estimates of ionosphere over 2π sterradians at every site.

Backer 1975 AA 43 395.



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$$\boxed{B_s \sim 10^5\,H_z \left(\frac{DM}{100}\right)^4 \nu_9^4}$$

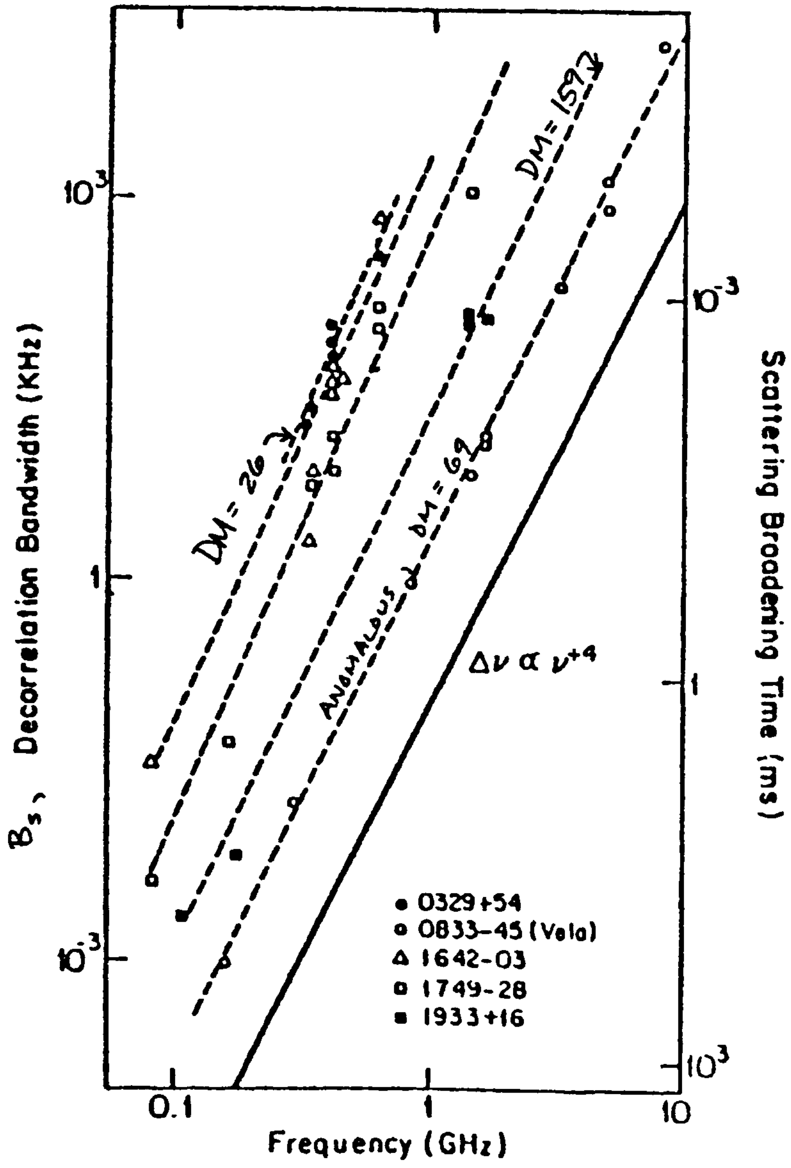
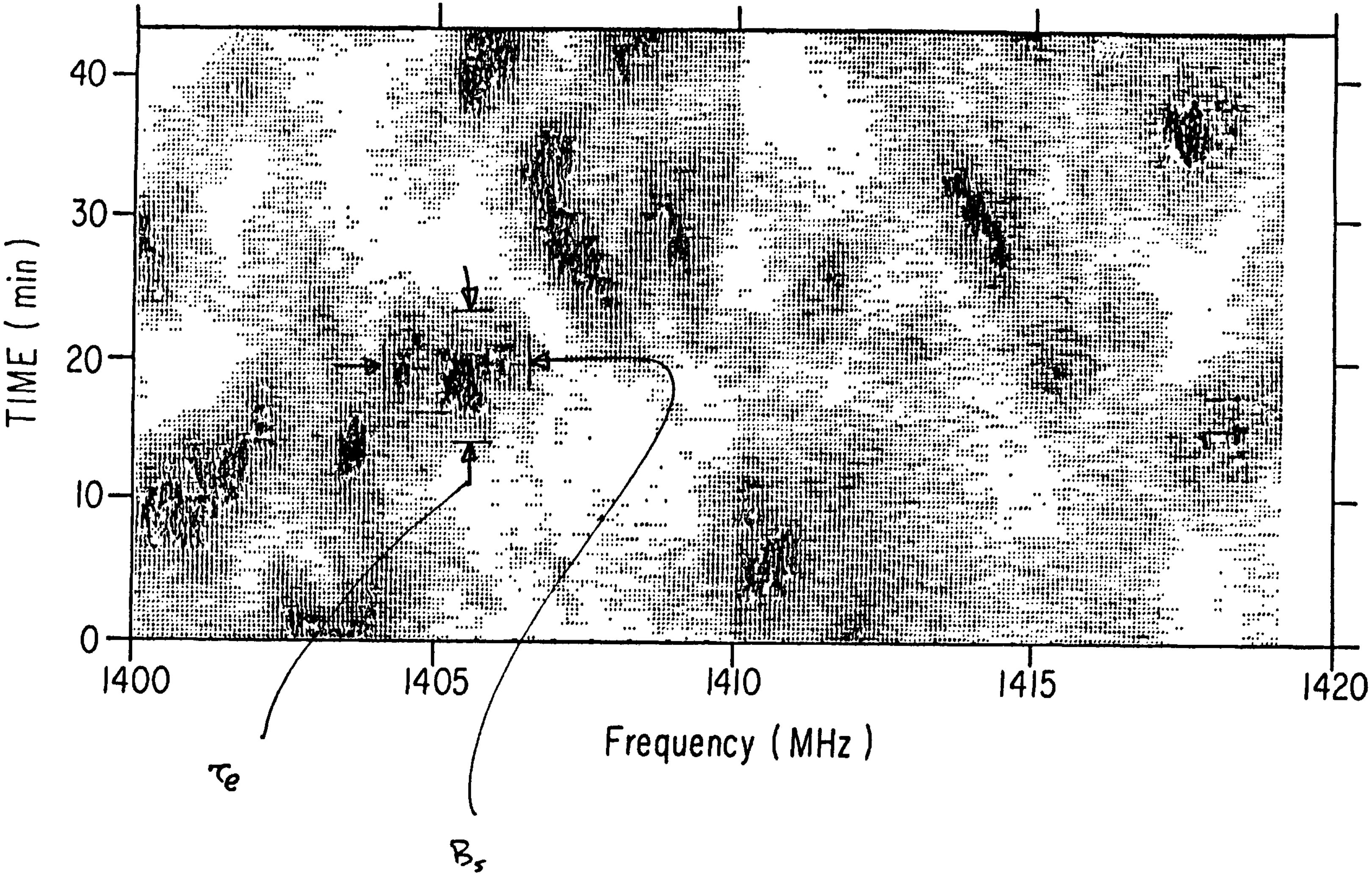


Figure 11


TIME (min)
0
10
20
30
40
1400
1405
1410
1415
1420
Frequency (MHz)
τ_e
B_s

$DM \approx 70$