Astronomy with Millimeter and Submillimeter Wave Interferometry
ASP Conference Series, Vol. 59, 1994
M. Ishiguro and Wm. J. Welch (eds.)

MMVLBI

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ABSTRACT VLBI has now made its breakthrough into the mm-wavelength region and is becoming a viable and important new instrument. In this talk I aim to convince you that VLBI will be an important user of your instruments in the future.

INTRODUCTION

VLBI at mm wavelengths has been developed during a ten year period, with the first experiments around 1982. It is still very much experimental and involves a large international group where each telescope is represented. I must stress that the setup of receivers and recording backends is a very difficult and time consuming task at these telescopes, especially since they are usually not involved in VLBI network operations and therefore do not have any standard inhouse equipment for VLBI. It is necessary to transport H-maser and VLBI backends to several of our sites for each experiment. Such transports have shown to involve hazards, e.g. a H-maser was lost for a week in transport from Canada to Hawaii.

Many of our experiments also suffer from lack of resources. These experiments are outside all normal VLBI networks and therefore we have to use whatever recording tapes are left over from the network sessions, and the processing capacity that are free after the networks have used their part. This has partly been solved by that several of the sites have invested in mmVLBI tapes, but we still need to share processors with the networks. We hope this problem can be solved in the future and that mmVLBI can be run on a more regular basis.

λ7MM VLBI

λ7mm VLBI is in many ways different from λ3/1 mm VLBI. At λ7mm we involve mostly network type telescopes, which operate close to the limit of their performance. The VLBA is now ready to observe regularly at 7mm, and it should very soon become a network operated wavelength band.

VLBI at λ7mm has been pioneered by the Bonn group in close collaboration with groups at Onsala, Caltech, NRAO, Haystack, and Nobeyama. A good overview of this work has been recently given by Krichbaum (1993). Also spectral line observations can be done in the wavelength band, especially the SiO line (Colomer 1993) which has been detected on baselines across Europe, USA, and Japan.

λ3MM VLBI

VLBI at wavelengths shorter than 7mm involves a different set of telescopes. Here we use telescopes designed for λ3mm and shorter wavelengths, and therefore our calibration may actually be *better* than at λ7mm. The telescopes of the VLBA will work also at 3mm (86GHz) and will add a significant amount of collecting area and u,v-coverage to our present network (Figure 1 and Table 1).

VLBI at these short wavelengths is pioneered by an international group from Onsala, Nobeyema, Haystack, OVRO/Caltech, Kitt Peak/NRAO, Hat Creek, Quabbin, and Haystack. The group consists of about 20 people at the moment, and is still growing while we add more telescopes to the network. In the last two years we have added SEST in Chile and JCMT on Hawaii, and the next year we hope to add Pico Veleta in Spain and Effelsberg in Germany. This is quite a significant network, with the very best antennaes at very good and high altitude sites. Such networks have enabled us to make hybrid maps of several objects (Bååth et al. 1992) with a resolution of about 40 μarcsecs., the highest angular resolution in any field of science.

Fringes at these short wavelengths can only be found by fitting station based delay and rate offsets simultaneously to all data within each timesection. The technique we use has been described in Bååth et al. (1992). The necessity to use a global fringe finding technique means that fringe search cannot be done to each station individually online at the processor. We therefore usually also record one channel with a band in the cm-range (3.6 or 6cm), using the 40m antenna at OVRO as a large collecting area for reference. The delay and rate from the cm-band is then used to predict these parameters for the 3mm band. This technique has shown to be very successful even though it involves a considerable amount of work at the mm-sites to setup a cm-receiver for which the telescopes were not designed.

The detection limit of the network specified in Table 1 is about 200mJy with 112MHz bandwidth, i.e. full bandwidth with the MkIII recording system. This limit refers to a 7 sigma detecion on 6.5 mins. (one scan) solution time. The coherence time, defined as the integration time when the amplitude starts to decrease, is usually about 20 secs., but the thermal noise drops faster than the coherence loss of signal so a longer solution time will gain in SNR and can be used to find the delays. The detection limit will be further decreased when the new MkIV system is fully developed at Haystack. The new system will allow recording of up to 512Mhz bandwidth. However, even the present limit of 200mJy allows us to detect and map a large number of active galactic nuclei. The theoretical noise level in the final hybrid map will be about 70mJy.

λ1MM VLBI

If VLBI at λ3mm still is very experimental, then VLBI at λ1mm is even more so. This is still very much a pioneering effort, where we have now made four attempts and only been able to show marginal fringes on one baseline (OVRO to Kitt Peak) at one time (Padin et al. 1990). The success we have had at λ3mm does, however, encourage us to continue our tests at λ1mm, and we are confident that fringes will be found within the near future. The latest test

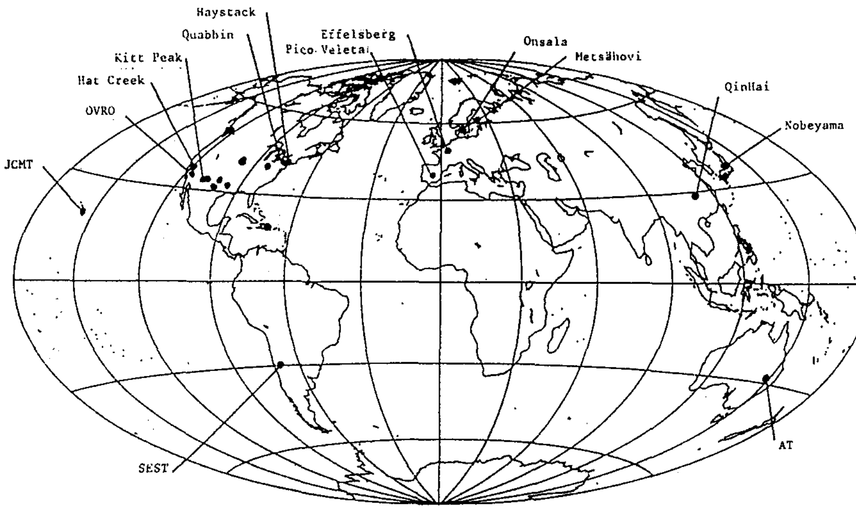

FIGURE I Telescopes available at $\lambda 3$mm. Dots without label refer to VLBA antennaes.

TABLE I Available antennaes for $\lambda 3mm$ VLBI. S_{sys} refer to the systemtemperature in Jansky at the top of the atmosphere.

Antenna	diameter	eff.	S_{sys}	experiment
Nobeyama	45	0.30	1500	88,89,90
Onsala	20	0.48	5400	88,89,90,92
Owens Valley	3×10.4	0.60	2700	88,89
Hat Creek	3×6.1	0.60	13000	88,89,90
Kitt Peak	12	0.60	8000	88,89,90
Quabbin	14	0.50	8700	88
SEST	15	0.60	3900	90
JCMT	15	0.60	3700	planned 93
Pico Veleta	30	0.50	1200	92
Haystack	37	0.15	4200	planned 93
Effelsberg	60	0.10	2500	92
Metsähovi	14	0.30	18000	
Quing Hai	14	0.30	15000	

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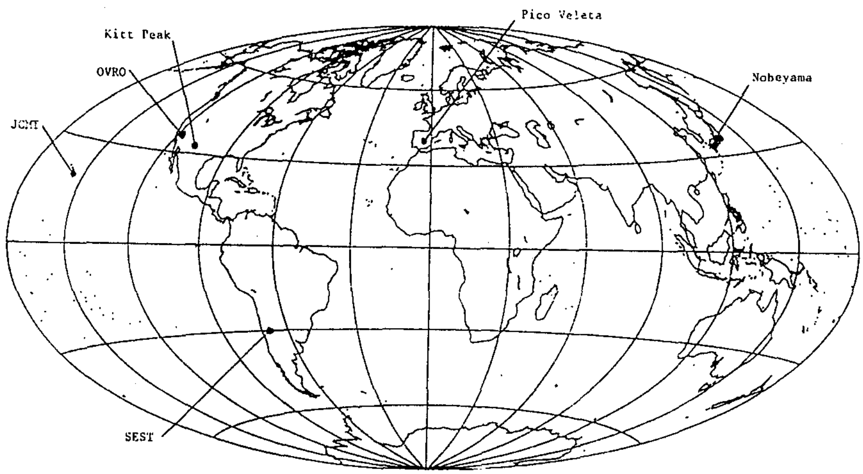

FIGURE II Telescopes available at λ1mm.

experiment was done earlier this year between SEST, JCMT, and OVRO. The data are presently at Nobeyama and we aim to do fringe search immediately after this conference. At λ1mm fringe search to indiviual stations is not possible online, and it may even be extremely difficult to transfer the fringe parameters from the cm-band to the 1mm band. In the future it may be necessary for us to observe simultaneously at 3 and 1mm. We are confident to find most fringes at 3mm and can apply those solutions directly to the 1mm band. It was not possible in our 1992 experiment to run any VLBI at 3mm, so the fringe finding at 1mm may be very difficult indeed.

The possible network at λ1mm is outlined in Figure 2 and Table 2. The u,v-coverage from such a network is sufficient to make hybrid maps, even though they may not be of very high dynamic range. The resolution will be extremely high though, about 15 μarcsec., better than any other existing instrument. The detection limit at 1mm is about 800mJy at present. Here new development of receivers and recording techniques will be very important in order to achieve hybrid maps. The present technique can only allow us to detect and map the most compact and powerful active galactic nuclei.

THE IMPORTANCE OF MM-VLBI

VLBI observations at short wavelengths already, and will in the future even more so, make it possible for us to make images of AGN's of areas very close to the cores. The linear dimension we may observe at λ3mm is about 10^{17}cm or smaller, giving us access to areas well within the narrow line region. Since this is presumably where the radio jet is being formed I believe that high resolution at shortest possible wavelengths is more important to our understanding of the nature of Active Galactic Nuclei than achieving high dynamic range maps. I also want to stress that it is very important to have such high resolution at *short* wavelengths since the core will be optically thick at cm waves. Therefore

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TABLE II Available antennaes for $\lambda 1mm$ VLBI. S_{sys} refer to the systemtemperature in Jansky at the top of the atmosphere.

Antenna	diameter	eff.	S_{sys}	experiment
Nobeyama	45	0.10	10000	planned 93
Owens Valley	3×10.4	0.45	9600	89,90,92
Kitt Peak	12	0.40	36000	89,90
SEST	15	0.50	12400	90,92
JCMT	15	0.60	8700	92
Pico Veleta	30	0.27	5600	planned 93

ground-to-satellite VLBI at cm wavelengths will not be able to observe these regions, no matter how high the resolution or how high dynamic range can be achieved by such instruments. On the other hand, mm-VLBI does not show much of the jet, the core and new components at very early stages are by far the dominant features. Thus ground-to-satellite VLBI at cm wavelengths will be a very important tool to observe fine structures such as turbulence or Kelvin-Helmholz instabilities within the jet flow. It will therefore in the future be necessary to have access to data from both these new instruments in order to follow the birth of new components within the core and follow their development when they travel outwards while they, presumably, expand and die out at short wavelengths to become more prominent features at longer wavelengths.

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https://doi.org/10.1017/S0252921100019072 Published online by Cambridge University Press

DISCUSSION

R. Ekers Why not make more use of a simultaneous lower frequency (eg 22GHz) to predict the phase for the higher frequencies. This would allow coherent integration at the high frequency and a greater improvement in S/N than some of your other suggestions.

L. Baath A simultaneous lower frequency would be very difficult in most of our telescopes because of lack of space in the focus cabins. You are correct though that this would certainly help and we will look into the possibility to run simultaneously at λ3 and 1mm to improve S/N at λ1mm.

M. Inoue Comment: Our K-4 burst mode system has 4 Gbps with 2 bit sample.

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