Arecibo and High Resolution Astronomy – A Few Discussion Points
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1 Introduction

Charting the course of VLBI science in the US for the decade of 2010, the Taylor and Lonsdale Committee (2004) noted, “Provided certain highly cost-effective steps are taken, the scientific reach of the VLBI technique will lengthen dramatically within 10 years. In practical terms, this means that a steadily wider range of targets, from stars to masers to star-forming galaxies and gamma ray burst afterglows, will become accessible to this powerful technique”. The report also produced a pathway to technical developments that it considered part of those “cost-effective steps”. Over the past three years, both we at NAIC and our colleagues at NRAO have been following the above path in terms of equipment procurement and technique development. This has been with the help of highly successful collaborations with MIT-Haystack and the European VLBI Network (EVN). The conversion to totally disk-based operations has already taken place, and the planned upgrade to data recording speeds of up to 4 Gbps during the next three years will provide us with a 4-fold increase in sensitivity from today’s standard VLBA+Y27+GBT+Ar observations (at 256 Mbps rate). We are also actively pursuing frequent eVLBI tests in collaboration with the EVN.

The scientific topics that would benefit immensely from these will be highlighted in the September 12 and 13th meeting by other contributors, and the white paper authored by S. Chatterjee addresses the issues related to pulsar astrometry. In this document, we first bring attention to a couple of topics where VLBI techniques are just becoming relevant and we believe, will see a growth over the next few years. We then explore an area where VLBI-related techniques could be grafted into the Arecibo Observatory’s existing and planned receiver systems and bridge the gap between today and the “SKA era” when wide-field mapping with milliarcsec resolution will become the norm rather than the exception.

2 Astrometry - Non Pulsar

In a white paper submitted to the NSF ExoPlanet Task Force, Bower et al. (arXiv:astro-ph/0704.0238v1) explore the possibility of “Radio Astrometric Detection and Characterization of Extra-Solar Planets”. Utilizing the better than 100-microarcsec positional accuracy routinely achieved by the VLBA, they propose carrying out a Radio Interferometric PLanet search (RIPL) that will survey 29 low-mass, active (radio-loud) M-dwarf stars over 3 years. This would have sub-Jovian planet mass sensitivity at distances of about 1 AU from the star.

They also note that, “Radio astrometric planet searches occupy a unique volume in planet discovery and characterization parameter space. The parameter space of astrometric searches gives greater sensitivity to planets at large radii than do radial velocity searches. For the VLBA and the expanded VLBA, the targets of radio astrometric surveys are by necessity nearby, low-mass, active stars, which cannot be studied efficiently through the radial velocity method, coronography, or optical interferometry.”

The current measurement errors are limited by the number of nearby compact sources that are well above the detection threshold of their observations and which can be used as reference sources in their differential measurements. The addition of Arecibo in such surveys would increase the detection sensitivity by a factor of four, making it possible to venture into the study of objects with one third of the mass of Jupiter as companions of similar stellar types.

However, as Arecibo’s primary beam is much smaller than other telescopes, and the slew rate is rather slow, innovative techniques involving the use of multibeam receivers might prove to be highly beneficial for taking such studies down to thermally emitting stars.
3 VLBI Measurement of Trigonometric Parallax of Star Clusters - A Broad-impact Astronomical Measurement

In an impressive work using the VLBA at 8 GHz, Menten et al. (arXiv:/astro-ph/0709.0485v1) have determined the trigonometric parallax of several stars in the Orion BN/KL region. This has allowed them to derive the most accurate value so far (414 ± 7 pc) for the distance to this region. This estimate is about an order of magnitude better than the previous value of 361$^{+168}_{-87}$ pc, determined from the optical parallax measurement of a single star in this molecular complex by Hipparcos. Luminosity-based distance estimates of star-forming regions could be adversely affected by the often poorly known extinctions, and the radio technique described in this paper is an important way to improve the estimation of distances, and hence luminosities, with subsequent impact on star-formation theories.

As in the previous case, the inclusion of Arecibo would permit the extension of such studies to fainter, much further away, star-forming regions.

4 Widefield Mapping - AO Multibeam VLBI?

Traditional VLBI imaging has been concentrated over regions of less than an arcsecond around high-brightness objects, where the field-of-view (FOV) is determined not by the primary beam of the telescopes, but by the frequency and time sampling during data correlation.

However, recent advances in data analysis technique, together with hugely expanded data recording/storage and processing capabilities, have made mapping a good fraction of the entire primary beam at mas resolution a reality. The science enabled by such mapping includes detailed studies of large-separation gravitational lens systems, supernova remnants in M82, and characterization of the sub-milliJansky population of the Hubble-Deep-Field-North (HDF-N, Garrett et al. in “Future Directions in High Resolution Astronomy”, Eds. Romney & Reid, 2004, ASP Conference Series). The long term goal of the HDF-N type of surveys is to constrain the contribution that active galaxies make to the faint radio source population in general, and to optically faint radio/sub-mm sources in particular.

The presence of Arecibo in such studies would enable such maps to probe sources that are almost an order of magnitude fainter than at present. However, for some of these observations, Arecibo’s smaller primary beam would become the limiting factor in determining the FOV. In addition, the oft-used in-beam phase calibration technique would also provide a smaller number of potential calibrators within the relatively smaller beam size of the 305-m dish.

Both of these limitations could be lifted if multiple-beam data could be recorded at Arecibo, and then be correlated with other stations to generate a much wider effective field of view. The current Arecibo VLBI data acquisition rack can take only two inputs (and has 8 double-sideband mixers, each with a bandwidth up to 16 MHz). The Digital Back-End now under development by the Haystack/CASPER/NRAO groups will have 16 parallel input data streams. One can then imagine data coming from a multibeam system, (say the 7 dual-pol ALFA beams, or the simultaneous beams of a focal-plane-phased array), being channeled to the data recorder. These could be used in many different ways for wide-field mapping, including helping in the traditional phase-referencing where two independent beams could be tracking the calibrator and the source simultaneously.