Microarcsecond Astrometry using the SKA

E. Fomalont[a] and M. Reid[b]

[a]National Radio Astronomy Observatory
520 Edgemont Road, Charlottesville, VA 22903 USA

[b]Center for Astrophysics
60 Garden Street, Cambridge, MA 02138 USA

The sensitivity and versatility of SKA will provide microarcsec astrometric precision and high quality milliarcsec-resolution images by simultaneously detecting calibrator sources near the target source. To reach these goals, we suggest that the long-baseline component of SKA contains at least 25% of the total collecting area in a region between 1000 to 5000 km from the core SKA. We also suggest a minimum of 60 elements in the long-baseline component of SKA to provide the necessary (u-v) coverage. For simultaneous all-sky observations, which provide absolute astrometric and geodetic parameters, we suggest using ten independent subarrays each composed of at least six long-baseline elements correlated with the core SKA. We discuss many anticipated SKA long-baseline astrometric experiments: determination of distance, proper motion and orbital motion of thousands of stellar objects; planetary motion detections; mass determination of degenerate stars using their kinetics; calibration of the universal distance scale from 10 to 10^7 pc; the core and inner-jet interactions of AGN. With an increase by a factor of 10 in absolute astrometric accuracy using simultaneous all sky observations, the fundamental quasar reference frame can be defined to < 10 μas and tied to the solar-system dynamic frame to this accuracy. Parameters associated with the earth rotation and orientation, nutation, and geophysical parameters, can be accurately monitored. Tests of fundamental physics include: solar and Jovian deflection experiments, the sky frame accuracy needed to interpret the gravity wave/pulsar-timing experiment, accurate monitoring of spacecraft orbits which impacts solar system dynamics.

1. INTRODUCTION

The position and motion of celestial objects provide a crucial understanding of many astrophysical problems. With the impressive sensitivity of SKA, which will detect extremely faint radio sources, its design must not preclude the ability to make microarcsec accurate astrometric measurements of these faint objects. With this goal in mind, we discuss the present SKA technical specifications in §2, and suggest modifications which will strengthen its astrometric and imaging capabilities, as well as its milliarcsec imaging potential. In §3 we describe the most exciting science associated with motion of celestial objects, and in §4 we outline some of the astrometric and geodetic experiments, and conclude with tests of fundamental physics. A short summary is given in §5.

2. TECHNICAL IMPROVEMENTS FOR THE ASTROMETRIC USE OF THE SKA

The present specifications of SKA [10] are anchored by a sensitivity of $A/T = 20000$ m^{2}K^{-1}. For many continuum VLBI observations at 8 GHz will provide good resolution, so sensitivity calculations will be made at this frequency. With a bandwidth of 2 GHz for two polarizations, the RMS noise for SKA in 10 min is about 0.1 μJy and in 12 hours about 0.013 μJy. For comparison, the VLA sensitivity is $A/T = 220$ m^{2}K^{-1} at 8 GHz (The EVLA will be 370) with a maximum bandwidth of 100 MHz in each of two polarizations. Hence, the sensitivity of SKA for wide-band continuum observations at 8 GHz will be more than

400 times that of the VLA[1], with an RMS noise in 10 min of about 45 μJy. This giant leap in the sensitivity of SKA will open up a whole new paradigm of radio astronomical research..

Since SKA will be the premier radio interferometer in the future, its high resolution capabilities should be maximized for astrometric use and milliarcsec radio source imaging for the faint sources that SKA will detect—without significant impact to the lower resolution astronomical goals. For this optimization, we recommend that SKA long-baseline components should:

- have 25% of its collecting area in these long baselines to reach faint sources and to insure 'in-beam' calibration up to 22 GHz.
- contain at least 60 separate elements relatively uniformly spaced between 1000 km and 5000 km from the core SKA.
- observe simultaneously with at least ten independent subarrays, each with at least six elements, with the core SKA.

The reasons for these recommendations are given in the remainder of this section.

2.1. The VLB Component

Since the core of SKA will be contained in a small area (even 150 km is considered small for astrometric use), the VLB component of SKA will consist of many small elements located thousands of kilometers from the core SKA. Significant astrometric precision and high resolution imaging can be obtained if the maximum baseline length is about 5000 km. Longer baselines would be desirable, but the gain in astrometric accuracy does not increase as fast with longer baselines because of the unavoidable use of low elevation observations. The VLB configuration should be well distributed in length and orientation, and the core SKA should be located at one extremity of the VLB array to maximize the sensitivity on the longer baselines.

The VLB elements will be correlated only with the central element (core SKA) since correlation among the outlying elements themselves will have insignificant sensitivity. This limits the (u-v) coverage since the number of usable baselines varies only with the number of VLB elements, rather than the square of the number. A reasonable goal is to have (u-v) coverage better than that for the VLBA with good instantaneous beam characteristics for short observations. We believe that 60 elements, well distributed in distance and orientation from the central core, is the minimum number for VLB elements to adequately fill the (u-v) plane in order to obtain high dynamic range images of complex objects. Such high dynamic range images are also important for astrometric consideration since all AGN (the typical radio calibrator) are variable and their apparent core locations must be accurately monitored. Sixty elements is also a minimum number when splitting the SKA-VLB capabilities into many independently observing subarrays, see §2.4.

It is expected that the low resolution part of SKA will be used the majority of time for the many exciting low-resolution astronomical experiments, and, thus, will not observe with the VLB elements. However, the VLB elements alone, with at least 60 elements, will be a useful instrument for simultaneous observations of relatively bright sources (> 10 mJy) for astrometric or other purposes. Hence, we envision two modes of operation of the VLB elements: 1) with the entire SKA for accurate astrometric measurements and high quality imaging of weak sources, and 2) in a stand-alone mode with capabilities better than existing VLBI arrays on stronger sources.

Although 5000 km is smaller than existing VLBI arrays, these baselines will provide SKA with sufficient resolution to make high resolution images and determine microarecsec astrometric accuracy. However, SKA will undoubtedly be used in a VLBI mode with other existing large telescopes on the earth to increase the baseline length. With several orbiting radio telescopes possibly operating around 2020, the core SKA will be the crucial earth-based element for baselines as long as 100,000 km.

[1] see http://www.vla.nrao.edu/astro/guides/exposure/calc.html using 200 MHz effective bandwidth, 27 antennas, 0.1 h on source.

2.2. SKA-VLB Sensitivity

The SKA-VLB sensitivity depends on the amount of collecting area in the VLB elements associated with SKA. If η is the fraction of the SKA area which is contained in VLB elements more than 1000 km from the core SKA, then the VLB (mas-scale size) sensitivity, v, with respect to the nominal SKA sensitivity is $v \approx 0.8\sqrt{\eta(1-\eta)}$. (The estimated factor of 0.8 will depend on how the core SKA is phased to obtain one large effective telescope.) With the present nominal SKA long baseline specification that 25% of the baselines should be longer than 150 km [10], we guess that approximately 15% of the baselines will be longer than 1000 km. This leads to a SKA-VLB sensitivity which is 28% that of the SKA, giving an RMS noise in 10 min of 0.35 μJy, and 0.05 μJy in 12 hours. The stand-alone VLB elements alone have an RMS which is 15% of the entire SKA, or an RMS of 0.70 μJy in ten minutes. With the existing ground instruments the best sensitivity that is available for VLBI (the EVN + phased-VLA + phased-Westerbork + one DSN-70m telescope, with two polarizations, each at 1 GHz bandwidth, one bit correlation) gives an RMS in 10 min is 25 μJy, a factor 70 less sensitive than the SKA-VLB.

2.3. SKA-VLB Calibration, Image Quality, Position Accuracy

The excellent SKA-VLB sensitivity can only be fully utilized by accurate calibration of the data. For baselines over 1000 km, the dominant phase errors are associated with the large and rapidly moving tropospheric and ionospheric phase screen over each telescope. These changes are smaller at kilometer baselines, although still a problem. Direct methods to measure and remove the effect of the variable phase screen (water vapor radiometry, global satellite transmission properties) have had limited success. For the stronger sources which can be detected within one coherence period (typically five minutes at 8 GHz), self-calibration techniques can be used to calibrate and image the source. The minimum correlated peak flux density that can be self-calibrated will depend on details about the SKA-VLB array, but a reasonable minimum value is 5 μJy at 8 GHz. The image quality can be quite good, and is often limited by signal-to-noise considerations. *However, positional information is lost with self-calibration.*

To determine the relative position of a radio source, or to image a target source which cannot be detected within a coherence time, an adhoc calibration scheme known as *phase referencing* is used. A relatively strong, small-diameter source (calibrator) which is within a few degrees of the target, is also observed simultaneously with the target if possible [9], or by quickly alternating observations with the target. The phase changes in the direction to the calibrator for each telescope can then be determined, using the self-calibration technique, and then applied to the target source as a good approximation of the propagation errors in the direction to the target. This approximation decreases in accuracy, roughly, with the calibrator-target separation. For a one degree calibrator-target separation for VLB observations, the residual phase errors in the target limit the dynamic range of the image at 8 GHz is 30:1, or to a position accuracy with respect to the calibrator or about 1/60 of the resolution, which will be about 3 mas.

However, with the superb sensitivity of the SKA-VLB and its relatively large field of view (the area of sky for which images can be instantaneously made), suitable calibrator sources will be detectable within the field of view chosen for any target at all but the highest planned SKA frequencies. This 'in-beam' calibration technique will greatly enhance the SKA-VLB imaging quality and astrometric accuracy for several reasons: The calibrators and targets can be observed simultaneously; the calibrator target separations are small; and with the use of several calibrators, the angular properties of the phase screen over each telescope can be determined, to produce a near perfect calibration in the direction of the target.

An estimation of the in-beam calibration potential for the SKA-VLB is as follows, using a frequency of 15 GHz. (At the lower frequencies, many tens of sources will be detectable). We will take the present SKA specification that the field of view is one degree diameter at 1.4 GHz, or

0.1 degree at 15 GHz.. The density of sources at 15 GHz with a correlated flux density greater than 5 mJy at a baseline of 3000 km is about 1 source per square degree[2]. A reasonable extrapolation to lower flux densities is that the density of sources increases inversely with flux density. Assuming a detection limit of 10 μJy at 15 GHz (using $\eta = 0.15$), about 5 sources within the field of view can be detected. At 22 GHz, there are about 2 sources detectable above the expected detection level. However, any decrease in the nominal sensitivity of SKA [10] will endanger calibration of the SKA-VLB at 22 GHz and higher frequencies. In fact, the assumption of $A/T = 20000$ at 22 GHz maybe optimistic by a factor of three.

The ultimate dynamic range can be estimated as follows: Using two calibrators, the closest about 1 degree from the target, a dynamic range of 100:1 has been obtained [7] at 8 GHz, as shown in Fig. 1. With several calibrators available within a separation of a few arcmin, a dynamic range, the changing phase gradient in the vicinity of the calibrators and target can be determined and removed. This will lead to images after calibration with a dynamic range of 1000:1 or better. At 8 GHz with the SKA-VLB system, the brightest source within the field of view is about 1 mJy; hence, a dynamic range of 1000:1 would produce an effective noise of 1 μJy near this source and about 0.1 μJy elsewhere in the field of view. Although these dynamic range limits are still somewhat larger than that expected receiver noise noise, extremely accurate images of weak sources can be obtained.

The use of close, multiple calibrators to targets not only produces high quality images, but accurate positions with respect to the calibrators. In the example from Fig. 1, the positional accuracy of the bright core of the radio source decreased from 35 μsec to 10 μsec using two calibrators. As a general rule, the astrometric accuracy is equal to the resolution divided by the dynamic range of the image. Thus, the SKA-VLBA at 8 GHz, with a resolution of 3 mas and a dynamic range of 1000:1 can determine positions to an accuracy of about 3 μas. At this level, the precise positions of the calibrators and their evolution of time must be also determined, and will be discussed in §4.x.

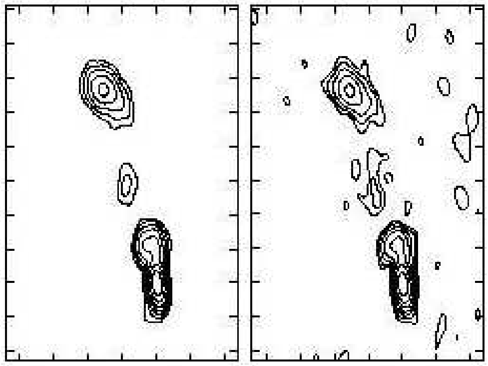

Fig 1: (left) A radio source image after calibration using two nearby calibrators, one 0.8° to the east and another 3.2° to the west. (right) The radio source image after calibration using only the nearer calibrator. The minimum contour level on both plots is 3 mJy and increase by a factor of 2. The tick marks are separated by 2 mas.

In conclusion, it is clear that if an appreciable component of SKA is contained in elements which are more than 1000 km from the core SKA, then milliarcsec-resolution images and microarcsec-accurate positions can be obtained as long as in-beam calibrations are possible. With the present SKA design with $\eta = 0.15$, it is possible that such calibrations will be difficult at frequencies at or above 20 GHz; hence we recommend that 25% of the SKA collecting area be located at least 1000 km from the core SKA.

2.4. Global Astrometry

Absolute astrometric and geodetic experiments require observations of relatively strong, small-diameter sources over the entire sky in as short a time as possible in order to separate many astrometric and geodetic effects by virtue of their different angular and temporal behaviors. Because of the small number of elements in current VLBI arrays, such observations are only possible by serially observing sources over the sky with the entire array, and this limits the determination of simple tropospheric solutions to every 30 minutes to one hour. The resultant imprecise tropospheric solutions are the main limitation to all-sky astrometric accuracy and derived geophysical

[2]Source count at 8 GHz [19], modified to 15 GHz, and assuming 30% of flux density is in a core component.

parameters.

The present SKA specification includes the use of at least 10 subarrays. This means that 10 independent, simultaneous VLB-type observations, can be made on sources over a large part of the sky. Because relatively strong and simple sources can be used for these astrometric observations, short observations with modest (u-v) coverage are sufficient. Within about 5 minutes of observing time (each subarray need only integrate on a strong source for about one minute), the temporal and angular properties of the tropospheric/ionospheric refraction screen over the SKA could be accurately determined, and its effect removed.

Hence, it is not primarily the sensitivity of the SKA which is crucial to these absolute astrometric and geodetic observation, but its ability to observe at least ten independent parts of the sky simultaneously. If we assume that the SKA-VLB component contains 60 elements, as needed for the imaging of complex sources, then each of the ten independent SKA-VLB arrays will have only six baselines each. However, this (u-v) coverage, although marginal, should be sufficient when using strong, small-diameter sources, of which many will be known.

We estimate that the SKA-VLB, when used with at least ten subarrays, would improve the absolute astrometric accuracy by at least a factor of 10 over current day observations. These all-sky astrometric programs are also those which determine the earth orientation and rotation, nutation, and dynamically link the quasar reference frame to the planetary reference frame with observations of spacecraft, beacons and solar-system objects and pulsars.

3. RELATIVE ASTROMETRY: THE MOTION OF CELESTIAL OBJECTS:

By relative astrometric observations, we mean the determination of the position and motion of a celestial object *with respect to nearby background quasars*. This type of astrometry will form the bulk of the anticipated use with the SKA, and it is here that the *in-beam* calibration method will be crucial in obtaining high astrometric precision, as discussed in §2.3 For a 1 mJy source, observed over one hour with the SKA-VLB with our recommended array properties, the potential astrometric accuracy is 3 μas. This accuracy is sufficient to determine the parallax of any detected galactic object and the proper motion and rotational speed of galaxies within about 30 Mpc.

3.1. Galactic Objects

The distance determination using trigonometric parallax to all radio stars in our galaxy with a flux density greater than 0.5 mJy can be determined with four six-hour SKA-VLB observations, spaced every six months over a two-year period. Distances to objects as weak as 25 μJy can be measured within 1 kpc, while distances to stronger sources can be done in much shorter integration times. Several maser transition lines are also available: OH at 1.6, 5, 6 GHz; CH3OH at 6.7, 12.2 and 23.2 GHz, H_2O at 22.2 GHz and, possibly SiO at 43 GHz. Observations lower than 5 GHz are affected by the ionospheric refraction, however, the wide SKA bandwidth will permit the removal of the ionospheric component because of its ν^{-1} phase behavior [1]. Thus, the distance of thousands of pulsars can be obtained and comparison with dispersion measure and the rotation measure of nearby calibrator sources are a tracer of the density, temperature and turbulence of the interstellar medium. The comparison of the interferometric-derived positions and timing-derived positions improve the modeling of pulsar properties, as well as aligning the quasar inertial and the solar-system dynamic frames.

Two experiments which determine the zero-point of the universal distance scale can be significantly improved: measuring the distance of stars in the the Hyades and Pleiades clusters which are faint and need SKA sensitivity, and an improved calibration of the Cepheid period/luminosity relationship.

The proper motion of galactic objects are easily measured within a period of a few years. An example of the astrophysical ramifications of such a measurement is illustrated in Fig. 2 which shows the proper motion of Sgr A* over a 7 year period [17]. The residual motion of Sgr A* of < 1 km s^{-1}, from that expected from the reflexive motion of the sun around the galactic center, gives a minimum mass of the Sgr A* of $\sim 10^6$ $M_\odot$, essentially requiring a black hole. With the SKA-VLB, the parallax could easily be measured, providing a direct determination of the fundamental parameter, R_0 to 1% accuracy. Changing R_0 directly affects measured masses and luminosities of almost all objects in the Milky Way, as well as for the Milky Way itself.

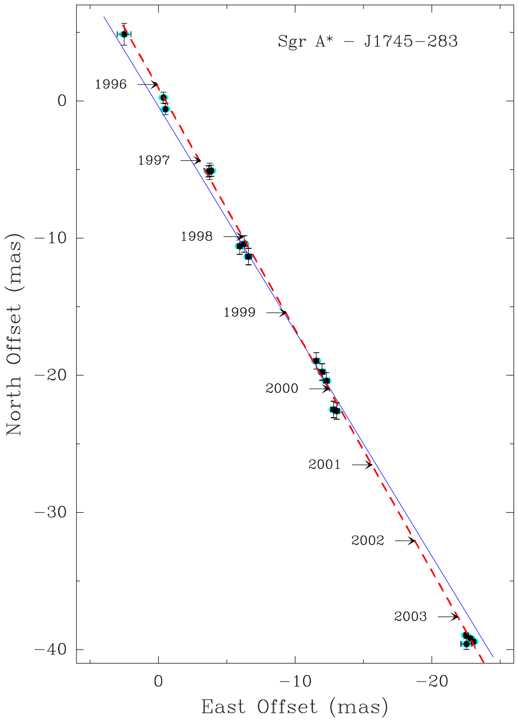

Fig 2: The motion of Sgr A*, measured with respect to the quasar J1745-283: The plotted points show the measured position and error estimate of the location of Sgr A* between 1996.3 and 2003.5. The dashed line shows the best fit to the proper motion, and the solid line shows the orientation of the galactic plane, arbitrarily aligned with Sgr A* in 1999.6. The apparent motion of Sgr A* is produced by the solar motion around the galactic center, including the motion perpendicular to the galactic plane plus a residual motion which determines a lower mass limit of Sgr A*.

Other astrometric experiments with galactic objects are the stability and dynamics of clusters, the use of maser tracers to determine the turbulence and shocks of expelled material around dying stars or infalling material around new stars.

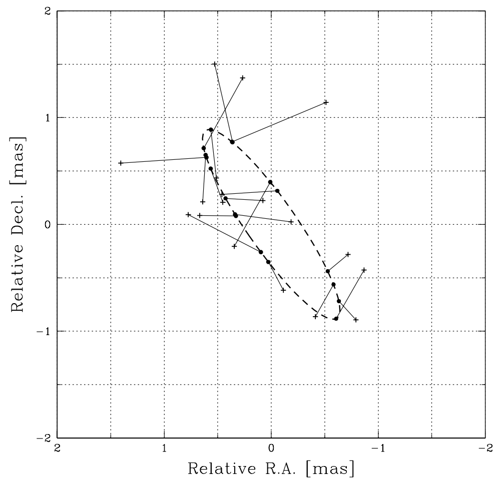

Fig 3: The Orbital Motion of HR8703: The dashed line shows the best fit orbital motion associated with HR8703 after removal of the parallax and proper motion based on 4 years of observation. The plotted crosses show the measured residual positions, and the dots show their expected location on the orbit with a 2.5-day period.

The orbital motion in many binary systems will be readily detectable; hence the mass function of many such systems can be accurately determined. An example of current day accuracy is given in Fig. 3 for the RS CVn binary, HR8703 (IM peg) [16]. This is the reference star that the Gravity-Probe B mission is using to measure the two gravitational precession terms predicted by General Relativity as the spacecraft orbits the earth. The figure shows the residual orbital motion of the radio emission (associated with the brighter star) after removal of the proper motion and parallax. The 16 observations covered a period of 4 years and the orbital period is 2.5 days. With the SKA-VLB, the orbit determination will be improved by over a factor of 10 because of the much improved calibration and sensitivity. A similar experiment, the detection of Jupiter-sized planets around stars up to a distance of 1 kpc, can be detected from the planetary reflex motion of the star.

X-ray binaries have properties which are similar to quasars and other AGNs, but which evolve at a rate which is 10^7 times faster than AGNs. Several examples are GRS1915+105 [3], SS433 [15,13] and Sco X-1 [4,5]. The motion of the lobes and material in the jet and comparison with the x-ray emission provide insights into the interaction of accretion disks around black holes and neutron stars and the stability and lifetime of jets. All of these phenomena are also seen in AGN, but are more accessible using observations of these galactic objects. The imaging and astrometric capabilities of the SKA-VLB will open up observations to hundreds of these galactic microquasars. Their rapid evolution over a few minutes of time are barely accessible with current arrays, but will be easily followed with SKA.

3.2. Nearby Extragalactic Objects

Since most standard candles used for extragalactic distances are tied to the distance of the LMC, direct measurement of this galaxy and others out to the Virgo Cluster could improve the distance scale calibrations to 1% accuracy. Unfortunately, direct parallax measurements are only just reachable for the LMC by the SKA. However, the proper motion associated with the rotation of stars in galaxies as far as the Virgo Cluster are about 5 to 100 μas/yr, and can be accurately measured by SKA over a few years. These angular velocities can be used as a direct measurement of the galaxy distance by comparing them with the known rotational velocities obtained by a variety of methods. Fig. 4 illustrate the results from recent VLBA observations [2] which have measured the proper motion between two H_2O maser sources that lie on the opposite sides of M33. The derived distance estimate is already better than 15%. Similar observations of masers by SKA will detect many more examples and determine the distance scale to 1% accuracy out to 30 Mpc.

The luminous OH and H_2O megamasers are associated with the dense material in accretion disks of AGN, and the study of their motion can reveal the dynamics of the accretion disk and the nuclear (black hole) mass. The high velocities expected in the latter stages of galaxy-mergers, as in Arp220, may be measurable out to 100 Mpc with SKA.

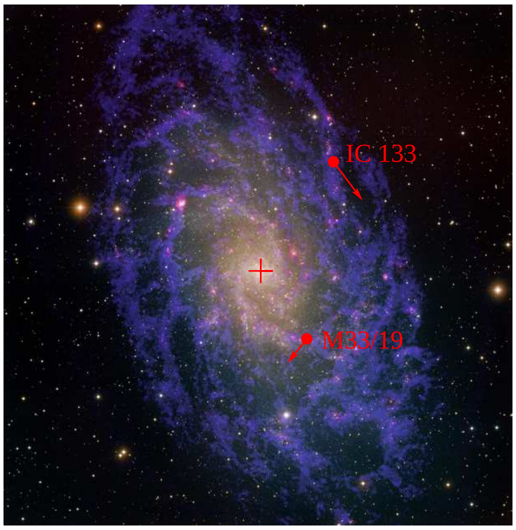

Fig 4: The Motion of Two Maser Sources in M33: The arrows show the expected motion of the maser source IC133 (100 km/s) and M33/19 (62 km/s) with respect to the radio core, derived from the known rotation model for the galaxy. The radio observations of the relative motion of the two maser sources were made over a 2.5 year period and give a distance uncertainty to M33 of 15%.

3.3. Distant Extragalactic Objects

The milliarcsec imaging of quasars and AGN, although an important aspect of the SKA, is not the main concern in the chapter. Detailed images of the fainter radio sources which are dominated by the star formation process, will doubtlessly uncover the wealth of complexity in these distant galaxies. Comparison with observation at sub-mm, infrared, optical, ultraviolet, X-ray and gamma ray energies will be an important aspect in the understanding of galaxy formation and evolution at early epochs. Recent VLA and MERLIN observations are beginning to show the complexity of the radio and optical emission from these distant galaxies [8,14]

However, one feature of quasars and AGNs as astrometric calibrators is important: they are variable. The radio emission from the smallest component of a radio source, called the radio core, come from the base of the jet which is formed by an accretion disk around a massive black hole. The jet is optically thick at SKA radio frequencies and its apparent position is a function of frequency. The massive outflows and shocks in the jet further change the intensity and the structure of the radio emission. Hence, the position of the so-called radio core is variable by about 0.05 mas in most AGN [18]. Thus, the calibrators used to determine the SKA astrometric precision to better than 10 μsec as subject to the calibrator position jitter which is somewhat larger. In order to reach the intended angular precision, the change in position of the calibrators must be determined. With knowledge of the evolution of radio cores and the monitoring of a basic set of primary calibrators, we believe that the calibrator grid can be determined to 10 μas or better. The use of many calibrators in the field of view also diminished the net effect of position jitter.

4. ABSOLUTE ASTROMETRY AND GEODESY USING THE SKA

By absolute astrometry we mean the determination of the true positions of a radio source defined in a well-defined inertial-frame system. The SKA by virtue of its ability to observe sources over the sky in a very short period of time, will be as competitive in this endeavor as any of the currently planned orbiting optical astrometric satellites.

4.1. The Fundamental Reference Frame

The fundamental reference frame is currently defined by the quasars which are so distant that they are essentially fixed in the sky. Based on millions of radio observations of quasars around the sky from the 1970's, an inertial reference frame tied to the quasars was established in 1995, the International Celestial Reference Frame (ICRF) [12]. The frame origin is tied to the solar system barycenter and its orientation in space is currently known to 50 μas accuracy. The main limitation of the accuracy is the tropospheric refraction which affects radio observations. The large-scale tropospheric refraction can be estimated by observing many radio sources over the sky in a short period of time. However, at present the determination of the global troposphere properties can only be estimated in about one hour, and smaller angular-scale variations can not determined.

The SKA, by using observations in ten subarrays, on strong radio sources around the sky, will determine the tropospheric properties on timescales which may be as short at five minutes. The resultant tropospheric models will then include not only the changes of the global property of the refraction, but deviations in its azimuth and elevation dependence. Thus, the stability of the reference frame should be reduced by about a factor of 10 from current day precision, so that the non-stationarity of the quasars themselves, may become the dominant error.

4.2. Geodetic, Earth and Solar System Dynamics

In reaching toward an inertial frame which is consistent to $< 10\ \mu$as, all aspects of the motion of the SKA on the earth's crust as it spins and wobbles in space in a solar orbit which is perturbed by the planets and other solar system bodies, while moving around the center of the galaxy, must be determined. This information is used by geodesists to monitor the motion and stresses within the earth, and the interaction of its spin and nutation with terrestrial phenomena.

The dynamics of the solar system bodies, through their effect on the earth and the SKA, can be tied precisely to the quasar inertial frame. SKA observations of spacecraft and beacons in space will aid in this tie. Comparison of the interferometric position of pulsars (tied to the quasar frame) and their timing-based position (tied to the motion of the earth) are also important. Short-term fluctuations in the earth rotation will be easily determined from SKA, and these changes can be associated with deformations (earthquakes?) in the earth.

When the core SKA is engaged in low resolution astronomical observations, the VLB elements alone (or possibly with a small portion of the core SKA) could be used for many of these all-sky astrometric observations which use only the stronger sources. This is another reason to have a sufficiently large VLB component of SKA so that it can stand alone and provide observations of this type.

4.3. Tests of Fundamental Physics

The general relativistic effects of the interaction of space and time become important in the determination of an accurate inertial system, and the future inertial frame must be fully four-dimensional where space and time are intertwined in accordance with GR. The monitoring of spacecraft trajectories, the bending of radio waves from the sun and Jupiter [11,6], and the delay of signals from spacecraft can be used as precision tests of Einstein's formulation of gravity in the low field region of the solar system.

One of the most important projects of SKA, the detection of low frequency gravity waves from changes in the global timing properties on many pulsars, is dependent on the precise knowledge of the inertial frame, tied to the quasars. A slight deviation between the quasar inertial frame and the dynamical frame associated with the solar system will produce a global timing analysis residual which can mimic that of a gravity wave passing through the solar system.

5. SUMMARY

The SKA, with about 25% of its collecting area in elements from 1000 km to 5000 km from the its core, will provide astrometric capabilities which are a factor of 10 more accurate than now available. These high resolution observations will concentrate at the higher SKA frequencies, from 1 GHz to 23 GHz, although even higher frequencies would be useful.

The sensitivity of SKA will permit the measurement of the motion of a large number of relatively weak and interesting radio sources to the microarcsec level, and provide excellent calibration of tropospheric refraction for good image quality. The versatility of SKA to observe objects simultaneously over the sky will improve the fundamental astrometric and geodetic experiments to an accuracy of 10 μJy.

We believe that the scientific payoff, as outlined in this paper for high resolution capabilities of SKA, will more than compensate for the slight loss of sensitivity for the many exciting, but lower resolution, SKA experiments. The data links between the core SKA and the VLB elements will not be expensive or technologically challenging, and the data rates associated with most SKA-VLB experiments will be less than envisioned in many other SKA key science projects.

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