Extra-solar planets with SKA

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Abstract.
SKA would have distinct capabilities for studies associated with extra-solar planets, their formation and properties.

1. Introduction

This paper discusses the use of SKA in the study of extra-solar planets. It assumes a SKA with a collecting area of a square kilometre, but with many of its antennae spread over some hundreds of kilometres, giving an angular resolution of 0.1 arcsec at 20 cm. The spectral range assumed is from 2 cm to 1 metre, with the short wavelength limit determined in part by the ALMA performance.

2. Present extra-solar planet knowledge

At present some hundred Jupiter-mass planets have been detected orbiting nearby stars by the radial velocity method. This method gives the orbital radius, the orbit eccentricity and a lower mass limit. Statistically, the true planet masses should average some 30% greater than these lower limits. The mass lower limits are in the range of 0.1 to 15 Mjupiter and the orbital radii are the range 0.04 AU to 6 AU. Orbital eccentricities are in the range 0.0 to 0.7. The limits and distributions within these ranges are affected by observational selection effects. One planet has been detected to transit its parent star, so a precise mass and radius can be derived. For this planet, the presence of sodium in the atmosphere has been detected through transit spectroscopy. Another planet has had its astrometric motion measured by the HST Fine Guidance Sensor, giving the mass. A few stars have two or three planets. The parent stars tend to be metal-rich. Two other transiting planets have been claimed but with limited data. Microlensing searches have not yet found any planets. Theories of planet formation are still in dispute both for giant and terrestrial planets, as are the details of the migration processes that produce the close-in Jupiters. However theoretical calculations of the masses, sizes and compositions of the close-in Jupiters are giving reasonable good agreement with observations.
3. Extra-solar planet knowledge when SKA begins

Over the next decade or so ground work will become much more powerful. The radial velocity searches should find many more planets, and be able to detect Neptune-mass planets, and Jupiters in 12 year orbits. Ground-transit searches should also detect many planets, a few bright enough to permit more detailed studies. Micro-lensing searches will probably have detected planets, and if some plans come to fruition, be able to detect Earth-mass planets. Direct imaging detection through AO should detect some bright nearby Jupiters. If the ELT 30-metre to 100-metre telescope come about, there are claims that they will be able detect Earths.

Over the same timescale there will be a revolution in space work. Table 1 shows the presently funded (apart from Darwin/TPF) missions which are either directly for extrasolar planet work or will be able to study them.

| Planet Type | Mission   | Method     | Date  |
|-------------|-----------|------------|-------|
| Jupiter     | MOST      | reflection | 2003  |
| Large Earth | COROT     | transit    | 2005  |
| Earth       | Kepler    | transit    | 2007  |
| Earth       | Eddington | transit    | 2007  |
| Large Earth | SIM       | astrometry | 2010  |
| Jupiter     | JWST      | imaging    | 2011  |
| Jupiter     | GAIA      | astrometry | 2012  |
| Earth       | Darwin/TPF| imaging/spectra | 2015 |

Table 1. Future planet-related space missions

These missions will detect many thousands of planets and determine the frequency of occurrence and properties of many types of planets from Earth size to Jupiter size.

4. Other planet-related work

4.1. Protoplanetary disks

Much work is being done on the early stages of formation when the planets form out the protoplanetary disk, both observationally and theoretically (see e.g. Boss, 2001 and Mayer et al, 2002), but many uncertainties remain. For example, it is not understood how planetesimals coalesce to form the terrestrial planets. Optical, millimetre and sub-millimetre imaging and spectroscopy have given information on some protoplanetary disks on the 10s of AU scales.

4.2. Circumstellar disks

Around certain old stars, there exist circumstellar disks. These are of interest for extrasolar planets because they provide information on the outer regions of planetary systems for objects similar to Kuiper Belt objects, and structures in
these disks can be interpreted as due to the influence of interior planets. For a review see Zuckerman (2001).

4.3. Planetary non-thermal emission
Jupiter emits coherent cyclotron radiation from electrons travelling along field lines into the auroral regions and there is decametric radiation from the Io-Jupiter interaction. There was water maser emission from Jupiter when the Shoemaker-Levy 9 comet hit Jupiter.

4.4. Prebiotic molecules in the ISM
Prebiotic molecules in the interstellar medium (see e.g. Hjalmarson et al, 2001) are of interest for the composition of extrasolar planets, as these molecules will have been included in the chemical processes of their formation and in subsequent delivery by comets. They may also be relevant to the origins of life on terrestrial planets. Many long-chain molecules have been discovered so far, with H2C6 the longest cumulene currently known.

4.5. Pulsar planets
Four planet-mass objects have been detected orbiting two pulsars (see e.g. Konacki et al, 2000). Two of these are Earth mass, and one is Moon mass. The detection method is to look for variations in the pulse epochs due to the Keplerian orbit of the pulsar. No widely accepted theory of the formation or nature of these objects has been made.

5. SKA work on extrasolar planets
The prospects for SKA have to be seen in the light of the work that will be done with ground and space investigations over the next decade or so.

5.1. Protoplanetary disks
These disks become optically thick due to dust obscuration in the central regions. SKA continuum and line (such as NH3) observations will give structure and dynamic imaging of the dense molecular gas associated with star formation cores on sub-AU scales.

5.2. Circumstellar disks
The sensitivity of SKA will permit the radio-wavelength thermal emission from circumstellar disks to be detected. This will complement the millimetre and sub-millimetre work by ALMA.

5.3. Astrometric planet detection
The milliarcsec capability in astrometry of SKA, when in the dilute array configuration, for nearby stars will be inferior to the performance of the SIM and GAIA space missions, both in accuracy and number of targets, and is thus unlikely to be of significant value.
5.4. Direct detection

Thermal emission The thermal emission from a close-in Jupiter at 1000K at a
distance of 1 pc at 1cm wavelength would be 500 nJy, compared to the 300 \( \mu \)Jy
from the star (de Pater, 2002). The planet spectral shape thus might just be
distinguishable from the star spectral shape. The angular separation would be
0.05 arcsec, compared with SKA resolution of 2 arcsec if configured as a large
array, so they could not be resolved.

Non-thermal emission de Pater (2002) has calculated the possible emission
from some known extrasolar planets from coherent cyclotron radiation from
electrons travelling along field lines into the auroral regions., and finds fluxes of
the order of mJy at 40-300 MHz, easily detectable by SKA. The fluxes may be
much higher during active periods in the stars. de Pater also points out the pos-
sibility of detecting decametric radiation, similar to the Io-Jupiter interaction,
from a planet-satellite or a star-planet interaction.

Recently, there has been a claimed detection (Cosmovici, 2002), but not
confirmed (Butler et al, 2002), of emission from three extrasolar planet systems
of water maser emission. This has been postulated as coming from the same
pumping process that was observed when the Shoemaker-Levey 9 comet hit
Jupiter. SKA would be able to search for such radiation with great sensitivity.

5.5. Prebiotic molecules in the ISM

To reach longer chain molecules than presently detectable, increased sensitivity
will be essential. As such molecules will have larger moments of inertia, their
emission will be in the centimetre range, and as there are many transition modes,
the energy for each transition will be less. Calculations predict a lower abun-
dance for these larger molecules. Further, it will be essential to look for these
molecules in dense regions and the better sensitivity and angular resolution of
SKA will permit more powerful searches for small sources, and also by mapping
their surroundings understand their evolutionary phase.

5.6. Pulsar planets

Resolving the puzzle of the origin and nature of the planet-mass objects orbiting
two pulsars will depend on detecting and studying more of them. The sensitivity
of SKA will permit greatly enhanced pulsar searches to be made.

Acknowledgments. Much of the discussion in this paper was informed by
the SKA Science Case available at the SKA telescope web site \(^1\) and by other
SKA project documents.

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\(^1\)http://www.skatelescope.org/ska_science.shtml
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