

Report of the SKA Science Working Group:
Milky Way and Local Neighborhood Galaxies

Bologna, Italy
14-15 January 2002

1 Membership and Charge

As a subset of a week-long meeting devoted to SKA in Bologna during January 2002, the Science Advisory committee for SKA arranged a workshop dedicated to refining the science case of the telescope. Eight scientific areas had been identified; introductory talks for each of these began the meeting, including a reports from the science subgroups chairs at the previous meeting in Berkeley. The meeting then broke into parallel subgroups, with conference members attending the subgroup of their choice. Those attending the Milky Way and Galaxies in the Local Neighborhood subgroup were:

Bryan Gaensler	Harvard-Smithsonian CfA, USA
Peter Kalberla	University of Bonn, Germany
Namir Kassim	Naval Research Lab, USA
Penny Sackett	Kapteyn Institute, Netherlands
Evan Skillman	University of Minnesota, USA

Penny Sackett served as Chair for this working subgroup both in Berkeley and at the Bologna meetings.

Subgroups were charged with identifying Level I (high priority, unique to SKA) and Level II (high priority, complementary to other instruments) science within their area and to determine the technical requirements such science would place on SKA, compared to the Strawman Technical Specifications circulated at the meeting. Subgroups were also asked to consider questions that remained to be answered in order to refine these science cases.

2 Key Questions driving the Level I (and II) Science Case

The working group identified six key science questions in this field that will be addressed by SKA:

- What is the global and local strength and shape of a galactic B field
. . . and what determines it?
- Where are the relativistic electrons in galaxies
. . . and what accelerates them?
- How does the distribution of HI compare to that of molecular gas
. . . and what governs this on scales relevant to star formation?

- On what scales does turbulence operate
... and through what physical processes?
- What is the global 3D distribution of different phases of ISM
... and what determines their physical balance?
- What does the ISM look like at the very faintest levels
... and how does it interact with and merge into the general IGM?

Magnetic fields are thought to play a crucial role in the formation of stars and their planetary systems, and may help to shape the formation and evolution of galaxies themselves. Early on, the Milky Way subgroup concluded the study of magnetic fields in star forming regions, the interstellar medium and galaxies in general will be the unique terrain of SKA. In our own Galaxy, these processes can be studying on small size scales appropriate to star formation; in the local galactic neighborhood more global processes can be compared in a variety of galactic types. The dissipation of gas is a key process in the formation of galactic disks, bars, and accretion disks, yet its astrophysics is not fully understood. The sensitivity of SKA may allow the spatial power spectrum of gaseous dissipation to be studied on unprecedented scales. Finally, the transition from neutral to molecular gas is a first, but ill-understood step in the formation of stars from the interstellar medium. Through complementary studies with ALMA, NGST and GAIA/SIM, SKA will complete the picture by delivering the sensitivity and spatial resolution with which to study the neutral medium throughout the local galactic neighborhood on the appropriate scales. Because the star and galactic structure formation is a detailed feedback process among many components, the working subgroup concluded that the primary science case, **Galactic EcoSystems**, should be described as a single unit.

3 The Hitchhiker’s Guide to our Galaxy ...

The Milky Way is an unique and remarkable laboratory for the detailed study of physical processes on scales relevant to stellar-ISM interactions. Optical instruments like GAIA/SIM will map stellar locations throughout the Galaxy to high precision. For specified fields, ALMA will provide rich detail about molecules and role in star formation in the Galaxy. To provide the missing links that are only available at radio wavelengths, the working group sketched the skeleton of a science plan which would result in a detailed, three-dimensional atlas of the Galaxy. Once integrated, this Galactic Atlas would be used for a host of scientific questions, and could also provide a magnificent visualization tool for public education. This “Hitchhiker’s Guide to Our Galaxy” would include several components observed on a vast range of physical scales using SKA and a host of radio techniques, some of which could be carried out simultaneously at 20 cm:

Magnetic Field	HI Zeeman, Faraday Rotation, Cont Polarimetry	sub-pc to kpc
Ionized Gas	Pulsar dispersion measures (10,000 pulsars TBD)	sub-kpc
Cold Clouds	HI Absorption against faint background sources	pc
Neutral Gas	HI Emission Survey	pc to kpc
Precise Structure	Astrometry and Parallax of OH and H ₂ O masers	kpc
HI to H ₂ Transition	Targeted Deep HI (Emission) Fields	sub-sub-pc

The 10,000 pulsars expected to be detected by SKA will not only be a complete Galactic census, but can also provide background sources against which to map out the ionized gas. Together with Faraday rotation measures, this provides an estimate of the magnetic field strength along different lines of sight, which can also be estimated from continuum polarimetry and Zeeman splitting of the 21 cm line. Moderately long baselines would allow astrometry of all Galactic masers for precise distance determinations. Cold gas clouds could be mapped through the Milky Way with 5' resolution using HI absorption against the very faint and numerous background continuum sources to which SKA will be sensitive. A few deep fields would provide a view of the cold gas on scales comparable to (nearby) and somewhat larger than (at 8 kpc) a single Stromgren sphere! The resulting 3-D Galactic Atlas will certainly be one of SKA's great legacies.

3.1 . . . and our Galactic Backyard

The galaxies in our "backyard" (within 5 Mpc) span a wide variety of galactic ecosystems for comparative studies including four galaxy groups, namely, the Milky Way, Sculptor, M81 and Centaurus A groups. About 100 galaxies are contained in this volume, of which 20 are large "normal" galaxies. The rest include a range of morphological types, including the M81/M82 interacting system, the Cen A AGN, a starburst nucleus galaxy, and a large number of dwarfs.

Similar science as described for the Milky Way can be performed with SKA in these galaxies. Their larger distances the finest resolutions possible in the Galaxy, but also allows cleaner, less ambiguous lines of sight. As for the Milky Way Atlas, a Backyard Galactic Census must be performed with SKA entailing the following components:

Magnetic Field	Faraday Rotation, Cont Polarimetry	pc to kpc
Relativistic Gas	Synchrotron Emission (diffuse and discrete sources)	pc to kpc
Cold Clouds	HI Absorption against faint background sources	sub-kpc
Neutral Gas	HI Emission Survey	pc to kpc
HI to H2 Transition	HI Emission Survey	pc

4 Technical Demands on SKA

$A_{\text{eff}}/T_{\text{sys}}$	Assumed	
Frequency	1 to 10 GHz	+ <i>possibly 22 GHz</i>
Imaging FOV	minimum 1 sq deg, 10 preferred	MW Surveys
N of Pencil Beams	No Constraint	
<i>Angular Resolution</i>	0.1" - 0.2" at 20 cm	Continuum Surveys
<i>Angular Sampling</i>	1" - 30' or more	
N of Spatial Pixels	10^{10}	Continuum Surveys
N of Spectral Channels	$> 2 \times 10^4$ <i>minimum</i>	Continuum Surveys
<i>Surface B Sensitivity</i>	10 mK/arcsec ²	Polarimetry
Instant Bandwidth	Strawman is ample	
<i>Dynamic Range</i>	10^6	HI absorption Surveys
Polarization Purity	-40 dB all pixels & channels	Polarimetry
Sampling time	< 1 second	UV samp at edge of FOV
Hemisphere	Southern	Cen A, LMC, GC, ALMA

In the table above, the working group itemized its estimates for the technical specifications required by SKA if it were to be able to carry out the science described here in a reasonable amount of time at appropriate sensitivities and resolutions. The parameters of the Strawman Technical Specifications have been listed, and (in the case of the last two items) augmented. Requirements that are more stringent than the Strawman are shown in **boldface**. Those for which the Strawman is just adequate, are shown in *italics*, while those for which the Strawman SKA are ample are shown in regular typeface. Facets of the program that determine these constraints are given in the last column.

The most stringent technical constraints are driven by the need to main SKA sensitivity over the full field of view and the need to map large portions of the sky. Note that a Southern Hemisphere SKA (or component to SKA) is crucial to the Galactic science case and for comparison studies with ALMA.

5 Outstanding Issues

Due to lack of time or individual expertise, the working group was unable to address all of the issues that were raised during its discussions in Bologna. Some of these outstanding issues are listed below, and would provide a good basis from which to continue refining the science case, preferably through individual studies before the next formal meeting.

- What would very faint neutral gas around galaxies (cosmic web) look like at the levels that SKA could reach and how large would these structures be for Local Neighborhood galaxies?
- On what scales could gas turbulence be studied in Galaxy if HI absorption surveys were performed with SKA against extended sources?
- What sensitivity is required to detect a 1 μ Gauss B field via the Zeeman effect at 5σ assuming 50 K HI emission cloud?
- What sensitivity and resolution are needed to measure proper motions and parallaxes for all masers in the Galaxy?
- Would RFI from (future) satellites affect Galactic SKA surveys at some positions and, if so, how could this be minimized?
- Should the fields in the halo of the Milky Way be imaged differently than those near the Galactic plan, and how can the two be done most efficiently?
- How can SKA surveys be characterized so as to recognize the trade off between collecting area, receiver sensitivity, field of view and observing time, especially when more than one science goal (perhaps even spanning subdisciplines) may be met with the same observations?