Recommendations on "Level 0" Science

Report of the International Science Advisory Committee to the International Square Kilometer Array Steering Committee

INTRODUCTION

Defining Level Zero Science

A crucial part of defining the Square Kilometer Array (SKA) project, both within the SKA community and to a wider audience, is to develop a small set of "level 0" science topics, corresponding to key projects in which the SKA can make a fundamental contribution. The level-0 science topics will be used to attract funding and publicity, will be the focus of efforts to ensure that SKA capabilities will be complementary to those of other future telescopes, and will be those projects which will primarily constrain the choice of design and site for the SKA.

To identify level-0 science topics, the International Science Advisory Committee (ISAC) formed a Level Zero Subcommittee, who throughout 2003 have formulated and then coordinated the process through which the ISAC has converged on level-0 science. See Appendix A for the report which the Level Zero Subcommittee presented on the details of this process. To summarize, the criteria adopted in Geraldton for level-0 science were:

1. Can address important but currently unanswered questions in fundamental physics or astrophysics.
2. Is science which is either unique to the radio band and to the SKA, or is something which is complementary to other data-sets but in which the SKA plays a key role.
3. Excites the broader community, and is of relevance and interest to funding agencies.

Call For Proposals

A "call for proposals" for level-0 science was issued to the community in Aug 2003 (see Appendix B). 21 one-page proposals for level-0 science were received in response to this call. These were reviewed by the Level Zero Subcommittee, who provided feedback and allowed proposers a brief chance to revise and merge proposals. 17 final proposals were accepted, as listed in Appendix C.

Ranking by ISAC

The 17 final proposals were distributed to the ISAC in Nov 2003. ISAC members were asked to vote on each proposal, providing a rating from 1 (no compliance) to 5 (complete compliance) for each of the above three criteria. From the collected responses, the highest and lowest vote for each topic was discarded, and the remainder averaged together, resulting in the rank ordered list of proposals given in Appendix D. The results of this voting process were presented and discussed at the SKA Science Retreat in Leiden in Nov 2003.

RECOMMENDATIONS OF THE ISAC

Level 0 Science

The list of ranked proposals in Appendix D shows a clear gap between the top eight proposals and the bottom nine. The ISAC consequently decided to exclude the bottom nine proposals from further consideration.

The eight remaining proposals are all closely spaced in rankings. The ISAC consequently did not feel it a productive exercise to revote on or cull this list of eight proposals further. However, these eight proposals can be regrouped into five coherent projects, which we consequently present to the ISSC (in no particular order) as the ISAC's recommendation on level-0 science for the SKA:

- **Strong Field Tests of Gravity Using Pulsars and Black Holes:** Pulsar surveys with the SKA can discover tens of thousands of pulsars, amongst which we expect to find a pulsar in orbit around a stellar-mass black hole, thousands of millisecond pulsars which can form an immense pulsar timing array, and pulsars in close orbit around the supermassive black hole at the Galactic Center. These data can be used to provide fundamental and detailed tests of our understanding of gravity, in regimes that cannot be probed by any other experiment.

- **Probing the Dark Ages:** The epoch at which the first luminous objects in the Universe formed, and then reionized the neutral IGM, can only be studied at near-IR through radio wavelengths. In the redshifted H I line the SKA can map out the complicated processes occurring during the Epoch of Reionization; through redshifted CO, the SKA can detect star-forming galaxies at these redshifts; with deep continuum observations, the SKA can detect the first AGNs. The ensemble of these data can provide unique information on how the first galaxies and black holes assembled themselves, and how they influenced their environment. *[This topic is a combination of the "origins" aspects of proposals on the EoR, on Galaxy Evolution, and on Supermassive Black Holes.]*

- **The Origin and Evolution of Cosmic Magnetism:** Clearly radio astronomy is uniquely placed in its capability to study magnetic fields at large distances through Faraday rotation and polarization. Through an all-sky continuum survey, the SKA could measure rotation measures for 2×10^7 extragalactic sources, with an average spacing between sightlines of $\sim 90''$. The sheer weight of statistics in these data would allow us to completely characterize the evolution of magnetic fields in galaxies and clusters from redshifts $z > 3$ to the present, to measure the strength and structure of the magnetic field in the IGM, to determine whether there is a connection between the formation of magnetic fields and the formation of structure in the early Universe, and to provide solid constraints on when and how the first magnetic fields in the Universe were generated.

- **The Cradle of Life:** There is increasing interest in the community in astrobiology and in the search for other Earth-like planets. The SKA has the unique potential for finding evidence of extra-solar terrestrial planets and of other life like us. At 20 GHz, the SKA will provide thermal imaging at 0.15-AU resolution out to a distance of 150 pc, encompassing many of the best studied Galactic star forming regions. Such observations will allow us to study the process of *terrestrial* planet formation; such systems will evolve on timescales of months. For the first time with the SKA, we will have the capability of detecting leakage radiation from ETI transmitters out to a few hundred parsecs, involving of order a million solar type stars. Finally, the SKA will have the resolution and sensitivity to study the $J = 1 - 0$ transitions of amino acids and other complex carbon biomolecules, and to follow their progress from molecular clouds to protoplanets. *[This topic is a combination of the proposals on SETI/Astrobiology and on Protoplanetary Disks.]*

- **The Evolution of Galaxies and Large Scale Structure:** The original motivation for building the SKA was to detect H I in normal galaxies at high redshift. Such an experiment promises a particularly exciting result, in that the vast volume of space probed by an SKA H I galaxy survey will provide an exquisite matter power spectrum, with which we can compute the Universe's Equation of State, and map out the strength of Dark Energy as a function of cosmic epoch. At the same time, the SKA's unique capability to observe the neutral component of gas in galaxies

will allow us to chart the kinematics, merger history and environment of ordinary galaxies as they evolve from redshifts $z \approx 5$ to the present. *[This topic is a combination of the proposal on Dark Energy, and the evolutionary aspect of the proposal on Galaxy Evolution.]*

Why a Square Kilometer?

A key part of the case for an SKA has always been the need for a full square kilometer of collecting area. This was originally motivated by the need to detect normal galaxies in H I at high redshift.

However, most of the level-0 topics recommended above will involve large surveys rather than single pointings, and thus survey speed or sky coverage are potentially more useful requirements than raw collecting area. The ISAC thus raised the the issue in their discussions as to whether one should abandon the basic requirement of one square kilometer of collecting area. Ultimately there was strong opposition to this proposal, most participants feeling that the concept of 1 km^2 was a simple and powerful idea.

The ISAC thus recommends that the need for a square kilometer of collecting area be retained as the underlying specification for this telescope. Within the level-0 topics recommended above, this specification is still motivated by the need to detect H I in galaxies at high redshifts, although other science goals (e.g., thermal imaging of protoplanetary disks at sub-AU resolution) also drive one to comparable requirements. In any case, the ISAC strongly recommends that the entire SKA community adopt a unified response as to why a square kilometer is required, and that this response be directly based on the requirements for level-0 science (as listed in Table 1 below).

Synergy with National and Institutional Roadmaps

The ISAC have reviewed the science cases of various other organizations and projects (e.g., NASA, ESA, NSF). Most major astronomical initiatives for the 21st century seem to be grouped into three main thrusts: "The Origin of Galaxies", "The Origin of Life", and "Tests of Fundamental Physics". We have expressly avoided adopting these broad themes to be level-0 science topics in themselves, but have ensured that all five recommended topics do fit within one of these themes. In this way, we feel that our five proposed projects will be of interest to the wider community and to funding agencies, but retain the requirement that they represent unique SKA science.

Risk vs Reward

In adopting any key science project, there is always a trade-off between higher risk science with huge potential rewards, and projects which will have guaranteed results but which come with a less exciting pay-off. The ISAC feels that each of the recommended level-0 projects contains aspects which include both high-risk and guaranteed projects, so that each topic contains a solid promise of fundamental new advances in our understanding, without raising excessive concerns that the project might not be realistic or feasible.

Exploration of the Unknown

At a wider level, the ISAC wishes to emphasize the incredible contributions made by radio astronomers over the last 70 years, more often than not simply by designing instruments with new and innovative capabilities. In the 21st century, the SKA offers an unparalleled opportunity to add to the many discoveries of unexpected phenomena made by radio astronomers in the 20th century. Thus, while there was general consensus that topics like "The Exploration of Phase Space" or the "Transient Radio Sky" do not easily fit the criteria for level-0 science, and probably could not be effectively used to sell the SKA, the ISAC recommends that an underlying philosophy of the design process should be that, whenever cost and engineering constraints allow, the SKA be maximally flexible.

IMPLICATIONS FOR SKA SPECIFICATIONS

Table 1 shows a flow-down from level-0 science goals to SKA design specifications. High sensitivity (i.e., an "SKA") is clearly an "enabling" aspect of the SKA for all programs, although the requirement that $A_{\rm eff}/T = 20\,000$ m^2 K^{-1} can be relaxed at the lowest (due to increase in $T_{\rm sys}$) and highest (due to decreased efficiency) frequencies without precluding the level-0 science. The low frequency limit ($\sim$ 100 MHz) is set by observations of the neutral IGM during the EoR. The high frequency limit ($\sim$ 20 GHz) is driven by observations of terrestrial planet formation and molecular line emission from objects within the EoR, although both pulsars and cosmic magnetism have an important high frequency component. Increase to 35 GHz is desirable, but not fundamental to achieving the level-0 goals. Baselines out to a few thousand kilometers are required for imaging protoplanetary disks on sub-AU scales, pulsar astrometric programs, and imaging the synchrotron emission from the first supermassive black holes.

All of the programs have a survey component, and hence could benefit from a field of view larger than the nominal specification of 1 deg^2 at 1.4 GHz, but in most cases the goal can be met within this specification. The one exception is constraining the equation of state of "Dark Energy" through the study of very large scale structure. This program is fundamentally enabled through a large increase in the FOV, since the "cosmic mapping speed" becomes dramatically faster than planned optical surveys.

Multifielding is clearly desirable in general, but again not fundamental to any of the level-0 science goals. The nominal SKA specifications in other areas, such as the correlator and bandwidth, are all acceptable in the context of the level-0 science goals. Very fast response times (of order seconds or less) is not demanded by the level-0 science goals.

Table 1. SKA specifications implied by Level-0 Science goals.

Topic	$A_{\rm eff}/T$ (m^2 K^{-1})	Frequencies (GHz)	Baselines (km)	Special
Gravity	20 000 at 1.4 GHz timing array	0.5–15 Galactic Center pulsars	3000 astrometry	multifielding desirable but subarray acceptable for searches
Dark Ages	10 000 at 0.1 MHz & 20 GHz CO emission at $z > 6$ (M 82) H I structure at $6 < z < 13$	0.1–20	3000 H I absorption SMBH studies	35 GHz desirable for CO studies
Magnetism	20 000 at 1.4 GHz RM grid	0.3–10 large RMs	300 confusion-limited imaging	–40 dB pol'n purity
Cradle of Life	10 000 at 20 GHz 10 K rms at 1 mas in 100 hrs	≥ 20 terrestrial planet formation	3000 0.15 AU at 150 pc at 20 GHz	100 pencil beams within PB for SETI searches
Evolution & LSS	20 000 at 1.4 GHz M_* galaxy at $z = 2$	0.3–1.4 galaxies to $z = 4$	300	dedicated beam with FOV of 50 deg^2 at 1.4 GHz is highly desirable to compete with optical

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Level 0 Subcommittee: Bryan Gaensler (chair), Frank Briggs, Sean Dougherty, Steve Rawlings, Chris Carilli (ex-officio), Richard Schilizzi (ex-officio)

Submitted on behalf of the International Science Advisory Committee
November 2003

APPENDIX A — THE PATH TO LEVEL 0 SCIENCE

Introduction

Radio astronomy has a long history of developing innovative instrumentation and of making groundbreaking astronomical discoveries. Using this heritage as a foundation, an international consortium of scientists and engineers is planning the Square Kilometer Array (SKA),[1] a next-generation radio telescope to be constructed 10–15 years hence. Several designs and sites have been proposed for the SKA,[2] all of which are currently being evaluated and iterated on by various consortia, coordinated under the International SKA Steering Committee (ISSC).

The SKA represents a great leap forward over the capabilities of current radio telescopes. Thus the list of proposed SKA science projects is very long.[3] Many of these projects have conflicting requirements in terms of frequency coverage, array configuration and siting. Some of these projects have considerable synergy with future initiatives in other wavebands, while others are unique to radio astronomy. There is a need to prioritize and classify all the various science goals, so as to establish which science goals should constrain design and siting decisions, and also to identify which scientific goals should be used to "sell" SKA to the astronomical community, to funding agencies, and to the public.

The ISSC has correspondingly appointed an International Science Advisory Committee (ISAC),[4] who have been charged with identifying, developing and prioritizing the science goals for the SKA. The ISAC has formed nine working groups representing a broad range of science topics. Within each working group, various proposed science projects have been classified as:

- "Level 1" — unique and important SKA science
- "Level 2" — important science, but not uniquely addressable by the SKA
- "Level 3" — other interesting projects, which may well make up the "bread and butter" of SKA observations, but which are not anticipated to have far-reaching consequences for our understanding

This process has culminated in the "ISAC Matrix", which identifies 18 level-1 science projects, and for each such project rates the capability of the seven currently proposed SKA designs.[5]

Level 0 Science

While the work carried out by the ISAC to date has proven very useful, there is a strong feeling that the SKA community needs to identify a handful of "level 0" science goals, which will be used to attract funding and publicity, which will be the focus of efforts to ensure that SKA work complements work which will be done by other future telescopes, and which will be those projects for which the SKA design will be specifically optimized.

Accordingly, the ISAC has formed a "Level Zero Subcommittee" (LZSC), whose charge is to:

- Propose a set of definitions for "level 0" science.
- Suggest a preliminary list of level 0 topics.

[1] See `http://www.skatelescope.org`.
[2] Individual white papers are available at `http://www.skatelescope.org/ska_documents.shtml`.
[3] See `http://www.skatelescope.org/ska_science.shtml`.
[4] A current list of ISAC members is available at `http://www.skatelescope.org/ISAC.shtml`.
[5] The current matrix is listed at `http://www-astro.physics.ox.ac.uk/~sr/ska/ska_matrix.html`.

- Identify a process through which the ISAC can converge on a specific set of level-0 science topics, and coordinate the corresponding process through which level-0 topics are proposed, reviewed and refined.

The LZSC was convened in May 2003 and currently consists of ISAC members Bryan Gaensler (chair), Frank Briggs, Sean Dougherty and Steve Rawlings. Below we summarize the progress of the LZSC on the above issues.

Definitions for Level-0 Science

A variety of definitions have been proposed for level-0 science. These include "uniquely addressable by SKA", "drive design of telescope", "use to sell to funding agencies", "up front on WWW page / talks", "lose large section of radio community if disallowed by design", and "most interesting to wider (non-radio) astrophysics community". The LZSC has considered these and other definitions, and has also looked at what constitutes the equivalent of level-0 science for other future telescopes such as *JWST*, ALMA and *Constellation-X*. We propose the following definitions for level-0 SKA science, for consideration by the ISAC:

1. Can address important but currently unanswered questions in fundamental physics or astrophysics.

2. Is science which is either unique to the radio band and to the SKA, or is something which is complementary to other data-sets but in which the SKA plays a key role.

3. Excites the broader community, and is of relevance and interest to funding agencies.

Regarding criterion (1), the LZSC recommends that of the final list of level-0 topics, at least some should address outstanding issues in fundamental physics,[6] while others should be focused on more traditional astronomical questions.[7] Ideally, level-0 topics should offer "transformational" advances, rather than just incremental steps such as better statistics or smaller error bars.

Careful consideration needs to be made regarding criterion (2). On the one hand, science which is completely unique to the SKA is particularly appealing to the radio community, but might not be of interest to researchers working in other wavebands. On the other hand, there are many profoundly important topics to which SKA might contribute, but for which another telescope might already have addressed the outstanding issues by the time the SKA begins observations. There must therefore be a trade-off between science which is uniquely addressable with the SKA, and that which represents the outstanding questions in astronomy, and which many telescopes might be able to address.

Regarding criterion (3), the SKA consortium needs to ensure that the level-0 projects align with the broad themes and priority areas laid out by various funding agencies (for example, NASA emphasizes topics such as "origins", "structure" and "evolution"). The demand for topics which are of interest to the broader community entails that we should not just be looking to promote some subset of the existing 18 level-1 topics, but rather should be looking for themes which encompass many topics or experiments.

We note that the above definitions potentially exclude: topics which are currently interesting but will be addressed by other experiments (e.g. LOFAR or ALMA); topics which are of ongoing interest to radio astronomers but don't have broad appeal to the astronomical community; measurements which can be done now or in the near future, but for which we can find fainter objects or accumulate more statistics with an SKA.

[6] As outlined, for example, in "Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century" (US National Research Council, 2003).

[7] A useful summary of such issues is the McKee & Taylor US Decadal Review, "Astronomy and Astrophysics in the New Millennium" (US National Research Council, 2001).

One issue of much discussion has been that of serendipity. Just has been the case with earlier radio telescope, there is certainly no doubt that the SKA will make many serendipitous discoveries, and indeed such discoveries may be the SKA's defining contribution to science. However, the topic of "serendipity" does not meet the definitions outlined above. The recommendation of the LZSC is therefore that serendipitous discoveries and the expansion of phase space not be included as level-0 science, but that serendipity be explicitly included in the science case as an additional motivation for building the SKA.

Process for Identifying Level-0 SKA Science

The LZSC proposes that the final list of level-0 science should contain 3–5 projects. Less than this will result on over-reliance on particular predictions or extrapolations and might lack broad appeal; too many projects will send a confusing message to the wider community.

A brief roadmap of how this process might proceed is as follows:

- Aug 2003: A call for proposals will be issued to the ISAC and Scientific Working Groups, and through them to the various science working groups and wider community. A response to this call should take the form of a brief (one page or less) submission, outlining a particular topic and explaining how it meets the criteria outlined above.
- 1 Oct 2003: Proposals for level-0 science due to LZSC.
- Oct 2003: Short response from level-0 subcommittee, followed by a brief opportunity for mergers and iteration.
- Nov 2003: Vote, ranking and culling of proposals by the ISAC (the initial results of this process will be announced at the Leiden science retreat).
- early 2004: Review of topics and rankings by external panel; simulations carried out by the SKA Simulation Working Group.
- mid 2004: "Level 0" chapters for science book; Berlin SKA/ALMA/JWST/ELT meeting.
- mid 2004: Shortlist and recommendations submitted to ISSC for final decision on 3–5 level-0 projects.
- 2004+: Topics and science case on WWW site, in outreach materials and in proposals.

Throughout the process of converging on a list of level-0 topics, two important points need to be kept in mind. First, we acknowledge that many important SKA discoveries will come from unexpected areas, not covered by the final list of level-0 (or even level-1) topics. In finalizing the list of level-0 goals, it is thus important to bear in mind that even if these projects drive and constrain the design, the telescope should still be kept sufficiently flexible so as to be capable of many other experiments. Second, while the final list of level-0 topics will not necessarily encompass all level-1 science, the corresponding instrumental specifications should ideally not prevent most level-1 science topics from still being carried out. Overall, the LZSC encourages the community to identify those science topics which are most compelling, rather than to be concerned about one's own favorite project missing out on being designated as level-0 science.

Examples of Level-0 Topics

As a starting point for further discussions, the ISAC has identified a variety of potential topics which might meet the criteria for level-0 science outlined above. These topics (in no particular order) are:

- The origin of cosmic magnetic fields
- Probing gravity through pulsars
- The Dark Ages and Epoch of Reionization
- Large scale structure and Dark Energy
- Formation of supermassive black holes
- Cosmic accelerators
- Galaxy formation and evolution
- The transient Universe
- The search for extraterrestrial intelligence
- The origin and evolution of the intergalactic medium
- Protoplanetary disks

SKA Level-0 Subcommittee
v2.0, 2003 August 5

APPENDIX B — CALL FOR PROPOSALS

From: Bryan Gaensler <bgaensler@cfa.harvard.edu>
Date: Thu, 7 Aug 2003 21:10:46 -0400
Subject: SKA level 0 : call for proposals

[-- Attachment #1 --]
[-- Type: text/plain, Encoding: 7bit, Size: 0.5K --]

Dear all,

Please find attached a call for proposals for level-0 SKA science.
This email is being sent to all members of the SKA ISAC, and to
chairs/representatives of the other various national/international SKA
consortia. Please ensure that all your constituents are made aware of
this opportunity, and that they contact the appropriate ISAC member
(see attachment) to coordinate proposal writing.

The deadline for proposal submission is 1 Oct 2003.

Bryan Gaensler

[-- Attachment #2: call_level0.txt --]
[-- Type: text/plain, Encoding: 7bit, Size: 3.6K --]

Call for Proposals - Square Kilometer Array Level 0 Science

The Square Kilometer Array (SKA) is a next-generation radio telescope,
to be constructed 10-15 years hence. Extensive information on this
project is available at http://www.skatelescope.org .

The International SKA consortium is in the process of refining the SKA
science case. A crucial part of this undertaking is to identify three
to five "level 0" science topics, corresponding to key areas in which
the SKA can make a fundamental contribution. The level-0 science topics
will be used to attract funding and publicity, will be the focus of
efforts to ensure that SKA capabilities will be complementary to those
of other future telescopes, and will be projects which will provide the
main constraints on the choice of design and site for the SKA.
A call is now issued for proposals for level 0 science. The criteria
which such topics must meet are:

* Can address important but currently unanswered questions in fundamental
physics or astrophysics.

* Is science which is either unique to the radio band and to the SKA,
or is something which is complementary to other data-sets but in which
the SKA plays a key role.

* Excites the broader community, and is of relevance and interest to
funding agencies.

A more detailed discussion of these definitions, and of the process
through which the choice of level-0 science topics will be made, can be
found at http://hea-www.harvard.edu/~bmg/ska/ska_level0.pdf .

Proposals for level 0 science should take the form of a ONE-PAGE document,
in PS or PDF format, and should contain the following components:

1) A concise title for the proposed topic.

2) A scientific justification, which:

    - provides brief background and context

    - explains the issues which this topic will address

    - describes the corresponding experiments which might be carried out
      with the SKA

    - briefly outlines the most relevant SKA specifications (e.g.
      high frequency capability, long baselines) needed to accomplish
      this project (strawman specs for the SKA are given at
      http://www.skatelescope.org/ska_concept.shtml .)

3) Clear explanations of how the proposed topic meets the three criteria
   for level-0 science outlined above.

Proposals should be submitted by *** 01-Oct-2003 ***. The level-0
subcommittee of the SKA International Science Advisory Committee (ISAC)
will then provide a short set of comments and feedback on proposals, after
which there will be a brief opportunity for revision. In Oct/Nov 2003,
proposals will be voted, ranked and culled by the ISAC, and then subjected
to external review. A final list of 3-5 level-0 science topics will be
identified by the International SKA Steering Committee in early 2004.

In order to coordinate proposals and avoid duplications, those interested
in proposing should make contact with one of the ISAC members listed
below:

* Frank Briggs (fbriggs@mso.anu.edu.au); cosmology and large scale structure
* Thijs van der Hulst (vdhulst@astro.rug.nl); galaxy formation and evolution
* Heino Falcke (hfalcke@mpifr-bonn.mpg.de); supermassive black holes and AGN
* John Dickey (john@astro.umn.edu); the Milky Way and nearby galaxies
* Sean Dougherty (Sean.Dougherty@hia.nrc.ca); life cycle of stars
* Joseph Lazio (Joseph.Lazio@nrl.navy.mil); transients, pulsars and SETI
* Chris Carilli (ccarilli@aoc.nrao.edu); solar system science

* Dayton Jones (dj@sgra.jpl.nasa.gov); astrometry, geodesy & spacecraft tracking
* Luigina Feretti (lferetti@ira.bo.cnr.it); galaxy clusters and the IGM

Please submit proposals and direct general queries to Bryan Gaensler, bgaensler@cfa.harvard.edu .

APPENDIX C — PROPOSALS CONSIDERED FOR LEVEL-0 SCIENCE

A total of 17 proposals were considered for level-0 science, as listed below. Note that the name next to each proposal indicates the contact person for, not necessarily the author of, each proposal.

The full text of all 17 proposals can be found at `http://hea-www.harvard.edu/~bmg/ska/level0`.

- "Black Holes — Light from the Gates of Hell" — Heino Falcke
- "Studying the Dark Energy" — Chris Blake
- "Imaging the Cradle of Life" — Sean Dougherty
- "The Cosmic Web and The Intergalactic Medium" — Eric Wilcots
- "Temperatures and Magnetic Fields in the Warm and Cold Atomic ISM" — Carl Heiles
- "The Origin of Cosmic Magnetism" – - Rainer Beck
- "Strong Field Tests of Gravity Using Pulsars and Black Holes" — Michael Kramer
- "The Exploration of the Unknown" — Peter Wilkinson
- "Life Among the Stars?" — Joseph Lazio
- "A Revolution in Planetary Exploration" — Dayton Jones
- "The Dynamic Radio Sky" — Joseph Lazio
- "Measuring the Universe with a Precise Radio Yardstick" — Leonid Gurvits
- "Massive Star Formation in Galaxies" — Michael Burton
- "The Dark Age and Epoch of Reionization" — Frank Briggs
- "Constraining Variations in the Fundamental Constants" — Steve Curran
- "Galaxy Evolution and SKA" — Thijs van der Hulst
- "Central Black Holes in Normal Galaxies" — Lourent Sjouwerman

APPENDIX D — RANKING OF LEVEL-0 PROPOSALS BY THE ISAC

The table below lists the ranking of the 17 proposals listed in Appendix C. Each ISAC member was asked to vote on each project, providing a score from 1 (worst) to 5 (best) for each of the three level-0 criteria. 22 of the 27 ISAC members voted during this process. The highest and lowest vote for each project was discarded, and the remaining votes averaged together, to produce the list below. Errors on each figure correspond to the RMS. The solid line divides the top eight from the bottom nine proposals.

Rank	Topic	Criterion 1 (Important?)	Criterion 2 (Need SKA?)	Criterion 3 (Interesting?)	Total
1	Probing Gravity with Pulsars	4.73 ± 0.40	4.66 ± 0.48	4.54 ± 0.57	4.64 ± 0.50
2	Dark Age & EoR	4.75 ± 0.43	3.85 ± 1.18	4.65 ± 0.55	4.42 ± 0.89
3	Terrestrial Planet Formation	4.03 ± 0.73	4.00 ± 0.76	4.58 ± 0.51	4.20 ± 0.73
4=	Magnetic Universe	4.18 ± 0.51	4.73 ± 0.51	3.44 ± 0.60	4.11 ± 0.76
4=	SETI & Astrobiology	3.83 ± 0.87	3.93 ± 0.48	4.58 ± 0.62	4.11 ± 0.75
6	Dark Energy	4.50 ± 0.72	3.08 0.84	4.56 ± 0.50	4.05 ± 0.98
7	Galaxy Evolution	4.03 ± 0.73	4.23 ± 0.73	3.58 ± 0.78	3.94 ± 0.80
8	Supermassive Black Holes	3.93 ± 0.76	3.55 ± 0.85	4.35 ± 0.65	3.94 ± 0.83
9	Fundamental Constants	4.09 ± 0.70	3.20 ± 0.51	3.43 ± 0.79	3.57 ± 0.78
10	Dynamic Radio Sky	3.13 ± 1.00	3.98 ± 0.73	3.28 ± 0.94	3.46 ± 0.97
11	Cosmic Web & IGM	3.43 ± 0.66	3.73 ± 0.70	3.19 ± 0.58	3.45 ± 0.68
12	Measuring the Universe	2.83 ± 0.84	3.43 ± 0.98	2.98 ± 1.10	3.08 ± 1.01
13	BH in Normal Galaxies	2.85 ± 0.84	3.10 ± 0.83	3.13 ± 1.05	3.03 ± 0.92
14	Exploration of Unknown	3.15 ± 1.53	3.15 ± 1.45	2.43 ± 1.32	2.91 ± 1.47
15	Planetary Exploration	2.10 ± 0.96	3.25 ± 1.11	3.08 ± 1.21	2.81 ± 1.21
16	Star Formation in Galaxies	2.63 ± 0.67	3.10 ± 0.68	2.65 ± 0.71	2.79 ± 0.72
17	Atomic ISM	2.58 ± 0.62	3.73 ± 1.03	1.83 ± 0.75	2.71 ± 1.13