Report of the 2013 External Review Committee for the Institute for Cosmic Ray Research

The Committee reviewed the scientific, educational, and outreach activities of the Institute for Cosmic Ray Research and the efforts to enhance scientific outputs of the collaborations hosted by the institute. The hearing session was held on January 16, 17, and 18, 2013 at the institute on the Kashiwa campus of the University of Tokyo. The Committee's evaluation on the completed, on-going, and future projects/programs is summarized in this report. Recommendations on priority setting of fund requests, resource managements for projects/programs, and relation with co-hosting institutions, universities, and scientific communities are made in this report.

I. Executive summary

Ia. Executive summary on the overall scientific activities

Many exciting science results have been obtained by projects and programs hosted or co-hosted by ICRR since the last External Review in 2006. The committee notes that the following accomplishments are especially admirable.

- Super-K has continued to lead the world in neutrino astrophysics: it determined the θ_{23} mixing angle in the range $0.39 < \sin^2 \theta_{23} < 0.63$ and obtaining the first evidence for ν_τ appearance.
- T2K has obtained the first evidence of ν_μ -> ν_e conversion which means that the mixing angle θ_{13} is non-zero. The group also reported the first ν_μ disappearance analysis and measured θ_{23} and Δm^2_{32} by using the off-axis pion beam, which enhances the future prospect of T2K.
- In gamma-ray astrophysics and cosmic-ray air shower experiment, Telescope Array confirmed the rapid decline in the ultra high energy cosmic rays (UHECR) above ~4.10^{19}eV and Tibet As-γ detected gamma-rays associated with the Cygnus region and pulsars in tens of TeV energy range.
- Observational cosmology group is beginning to analyze data taken with Hyper Suprime-Cam and ALMA sub-millimeter array along the tradition developed in ICRR participation in SDSS. Research in theoretical particle physics and astrophysics are also gaining wide international recognition.

The committee congratulates ICRR, its collaborating institutions and the related science communities for successfully launching several new projects and programs in this difficult time. Among them the most noteworthy is the novel gravitational wave detector (KAGRA) to be installed in Kamioka Mine. A large Grant-in-Aid has been won to build one 23m Cherenkov telescope as the first step of a larger Japanese contribution to the international project, Cherenkov Telescope Array (CTA). Two experiments in Kamioka Mine, XMASS to search for dark matter and GADZOOKS! to search for historic supernova neutrinos, are making steady progress toward their full-scale implementation.

ICRR is now recognized as a multi-disciplinary institute covering a wide range of science fields.

As the committee walked through the diverse projects and programs, on-going, under construction, and proposed, it became clear that ICRR is entering a new era in its project/program management history. ICRR has been fulfilling the mandate given by the Japanese cosmic-ray community to provide support and services untenable in small university groups like construction and operation of large-scale experiments such as AGASA, CANGAROO and Kamiokande. Their typical size was 10 million USD in funding and 5 ICRR staff members in human resources except for Kamiokande, which was built in major collaboration with KEK and Faculty of Science, Univ. of Tokyo. Kamiokande has been upgraded several times to become Super-Kamiokande (Super-K), a large international collaboration consisting of about 110 members. Now KAGRA is about to exceed Super-K in its funding and in technical complexity, implying needs for 100 or more engineers and scientists. CTA, XMASS-1.5, and the TA upgrade probably require funding 15-50 million USD each, which is close to or exceeds the upper limit of Gran-in-Aid. Hyper-Kamiokande (Hyper-K) will probably require funding exceeding 500 million USD. The totality of the required fund and human resources are much more than what ICRR has been managing. The institute has to set clear priority to the proposed projects and programs, and lay out a strategic plan for fund request and allocation of human resources.

The committee is very pleased to see that ICRR has begun to make more efforts to enhance its graduate programs on the main campus (Hongo Campus) of University of Tokyo. It commends the launching of the ICRR Spring School targeted to undergraduates and is pleased to hear that these efforts are already bringing positive results.

The committee congratulates Prof. Takaaki Kajita, the Director, for the 2012 Japanese Academy Award. This award testifies to the great contribution Prof. Kajita, ICRR, and the Kamiokande/Super-K group have made in the discovery of the neutrino oscillation.

I. Executive summary of individual projects/programs

1. Neutrino and Astroparticles

1-1) Super-K

Since the recovery from the catastrophic breakage of phototubes, the collaboration has completed two runs and added more than 13k atmospheric neutrino events and 28k solar neutrino events. Based on the total atmospheric neutrino data accumulated until 2012, they studied ν_μ->ν_e and ν_μ->ν_τ oscillations in greater detail than before and obtained the tightest constraint to the mixing angle θ_{23}. The broad energy and zenith angle coverage enabled to determine the parameters in the 3 flavor mixing scheme for the first time. They have demonstrated that θ_{13}, the mass hierarchy and the CP violating phase δ can be determined on the atmospheric neutrino data. The collaboration has completely renovated the electronics and data retrieval system which will enable to record 6 million events per second. Super-K will remain to be the leading instrument in this field.

1-2) T2K

T2K began science operation in February 2010 and collected data until the East Japan Earthquake damaged the beam line in Tokai Laboratory in March 2011. Until then, the proton synchrotron had delivered 3×10^{20} protons on target. With the delivered beam T2K has reported the first evidence of ν_μ -> ν_e conversion demonstrating that θ_{13} is non-zero, the first ν_μ disappearance analysis, and the measurements of θ_{23} and Δm^2_{32}. These studies have demonstrated that significant constraints on the CP violation can be obtained by increasing the beam intensity of the Tokai proton synchrotron.

1-3) XMASS

Data have been reported from the prototype detector with a fiducial volume of 100 kg: An energy threshold of 0.3 keV has been achieved which makes XMASS competitive with DAMA for light dark matter. Upper limits on the solar axion have been obtained in the mass range below 40 keV. This XMASS limit is lower than those given previously by CoGeNT and CDMS in the axion mass ranges <<1keV and 10-40keV. Important sources of background have been identified and removal of them will be crucial for the proposed upgrade to the 1 ton detector, XMASS-1.5.

1-4) Hyper Kamiokande R&D

Hyper Kamiokande (Hyper-K) is the next-generation of long-baseline neutrino oscillation experiments designed to obtain decisive information on the CP violation and the mass hierarchy in the neutrino sector. It will require a long-term availability of a very stable mega Watt class proton beam and a gigantic detector with a sensitivity far surpassing Super-Kamiokande. At present ICRR and KEK are collaborating on refinement of the proposal. The accelerator and the beam at J-PARC also require a major upgrade.

2. High Energy Cosmic Rays

2-1) Cherenkov Telescope Array (CTA) R&D

The group has won a large Grant-in-Aid to complete the first mirror and camera system for the Large Size Telescope, an important subsystem of CTA. The R/D phase is proceeding well and the key components have been prototyped successfully. The Japanese CTA consortium plans to contribute four Large Size Telescopes each for the Northern and Southern sites which will greatly improve the sensitivity of cosmic γ-ray observation in the 20 – 200 GeV range. The group needs additional funding of about 40 million USD by 2016.

2-2) Tibet As-γ

Anisotropies of cosmic rays at multi-TeV energies have been observed in addition to the discovery of multi TeV gamma-ray sources in the Cygnus region and at known pulsar locations. The group is finding a hint that the comic-ray mass composition becomes heavier above the knee region (3×10^{15} eV). The data collected over 15 years on the solar shadow and the anisotropy of cosmic-ray arrival direction are enabling the group to study the magnetic field distribution in the solar system. The group is adding muon detectors to improve gamma-ray selection and 100 burst detectors in the central part of the array to improve proton, alpha, and heavier nuclei separation in the Knee region.

2-3) Telescope Array

The Telescope Array was brought into full operation at an impressive speed. Cosmic-ray spectrum above 1.6×10^{18} eV has been published showing clear evidence for a rapid decline in the flux of events above $\sim 4 \times 10^{19}$ eV. The collaboration is preparing for the low-energy extension (TALE) and considering 3 near-future options: 5 more years of operation with the current configuration, increase of the area of the surface detectors by a factor of 4, and addition of a fluorescence detector if a new funding becomes available.

2-4) CANGAROO

The Cangaroo Observatory has been brought to a successful conclusion with the detection of a number of sources also observed by the H.E.S.S. telescope system.

2-5) Ashra

Ashra is a wide-angle telescope to detect various transient events in the optical waveband. The first Ashra telescopes constructed in Hawaii have demonstrated the function of the concept. However, execution of the project was delayed due to shortage of manpower and resources. The project is far behind its initial goals while its competitors are already publishing results.

3. Astrophysics and Gravitational Waves

3-1) KAGRA: Large Scale Construction

The group won funds to build the cryogenic gravitational wave detector, KAGRA, in the Kamioka mine. Its design has been based on the experience the group has gained through construction and operation of the 100m cryogenic locked interferometer system (CLIO) between 2003 and 2009. This prototype demonstrated some reduction in thermal noise with use of cryogenic mirrors but additional improvement is needed to reach the goal set for KAGRA. KAGRA will be the world-first cryogenic gravitational wave detector operated at an underground site. An international team is now forming around ICRR and several workshops have been organized to recruit young collaborators.

3-2) Observational Cosmology

The Observational Cosmology Group has played a major role in the Sloan Digital Sky Survey collaboration studying many topics including the baryon acoustic oscillation, Type Ia supernovae and their host galaxies, and strong lensing of quasars. More recently they have studied the re-ionization history by measuring the optical depth of the Ly-alpha emission. Research efforts based on the data from Hyper Suprime Camera (HSC) at Subaru and ALMA have begun, marking a new start of observational cosmology at ICRR after SDSS.

3-3) High Energy Astrophysics (Theory)

The group has been studying astronomical acceleration sites including millisecond pulsars and magnetars to estimate their contribution to the observed cosmic-ray positron flux.

3-4) Theory

The theory group covers particle physics and cosmology. They obtained a limit on the mass of unstable gravitino from the abundance of light nuclei, a limit on the dark matter annihilation rate from the CMB angular power spectrum, and a limit on the axion density from the decay of the axionic string and domain wall. The group also studied a possible SUSY breaking scenario consistent with the Higgs discovered at LHC.

3-5) Primary Cosmic Rays

Important measurements of ^{14}C in tree rings and of ^{10}Be in ice-cores have been used to gain better understanding of the earth's climate system going back to 5200 BC. The main proponent of this study is moving to a university faculty position elsewhere.

II. Evaluation of individual projects/programs

1. Neutrino and Astroparticles

1-1) Super-K

The last External Review took place in 2006 just after the full recovery of the facility from the 2001 accident of PMT breakage. After the recovery from the accident, the collaboration completed SK-III run and began SK-IV, and added more than 13k fully or partially contained atmospheric neutrino events and 28k solar neutrino events to the already impressive archive of neutrino data. Since then Super-K has resumed its status as the world leader.

The committee noted important accomplishments in three areas: the first is in the area of the atmospheric neutrino. Using the total data accumulated until 2012, the group studied ν_μ->ν_e and ν_μ->ν_τ oscillations in greater details than before and determined mixing angle θ_{23} and mass difference Δm_{23} to a better accuracy; determined for the first time the mixing parameters in the 3 flavor mixing scheme. The latter work has shown the path to solve the degeneracy between the two mass hierarchies and measure the CP violation phase in the leptonic sector.

The second area of their contribution is in the area of solar neutrinos: the measurements on θ_{12} and Δm_{12} have been improved significantly. The third accomplishment is improvement in the detector system. The collaboration has completely renovated the charge measurement electronics to QTC (charge-time-conversion) and data retrieval system to an Ethernet-based system. This allows very fast data taking, up to 6 million events per sec, Super-K is now able to record the 2.2 MeV γ-rays from neutron capture by hydrogen atoms and ~20 million neutrinos from a near-by supernova explosion (e.g., Betelgeuse).

The future plans of Super-K include GADZOOKS!, an experiment to detect background neutrinos from historical SNs. It will complete the feasibility study in a year and proceed to a full project if the study is successful.

Independently of the future plans, the Super-K experiment will continue to add statistics and try to solve the mass hierarchy problem, find CP violation in the lepton sector while waiting for a supernova explosion in the Galaxy, and the proton decay.

For several more years, Super-K group will continue to lead the field. However, great discoveries may not come in the near future and the work will be focused more on the refinement of the past analyses. The Committee sees possible issues in the recruitment of good graduate students as well as in keeping high morale in the group. GADZOOKS! will be an interesting and important new initiative to mitigate these issues.

1-2) T2K

The T2K experiment started data taking in early 2010 with a modest beam power and reaching $\sim 10^{14}$ protons per sec on target in early 2011 when the Eastern Japan earthquake inflicted serious damage to the beam line. The group analyzed the data accumulated at that time with additional data taken 2012 to constrain the mixing angle θ_{13}.to be $0.033<\sin^2(2\theta_{13})<0.188$, or rejected $\theta_{13}=0$ at 3.2σ. This observation of the transition of the muon neutrino state into the electron neutrino state, or appearance of the electron neutrino was the first in the world. The next immediate goal of this experiment is to improve the precision of the measurement with an increased intensity of the beam from the Main Ring and longer data taking time. The aim is measurement of the ν_e appearance probability within <10% which will require $\sim 8\times 10^{21}$ protons on target (POT). The other important goal for the long-baseline neutrino experiments is the measurement on the muon neutrino disappearance, or determination of $\theta_{23,}$ to accuracy ~1% and of Δm_{23} to accuracy ~3%. When these high precision measurements are combined with the results from neutrino experiments at nuclear reactors and Super-K atmospheric neutrino experiment, T2K (possibly with other long-baseline experiments) will be able to set important constraints on the CP violation and the mass hierarchy in the neutrino sector. These results may possibly give some clue to the solution of the mystery of the matter dominance of the Universe. The precision achievable will depend on the values of the mixing angles and the CP violation parameter and may require combinations of measurements on neutrino and anti-neutrino beams and/or measurements at different base-line lengths. The T2K experiment in the next five years will also serve as an R&D experiment toward a next-generation of the long baseline neutrino oscillation experiment.

1-3) XMASS

XMASS is an experiment to search for particle dark-matter and installed in the Kamioka mine. The experiment consists of a single-phase liquid xenon detector placed inside a new water tank. When compared with dual-phase detectors such as XENON and LUX, it has an advantage in scalability which will dramatically improve the self-shielding. On the other hand vertex location and fiducial definition is poorer near the detection limit and background rejection somewhat inferior. It seems too early to judge which concept is superior when driven to the required one-ton target masses.

The XMASS collaboration completed a 100kg detector (XMASS-I) in October 2010 and collected data until May 2012. On these data they published two science papers: an upper limit to the WIMP in the low mass region at a level comparable to that by DAMA but short of ruling out that by CoGeNT

2011; an upper limit to the solar axion (axion-like-particle) lower by a factor of 2 than that given by CoGeNT and CDMS in the mass range below 1keV and a best limit between 10 and 40 keV.

As is not uncommon for low-background instruments, the initial operation revealed unexpected sources of background. As a short-term solution, work is underway to shield the contaminants, and in the longer run to replace it by radioisotope-free materials. The collaboration will start a new run with the refurbished detectors in 2013 with a goal of setting an upper limit in the high mass region at a level comparable with Xenon 100.

While the group's future plan, XMASS 1.5, is a natural step towards a ton-scale installation, securing appropriate funding may be a challenge, as the estimated cost will require a funding of $13M, the maximum given as a Grant-in-Aid. The Committee foresees severe competition between Xenon, LUX and/or CDMS.

1-4) Hyper-K R&D

The next-generation of long-baseline neutrino oscillation experiments seek to obtain decisive information on the CP violation and the mass hierarchy in the neutrino sector. Such an experiment will require a long-term availability of a very stable mega Watt class proton beam and a gigantic detector with a sensitivity far surpassing Super-Kamiokande. Hyper Kamiokande has been proposed as such a detector. If realized, it will also become the ultimate instrument for nucleon decays and cosmic-relic neutrinos. At present the technical development for Hyper-K is at an advanced stage. ICRR and KEK are collaborating on refinement of the proposal for the next long-baseline experiment and will work toward realization of a MW-class proton beam at J-PARC. The latter effort requires a major upgrade including replacements of major accelerator components and the neutrino beam line, whose R&D need to be pursued in parallel.

The final precisions on $\sin^2\theta_{13}$ and CP violation (δ) will depend on the systematic error of the experiment including the uncertainty in the neutrino flux measurements and the neutrino interaction cross-sections. Each contributing systematic error has to be calibrated and/or measured to 5% or better in independent experiments to achieve an overall systematic error of 10%.

2. High Energy Cosmic Rays

1) CTA – R&D

CTA is a large international project to study astrophysics, particle astrophysics, and cosmology using two large arrays of atmospheric Cherenkov telescopes, one each in the southern and northern hemispheres. The array will be able to detect high energy gamma rays in a broad energy range (~20GeV to ~100TeV) and resolve point-like sources to a few arc-minutes in angle. They expect to find ~1000 sources, including active galactic nuclei (AGN), star-burst galaxies, pulsars (PSR), pulsar wind nebulae (PWN), compact star binaries, and dark matter annihilation signals. A main motivation is that TeV observations yield unique information on the most violent processes that represent a significant fraction of the Universe's overall energy budget and have been playing an important role in cosmological evolution. The project also presents unique opportunities for discovery including the search for dark matter, the identification of the sources of the cosmic rays, the determination of the infrared universal background and the possible detection of the quantum structure of space-time.

The Japanese CTA consortium led by ICRR will take a major responsibility by building 4 Large Size Telescopes (LST) at each site. LST will cover the lower end of the energy coverage (20 - 200GeV) and cost approximately 45 million USD of which the group secured 4 million as a Grant-in-Aid from JSPS/MEXT. Design and prototyping of the camera assembly are proceeding successfully. Eight hexagonal mirror segments have been produced and read-out electronics have been prototyped. The group is now designing the mechanical mount and actuator.

The plan is to complete one 23m mirror, install and operate at the construction site in 2016. While challenging, the risks are reduced because the telescope designed is grounded on experience with the construction and operation of the MAGIC telescopes. The present level of personnel is probably not sufficient to deploy the first mirror, photon sensor array and readout system at the construction site far from Japan in 2016. A bigger challenge will be to secure the funding of additional ~$40MUS and build up the man power by 2016 for the deployment and operation of the four telescopes. Considering the importance of the project in high energy astrophysics in Japan, we encourage the PI, ICRR Director, and Japanese CTA consortium to lay a workable plan and begin to interact with the funding agents.

2) Tibet AS – γ

The Tibet AS-γ, a joint Chinese/Japanese air-shower array, has been designed to study cosmic ray anisotropies at tens of TeV energies, to detect of sources in γ-rays at these energies and to measure the energy spectrum and mass composition of cosmic rays in the region of the knee at ~ 3 x 10^{15} eV. The shadows of the moon and the sun in the high-energy cosmic-ray arrival direction have been used to map the magnetic fields in the solar system. Important measurements have been made on the Milagro and Fermi gamma-ray sources of which 7 are found to emit γ-rays up to at least 35 TeV: they are all correlated spatially with known pulsars. Emission from the Crab Nebula has been observed up to 40 TeV. Interpreting these data must be of interest to theorists working on acceleration processes in the High Energy Astrophysics and Theory group. The energy spectra of protons and of all charged particles have been measured suggesting that the mean mass of nuclear cosmic rays increases through the knee region.

The future strategy of the group is to upgrade the instrument by addition of muon detectors distributed in the array and burst detectors in the core region of the array. The plan for the muon detectors is to add 12 of which 5 are presently under construction: 4 funded by Japan and 1 by China. The plan for the burst detectors is to add 400 of which about one quarter are under construction. The muon detectors will enhance the ability to identify γ-rays and the burst detectors will help to differential protons and heavy ions.

Longer term plans to add a muon detector of 10^4 m^2 and 400 burst detectors should be encouraged. Additionally it would be helpful to develop interactions with the KASCADE group and other groups modeling nuclear cascades in the atmosphere so that data interpreted with improved hadronic interaction models.

2-3) Telescope Array

The Telescope Array (TA) was constructed to check the results of the AGASA Observatory which showed no evidence of the spectral steepening predicted as the GZK cut-off. AGASA claimed detection of 11 events with energies greater than 10^{20} eV. Absence of a steepening suggested that new exotic physics might lie in the energy range and check of the AGASA results became of the great importance in the field of cosmic ray physics.

The TA was built up at an impressive speed in Utah, USA, as an US-Japan collaboration. The array covers an area ~ 7 times that of AGASA and has additionally 3 fluorescence detectors, allowing operation in the ‘hybrid mode’ with about 10% of events measured by both techniques. The fluorescence method enables the primary energy to be determined independently (at ~10% level) of the mass composition of the incident cosmic rays. The TA leadership has successfully integrated

140 scientists from 19 Japanese institutions and 17 ICRR scientists, into a major, high-profile, international project. The Japanese make up ~ 60% of the manpower of TA.

An energy spectrum, based on nearly 3 years of observation (May 2008 to April 2011), has been published and shows strong evidence of a steepening at around 4×10^{19} eV, in good agreement with earlier results of similar statistical weight from HiRes and with a more extensive data set from the Auger Observatory. Whether or not this steepening is evidence of the GZK effect or of source exhaustion is still unclear. It has also been shown that the energy measurements by the fluorescence are about 1.27 times smaller than given by the surface array. A similar discrepancy has been noted by the Auger Collaboration. The reason for the 27% discrepancy is not yet known and needs to be explored.

At present there is a striking and puzzling disagreement between the analyses by Telescope Array and by Auger in the energy dependence of the shower maximum. Understanding the differences between TA and Auger is essential for a coherent interpretation of the valuable data sets. This matter needs to be resolved before supporting major funding for the future projects like World Observatory. Good relations exist between the two groups and there is a strong desire to understand the differences but these cannot be overcome unless TA accumulates data comparable to Auger.

There is a possibility that the differences between the TA and Auger observations may come from the difference in the source populations in the two hemispheres. Accordingly we strongly support the fund request of about 5 million USD to increase the TA area by a factor of 4. If funded, a 2-year period of building would realise an additional 10,680 km^2 sr yr by 2019. Non-Japanese funds should also be explored for this endeavor in addition to the new fluorescence detector that is expected to be funded by the US.

While searching for funding of the extension, the group should concentrate its efforts on the continued running of TA in its present form, maximizing the output of science by applying the new energy calibration system (ELS), making comparative studies of the spectrum and arrival direction distributions from that part of the sky common to TA and the Auger Observatory.

2-4) CANGAROO

The CANGAROO telescopes were the first Cherenkov telescopes in the southern hemisphere, pioneering the high-energy view of the southern sky. The CANGAROO I telescope with a 3.8 m mirror was operated from 1992-1998, followed by the CANGAROO II telescope with a 7 m dish, later expanded to 10 m. From 2002 to 2011, the CANGAROO III stereoscopic system of four 10 m telescope was built up and operated. Unfortunately, the potential of this installation could never be fully exploited, with CANGAROO I and II suffering from – at the time – poorly understood systematic effects in the image analysis, and with single-telescope images being rather susceptible to broken or noisy pixels. The CANGAROO III system also suffered from – in retrospect – less than ideal design choices regarding mirrors and electronics, and early degradation of the first 10 m telescope, so that only three telescopes could be used after 2005. A number of initial spectacular results reported by the CANGAROO instruments could not be reproduced by instruments such as H.E.S.S.

The last years have seen a careful and very systematic effort to review and – where appropriate – to correct earlier CANGAROO results; the ICRR members are to be congratulated for this very remarkable effort, and for the open discussion and clear documentation of their early work. Additionally more recent CANGAROO data have been used to confirm H.E.S.S. data on a range of sources. After the planned summary publication, this is the time to close this chapter of ICRR work and to concentrate on the planning and construction of CTA as the next-generation instrument which will be about 100 times more sensitive than CANGAROO III.

2-5) Ashra

The Ashra wide-angle telescope represents a highly interesting and novel technological development, with a rather broad range of potential applications. The first Ashra telescopes operational in Hawaii have demonstrated the function of the concept.

However, the collaboration didn't take shape, and most of the telescopes are still to be completed. In this situation, ICRR will have to recognize Ashra as a highlight in instrument development and not to continue efforts towards full deployment.

3. Astrophysics and Gravitational Wave

3-1) KAGRA: Large Scale Construction

KAGRA is a 3 km long underground gravitational-wave detector under construction in Kamioka Mine. Funded in 2010 at a level of 9.8 billion yen (~100 million USD) for the detector construction plus 3.34 billion yen (~34 million USD) for tunnel excavation, KAGRA is the largest project in the past 20 years in the ICRR research portfolio. KAGRA will search for gravitational-wave events from compact binary mergers, supernova, neutron stars, and other possible gravitational-wave sources. The detection of gravitational waves will open a new window to astrophysics and particle astrophysics, and KAGRA will position ICRR as a world leader in the field. Most importantly, the addition of KAGRA to the global gravitational-wave network will bring significantly higher resolution in localizing gravitational-wave events in the sky. Sponsored by ICRR and the co-hosting institutions, NAOJ and KEK, KAGRA has formed an international collaboration with ~190 members, approximately 70% of which come from Japanese institutions and universities and 30% from oversea institutions and universities.

Unlike other large scale gravitational-wave interferometers currently under construction (Advanced LIGO and Advanced Virgo), KAGRA is designed with two innovations – underground operation (to reduce seismic noise) and cryogenic cooling of the test mass mirrors (to reduce thermal noise). KAGRA will be accomplished in two stages. Stage 1 (iKAGRA) will use room temperature mirrors and a Fabry-Perot Michelson interferometer configuration and will be operated in a short observational run in 2015 as a technology demonstrator. Stage 2 (bKAGRA) is the cryogenic dual-recycled Fabry-Perot Michelson interferometer designed for full sensitivity and is scheduled to be operational in 2017, with high sensitivity operations aimed for by 2018. Once operational at its design sensitivity, KAGRA will play a critical role in the global ground-based gravitational-wave network. An MOU for preliminary data sharing with the LIGO Science Collaboration and the Virgo Collaboration has been signed.

The Committee views KAGRA as the highest priority for ICRR in the next six-year period. Significant progress has been made in tunnel excavation at Kamioka, in the fabrication of beam tube segments for the vacuum system, and in the development of cryostats. A project structure has been developed, subsystem leaders have been named, and work on subsystems is moving forward.

Due to the nature of the review, the Committee was not asked to make a detailed technical evaluation of KAGRA. Nonetheless, the Committee identified two significant issues which we report on here. We feel that successfully addressing each of these issues is absolutely critical to the successful completion of KAGRA. The first issue is the need for increased funding. A detailed costing was not presented, but based on presentations the Committee estimates that approximately 1-2 billion yen (~10 – 20 million USD) will be needed additionally. The second critical issue is a lack of manpower. Although there is a large collaboration KAGRA has only ~33 FTEs (technical personnel included) working on KAGRA. Comparing with other gravitational-wave projects, the Committee felt this level of manpower is seriously inadequate. The Committee feels strongly that efforts to increase both the baseline funding and project manpower shortfall should be pursued with the highest priority. In addition to pursuing traditional funding sources (eg, MEXT, Japanese Grant-in-Aid programs), it may be possible to grow the manpower base by establishing ties with other universities, particular local universities near the Kamioka site. The participation of KEK and its expertise in engineering will offset the shortfall. The Committee encourages ICRR to further involve the engineering expertise of KEK and recruitment of retirees from industry to the fullest extent.

3-2) Observational Cosmology

This group made major contributions to the Sloan Digital Sky Survey (SDSS) and enhanced visibility of ICRR in this field. Important contributions of the Japanese SDSS group include the photometric system of SDSS. Many important papers have been published using this system. In the past 5 years, the cosmology group of ICRR has contributed to the morphological study of galaxies, the baryon acoustic oscillation, Type Ia supernovae and their host galaxies, and strong lensing of quasars. Some members participated in the resolution of the “missing baryon” problem by measuring reddening of distant quasars by dusts in the halo of lensing galaxies. This line of research has been carried to a new stage to determine the completion time (z~6.0) of reionization by precise measurements of Lynman-alpha luminosity with Subaru and Keck telescopes.

The committee noted that younger staff are playing more active roles in observational projects with Subaru and Hyper Supreme-Cam (HSC), ALMA, HST and other telescopes. ICRR is now engaged in developmental works on HSC in close collaboration with NAOJ and Kavli-IPMU.

3-3) High Energy Astrophysics (theory)

A new theory group has been created three years ago that describes itself as the “theoretical engine” for experimental high energy astrophysics at ICRR. It consists of the group leader and a tenured research associate to be hired this year, two postdocs and 4 graduate students. A theoretical team in support of the experimental program is an important part of institutes similar in size to ICRR. The members of the group cover the physics topics relevant to their task: the physics of cosmic accelerators, the physics of potential cosmic ray sources, solar system plasma physics as well as research on some more specialized problems such as the detection of dust grains with radio techniques and the detection of ‘atmospheric” neutrinos produced at the surface of the sun. The work ranges from theoretical to something directly related to specific experiments. An example is the theoretical support for the electron imaging calorimeter CALET on board of the space station that will cover the GeV to PeV energy range. An example of the original work in the group includes the correlation study between giant radio pulses and excess in the hard X-ray pulses of the Crab pulsar.

3-4) Theory

The theory group leads theoretical studies related to the research conducted at ICRR from the particle physics side. The group includes two staff positions, three postdocs, six graduate and three master students. Their present interests are typical of particle theory groups covering problems in cosmology and astroparticle and particle physics. Recent accomplishments include the study of nucleosynthesis in inflationary supersymmetric models, consequence of the larger-than-expected Higgs mass relative the expectation in supersymmetric models, and, constraints on dark matter particles and axions from cosmological observations. The group collaborates extensively with Kavli-IMPU scientists, which is bringing a significant benefit to ICRR.

The Committee was impressed with the level and quality of the scientific output of the Theory Group and encourages continued support by ICRR.

3-5) Primary Cosmic Rays

A number of groups in Japan have exploited the low-background facility that is maintained for studies of low-level radioactive isotopes at ICRR. In particular the ICRR group have made a variety of important measurement on ^{14}C and ^{10}Be in tree-rings and ice cores respectively to study long term variations in climate to 1 year accuracy.
Important studies have been made on the relationships between the solar cycle period and solar activities, and also of the relationship between climate and the variation of cosmic-ray intensity.

The staff member involved in this activity is moving from ICRR to a university faculty position. The committee recommends that the staff post thus released to be used to strengthen a high-priority area. However it important that this low background facility is maintained and supported by ICRR for the benefit of outside users.

III. Evaluation of fund requests and resource managements

The experimental and observational research areas covered by ICRR have evolved rapidly in recent years and a few well-defined major research goals have been identified. They include discovery of CP violation in the lepton sector, resolution of the neutrino mass hierarchy, discovery or characterization of the dark-matter particle(s), understanding the cosmological dark energy, detection of gravitational waves and neutrinos from cosmic explosive events, and, characterization of high energy cosmic ray sources. Since the last ICRR External Review, various approaches to these exciting research topics have been proposed world-wide and their requirements on technologies and funding are understood reasonably well. To be competitive internationally each project is likely to consume a significant fraction of the resources available in one mid-size institution like ICRR. Hence all projects are seeking strong international collaborators and mid-size institutes like ICRR are becoming very selective in hosting or co-hosting projects.

The committee finds a similar trend among the projects at ICRR: they have grown in funding and human resource dramatically since the last external review. Historically Super-K was the only large-scale project whose cost was at 100 million USD scale. Most other ICRR projects have been constructed on a few modest special designated funds (8-20 million USD) and/or Grants-in-Aid of a few million USD. Human resource requirements for these projects other than Super-K have been a few FTEs at ICRR. Most technical expertise has existed in the cosmic ray and/or neighboring communities. This situation is changing most drastically with coming of KAGRA.

Regarding KAGRA, the committee commends the long and hard works by the Japanese gravitational wave group and ICRR which brought it to reality. The big budget entails various responsibilities some of which are new to ICRR. The committee identified these responsibilities by referencing to experiences of LIGO in this report.

Super-K has become the flagship of ICRR after Kamiokande and T2K has been a natural extension to fully exploit Super-K as the far detector in the long-baseline neutrino experiment. The committee is strongly convinced that the two experiments (Super-K and T2K) have to remain at the top priority for production of scientific results at ICRR for the next several years or more. It also believes that ICRR has to remain involved and to extend its commitments in other selected areas while successfully completing KAGRA and operating Super-K, T2K, and KAGRA. High precision measurements on cosmic rays are very crucial to the study of the two central issues in the present cosmology, the dark matter and the dark energy. When confronted to the reality in funding and limitation in available positions, ICRR has to be very selective in choosing projects. Since ICRR has been supported by the

Japanese cosmic-ray, astrophysics, and particle physics communities, a broader consensus will also be needed. The committee spent a significant time on these issues including two hearings from the strategic committee on astroparticle physics in Japan (Prof. Yoshitaka Itow) and the committee on the future projects in ICRR (Prof. Toshio Terasawa). The committee's recommendations on these issues can be found in this report.

IV. Evaluation of graduate education, relation with universities, and public outreach

The committee is very pleased to see that ICRR has begun to make more efforts in reaching out to undergraduates on the main campus of University of Tokyo and on campuses of other universities. Visibility of ICRR faculty members as potential advisers has been rather low until now. Having an office for the ICRR faculty on the main campus (Hongo Campus) will enhance its visibility among undergraduate students. The committee is also pleased to hear that the ICRR Spring School targeted to undergraduates from Japanese universities has been successful and is bringing positive results. The committee also appreciates the extra efforts ICRR has put in organizing a series of public lectures in Toyama Prefecture near Kamioka and in Kashiwa.

ICRR's relation with the physics and astronomy departments of Univ. of Tokyo, National Astronomical Observatory (NAOJ), Kavli-IPMU, and KEK is becoming much more important. For the success of KAGRA and T2K, a long-term collaboration with NAOJ and KEK will be essential. Relation with Japanese cosmic-ray community (CRC) as well as the international communities participating in the collaboration will also become critical for the success of KAGRA..

V. Recommendations

A. Project selection

All faculty members are allowed to submit a proposal for grants in Japanese academic institutions if their superior (the director for ICRR) endorses the proposal, which follows more-or-less automatically. Some R/D proposals get funded and others fail, all without any consultation with the director. The allotted fund is most likely not enough and so is the available human resource. While building up KAGRA and launching other new projects, this management style will not work.

To carry out the research agenda in the next 10 years, the Director and scientists have to win funds most aggressively and manage its resources most effectively. ICRR has set up an internal refereeing mechanism for Grant-in-Aids submission in 2009. The committee urges ICRR to strengthen its function further. In the proposal form of high-priority projects, the director may add a paragraph explaining why they have been given higher priority at ICRR. The discretionary funds and staff positions have to be allocated accordingly.

B. Engineering support

The committee notes that ICRR has significant disadvantage when compared with other comparable institutions outside Japan. Being in the Japanese university system, ICRR doesn't have job categories for high-level engineering and high-level technical works. The lack of such job categories has been supplemented partially by hard-working scientists and students. The level of expertise required for KAGRA is much higher and cannot be supplemented in the same way. The Director may have to negotiate with MEXT and University of Tokyo to solve this issue. Even then it will be difficult to build up professional engineering in ICRR alone and will require close cooperation with co-hosting institutions and collaborating industry.

C. Individual projects/programs

The committee reiterates that successful completion of KAGRA should be at the highest priority for ICRR until KAGRA will become operational in 2017-2018. For production of world-class scientific results, Super-K and T2K have to remain at the highest priority as long as they are the highest sensitivity neutrino experiments in the world.

The committee also recommends ICRR to remain involved in multiple world-class experimental high-energy astrophysics and non-accelerator particle physics projects/programs. The proponents are strongly encouraged to continue their scientific efforts to produce highest-level scientific outputs.

R&D efforts for the 2 future projects, CTA and Hyper-K, are well-advanced. The committee found that the level of funding and human resources required for Hyper-K is far beyond the current ICRR budget and man power and hence beyond the charge given to this committee. As for the CTA project, the committee believes that successful completion of the current CTA R&D will enable ICRR and Japanese CTA Consortium to build all Large Size Telescopes within the traditional funding level of ICRR. The challenge is coordination with the KAGRA funding schedule. Coordination within University of Tokyo, among co-hosting institutes, and related science communities will be required.

The committee found that the near-future upgrades proposed by Tibet-γ and Telescope Array have important scientific merits and can be completed with a large Grant-in-Aid each. The Director and ICRR faculty have to be selective in requesting Grant-in-Aids, coordinate with the collaborating non-Japanese funding agents, and maximize the science outputs as mentioned in the previous subsections.

Acknowledgments

The 2013 External Review Committee extends sincere thanks to the Director Professor Takaaki Kijita, Professor Masahiro Teshima, ICRR staff and students, and Prof. Yoshitaka Itow of Nagoya University for sparing much time and effort for this review. Without their cooperation, the review process would have been more difficult and painful. The committee wishes that this report will prove useful for ICRR in formulating strategy to secure funds and in allocating resources to carry out its world-class research projects.

Appendix I: External review committee members

Halzen, Francis: Professor, University of Wisconsin-Madison

Hofmann,Werner: Director, Max-Planck-Institut für Kernphysik in Heidelberg

Kaifu ,Norio: Professor, The Open University of Japan and Director Emeritus, National Astronomical Observatory of Japan

Kamae, Tsuneyoshi (Chair): Professor emeritus, Stanford University and University of Tokyo.

Nishimura, Jun: Professor Emeritus, Institute of Space and Astronautical Science and the University of Tokyo.

Reitze, David: Executive Director, LIGO Laboratory, California Institute of Technology

Suzuki, Atsuto: Director General, High Energy Accelerator Research Organization (KEK)

Watson, Alan: Professor, University of Leeds

Appendix II: External review committee agenda

16. Jan. 2013 (Wed)

9:00	Pickup at Hotel		
9:30	Arrival at ICRR		
	Coffee		
10:00	Discussion on the review (Closed session)	Reviewers, Director, Secretary	(30)
10:30	Introduction of ICRR	Takaaki Kajita	(20+10)
11:00	Telescope Array	Hiroyuki Sagawa	(20+10)
11:30	CANGAROO	Takanori Yoshikoshi	(20+10)
12:00	Tibet AS-gamma	Masato Takita	(20+10)
12:30	Lunch		
14:00	Ashra	Makoto Sasaki	(20+10)
14:30	CTA R&D	Masahiro Teshima	(20+10)
15:00	High Energy Astrophysics (theory)	Toshio Terasawa	(20+10)
15:30	Coffee		
16:00	Gravitational Wave	Kazuaki Kuroda	(20+10)
16:30	Observational Cosmology	Masami Ouchi	(20+10)
17:00	Primary Cosmic Ray	Hiroko Miyahara	(10+5)
17:15	Discussion (Closed session)	Reviewers	(30)
18:00	Dinner at Cafeteria (Reviewers and ICRR members)		
20:30	Return to Hotel		

17. Jan. 2013 (Thu)

9:00	Pickup at Hotel		
9:30	Arrival at ICRR		
	Coffee		
10:00	Super-K	Yoichiro Suzuki	(30+10)
10:40	T2K	Yoshinari Hayato	(15+10)
11:05	Hyper-K R&D	Masato Shiozawa	(15+10)
11:30	XMASS	Shigetaka Moriyama	(20+10)
12:00	Theory	Masahiro Kawasaki	(20+10)
12:30	Lunch with young scientists at the lecture hall in the Kashiwa research complex building 6F		
14:30	Interim report from Cosmic Ray Committee (CRC)	Yoshitaka Itow	(15+5)
14:50	Interim report from the future planning committee of ICRR	Toshio Terasawa	(15+5)
15:10	Discussion (Closed session)	Reviewers	(30)
15:40	Coffee		
16:00	Interviews with project, A, B, C, D,,,,	Reviewers + individual project leader	(90)
17:30	Discussion (Closed session)	Reviewers	(30)
18:30	Dinner at the restaurant Kisoji with division leaders		
20:00	Return to Hotel		

18. Jan. 2013 (FRI)

9:00	Pickup at Hotel		
9:30	Arrival at ICRR Coffee		
10:00	Discussion (Closed session)	Reviewers	(60)
11:00	Preliminary Report from Review committee	Reviewers, Director, Secretary	(60)
12:00	Lunch		
14:00	Return to Hotel		