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Report of the 2019 External Review Committee for the Institute for Cosmic Ray Research

The Committee reviewed the scientific and educational activities of the Institute for Cosmic Ray Research (ICRR) and the efforts to enhance scientific outputs of the collaborations hosted by the institute. The hearing session was held on May 15, 16, and 17, 2019 at the institute on the Kashiwa campus of the University of Tokyo. The Review Committee summarized impressions immediately after the hearing as the preliminary evaluation report. After that, referring to the preliminary report and exchanging opinions in mail by the Committee members, the final external evaluation has been summarized in this report.

I. Executive summary

Ia. Executive summary on the overall scientific activities

The Committee is very pleased to hear brilliant scientific achievements, progress of the construction projects, and the construction of international joint research since the previous External Review Committee in 2013.

The Committee notes the following excellent progress and science achievement.

- The Committee admires important accomplishments continuously coming out from Super-Kamiokande (Super-K). It is highlighted by an observed preference to the normal hierarchy with a significance exceeding 90% CL, and a weak indication for Dirac CP phase around $3\pi/2$.
- The T2K experiment has accumulated $1.51\text{x}10^{21}$ POT neutrino data and $1.65\text{x}10^{21}$ POT antineutrino data and providing 7.3 σ significance in ν_e appearance, 90% or stronger hint of non-zero δ_{CP}.
- The observational results by Telescope Array (TA) had indications for anisotropies that could be related to sources or source regions (latitude-dependent flux and hot spot).
- After the last external review, KAGRA completed several key milestones in the construction of the gravitational detector. It is planning to join with the two LIGO (LL) and one Virgo (V) detectors toward the end of the 'O3' (third) observing run in late 2019 or early 2020.
- The activities of the observational cosmology group and the theory group are very high and there have been many excellent papers after the previous external review.
- The Japanese CTA project plans to build 4 Large Sized Telescopes (LSTs) in La Palma, Spain (Northern Site) by 2021 and 4 more LSTs in the southern hemisphere at Paranal, Chile (Southern Site). The group secured funding for this first portion in 2016 and construction is well underway. The completion of the first LST at La Palma site under the leadership of ICRR is a highlight in the field.

The Committee congratulates the SK and T2K teams for the world leading accomplishments in neutrino oscillation study highlighted by Nobel Prize to Dr. Kajita and Breakthrough Prize in physics to both teams.

The Committee realized the importance of the future plan of the next decade, Hyper-Kamiokande (Hyper-K), which has the potential to lead the world in resolving the critical question of CP violation in the neutrino sector and hence possible insight into the dominance of matter over antimatter in the universe. Other important science goals include search for proton decay and detection of supernova neutrinos. Technically the project appears ready for funding. The Committee strongly supports the implementation of this project on a time scale that will allow the world leadership in these important areas of physics.

In order to make progress on such a large project as Hyper-K (which requires the participation of a large number of researchers and a large budget from multiple sources), ICRR should continue to establish a strong system for the project management, including good system engineering.

KAGRA is transitioning from a construction project to an operational detector. Key to its success is a continued focus on commissioning and development of a model for long term sustainable operations. We encourage KAGRA (and other gravitational wave detector projects) to develop personnel exchanges to help KAGRA (and all detectors) advance their science goals.

The Committee strongly supports ICRR to seek funding for four LSTs at the southern CTA site.

The Committee had the opportunity to interview young researchers. Young researchers appeared to be generally satisfied with the ICRR research environment. However, the Committee heard that there were several requests for more frequent exchanges and interactions with other research fields.

The Committee encourages ICRR to further develop its diversity policy and program including, for example, opening postdoc position in summer to accommodate applicants from overseas.

Ib. Executive summary of individual projects/programs

1. Neutrino and Astroparticles

1-1) **Super-K:** Super-K has observed a preference to the normal hierarchy with a significance exceeding 90% CL, and a weak indication for Dirac CP phase around $3\pi/2$. These are the remaining primary questions in the PMNS paradigm. The solar neutrino analysis has further lowered the threshold and the day-night asymmetry has been observed at 2.9 σ level. The tension found in Δm^2_{21} measurements is notable. Apart from oscillation, the world-leading searches for WIMP self-annihilation, nucleon decay, galactic supernova, and supernova relic neutrinos have been conducted. The detector has been refurbished and the water leak has been successfully fixed. It is an important step toward the realization of SK-Gd.

1-2) **T2K:** The T2K experiment has accumulated 1.51×10^{21} POT neutrino data and 1.65×10^{21} POT antineutrino data and also continuously improving the analysis. T2K has provided 7.3 σ significance in ν_e appearance, 90% or stronger hint of non-zero δ_{CP}. The coming gadolinium addition in Super-K will help improving antineutrino analysis. Also, accelerator and near detector upgrades will improve both the statistics and systematic errors. There are ongoing efforts of joint analysis between T2K and NOνA for better understanding of systematics.

1-3) **XMASS:** The XMASS detector has completed its data taking achieving the largest exposure of a xenon detector to possible dark matter (1330 tonne days). It achieved the highest photoelectron per unit energy deposit of liquid xenon detectors and the resulting sensitivity to low energy electrons has allowed a sensitive search for annual modulation in the signal as reported by DAMA but this report has not been confirmed. Final analysis is underway. The group will move its focus to the XENONnT project.

1-4) **Hyper-Kamiokande:** The ICRR has initiated the major international project Hyper-K and has provided the scientific and technical leadership for this exciting project. This project offers world-leading research in several critical areas of physics: it has the potential for discovery of CP violation in the neutrino sector with significance of up to 8 σ for favourable values of δ_{CP}; it can fix the mass hierarchy for neutrinos; it offers an order of magnitude increase in sensitivity to proton decay; it will provide new sensitivity to astronomical processes such as current and historical supernovae, and it will allow further study of atmospheric and solar neutrino oscillation.

2. High Energy Cosmic Rays

2-1) **Telescope Array:** Telescope Array (TA) is the largest detector for ultra-high energy cosmic rays (UHECR) in the northern hemisphere. Japanese groups, under the leadership of ICRR, are the driving force in building, extending, and operating TA. Data taken with TA are of absolutely essential importance to ensure full-sky coverage at the highest cosmic ray energies. Recent highlights of TA include the measurement of the energy spectrum over several decades in energy and indications of anisotropies at different angular scales. The physics reach of TA is mainly limited by event statistics at the highest energies. Therefore, the ongoing extension of TA to TAx4 is a scientifically well-justified upgrade that is of key importance. In addition to the increase of the aperture also the collection of composition-sensitive information will be very important.

2-2) **Tibet ASγ:** The Tibet ASγ experiment is an air shower array that operates in Tibet at high altitude. Focusing on very high-energy (VHE) gamma-ray astronomy and cosmic ray astrophysics, the experiment has been upgraded several times over the years. Recent scientific highlights include the detection of Galactic sources of VHE gamma rays extending above 100 TeV and studies of the coronal and interplanetary magnetic fields. Tibet ASγ is a running experiment with moderate operations costs. Accumulation of many years of data is necessary for the study of the solar magnetic field using the shadow of the sun and the detailed study of solar activity.

2-3) **Cherenkov Telescope Array (CTA):** CTA plans to observe very high-energy (VHE) gamma rays at two sites, in the Canary Islands, Spain (CTA-N) and at Paranal, Chile (CTA-S). The Japanese CTA collaboration led by ICRR is responsible for construction of 4 Large-Sized Telescopes (LSTs) at each site in collaboration with an international sub-consortium. The funding for the LSTs at CTA-N was granted in 2016; the first LST has been constructed and is being commissioned now. CTA-S is planned for completion on a longer time scale and we endorse the plan by ICRR to request the funding for the LSTs for CTA-S. Although the progress made by the Japanese CTA group is very impressive, the time-span required to harvest science and the remoteness of the sites will pose new challenges for the group beyond the tenure of key scientists.

2-4) **High Energy Astrophysics:** The group consists of the leader (Associate Professor), an Assistant Professor, one postdoc and two graduate students. As a theoretical group within ICRR, they are making an important contribution not only to the physics topics relevant to their task, the physics of cosmic accelerators, the physics of potential cosmic ray sources, etc., but also to the organization of seminars on special topics and educational seminars for students.

2-5) **Ashra (R&D):** Ashra is a novel detector developed to detect various transient events with wide FOV in the optical waveband. However, it is still a project in R&D stage although the development started more than 15 years ago. The publication record is poor since the last review in 2013, with no scientific results published in refereed journals. The project is far behind its initial goals while its competitors are already publishing results.

2-6) **ALPACA (R&D):** ALPACA is a proposed cosmic-ray/gamma-ray experiment to be built at a high-altitude site in Bolivia. As conceived, the experiment would consist of a moderate-sized air shower array and an underground muon detector. Studies have been carried out to estimate its performance and sensitivity to gamma-ray point sources, such as possible PeVatron sources.

3. Astrophysics and Gravitational Waves

3-1) **KAGRA:** The KAGRA cryogenic underground interferometer has been fully constructed and has entered in the critical commissioning phase to identify and reduce the detector noise sources to improve its sensitivity. Flooding of the KAGRA tunnels, a major problem encountered during construction phase, has been mitigated by installing waterproofing. KAGRA has a stated goal of joining the LIGO-Virgo ‘O3’ observing run in late 2019 or early 2020. Plans for a future upgrade of KAGRA to go beyond its current design goal are under development, and will require contributions from other countries.

3-2) **Observational Cosmology:** The Observational Cosmology Group is a productive group in ICRR using observations to study the cosmic re-ionization epoch and early galaxy formation and structure. They are the leading group in the Subaru Hyper Suprime-Cam (HSC) Collaboration for surveying high redshift galaxies.

3-3) **Theory:** The theory group is studying particle physics phenomenology and particle cosmology which are related to physics beyond the Standard Model of particle physics. The research topics covered by the group include dark matters, axions, SUSY and Higgs phenomenology, inflation in the early Universe, baryogenesis and the origin of primordial black holes.

II. Evaluation of individual projects/programs

1. Neutrino and Astroparticles

1-1) **Super-K:** The Committee admires important accomplishments continuously coming out from Super-K. Neutrino oscillation analysis is providing new exciting indications and the planned gadolinium addition will expand the frontier of neutrino research.

Super-K has been steadily improving the precision of neutrino oscillation parameters. It is highlighted by an observed preference to the normal hierarchy with a significance exceeding 90% CL, and a weak indication for Dirac CP phase around $3\pi/2$. These are the remaining primary questions in the PMNS paradigm. The significance of ν_τ appearance in atmospheric neutrino oscillation has been improved to 4.6 σ by employing a neural network-based analysis. The solar neutrino analysis lowered the threshold down to 3.49 MeV with various efforts in water system, DAQ and software. The observed day-night asymmetry is 2.9 σ level. The tension found in Δm^2_{21} measurements is notable. Apart from oscillation analysis, the world-leading searches for WIMP self-annihilation, nucleon decay and galactic supernova have been conducted. The lifetime limit of major nucleon decay modes reached more than or close to 10^{34} years by utilizing a new technique of neutron tagging.

The obtained flux upper limits of supernova relic neutrinos (SRN) already reached within a factor of model predictions. New search for SRN by tagging neutron capture on hydrogen has been performed with SK-IV data and the world best limit has been extended down to 16 MeV. The addition of Gadolinium in Super-K for neutron tagging is a major upgrade of the detector in this context to happen in early 2020. The necessary developments including water transparency and radiopurity are successful. Expected detection of SRN will open a new window to reveal the history of star formation. The Committee congratulates the success of fixing the water leak of Super-K as an important step toward the realization of SK-Gd. The speedy increase of Gadolinium concentration may be necessary to accumulate sufficient statistics before the HK start. The Committee recommends that the Super-K team pursues the investigation of flasher or dead PMTs, although it is a small fraction, for future large detectors using similar technology.

1-2) **T2K:** The T2K collaboration consists of about 470 collaborators from 12 countries and ICRR team is playing important roles with responsibilities on the main detector and modeling of neutrino-nucleus interaction. The experience developed in atmospheric neutrino analysis is well reflected to the T2K data analysis. The T2K experiment has accumulated 1.51×10^{21} POT neutrino data and 1.65×10^{21} POT antineutrino data and providing 7.3 σ significance in ν_e appearance, 90% or stronger hint of non-zero δ_{CP}. The team is continuously improving the analysis by larger fiducial volume with new sophisticated event reconstruction and new use of CC1π sample. The Committee admires these great accomplishments. The coming gadolinium addition in Super-K will help improving antineutrino analysis and T2K itself is also being updated by 2021 by means of accelerator upgrade and near detector upgrade. More positive participation in near detector from ICRR team will be helpful to reduce total systematic errors. NOνA is approaching the same target with different energy and different systematics. The Committee thinks the ongoing efforts of joint analysis between T2K and NOνA is very healthy. The Committee also recommends that it also involves atmospheric neutrino data in the joint analysis toward the evidence of non-zero δ_{CP} and determination of neutrino mass ordering. It will highly elevate the importance and visibility of ICRR.

1-3) **XMASS:** The XMASS project has successfully completed its data taking and is now in the final analysis phase. Backgrounds from the PMT support system have been reduced by almost an order of magnitude allowing interesting physics to be accessed. Important technical achievements include providing the exposure of 1330 tonne-days, which is the largest among existing xenon-based dark matter search experiments. It also achieved the photoelectron yield that is higher than that of any other xenon dark matter detector. This permitted a sensitive detection of low energy electron recoils. A particularly important impact has been a search for annual modulation in the low energy region where DAMA claims a signal. No support for such a modulation is seen even though the exposure and the statistical precision exceed those of the DAMA measurement. Seventeen papers were published in leading journals during the review period.

The project achieved the lowest radon background of the xenon detectors. However, the project has shown that the total backgrounds in the single-phase xenon detector are higher than in the dual phase detectors and this limits the sensitivity to the primary target which is the observation of WIMP dark matter. It has therefore been decided to stop the single-phase program and the group will join an existing project XENONnT to search for dark matter at the tonne scale with a dual phase detector. The Committee supports this decision. The team has clear expertise to bring to the project and this will allow Japanese access to a world leading facility for dark matter searches.

1-4) **Hyper-K:** This project has the potential to lead the world in resolving the critical question of CP violation in the neutrino sector and hence possible insight into the dominance of matter over antimatter in the universe. It also offers world leading capability for the discovery of proton decay – a key prediction of grand unified theories of the fundamental forces of nature. These are huge issues that will shape the future of basic science. It is a project that leverages the expertise in large water Cerenkov detection technology built up at the ICRR over the past 3-4 decades which has led to an impressive string of science discovery recognized by 2 Nobel prizes. The ICRR has provided the scientific and technical leadership for this exciting project. The Committee strongly supports the implementation of this project on a time scale that will allow the world leadership in these important areas of physics. In addition, it offers world leading extensions to the earlier programs in supernovae detection, atmospheric neutrino physics and precision solar neutrino physics.

During the period of this review the ICRR team has led the development of a detailed design for the project and the resulting design report has been subject to external reviews. In concept, the detector is similar to Super-K but there are many changes necessary to accommodate the order of magnitude larger volume and to take advantage of more modern technology. Much work has been carried out to establish a design for the excavation and support of the massive cavern. New phototubes offering much higher sensitivity and charge and timing resolution have been developed. Many simulations have been carried out to probe the sensitivity of the facility to new physics. Technically the project appears ready for funding.

The scale of this project requires a strong scientific and management team and it is critical that such the leadership of this team be identified very soon. The Committee is pleased to learn of the moves to establish a consortium of institutions in the University of Tokyo to provide this team. The Committee were shown the planned management organization and was satisfied that this would provide the structure needed for such a large and complex project.

2. High Energy Cosmic Rays

2-1) **Telescope Array:** The Telescope Array project has been initiated by ICRR scientists (Prof. Masaki Fukushima and colleagues) more than 10 years ago. It is a scientifically very successful cosmic ray observatory, and no competing instrument exists in the northern hemisphere. ICRR and other Japanese scientists have secured funding for the construction and operation of TA with its Low Energy extension (TALE) and also for its ongoing extension to TAx4. Within the international collaboration of TA, Japanese groups, led by ICRR scientists, are responsible for the surface detector array, two fluorescence detectors, and the Electron Light Source (ELS) to generate pseudo air showers for calibration, with additional contributions coming from Korean groups. The US groups of the host country have contributed to the third TA fluorescence detector, the TALE fluorescence telescope detector, and ongoing two TAx4 fluorescence telescope detectors.

We congratulate the ICRR group for their leadership role in conceiving, building and successfully operating TA, as well as for spearheading its timely extension to TAx4. TAx4 will ensure, for the first time, an approximately uniform coverage of the whole sky with two UHECR observatories, TA in the north and the Auger Observatory in the south. As it is expected that sources or source regions of UHECR can be identified by anisotropies in the arrival direction distribution of the particles, the full-sky coverage with uniform sensitivity is of key importance to make progress.

The Committee appreciates the smooth and successful transfer of leadership roles and management responsibilities in TA to a younger generation of physicists, which took place in recent years.

Scientific highlights of TA include the measurement of the cosmic ray spectrum over many decades in energy and various anisotropy studies. The strong indications for a declination-dependent shape of the suppression of the energy spectrum at the highest energies are very important and, if confirmed with higher statistics, will be a breakthrough in this research field. Related to this, the apparent anisotropies of the arrival direction distribution of UHECR, in particular the so-called hot-spot, are of central interest. Establishing these signatures, which are currently seen with a significance of about 3-sigma, beyond doubt will be the main goal of the field for the next decade.

In addition to being a world-leading UHECR observatory, TA has become a widely used test facility for R&D projects on new detection techniques and for testing prototype detectors for instruments of the next generation. The Committee regards very highly the support of ICRR of these activities that lay the ground for the future of the field.

2-2) **Tibet ASγ:** The Tibet air shower experiment started nearly 30 years ago with modest funding (JSPS Grants) in collaboration with Chinese institutions. The experiment has underdone regular upgrades over time and has produced a steady stream of scientific results, and some important discoveries. Tibet ASγ continues to operate smoothly and to produce results on a regular basis.

The highlights from recent results include measuring the diurnal anisotropy in the cosmic rays and use of the shadow in cosmic rays cast by the Sun to probe the astrophysical magnetic fields of relevance, including the coronal, interplanetary and geomagnetic fields. Clear evidence for variation in the cosmic ray deficits with solar cycle are seen and the two variants for the coronal field (potential field source surface and current sheet source surface) are studied. Indirect measurements of the interplanetary magnetic field can also be made.

An upgrade to add underground muon detectors was completed about six years ago. These detectors, using the water Cherenkov design, have now been operated for several years and provide key gamma/hadron separation in the study of astrophysical sources of gamma-ray emission. This allows Tibet ASγ to detect very high-energy (10-1000 TeV) gamma-ray sources using a complementary approach to imaging atmospheric Cherenkov telescopes. In addition, a dense array of air-shower core detectors permits Tibet ASγ to study the composition of cosmic rays near the knee region of the spectrum.

A highlight in the area of gamma-ray astronomy is the extension of known Galactic sources (e.g. Crab nebula and MGRO J1908) to energies of 100 TeV and beyond. Along with similar results from HAWC, these represent the first detection of astrophysical sources at energies above 100 TeV.

The Review Committee congratulates the ICRR group for being a critical participant in the successful operation of Tibet ASγ for many years and in producing a continual harvest of good-quality results relating to VHE gamma-ray astronomy, cosmic ray physics and solar physics.

We find the current scientific analyses pursued by the group to be very worthwhile and encourage this work to continue. In particular, this work includes the pursuit of spectral measurements of Galactic gamma-ray sources to the highest achievable energies and the study of separating Fe-initiated showers from proton-initiated showers with an eye towards measuring the cosmic ray composition.

2-3) **CTA:** The Japanese CTA group has been responsible for the major portion of funds, construction, and installation of four Large-Sized Telescopes (LSTs) and is expected to play the leading role in their operation and science analyses at the northern site of CTA (CTA-N) in del Roque de los Muchachos on La Palma in the Canary Islands, Spain. The responsibilities are shared with other international institutes in the LST Sub-Consortium consisting of scientists and institutions from Brazil, Germany, Spain, France, India, Italy, Poland, Croatia and Sweden. Prof. Masahiro Teshima of ICRR is the Co-PI of the Sub-Consortium.

The group has secured funding for the construction of 4 LSTs in 2016 and their construction in well underway. In fact, the first LST has been installed and is being commissioned now, well ahead of other telescopes being built elsewhere. CTA-N is scheduled to start initial operations by 2021-2022. The group plans to construct 4 more LSTs and install them at the CTA southern site (CTA-S) in Paranal, Chile. The installation is planned to be completed on a longer time scale.

The Committee regards very highly of the progress made by the LST group under leadership of Prof. Masahiro Teshima of ICRR. He has been playing the key role internationally as the co-PI for the LST sub-consortium.

The LST Array at CTA-N is expected to improve in astronomical gamma-ray detection sensitivity, angular resolution of source localization, and energy coverage, compared with astronomical gamma-ray instruments currently operating in similar energy ranges, MAGIC, HESS, VERITAS, and HAWC. The main scientific goals of CTA are to clarify the origins of cosmic rays, study high-energy phenomena around blackholes including blackholes, blackhole - neutron star merger, and neutron star – neutron star mergers, and carry out sensitive searches for gamma rays from dark matter annihilation.

Most of these research topics have long history and hence the CTA group is required to develop new methods, either or both in data analyses and theoretical interpretation. This requires many experienced scientists to be fully dedicated to the project.

2-4) **High Energy Astrophysics:** The group is very active and is making important contributions as a theoretical group to complement the experimental high energy astrophysics program at ICRR. We recommend that the group pursue both projects not directly related to the ICRR research portfolio and projects related to the major subjects of cosmic ray research of experimental groups in ICRR. The main members of the group cover the high-energy astrophysical interpretation of gamma-ray and charged-particle observations. The group is expected to contribute more to understand important cosmic-ray observational results including proton and nuclei spectra, which are not well understood by conventional theory (e.g. hardening of the spectra). It is highly positive that the group regularly organizes seminars of special topics and educational seminars for students in ICRR since these are excellent opportunities for young researchers to acquire advanced knowledge. Although the number of faculty is limited, the group should try to get more graduate students or post-doc researchers to enhance the group contribution, including data analysis of the direct cosmic-ray observations.

2-5) **Ashra:** The Ashra wide-angle telescope is an interesting concept to observe high-energy transient events and tau-neutrino induced showers using a novel technological development of image intensifiers. The first Ashra telescopes constructed in Hawaii have demonstrated the basic functionality of the concept. However, the observations are still far away from the proposed goals and are very limited to the level of conventional detectors. No substantial progress has been made since last review of ICRR in 2013. Given a limited size of the collaboration supporting this project and the corresponding manpower and resource limitations, it is hard to promote a new proposal for a continued project called NTA. In this situation, ICRR will have to follow the opinion presented in last review and to not continue efforts for further R&D and deployment.

2-6) **ALPACA (R&D):** The ALPACA effort aims to construct a cosmic ray/gamma-ray experiment at a high-altitude site near La Paz, Bolivia; the experiment would consist of a moderate-sized air shower array and a muon detector of the underground water-Cherenkov type.

The main scientific goals of ALPACA are gamma-ray astronomy in the 10-1000 TeV range and studies of cosmic-ray composition and anisotropy. Of particular interest is the search for PeVatrons - astrophysical sources capable of accelerating cosmic ray particles to PeV energies and above, with the goal of explaining the origin of the high-energy cosmic rays.

The initial design of ALPACA postulates an air shower array consisting of ~400 plastic scintillator detectors that cover an area of ~83,000 m^2. The muon detector would comprise an area of ~5,400 m^2. Much of the technical know-how from the Tibet ASγ experiment will be carried over to ALPACA. A prototype array consisting of approximately 20-25% of the full ALPACA experiment is being considered for deployment in the 2019-2020 period.

Simulations have been done to estimate the performance of ALPACA and to evaluate its sensitivity to various known sources, such as supernova remnants and the sources of diffuse emission from the Galactic Center region. In terms of integral gamma-ray flux, the estimated sensitivity is somewhat worse than current imaging atmospheric Cherenkov telescopes (i.e. HESS, MAGIC or VERITAS) and the air shower detector HAWC, but ALPACA would operate in a higher energy regime with best sensitivity near 100 TeV.

The Committee agrees that exploration of the southern sky by a sensitive wide-field experiment of the air shower type has strong scientific motivation, following up on the successes of Milagro, Tibet ASγ and HAWC in the northern hemisphere. We also note that a major new air shower facility, LHAASO, will be starting operation in China in the near future. A similar experiment in the southern hemisphere would have a strong scientific motivation (having access to the southern sky) and would also complement, and leverage, the large CTA-South array that uses the imaging atmospheric Cherenkov technique.

A huge community of international scientists is working towards the development of a major southern-sky wide-field gamma-ray experiment that would use the air shower technique and operate at high altitude. For example, several meetings have been held to develop the Southern Gamma-ray Survey Observatory (SGSO; see, e.g., https://arxiv.org/abs/1902.08429) concept. The SGSO collaboration is still being formed, but development of the experiment could make progress at a reasonable pace, given the scientific interest and a plausibly moderate cost. Within this context, the Committee considers that the ALPACA group needs to know the plan of the international future project, and to plan the project so as to bring out the characteristics of ALPACA. There is also a need to constantly open plans to the international community and endeavor to encourage the participation of foreign researchers interested in the features of ALPACA.

3. Astrophysics and Gravitational Wave

3-1) **KAGRA:** KAGRA is the world's first gravitational-wave interferometer constructed underground and operated with cryogenic test mass mirrors. Funded in 2010 and co-located with the Super-K neutrino detector in the Kamioka complex, the KAGRA detector has 3 km arm lengths, and is designed to reach a sensitivity of 153 Mpc (average inspiral range) to binary neutron star (BNS) mergers.

Since the last ICRR Review Committee meeting in 2013, KAGRA has completed the underground facility construction (tunnels and vacuum system), the installation of the all of the detector components, and carried out a one-month room temperature 'iKAGRA' run in the Michelson configuration (using fused silica test masses) in 2016. More recently, Initial 'bKAGRA' run was carried out April-May 2018 using sapphire test masses operated at 20 K, the first demonstration of a km-scale arm length interferometer operated in this regime.

Efforts in the past year have focused intensely on i) achieving cryogenic operation of all of the test mass mirrors and ii) commissioning the bKAGRA interferometer with the goal of joining the LIGO-Virgo 'O3' observing run in late 2019 or early 2020. The KAGRA Collaboration has the stated goal of reaching a BNS inspiral range of 8 – 25 Mpc by the time they join the run. At the 25 Mpc upper range, KAGRA will deliver quantifiably better sky localization of BNS mergers, particularly for the situation where only two of the three LIGO-Virgo interferometers are operating in science mode.

KAGRA management has established a Future Planning Committee (FPC) to begin planning for upgrades to go beyond the 153 Mpc current design goal. At present, a multi-stage program is envisioned. Budget or in-kind contributions for these upgrades will need to come from outside Japan to complete the upgrade program.

The Committee finds that KAGRA has made remarkable progress since the last ICRR Visiting Committee Report and wishes to congratulate ICRR and the KAGRA team on their accomplishments advancing toward a working observatory.

Among the significant accomplishments and milestones are:

- Successful excavation of the arm tunnels and detector halls
- Successful completion of vacuum system
- Suppression of floods that plagued the tunnels and experimental chambers due to seasonal flooding after snow melts in the Kamioka mountains
- Completion of installation of all detector components
- Operation of iKAGRA in a Michelson configuration
- Cool down to ~ 20K of the four sapphire test mass mirrors

KAGRA has achieved these goals by relying on dedicated scientific staff combined with heavy involvement of industrial partnerships to build and install key subsystems. The addition of Y. Saito as Project Manager in the KAGRA System Engineering Office has greatly benefitted the project.

The coming year will be critical for KAGRA as it commissions the fully cryogenic interferometer and continues to 'noise hunt' and improve KAGRA's sensitivity in advance of joining in the O3 run. Good progress has been made in recent months. At the time of writing this report (late June), all major subconfigurations of the KAGRA interferometer have been locked.

3-2) **Observational Cosmology:** The ICRR Observational Cosmology Group focuses on studies of the early universe – cosmic re-ionization and early galaxy formation using Subaru HSC, Hubble, and ALMA telescopes. Among the primary science results in the last six years are i) precision measurements of the UV luminosity function for high redshift galaxies, ii) an understanding of the star formation rate density evolution, iii) measurements suggesting that high-z galaxies are major re-ionization sources, and iv) the galactic dust origin of the cosmic infrared background. Since the last external review, the group has formally ended its affiliation with SDSS, and is now a member of the HSC Collaboration.

The group is headed by two faculty members (one associate professor and one assistant professor) hired in the last nine years. The exciting science program places this group in high demand by students from U. Tokyo. The faculty have been recognized for their work through both national and international prizes. Four students have won U. Tokyo Science awards since 2015.

This group is making very significant contributions to the understanding of early galaxy formation through its survey of high redshift galaxies and in particular UV luminosity function measurements.

The Observational Cosmology Group is very productive for a group of its size and composition. They are the leading group in the HSC Collaboration for high-z galaxy surveys. It is particularly noteworthy that both faculty and students are being rewarded for their work through prizes and awards. Funding support appears to be very adequate for this group.

3-3) **Theory:** The group includes two staffs, several post docs and a number of graduate students. Scientific outputs of the group are excellent. The group has a high global reputation and played a leading role in some research areas such as axion cosmology, inflationary model building and SUSY phenomenology.

The group is considered to be a world-leading research group on axion cosmology, particularly on the axion dark matter produced by topological defects such as axionic strings and domain walls. This can be confirmed by the invited review on axion cosmology published at Ann. Rev. Nucl. Part. Sci (2013). There are also a number of other works which had a significant impact on the worldwide research in the related topics. Those works include the two-loop calculation of the mass splitting between the neutral and charged winos, study of the phenomenological consequences of the pure gravity-mediated SUSY breaking, study of the Migdal effect in dark matter detection, inflation model building for smaller tensor-to-scalar ratio, study of primordial black hole formation in a double inflation model and axion curvaton models, and an improved analysis of the BBN constraints on long-lived massive particles.

To summarize, scientific outputs of the theory group are excellent and impressive. The Committee recommends a continuous support on the theory group.

During the last six years, the group published 199 papers in the refereed research journals, which is an impressive record. Many of those works are of high quality, and as noticed above some of them have significant impacts on the worldwide research in related subjects.

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

The spring school for university students, which began in 2012, is a good opportunity to educate young students about the activities of ICRR and also motivates participating students to advance to ICRR graduate students. ICRR graduate students are arranged in the same room for the first year of the master course and given the opportunity to have proper communication among students. The Committee understand the bachelor and graduate education in ICRR is at an active and proper level.

The Committee is pleased with the number of graduate students in the ICRR Masters and Doctors courses. The Committee thinks that it is desirable that the students who belong to the graduate school can find a job in a company. In these cases, also, the Committee thinks that it is appropriate to go out to society after obtaining a master or doctoral degree.

ICRR continues to conduct appropriate joint use and joint research activities as an Inter-University Research Center. Since 2012, the Committee highly appreciates that ICRR continues to operate more than 100 joint use projects annually. In addition, ICRR continues to work, accepting many researchers from overseas such as Kamioka Observatory and KAGRA Observatory. This activity is appropriate as an International Joint Usage/Research Center recognized from 2019. The Committee expects appropriate laboratory operation, such as utilizing the system to feed back the user's opinion in the future.

ICRR has several observation facilities. They are contributing to the achievement of research results by participating in ICRR projects. The Committee will evaluate their activities. Furthermore, not only contribution to the project of ICRR but also that providing the facilities to a group of several universities in Japan and achieving scientific results is a point that can be evaluated as a university joint use base. In particular, Akeno Observatory supports as observation facility of group of Tokyo Tech and Chubu University, and Norikura Observatory is promoting research from various universities utilizing high altitude environment other than cosmic ray research. And their activities should be evaluated. The Committee hopes that such academic research groups will produce interesting results.

The Committee thinks there is no problem with ICRR's public relations activities. Many citizens have a great interest in the research activities of ICRR, and the public's attention to various events is high, as Dr. Kajita received Nobel Prize. The Committee believes that ICRR's PR activities are adequately meeting the public's expectations.

IV. Recommendations

A. Evaluation of fund requests and resource managements

Some projects started small by 1-2 faculties and a few postdocs supported by modest grants. A few grew big through their heroic efforts and succeeded to win hundreds of million yen (a few million US dollar equiv.). Even when collaboration membership become international and grew past 50, there are cases that the projects have been operated without clear management structure. As Hyper-K will be a huge project as for the budget, schedule and the number of the members, the Committee feels that this “tradition” needs to be changed. The Committee think that it is necessary to identify candidates with adequate science background for the project management and system’s engineering and secure positions appropriate for them.

Super-K, Hyper-K and KAGRA are now three major projects at ICRR. Other plans are being implemented at competitive costs and various funds, but since these three major projects require large construction and operating costs, ICRR needs a large budget request directly to the government.

The Hyper-K project is a natural extension of the brilliant achievements of neutrino physics in ICRR, and the Committee supports its realization and the plan is well prepared. However, in terms of budget, even when compared to the overall budget of ICRR, it is necessary to make a large budget request (increased by an order of magnitude). For this reason, the Committee recommends that it is important to appeal to scientists from a wider range of fields about the scientific importance of Hyper-K and to gather broader support from the public.

In particular, with regard to Super-K, the Committee urges strongly that the government should continue to support Super-K until at least the time Hyper-K is put into operation, as important projects such as T2K and SK-Gd can be carried out.

As for the project management, the Committee has a high opinion of the project management in the Super-K collaboration. This success may be indebted to one individual who worked in the collaboration. Hyper-K is larger in all regards than Super-K and requires various agreements on funding and management with international agencies. The Committee recommends the Director of ICRR to identify candidates for such works and find an appropriate position at this stage of Hyper-K.

KAGRA is about to commission its first cryogenic operation stage (bKAGRA). In latter half of 2019 or early 2020, it will begin the observation run. Although ICRR hosts the collaboration, key members are scattered in ICRR, KEK, NAOJ, Kamioka, as well as outside of Japan. In the near future, KAGRA will move from construction to operation. Along with that, it seems necessary to readjust the division of roles of each research institution, but it is important to build a closer cooperation system in the future.

B. Young Researchers

In interviews with young researchers, there are several points where it would be good for the Committee to make recommendations specifically to the ICRR. There are several projects in ICRR, but for graduate students and young researchers, there may be little interaction with researchers outside the group to which they belong. Although the research group's site seems to be far apart, it is important to engage in research with a broad perspective while young. For this reason, some sites seem to continuously need to hold seminars that researchers from ICRR and other universities join. In addition, once or two times a year, ICRR needs an opportunity for a general discussion, and such a meeting should be recommended to include graduate students and young researchers.

For the participation of young researchers from overseas, postdoctoral recruitment from October should be taken into consideration. In addition, some young researchers had the impression that formal procedures have been not correctly announced regarding the acceptance of students from other universities. The participation of graduate students from other universities is valuable to ICRR, and students can receive education in an environment that cannot be experienced without ICRR. The Committee thinks that it is good to have an announcement of appropriate graduate student acceptance.

The number of female researchers in ICRR is still small. The Committee thinks that the ICRR should elevate its research institute in this regard and announce its stance on tackling the gender issue.

C. Engineer support

At the time of the previous external evaluation, a recommendation on engineer support was made. Some answers from the director, Dr. Kajita, were given in additional interviews. However, the Committee will continue to recommend that it strives to hire advanced engineers and technicians. In particular, in order to smoothly promote international cooperation such as Hyper-K and KAGRA, the Committee thinks that it is indispensable to acquire staff who can communicate in English and can also develop and operate creative technologies. In order to do this, the Committee thinks that it is important to set up a post that allows a high level of salary for technical staff.

D. Individual projects/ programs

Super-K & T2K:

The Committee recommends that the operation of both T2K and Super-K continue through the construction phase of Hyper-K. This will allow a timely study of the systematic effects to be measured by the new near and intermediate detectors, thus improving further the T2K results, but more critically, it will maintain the expertise in detector operation and analysis for the exploitation of Hyper-K. Loss of this expertise would be a serious setback to the Hyper-K program.

TA:

The Committee recommends the ICRR leadership to support the TA activities with high priority to ensure the completion and continuous operation of TAx4.

Central aim of the next years should be the collection of high statistics of cosmic ray showers at highest energies (TAx4) to obtain an independent, large-statistics data set for anisotropy studies.

High priority should be given to the continuous operation and data analysis of fluorescence detectors for both energy calibration and mass composition measurement (including an update of energy scale).

High priority should be given to thorough study of systematic uncertainties and their relation to the significance of various findings of anisotropies.

Interaction and cross-calibration with the Pierre Auger Collaboration should be continued and extended with the aim of reliably comparing and interpreting the data of both detectors.

Strong efforts should be made to attract master and doctoral students for data analysis to increase the manpower for data analysis and fostering a new generation of cosmic ray scientists.

Tibet ASγ:
We understand that the running costs for Tibet Asγ are moderate and hence, given the significant investment already and generally smooth operations, we encourage the ICRR group to continue involvement in the experiment and to continue the scientific results. However, given the recent upgrades made to the HAWC detector in Mexico and the upcoming operation of the LHAASO experiment in China, ICRR should carefully consider the future of Asy, including the end of the experiment, when the sensitivity of LHAASO significantly exceeds that of Tibet Asγ.

CTA:
The Committee recommends the ICRR leadership together with MEXT and the Japanese CTA consortium to find a framework or an administrative structure to facilitate participation of university-based scientists and graduate students in long-life international collaborations like CTA. Such structures exist in Europe (MPI, CNRS, INFN, etc.) located on or near university campuses. US universities have created research professorships and mechanism to minimize teaching duty of faculty members for a limited period.

The enthusiasm carried by the current Japanese CTA consortium needs to be handed down to next generations. Following thoughts by Committee members may be applicable:

- Nurture future leaders by enhancing their international visibility
- Intensify efforts to recruit talented students in all universities

ALPACA:
Although moderate in cost (~$5M) and making use of much of the know-how from Tibet ASγ, the ICRR Executive and related community groups should carefully consider the future prospects of ALPACA in the era of a larger southern air shower experiment being considered by an international group of scientists. ALPACA group must also consider the report from the future planning Committee of ICRR. Then as mentioned before the Committee considers that the ALPACA group needs to know the plan of the international future project, and to plan the project so as to bring out the characteristics of ALPACA. There is also a need to constantly open plans to the international community.

KAGRA:
The successful commissioning and scientific operation of KAGRA must remain as the top one or two highest project priorities for ICRR in the coming five-year period. KAGRA has increased its staff over the past few years, but the Committee believes it is not yet at a level necessary to ensure KAGRA's scientific success. While the scientific staff levels are likely sufficient, further staff - particularly dedicated engineers and technicians - will be needed to successfully carry out

KAGRA commissioning program.

To meet the KAGRA O3 sensitivity goal, the Committee strongly encourages the continuation and expansion of scientific exchange programs with LIGO and Virgo to enable ‘commissioning knowledge transfer’ among the three projects. This should be done as rapidly as possible given the limited time until O3 begins.

ICRR hasn’t yet developed a robust plan for KAGRA Observatory operations. The model currently adopted by KAGRA – observing shifts by scientific staff – can likely be maintained for the short O3 duration of a few months, however it is unsustainable for longer durations runs expected in the future.

THEORY GROUP:
The Committee encourages to continue the active collaborations with the IPMU theory group. The Committee also recommend to strengthen the communication with some of the experimental groups at ICRR, particularly with the Hyper-K and KAGRA groups.

Acknowledgments

The 2019 External Review Committee extends sincere thanks to the Director Professor Takaaki Kajita, Professor Masato Shiozawa, ICRR staff and students for sparing much time and effort for this review. Without their cooperation, the review process would have been more difficult and painful. The interviews with young researchers, in particular, showed the ICRR's free and dynamic research environment. Thank you very much for their participation in our discussions. 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

Kiwoon Choi, Professor of Institute for Basic Science;

Ralph Engel, Professor of Karlsruhe Institute of Technology;

Kunio Inoue, Professor of Tohoku University;

Tsuneyoshi Kamae, Professor emeritus of the University of Tokyo;

Shoken Miyama (chair), Professor (Special Appointed) of Hiroshima University;

Rene Ong, Professor of UCLA;

David Reitze, LIGO Executive Director;

David Sinclair, Professor of Carleton University;

Shoji Torii, Professor emeritus and Distinguished Guest Research Professor of Waseda University.

Appendix II: ICRR External Review 2019 meeting agenda

- Wednesday 15 May 2019

09:15-09:30	Leave the hotel	
09:30-10:00	Coffee	
10:00-10:30	Review Committee: Discussion (Closed session)	
10:30-11:00	Introduction of ICRR	Takaaki Kajita
11:00-11:30	Super-K	Masayuki Nakahata
11:30-12:00	T2K	Yoshinari Hayato
12:00-13:30	Lunch	
13:30-14:10	Hyper-K	Masato Siozawa
14:10-14:30	XMASS	Shigetaka Moriyama
14:30-15:00	Coffee Break	
15:00-15:40	KAGRA	Masatake Ohashi
15:40-16:10	Observational Cosmology	Masami Ouchi
16:10-16:40	Theory	Masahiro Kawasaki
16:40-17:10	Review Committee: Discussion (Closed session)	
17:30-19:30	Dinner (Reviewers and ICRR faculty members)	
19:30-20:00	Return to hotel	

- Thursday 16 May 2019

09:15-09:30	Leave the hotel	
09:30-10:00	Coffee	
10:00-10:30	Telescope Array	Hiroyuki Sagawa
10:30-10:50	Tibet AS-gamma	Masato Takita
10:50-11:00	ALPACA (R&D)	Masato Takita
11:00-11:40	CTA	Masahiro Teshima
11:40-12:00	Ashra (R&D)	Makoto Sasaki
12:00-13:00	Lunch with young scientists	
13:00-14:00	Review Committee: "Interviews with young scientists"	
14:00-14:30	High Energy Astrophysics (theory)	Katsuaki ASANO
14:30-14:50	Interim report from COSMIC RAY RESEARCHERS CONGRESS (CRC) for Japanese strategy on astro-particle physics	Shoichi Ogio
14:50-15:10	Report from the future planning Committee of ICRR	Masayuki Nakahata
15:10-15:40	Review Committee: Discussion & Coffee Break (Closed session)	
15:40-17:30	Review Committee: "Interviews with Director/SK/HK/KAGRA/TA/Tibet AS-Gamma"	

- Interview with Director — Takaaki KAJITA
- Interview with project SK — Masayuki NAKAHATA
- Interview with Project HK — Masato SHIOZAWA
- Interview with Project KAGRA — Ohashi, Tagoshi, Uchiyama
- Interview with project TA — Hiroyuki SAGAWA
- Interview with Project Tibet AS gamma — Masato TAKITA

17:30-18:00	Review Committee: Discussion (Closed session)	
18:30-20:00	Dinner (Reviewers and division leaders)	
20:00-20:30	Return to hotel	

- Friday 17 May 2019
- 09:15-09:30 Leave the hotel
- 09:30-10:00 Coffee
- 10:00-11:00 Review Committee: Discussion (Closed session)
- 11:00-12:00 Review Committee: Preliminary Report from Review Committee
- 12:00-13:30 Lunch
- 13:30-14:00 Return to hotel