Evaluation Report for the Division of Theoretical Astronomy of NAOJ

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1. Summary

We are impressed by the many accomplishments that have been made in the Theory and Computation Division of the National Astronomical Observatory of Japan (NAOJ) in the past four years. We agree with the self-evaluation report of the Division, which has highlighted many important areas of research to which the Division has made major contributions. In particular, we agree with their analysis of their scientific output: they have published a large number of papers with significant impact on the international community. If anything, the self-evaluation has been too modest. The Division of Theoretical Astronomy / Center for Computational Astrophysics (DTA/CfCA) is truly an international center of excellence in computational astrophysics, one of the most important centers of that type in the world.

Much progress has been made on the development and application of numerical algorithms as well as actual hardware which enable large scale computation in areas ranging from solar system formation to the emergence of structure in the Universe. The 4D2U initiative has produced an effective package for public outreach as well as a valuable research tool.

We strongly endorse future expansion of the theoretical effort especially in the development of innovative algorithms and state-of-the-art simulations. These simulations can provide predictions as well as interpretations of observations to be obtained from the various next-generation astronomical facilities. No matter how important direct observations and pure theoretical thought may be, their significance can only be understood through the bridge between the two that is provided by means of detailed simulations.

Eventually, it would be ideal to establish a national theory center which will serve as an intellectual environment to foster broad collaboration and complementarity between experts with different specialties. Such a center will also be a conduit for interaction between isolated theorists in small departments throughout Japanese universities. International collaboration is important in this respect as well, and can be strengthened through a vigorous visitor program and the organization of summer schools and workshops.

2. Areas of Current Strength and Weakness

DTA has produced research covering a broad range of computational astrophysical problems from planets and stars to the large scale structure of the Universe. The members are very productive. The results in almost every topic are highly visible internationally, and some of the publications are leading their field. Especially the simulation software developed and the expertise gained in their application will be extremely valuable for future observational missions. Examples are simulations of star formation, galaxy formation and cosmological structures; and of the processes that take place in dense stellar systems such as galactic nuclei. For observational projects that are central to NAOJ, such as ALMA and Subaru, these simulations can help both in interpreting the observational data and in assisting observational proposals. One current weakness is a relative lack of structure and direction, with each member working largely independently. Joint approaches such a Project Milky Way, mentioned in section 3.1, will do much to remedy this situation.

CfCA has provided excellent computational services to the domestic astronomical community. The rapid development of the GRAPE system overcomes partly the current weakness stemming from the postponed replacement of the VPP5000 computer, making the center unique in the world. In terms of the computer power of VPP5000, the research carried out in the center is both productive and visible, and it has achieved important functions similar to that of large telescopes, in terms of number of publications and citations. The new Cray XT4 together with the GRAPE-DR will make NAOJ the most powerful computational astrophysics center in the world, by the end of 2008. We discuss this situation further in section 3.2.

4D2U is invaluable for public outreach. The group members have combined their simulations and observational data to show how the Universe evolves, on many scales. The movies have reached many school children as well as adults through public musea. The group has invested a vast amount of effort in developing very advanced display methods, innovative in their use of hardware as well as software. The significance of their investment for science popularization cannot be underestimated. A current weakness is the lack of clear direction for continued development of visualization software. We address this point in section 3.3.

Given the unique situation of DTA/CfCA as the only national institute for theoretical astrophysics in Japan, we have noted as its major weakness the rather modest scales of the current visitor program and of the current program for workshops and summer schools. Sections 3.4 and 3.5 address these points, in different ways. As a final weakness we have noted that the current organizational structure of DTA/CfCA is far from transparent, to the point that we could not neither understand the structure that is in place now, nor the plans for modification. In Section 3.6 we recommend a restructuring that will make the functions and responsibilities of either component more transparent.

3. Recommendations for Further Strengthening the Theory Group

3.1. Scientific Projects: Project Milky Way

Currently, the largest project that is directly aimed at astrophysical applications is Project Milky Way. The project is designed to advance the understanding of galaxy formation through large-scale simulation. CfCA should have clear mid-term scientific goals around which the hardware/software development and computer system procurement are designed, and choosing galaxy formation as the primary one is a good choice.

The study of galaxy formation is important and timely, because of the following three reasons. First of all, it does have a strong impact on many other fields, including observational cosmology. The interpretation of observations of distant (high-z) galaxies requires a detailed view of how galaxies evolve, and currently we lack first-principle theoretical or numerical models for galaxy formation. This project will provide important connections with ALMA and Subaru, and eventually with the ELT.

The second reason is that increasing the resolution of the simulations will address important new problems. Currently, most of the "large" galaxy-formation simulations have been done with around 10^5 SPH particles, with a mass of SPH particles of around 10^6 $M_\odot$. With this approach we have not yet been able to resolve the 3D structure of the gas disk, and not much can be said about the evolution of the structure of galaxies. By increasing the resolution by, say, three orders of magnitude, the resolution will start to reach individual star-forming regions. This means that we will start to see the evolution of spiral structure and other features directly in numerical simulations. The CfCA members will be able to carry out such a program, with their large cluster of GRAPE-equipped PCs and soon with their GRAPE-DR additions, and with well-optimized parallel Nbody and SPH codes, making them world leaders.

The third reason is that to go beyond the current simplified models, we need to integrate knowledge of how stars form, how they evolve, what the effects are of supernova explosions, and so on. In short, effectively every aspect of stellar astrophysics and high-energy astrophysics should be integrated into a realistic galaxy formation model. Stellar dynamical ingredients such as the evolution of open and globular clusters and stellar systems around a central massive black holes are also essential. Thus, understanding galaxy formation requires a truly wide range of research and development in the near future. The current research staff members of CfCA/DTA cover most of the important areas, making them uniquely qualified for this project.

However, CfCA should not focus all its resources solely on the Milky Way Project. Ideally, they should continue their currently already very active research in planetary formation, star formation, star cluster dynamics, and cosmology, and develop further large collaborative projects in these fields of research. While it is prudent to focus on one major project for a few years, it is equally important to start preparing now for other projects that can take center stage in later years. One natural option would be a large-scale simulation project in conjunction with the ALMA observations.

A reasonable time scale for Project Milky Way would be three years, plus some additional time to wrap up and publish all the results. And depending on its success, the project could receive additional extension, with possibly a shift in emphasis. For such projects, it would be natural to create an extra theory position, someone who could act as a kind of 'glue', communicating between observers and theorists, while maintaining a strong base in theoretical simulations.

3.2. Computational Projects: GRAPE Project

Over the two decades of its history, the GRAPE project for developing special purpose hardware for simulations, has been extremely successful. After its start at the University of Tokyo, much of the development has now shifted to NAOJ, and the new GRAPE-DR is likely to become one of the first scientific Petaflops computers.

In many areas of astronomy, GRAPEs have had a major impact. If you attend any meeting on dense star clusters and nuclei of galaxies, you will hear that almost all the simulations reported there have been performed on GRAPEs of one kind or another. Currently, many dozens of places around the world have their own GRAPE facility, and with the advent of the GRAPE-DR, this number is likely to increase significantly.

The first GRAPE-DR chip has already proved to be the fastest programmable processor for high performance computation applications. When mass production will start, later this year, these chips will provide the astronomy community worldwide with computer power that is one to two orders of magnitude higher than what would be available with only general-purpose computers.

Given the unique and innovative character of the project, as well as the international visibility and impact, it is clear that NAOJ should support the development of the successor of the GRAPE-DR as one of the most important internal development projects. With the proven track record of the GRAPE team, they will be able to produce computer speeds of tens of Petaflops within several years. Quite possibly they will be able to build the fastest supercomputer in the world, or at least one of the fastest.

At the same time, it is important to provide the Japanese astrophysics community with more conventional computing power as well. In five years, NAOJ should replace the new Cray XT4 by another supercomputer or a PC cluster. It may be a difficult choice between the two, and it is conceivable that both options would be equally attractive, with the result that the available money could be split over a PC cluster and a supercomputer.

In either case, we recommend that half of the total budget should be spend on the GRAPE project, simply because its far superior cost-performance ratio, combined with the fact that the new GRAPEs are no longer special-purpose, but fully programmable. Still, since they do not cover all areas equally well, we also recommend that the other half of the budget be spend on a combination of supercomputers and PC clusters.

3.3. Visualization Projects: 4D2U Project

The separation of the development section and outreach section of 4D2U is long overdue. During the last few years, some of the central researchers in 4D2U have carried more than their fair share of work in doing outreach. Therefore, it is an excellent move to create a new group dedicated to outreach for 4D2U. Making the products of 4D2U available to a wide public carries a high priority.

However, an equally high priority is the ongoing development of new products for 4D2U. Until now, the brunt of the work has been carried out by postdocs on temporary positions.

While we are all deeply impressed by what they have produced, we cannot help feeling that it is not ideal to let postdocs carry the whole project. Postdocs should prepare themselves for their careers, and writing 4D2U software, unfortunately, does not give one sufficient scientific recognition.

Therefore, we very strongly recommend the establishment of a new permanent position for the lead person in the development of 4D2U, a type of Chief Technical Officer who can coordinate the efforts of the postdocs, who will contribute significantly on a purely technical level, and who can also play a management role for the whole development team.

Letting postdocs contribute part-time is an excellent idea. It is good for them to get a taste of outreach, and also it will help them in developing their own visualization tools, for their own research. The main point is to guarantee that they will also keep a significant fraction free for their own research, and that they will not be held responsible for the health and success of the project as a whole. This should be the task of the CTO.

3.4. Collaborative Projects: Visitor Programs and Conferences

The Division of Theoretical Astronomy forms the only national institute for theoretical astrophysics in Japan. What is more, there are no other national institutes with a theoretical astrophysics branch. The new Institute for the Physics and Mathematics of the Universe (IPMU) will provide some astrophysics connections, but not for all of astrophysics, and only for a limited period in time. Apart from DTA, there is no Japanese institute that can play the type of role that American and European institutes are playing, such as the Kavli Institute for Theoretical Physics in Santa Barbara, the Institute for Advanced Study in Princeton, and the Max Planck Institute for Astrophysics in Garching, Germany.

Given the unique role and responsibility of DTA, we recommend strengthening the following functions:

– an international visitor program

Currently, there is a visitor program that has attracted some excellent and highly visible international participants, but it is rather small in size. We recommend a significant increase in scale and scope. Specifically, we recommend that DTA acquires an equivalent of the salary of two full-time positions, to be used for medium-term to long-term international visitors. In that way a vibrant visitor program could be started and sustained. Some visitors will need full-time support, while others will only need reimbursement of local expenses. Therefore, such a budget could pay for three or four visitors on average. Such an international presence would for a permanent core, around which short-time visitors would aggregate.

Frequent interactions between longer-time visitors, short-term visitors, and permanent faculty as well as postdocs and students would create a center for astrophysics, unique in Japan. Especially for students and postdocs such international exposure is absolutely essential. Apart from the considerable scientific inspiration inherent in international exchange, it would help younger Japanese researchers to attain a higher level of fluency in English than is currently the case. In the current global society, if researchers are not totally comfortable mingling with others in English, the products of their research are not likely to receive the attention they deserve.

At the same time, inviting more foreigners to stay in Japan for longer time periods will enable at least some of them to reach some mastery in Japanese. As is the case with some other Japanese visitor programs, DTA may want to consider encouraging and providing payment for Japanese language study for those longer-term visitors who would be interested in learning more about Japan. In the long run, only a two-way native communication will provide the level of mutual understanding that is needed for joint enterprises that are both productive and respectful of the needs of both sides.

– a national visitor program

Recently, budget cuts and dwindling numbers of students have made it very difficult for small universities in Japan to sustain active research programs, especially in relatively small areas such as astrophysics. With only three major astronomy departments at the University of Tokyo, Kyoto University, and Tohoku University in Sendai, together with an active astronomy program in Nagoya University, most other universities will have difficulty protecting astrophysics research. This will be especially true for theoretical astrophysics, given the recent influx of money and visibility for observational astronomy.

We therefore recommend the construction of a new support program, in which researchers from any university in Japan will be invited to visit DTA for up to three months, with full support from NAOJ for themselves and for one or two research students that may want to accompany them.

Ideally, some researchers should be able to visit DTA for a sabbatical year or half year. Given that the Japanese university system currently does not support a sabbatical system, perhaps a new program could be initiated that offers astrophysicists the option to spend one year at DTA before starting a new permanent job at a university. Such a system would give them effectively a sabbatical year, in between their last postdoc and the beginning of their permanent position. If universities would be willing to postpone the entrance of new permanent faculty members by one year, a year spent by such researchers at NAOJ would benefit considerably both them and NAOJ.

– computational collaborations

We also recommend that some fraction of the total computational power of the CfCA will be made available to regional astronomers outside Japan, primarily East-Asian colleagues. Many smaller countries lack the type of resources that Japan can offer, and even a relatively small amount of supercomputer time can make a big difference for young astrophysicists, especially in South-East Asia.

In addition, sharing computational resources is a great way to stimulate international collaborations. The use of hardware can in turn lead to joint research in developing novel algorithms and software. One possibility would be to provide free computer cycles in return for the development – and most importantly, proper documentation – of software products that can be shared with other astrophysicists.

Initially, astrophysicists from China and Korea, with an already more established astrophysics tradition, will likely be the prime collaborators, but it would be great to see astrophysicists from countries such as Indonesia, the Philippines, Thailand, Vietnam, etc. contribute as well. In addition to strengthening academic traditions in those countries, such type of aid could contribute to the further development of those countries as a whole. It may well be that CfCA could obtain developmental aid directly from the Japanese government for this purpose.

– workshops and summer schools

Finally, we recommend that DTA will increase the number of workshops and summer schools that it will organize, both for students and researchers in Japan as well as for those from abroad. We think that this can be done without putting any extra burden on the faculty of DTA. While increasing the national and international visitor program, it would be very natural to ask some of those visitors to play a pivotal role in organizing many of the workshops and summer schools.

In fact, a similar approach is already underway at the Yukawa Institute at Kyoto University, and it seems to work quite well. We are especially thinking about astrophysicists from smaller universities in Japan, who would have a great opportunity to communicate with colleagues, national and international, if they were to organize a workshop during a three-month stay at DTA.

In addition, we suggest that DTA/CfCA conduct joint activities with sister institutions in Asian countries, such as APCTP (Asian-Pacific Center for Physics, Korea) and the Kavli Institute of Astronomy and Astrophysics in Beijing.

As for summer schools, we have received a very positive impression of the current N-body summer schools that have been organized recently. We recommend that this model will be extended to other areas in astrophysics, in addition to that of stellar dynamics.

3.5. Virtual World Projects: A Virtual Presence for NAOJ

Recently, on-line three-dimensional virtual worlds have become popular for research purposes. Based on the software technology of video games, each participant is represented by an avatar, a type of virtual representation of the person logging in to a virtual world. After logging in, each person can move his or her avatar through the three-dimensional world, seen in projection of his or her own computer screen. The shared space is persistent: if one person puts a picture in a room, that image will still be there later on, just like when you put a picture on a bulletin board in a department tea room.

In addition, users can put a PowerPoint presentation in a virtual world, hold seminars and conferences, use a joint editor to write papers together, scribble figures on a white board, and so on. In many ways, such a virtual world can replace actual physical meetings, and speed up remote collaborations. While the technology is still relatively simple, improvements are happening at a rapid pace.

So far, there is only one major on-line virtual world that is not game oriented. It is called "Second Life", and at any given time there are some 50,000 users present. A significant fraction of those users are scientists, and they have organized themselves in a large number of special interest groups. Some of the major American government organizations have established branches in Second Life, NASA being one of them. Many of the major universities, too, have their own space in Second Life.

In addition to Second Life, there are various other virtual worlds that are being developed, or are already available. For academic applications, the most mature company is Qwaq, which has developed applications that are very effective in remote collaborations. An example of a preprint that was written entirely within the virtual world of Qwaq is http://arxiv.org/abs/0707.3021, a collaboration between an astrophysicist in a small college in Pennsylvania, USA, and two astrophysicists in Amsterdam, Holland.

We recommend that NAOJ in general, and DTA in particular, explore ways to establish a virtual presence in these virtual worlds. Such a presence could be very well integrated with other activities, such as the organization of workshops, computational collaborations and other forms of distant interactions. Japan might even take the initiative of starting the world's first virtual department for theoretical astrophysics. It is clear that such a department will soon be established somewhere, and it would be a significant coup for DTA to be the founding agency for such a department.

3.6. Organization

Frankly, the evaluators found it extremely difficult to understand the current organizational structure of CfCA/DTA/4D2U. It seems that there are various historical strands of previous phases of organization, that have become entrenched in ways that probably are not very conducive to an optimal organization and a development of a clear strategy. We recommend that the current structure will be replaced by a more transparent one, more in line with the rest of NAOJ.

One important issue here is that since NAOJ is a national center for astronomy, CfCA/DTA should play the role of the national center not just for computational astronomy but also for theoretical astrophysics in general, and that means there should be more stronger program for visiting researchers, as we have indicated already above. One ideal result would be the establishment of something like KITP, hosting a large number of short-term visitors for selected topics. While that might be hard to realize in the near future, something along those lines should at least be considered.

Whether this function would be more appropriately handled by CfCA or by DTA is difficult to judge, at least for the current group of evaluators. Since NAOJ as a whole currently has a project-oriented structure, it would seem natural to let CfCA/DTA share the same structure as the other sections and projects have. This would then imply that CfCA would take on the role of providing a 'computational telescope', and thus become the primary organization responsible for decision making and managements. Such a change might make it easier to vigorously select and pursue specific scientific goals. Whether this will be the optimal way to strengthen the theory section is not completely clear, but at least it seems a promising approach.

The notion of a 'computational telescope' is more than a metaphor. Modern large-scale simulations can produce Terabytes of data that require sophisticated software analysis in order to 'reduce' the data in ways that have much in common with the way observers handle their data reductions. Results from simulations such as produced by the Milky Way Project could also be made available to the astronomical community for interpreting observational facts and for mining theoretical predictions. In this way, computational advances can also be beneficial to the observational projects, both in direct and in indirect ways.

CfCA has its roots in being a computer center with a mandate to provide service in terms of hardware availability. However, such a model is now clearly outdated. We strongly recommend letting CfCA grow into the equivalent of a computational observatory, with software support equally important, and staffed by active researchers who are all concretely involved in carrying out their own computational astrophysics simulations. According to that model, CfCA can grow into an organization on the same level as that of major observatories: instead of an optical or a radio observatory, it will instead be a theoretical observatory, but with the same type of funding and responsibilities.

As the DTA people rightly have stressed, the cost per publication and also per citation is currently much lower for CfCA than for other observatories, by a factor of several. So at least from a cost/benefit point of view, treating CfCA on a par with other observatories would be a profitable move. In addition, a structural change in this direction is likely to invite stronger links between computational and observational projects. Over the last decade, collaborations crossing multiple wave length bands, from radio to optical to X-rays, have become the norm. Extending these collaborations to include computational 'observations' would be most natural, timely, and cost effective.

4. Conclusions

During our visit to DTA/CfCA, we were happily surprised to see the very vigorous state of research, even more so than we had already expected, given the excellent reputation of the two centers. Clearly, the current faculty is pursuing a very active research program, with high international visibility. We recommend a modest restructuring, in order to make the currently rather opaque structure more transparent. In addition, we recommend additional funding for some of the major opportunities, national and international, that we have outlined above.

On the level of permanent positions, we recommend three extra positions to be created. One extra position should be reserved for a Chief Technical Officer for 4D2U, responsible for continuing development of new software products used for visualization.

A second permanent position should appear for CfCA/DTA, to act as a kind of ‘glue’, or liaison, between the computational group there and the observational groups elsewhere at NAOJ. Such a person should act as a kind of bridge between the various groups, but it is also important that this person would be active in carrying out his or her own program in simulations in some area of theoretical astrophysics, to avoid playing only a manager role. Hands-on knowledge is definitely needed to play this inter-project communication role.

A third permanent position should be created for the GRAPE initiative. Given their success in attracting of order a billion Japanese yen over the last several years, and the scope of their plans to proceed with Petaflops scale computing, a single additional position would be very modest, really a minimum level commitment by NAOJ for this important initiative that is the most internationally visible component of DTA/CfCA.

In addition to these permanent positions, we strongly recommend allocation of extra funding resources for temporary positions, ranging from short-term and medium-term visiting positions described above, to longer-term positions. In fact, DTA/CfCA would be very well served by adopting the model that is used by institutions such as the Yukawa Institute at Kyoto University and the new Institute for the Physics and Mathematics of the Universe. In both cases, researchers receive long-term appointments, for a duration of the order of ten years. Along these lines, we recommend DTA/CfCA to create several positions with a 5-10 year duration.