Airshower Astronomy

Submission to Decadal Plan Working Group 3.1

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April 2005

Science

Australia has been a pioneer of air shower studies since the late 1930's. The leaders in the field have been located at Mt Stromlo, the University of Melbourne, the University of Sydney, the University of Tasmania, and the University of Adelaide, more or less in chronological order. The science relates to photons and cosmic ray nuclei which arrive at the Earth with energies sufficient to produce particle cascading in our atmosphere. That is, energies above about 10^{10} eV.

Those accessible energies are now close to giving us a view of the electromagnetic spectrum which is continuous through the highest energy gamma-ray satellite observations to air shower observations (currently with a gap of less than one decade in energy, and about to be closed). They also give us a complete view of the spectrum of cosmic ray nuclei over 10 decades of energy, well past the energies of any observed photons.

Like results from the highest energy gamma-ray satellite observations at 1 GeV, ground-based observations, at least to 10^{12} eV, have recently shown that there are well-located very high energy gamma-ray sources which are UNKNOWN at lower energies. This has been a remarkable realization, and emphasizes the importance of observing at these energies. So far as astrophysics with cosmic ray nuclei is concerned, solid observations extend to 10^{20} eV. Again, this is remarkable, and is not explained by conventional astrophysics, which fails to explain particle acceleration past one ten thousandth of this energy.

The next decade will be the decade of astrophysics at these energies. A number of new VHE gamma-ray observatories are coming on line. These will be capable of observing and mapping known sources with observation periods of hours (to 0.05 Crab in 5 hrs) rather than months. They will enable astrophysically important multi-wavelength source variability measurements. Also, the giant Pierre Auger Observatory will be making key observations at particle energies above 1 Joule. Those latter observations (1) are guaranteed to locate the volume of the Universe from which such particles originate, (2) will almost certainly set new stringent limits on the intergalactic magnetic field strength and structure, and (3) will certainly set stringent limits on source processes through limits on observable neutrinos and gamma-rays at those energies.

Theory will be a key to understanding new results in this field. It relates to AGNs (their structure and mechanisms which finally relate to time variability), particles and fields in intergalactic space, diffusion and propagation of particles at their sources and in their passage to us, and the production of observable neutral particles such as high energy neutrinos and gamma-rays.

Technology

Technology for air shower studies has been advancing rapidly over recent years with an injection of expertise from high energy physics, where detector design is sophisticated, large-scale fabrication is the norm, huge datasets are produced, and there is an expectation that projects will involve at least hundreds of scientists. These advances have lifted the field beyond what we have previously seen in ground-based astrophysics. This having been said, the technology is still recognizably based on large mirrors, fast optics and electronics, and high data throughput. The major changes have been in the scale of the projects, in which $200M is becoming regarded as a modest cost.

Fast light collection, sampling, and data storage are at the core of the field and these are places in which Australia still has world quality expertise. Photomultipliers are still the basic tools of trade since they can be made large, are sensitive, and are fast. On the other hand, solid state detectors can have a better quantum efficiency and are getting larger and faster. It is possible that, within a decade, new detectors may be developed.

Training

Air shower astrophysics has a good track record of training in cutting edge areas of science. Like other astrophysics, it has provided data analysis and data handling skills which have proved to be in demand. It has also provided students with skills in hardware development, which have proved to be of broad utility well outside astrophysics. Of course, many graduates have successfully continued in the field of high energy (and other) astrophysics, at least through post-doctoral careers, before entering permanent positions in industry or universities. A strength of the field (like much of astrophysics) has been its international nature. This has been a key to maintaining the attractiveness of our graduates to future employers, as we have been able to train students to a recognizable world-class level in the face of declining funding.

Theory is a key player in our work through Adelaide and ANU. Our theoretically trained students have had access to high international quality training and many have become important contributors to Australian industry.

Australia's Contributions in the Next Decade

Particle Astrophysics at the Highest Energies

Australia is a key player in the Pierre Auger Observatory which will continue to be the world leader over the next decade. This represents a large investment, particularly of our time and the application of our expertise, over the past 14 years. The next decade will provide the pay-off from that investment. The Observatory will finally consist of a southern and a northern component. The southern site will be essentially complete by the end of 2006 and it is expected that the northern site will be complete by 2010, thus giving a complete sky view. In a field which, by its nature, studies large-scale sky distributions, the two complementary sites will be essential. This work will require a continuing investment from Australia at about the current hardware level of ~$100k per annum.

We have been successful well beyond our financial input, through our intellectual input. We need this to continue through our post-doctoral and visitors programs, which have been somewhat under funded. The best returns on our investment in the Auger project will come with a continuing, and improved, investment in people here. It goes almost without saying that adequate travel underpins this work. At present, travel funds represent a factor which is limiting our ability to obtain the best returns on our present overall investment. We are having to be over-selective on which site visits we are able to make, as well as the meetings and workshops that we attend.

Towards the end of the next decade, Auger should be running routinely and will be providing new and unexpected opportunities for research. However, by that time we would expect that new strong fields are likely to be emerging. We would be particularly interested in neutrino studies at the highest energies as neutrinos will undoubtedly be produced in sources of the highest energy cosmic rays. One promising technique is to use large masses of transparent material in the solar system (e.g. polar ice caps of Earth and icy moons of other planets transparent to light, and lunar regolith transparent to radio) as targets for neutrino interactions and Cerenkov radiators. A collaboration between Adelaide and ATNF called LUNASKA is actively developing this technique to search for neutrino radio signatures from the moon.

Gamma-Ray Astrophysics at Air Shower Energies (>10^{10} eV).

Very High Energy gamma-ray astrophysics has come of age. We now have the tools to study most known energetic objects, and to contribute images, fluxes, or useful astrophysical upper limits. There are presently rather few observatories with this capability but the number is rapidly increasing. We are NOW seeing new astrophysics being discovered on a regular basis.

Australia is currently involved with the Japanese-Australian CANGAROO project. This has been a pioneer project as the field has developed. It is currently somewhat behind the German HESS project in Namibia, but it has recently been upgraded to a 'stereo' system, which will reduce its susceptibility to noise, and an alternative analysis chain is being independently developed at Adelaide. Nonetheless, CANGAROO with its current upgrades will remain an important international player for at least the next five years. In fact, we see opportunities for important collaborative observations with HESS. In the next few years, the northern VERITAS will come on line, and other northern projects, which have lower thresholds close to satellite energies, will become operational.

Australian funding for CANGAROO has been hit and miss over the years, although stable funds have been available over the past four years and these have funded important parts of the CANGAROO upgrade to four 10m diameter telescopes. Australian funds to continue this work, at about $100k - $200k per annum, for hardware will underpin the (much larger) Japanese funding. Additionally, there is a need for further funding for the project over the next few years. CANGAROO needs some telescope retrofitting of the first 10m dish which was, in a sense, a prototype. Also, the useful life of the present CANGAROO system might be substantially extended by increasing the size of the fields of view of the telescopes. This would particularly assist with studies of extended sources and would improve the sensitivity at higher energies.

Out past the next five years, we see CANGAROO being stable and routinely usable to underpin Australia's particular interest in AGNs. Past that time, we feel that there will be a potential niche for us in extending our observations. We note that the proposed 5@5 project may well result in the first VHE gamma-ray observatory to run on conventional astronomical time assignment lines, and we wish to maintain a watching brief on the possibility of using that facility. However, our background and interests lead us to look to somewhat higher gamma-ray energies. We know that some of the sources which have been observed have hard spectra. This is intriguing, and offers the prospect of new physics in relatively nearby sources such as the Crab, micro-quasars, and X-ray binaries. Immediately below the PeV cut-off, we will then also be able to study AGN's with much improved statistics. These observations will fit with our interest in the highest energy particles, and with radio astronomical studies of synchrotron emission from high energy electrons.

We anticipate an observatory which operates between 10^{12} eV and 10^{16} eV. It would consist of a large number of modestly sized (< 4m diameter), and economical, light-collecting telescopes for studying the shower Cerenkov light. It seems likely that such a telescope could be operated at sea level, and that Woomera would be a satisfactory site. This is in contrast with moving to lower energies, where sites such as for 5@5, at the highest possible altitudes, would be preferred.

Researcher involvement.

Adelaide currently has:
3 academic staff
3 postdoctoral fellows
9 postgraduate students

ANU has:
1 academic staff
1 post doctoral fellow (?).

The Pierre Auger Observatory will cost about $130M when complete with two sites (US$50M per site).
The value of the CANGAROO installation is of the order of $30M.

We receive about $250k per annum for observational work plus substantial annual funding for theory from ARC.

Necessary Funding Levels

Present funding levels are marginal for Australia to continue to have a major role in this field. For example, we have a major intellectual input to Auger but our financial contribution to the project is below that of Slovenia – which has no historical interest in this field. We are currently limited by our travel funds, and by our inability to provide realistic baseline operating funds for our collaborations. We operate at a level in which small increases in funding would have large impacts on our science.

Two more postdoctoral fellows, or equivalent, on each of the Pierre Auger Observatory, CANGAROO, and LUNASKA projects would allow us to reap great rewards. We could then genuinely be long-term leaders in the fields.

We have found a mismatch between the style of ARC funding accessible to us, and the needs of a large international collaboration. It has been hard to argue for funding over long lead-times for the projects. The Pierre Auger Project produced one project refereed paper in 10 years – but will now dominate the field for the next decade. 'Operating funds' for the project (to provide shared resources on-site) have not been funded by ARC, but the projects cannot operate without local on-site staff and buildings at experimental sites well away from the home University. As another example, it would be difficult for us to find suitable funding schemes for the purchase of (say) 5000 photomultipliers, or 1000 water tanks or 1000 radio receivers since infrastructure funds are closely related to use by multiple Australian institutions.

<u>Funding Scenarios</u>

Funding for the Projects to Continue at About Their Present Levels

Present funding for both the Auger and CANGAROO projects are at about the level of $250k in total. As discussed above, those levels are marginal at best and make it difficult to get the best value from Australia's investment in the projects. To enable that, at least one more post-doctoral fellow is needed and more travel funding. **Say $175k in total is required annually for each project to maintain viability.**

Funding for the Projects to Develop Modestly Above Their Present Levels and Provide Value to the Australian Astrophysical Community

We can take advantage of the funds already invested in the **Pierre Auger project** by having **two more post-doctoral fellows**. One would work on the data analysis, which would enable us to target interests of the theoretical community in Australia. This would be because Auger will give us data related to AGN source spectra, and intergalactic fields. We would like to ensure that our thrust has a particular concentration in these areas once we have covered the baseline analysis tasks through our first postdoctoral fellow. The second new fellow would support our commitment to developing the environmental monitoring program for the project. We are currently key players in this and it is at the core of the project, which uses the Earth's variable and uncontrolled atmosphere as its detection medium.

The **CANGAROO** project also needs **two more fellows**. These would (a) have a close interest in developing analysis systems for the telescopes to take best advantage of the telescopes stereo fields of view and (b) work on the interpretation of the data, particularly for blazar sources, as an interface with the broader Australian astrophysical community, which would then be requested to join in with multi-wavelength campaigns.

Additional Funding for Substantial Development of Australia's Air Shower Experiments

We envisage that the requirements in the previous section are necessary to provide a base for our future work in the next three to five years. We also see a number of developments which follow logically from 2010 onwards – the second half of the next decade - and which will require preparatory work sooner than that.

Northern Auger

The southern Auger array is almost complete. The Auger project is then expected to be completed by the addition of a similar northern system, likely to be built in the United States by 2010. We anticipate that Australia would be part of that development, which would require infrastructure support as for the southern array, and related developmental funds which would be specific to the environment of that site.

When Auger is then complete, it will be a superb instrument for astrophysical studies of cosmic ray sources and the intergalactic fields. We do not yet know the likely details of that work, but it is clear that a modest investment of Australian astrophysics expertise will provide access to much fundamental knowledge. We see the possibility of discovery in the areas of neutrino astrophysics, gamma-ray astrophysics, galactic and intergalactic structures, and astrophysical fields. These are apart from the core business of cosmic ray astrophysics.

These studies will require at least one further astrophysicist, involvement in the astrophysical community through workshops and small conferences, and funding for the northern developments. ~ **$500k for hardware over 5 years, and an ongoing $180k per annum.**

PeV Gamma-Ray Astrophysics

Australia has had a long–term interest in astrophysics above 10^{14} eV. An extension of the techniques which have proved exceptionally successful in VHE gamma-ray astrophysics will enable us to study the hard spectra found at energies a decade or more lower. Such studies of more energetic photons would relate directly to the issue of cosmic ray acceleration within our galaxy, as well as to broader astrophysics.

Support for this initiative would come through an international collaboration with a serious input from Australian R&D. **~ $250k for hardware over three years, $180k per annum for five years** for technical and post-doctoral staff.

High Energy Neutrinos

Neutrinos have not yet been observed at the highest energies, but straightforward astrophysics suggests that they should exist and that they should give us important information on the distributions of fields and high energy particles in the Universe. LUNASKA will have the necessary very large collecting area for such work and it is likely that it will point the way to future serious neutrino detectors. We see this as a role for ourselves and the radio astronomy community as a possibility for exciting developments a decade from now. We now require a modest input into long-term R&D. ~ **$100k per annum for five years** for long term R&D in addition to present LUNASKA work.

Facility Name: **CANGAROO**

Funding Institution: Japanese Universities, University of Adelaide, Australian National University

Background: Describe the History of the Facility : Was developed at Woomera following use of the site by the University of Adelaide Bigrat Cerenkov Telescope in the late 1980's. CANGAROO I (3.8 m diameter telescope) was sited at Woomera in the early 1990's as a collaboration of Japan with Adelaide. Since the late 1990's a series of four 10 m diameter telescopes have been built to operate together as imaging gamma-ray telescopes. The final one became operational in 2004 with support from an ARC Infrastructure grant..

Role of the Facility: Study of gamma-ray sources at photon energies 10^{11} to 10^{12} eV using stereo observations to reduce the contamination by background cosmic ray events. The underlying aim is to identify exactly where, and how, high energy particles are produced in galactic and extragalactic objects. The lowering of the gamma-ray energy threshold (to just above EGRET) is important in allowing observation of extragalactic sources which suffer strong absorption at 10^{12} eV and above.

Immediate Future of Facility: CANGAROO is now operational with four telescopes. It is expected that it will be run for some time in that configuration with a normal upgrade programme.

High Profile Work Done by the Facility: A number of real source detections have been claimed by the facility. Some of these will prove to be real and some not. However, joint observations with H.E.S.S. are likely to be highly productive since many gamma-ray sources are highly variable.

Future Facilities

Facility Name: **Pierre Auger Observatory (Southern)**

Funding Country: 15 Countries

Description of Facility: 3000 square kilometre air shower array using ground-based water Cerenkov detectors and air fluorescence telescopes.

Description of Australian Access to this Facility: Australian collaborators have complete access to the dataset.

Description of Australian Use of this Facility: Use of the facility at energies above 10^{18} eV for anisotropy, composition, energy spectrum, atmospheric monitoring studies.

Future Australian use of facility (include any strategic opportunities): This is the current benchmark in the field. At only one third complete, it already has the largest UHE dataset, with unprecedented precision of measurement. Adelaide has an ongoing Collaboration membership.

Any High Profile Australian Research using this Facility? This is the major world-wide facility in the field and Adelaide is a key player.

Facility Name**: Pierre Auger Observatory (Northern)**

Probable Funding Institutions: 15 countries world-wide

Timescale of the Facility: Construction 2006-2010

Role of the Facility: Provide a view of the northern sky to complement the southern Pierre Auger Observatory.

What is happening with the Facility Now: Site selection almost complete (scheduled by mid-2005). Preliminary funding discussions with NSF.(~US$50M required in total)

Key issues facing Australian involvement with facility: Australia has had a major interest in applying the fluorescence technique to Pierre Auger work. There is a question of whether this will be used in the northern observatory, or whether it will be provided by a third party. In any case, Adelaide expects to be involved in data analysis and astrophysical interpretation.

Key Science Drivers of Facility: Search for the sources of the highest energy particles in Nature.