Australian Synchrotron Development Plan
Project Submission Form

Section A: Summary and Proponent Details

Project Title

A beam-line for atomic and plasma science, X-ray and IR/vis/VUV spectroscopy including detector development and diagnostics

Spokesperson

Name	Christopher Chantler, FAIP
Institution	School of Physics, University of Melbourne
Email	chantler@unimelb.edu.au
Phone	83445437

Executive Summary (approx. 100 words)

Within the Australian context, the initial suite of synchrotron beam-lines emphasized workhorse (high-user-demand) applications in a very successful manner. Necessarily, this neglected other researchers in atomic physics, plasma research and fundamental science who have perhaps felt excluded from Australian synchrotron developments and research. In this second-stage process however, it is important to engage this large community, not least as this community has a strong voice in ARC grant evaluations.

More, it is important to look towards novel advanced designs that do not exist anywhere in the world – a statement of innovation, intellectual leadership and quality. This proposal links IR/vis with wide X-ray ranges to a novel device, the Electron Beam Ion Trap, one of the great atom traps in the world, of which there are currently only a handful in existence leading cutting edge research in Japan, USA, Europe and China. The spokesperson has previously proposed that an EBIT be attached to a synchrotron, following a US investigation of the new opportunities from such a facility, and subsequently Germany, China and the US are preparing to pursue this. Combined with an IR/vis/X-ray line, this can yield enormous and unique advances in pump-probe, resonance, laboratory astrophysics, plasma dynamics and high accuracy fundamental science investigations.

Other proponents (add more rows if necessary)

Name	**Institution**	**Email address**
QED Group		
Prof Feng Wang	Swinburne University of Technology	FWang@groupwise.swin.edu.au
Dr L T Hudson	National Institute of Standards and	lawrence.hudson@nist.gov

	Technology, USA	
Prof IP Grant	University of Oxford, UK	i.p.grant@ntlworld.com
Prof JD Silver	University of Oxford, UK	josh.silver@eye.ox.ac.uk
Dr JD Gillaspy	National Institute of Standards and Technology, USA	john.gillaspy@nist.gov
Other proponents		
Prof Andris Stelbovics	Curtin	A.Stelbovics@curtin.edu.au
Prof Victor Flambaum	UNSW	v.flambaum@unsw.edu.au
Prof Stanley Brodsky	Stanford	sjbth@slac.stanford.edu
James Mitroy	Charles Darwin Uni, NT	jxm107@physics.anu.edu.au
Dr Greg Le Blanc, Mark Boland & Team	AS	greg.leblanc@synchrotron.org.au Mark.Boland@synchrotron.org.au
Roger Rassool & team	UMelb	rogerpr@unimelb.edu.au
Chris Ryan	CSIRO	chris.ryan@csiro.au
Prof Igor Bray	Curtin	I.Bray@curtin.edu.au
A/Prof Dmitry Fursa	Curtin	D.Fursa@curtin.edu.au
Dr Philip Bartlett	Murdoch	p.bartlett@murdoch.edu.au
Prof Anatoli Kheifets	ANU	A.Kheifets@anu.edu.au
Prof Birgit Lohmann	Adelaide	birgit.lohmann@adelaide.edu.au
Dr Adam Trevitt	UOW	adamt@uow.edu.au
Dr Matias Daniel Rodriguez	ANU	matias.rodriguez@anu.edu.au
Dr Wilfred Fullagar	Monash	Wilfred.Fullagar@sci.monash.edu.au
Dr Vera Grishina	UWA	vera@physics.uwa.edu.au
Dr Maitreyee Roy	NMI	maitreyee.roy@measurement.gov.au
Prof Klaus Bartschat	Drake Uni, USA	klaus.bartschat@drake.edu

Section B: Detailed Description
B1: Description of Proposed Beamline/Development Project

Current beam-lines at the Australian Synchrotron serve a large and growing community of chemists, engineers, biomedical and biopharmaceutical groups and others. However, few (synchrotron) beam-lines around the world have linked up in a useful manner to the atomic, plasma and fundamental science communities, who tend to find homes at CERN, ATLAS, particle accelerators and related locations. Indeed, there is a stronger atomic physics program at developing XFELs than at synchrotrons. This is partly related to the prevalence of strong laser sources at local laboratories, but the physics community can easily recognize strong potential at synchrotrons in the IR and possibly UV/vis regions. ALS and APS are perhaps the synchrotrons with the strongest prior links to the fundamental science / physics community, and have achieved remarkable work at synchrotrons accordingly. Again, there is strong physics and fundamental science research in the X-ray region, and in detector development and in diagnostic development, all of which are germane and strongly supportive of future endeavours in synchrotron technology development.

There is much to be gained for a constructive development and engagement of such communities. And this is an area where the Australian Synchrotron can be involved to its great advantage.

A recent US proposal suggested combining a synchrotron source with a novel and powerful trap technology, that of Electron Beam Ion Traps (EBIT), though this was not realized. Subsequently, and in the previous decadal plan submissions, Chantler et al. proposed the combination of an EBIT with our synchrotron. However, the initial suite of proposals emphasized (high-user-demand) workhorses and duty cycles relating to urgent and demonstrated need of large local user groups.

Recently, these ideas relating to EBIT and synchrotron coordination have been taken up in Germany[1], China[2], and the US[3], so that beam-lines are proposed which link an X-ray source with an EBIT source as an end-station. Some 3-4 years after the earlier decadal proposal, we have the new opportunity of a potential suite of beam-lines which can and should now focus on Australian leadership, not just to keep pace with other user groups around the world but to offer and attract new original ideas. More, there is now an entire conference series (the PEARL series) devoted to EBIT plus Synchrotron interactions.

The key ideas are as follows:

1. A synchrotron is a bright source of (X-ray) flux which can be used to calibrate and probe smaller (EBIT) trap sources to very high accuracy;

[1] Photoionization of ions in arbitrary charge states through the introduction of synchrotron radiation to an electron beam ion trap M. C. Simon, S. W. Epp, M. Schwarz, C. Beilmann, B. L. Schmitt, T. M. Baumann, K. Kubicek, R. Ginzel, R. Klawitter, V. Mäckel, S. Bernitt, P. H. Mokler, J. R. Crespo López-Urrutia, and J. Ullrich, ICPEAC July 2009, proceedings and J .Phys. CS in prep

[2] Roger Hutton et al 2009 J. Phys.: Conf. Ser. 163 012006 and private communication

[3] JD Gillaspy, private communication, 2009 experiment, E Silver, L Young, JD Gillaspy B Dunford et al.

Australian Synchrotron

2. An EBIT is a hot thermal trap which can trap plasma species and in particular highly ionized atoms of a (any) selected charge state[4], and can either extract such ions for later use or investigate fundamental plasma interactions[5] such as are relevant for astrophysics[6],[7], the constancy of the fine structure constant at intermediate epochs in Z, can test QED[8], plasma and spectral polarization[9], can investigate materials science and the production of single-photon quantum dots, and related phenomena[10]
3. High brightness sources[11] can drive resonance and pump-probe behaviour[12], whether at X-ray energies or more easily at much lower frequencies[13]

New ideas allowing even greater potential include

4. A single beam can be divided into two components by relatively simple optics, so that a central component can be monochromated by a standard DCM and a wide-band component in the IR/UV-vis region, and both can be focused to a small region such as the interaction region of an electron-beam ion trap
5. The IR/UV-vis component is ideal for investigating multi-polarity of discrete bound transitions[14], for assessing plasma properties, charge exchange and dynamics[15], for high-

---

[4] J. R. Sieber, X-Ray Spectrometry 29 (2000), 327 - 338

[5] J.D. Gillaspy, Y. Aglitskiy, E.W. Bell, C.M. Brown, C.T. Chantler, R.D. Deslattes, U. Feldman, L.T. Hudson, J.M. Laming, E.S. Meyer, C.A. Morgan, A.I. Pikin, J.R. Roberts, L.P. Ratliff, F.G. Serpa, J. Sugar, E. Takacs, *'Overview of the EBIT Program at NIST,'* Physica Scripta, T59, 392-395 (1995)

[6] Chen, GX, et al., The 3C/3D line ratio in Ni XIX: New ab initio theory and experimental results (vol 97, art no 143201, 2006), Phys. Rev. Letts 99 (2007) 109902

[7] Laming, J.M. et al., 'Emission-line intensity ratios in Fe XVII observed with a microcalorimeter on an Electron Beam Ion Trap,' Astrophysical Journal 545, L161 (2000)

[8] C.T. Chantler, D. Paterson, L.T. Hudson, F.G. Serpa, J.D. Gillaspy, E. Takacs, *'Absolute measurement of the resonance lines in heliumlike vanadium on an electron-beam ion trap,'* Phys. Rev. A62 (2000) 042501

[9] Endre Takacs, Eric S. Meyer, John D. Gillaspy, Jim R. Roberts, C.T. Chantler, L.T. Hudson, R.D. Deslattes, Charles M. Brown, J.M. Laming, U. Feldman, J. Dubau, M.K. Inal, 'Polarization measurements on a magnetic quadrupole line in Ne-like barium,' Phys. Rev. A54 (1996) 1342-1350

[10] Pomeroy, JM, Perrella, AC, Grube, H, Gillaspy, JD, Gold nanostructures created by highly charged ions, Phys. Rev. B 75 (2007) 241409

[11] Park, HS, Maddox, BR, Giraldez, E. et al., High-resolution 17-75 keV backlighters for high energy density experiments, Physics of Plasmas 15 (2008) 072705

[12] S. Ozawa, M. Wakasugi, M. Okamura, T. Koizumi, M. Fukuda, and T. Katayama, Journal of Physics: Conference Series **2** (2004) 134–142

[13] Hosaka K, Crosby DN, Gaarde-Widdowson K, Smith CJ, Silver JD, Kinugawa T, Ohtani S, Myers EG, 'Laser spectroscopy of hydrogenlike nitrogen in an electron beam ion trap,' Phys. Rev. A 69 (2004) 011802

[14] Fahy, K, Sokell, E, O'Sullivan, G, Aguilar, A, Pomeroy, JM, Tan, JN, Gillaspy, JD, Extreme-ultraviolet spectroscopy of highly charged xenon ions created using an electron-beam ion trap, Phys. Rev. A75 (2007) 032520

[15] Yunqing Fu et al., Plasma and Fusion Research 2 (2007) p028

accuracy spectroscopic investigations of (any) charge states[16], and perhaps particularly for pump-probe experiments[17]

6. The combination of high flux, pump-probe combination in two major energy regimes with a large range of plasma conditions, and high-accuracy calibration (to energies down to one part in 100000) allows an enormous range of experiments across most ionisation states for most elements. Super-EBITs can range to hydrogenic uranium (i.e. uranium with only one electron left) and e.g. CIV, SIV etc. are accessible by all EBITs.
7. This potential series of applications has only become feasible with recent generation sources – prior to this, a separate visible or perhaps near-UV laser resonance experiment occupied a whole beam access port and was extremely difficult if not infeasible. Equally, recent advances in EBIT operation permit trap expansion and decay dynamics to be investigated in off cycles, permitting a wider range of studies.
8. The whole experiment can be designed as an extended second hutch and be time-shared with beam, detector and diagnostic test development in an earlier hutch. Typical dimensions are on the web and quite suitable for the AS.
9. This proposal is unique in that the EBIT serves as its own source of an independent range of plasma and atomic spectra, enabling a range of tests of quantum field theory and quantum electro-dynamics, in addition to industrial and applied experiments, and perhaps new tests of parity violation. The combination is a qualitatively new definition for synchrotron science.

B1.1 Feasibility

Given the novelty, the question of feasibility is paramount. Within the synchrotron and particularly the machine studies group, there is strong interest in diagnostic and detector development, and also strong interest in engaging in plasma research, especially as it impacts upon beam stability and performance. Hence the human infrastructure exists as an important core.

Further, Australian involvement in implementation of such systems is at the forefront of such research worldwide, and the proponents include world experts in this field. Thirdly, the front-end optics are a variation upon two standard optics, and so should be relatively standard and stable in design and operation.

This leads to the most critical component being the EBIT itself. Designs, implementation and specifications are available from the expert proponents (and clearly do not fit in a proposal with submission deadlines of this timeframe), and this proposal was raised in the earlier decadal plan. In fact a series of designs have been elucidated in the references listed above. Size, space, cost and timeline all fit within the required rough 3 year timeframe.

---

[16] Gillaspy, J.D., et al., "Visible, EUV, and X-ray Spectroscopy at the NIST EBIT Facility," in *Atomic Processes in Plasmas* , ed. by Cohen, J.S., Mazevet, S., and Kilcrease, D.P., (AIP, New York, 2004) p. 245

[17] Ralchenko, Y, Reader, J, Pomeroy, JM, Tan, JN, Gillaspy, JD, Spectra of W39+-W47+ in the 12-20 nm region observed with an EBIT light source, J. Phys. B40 (2007) 3861-3875

Further, German and US groups have used a test source linked up to a synchrotron and proven the feasibility of the idea of combining the two sources; while the Chinese proposal, like this one earlier, proposes a full-scale source.

A final concern about feasibility would relate to what novel physics is actually realizable within a reasonable timescale. The plasma and laboratory physics applications are ideal and easily achievable with this new infrastructure. High-precision spectroscopy in X-ray and IR / VUV-vis regimes is fully implemented and defined by past work. Detector and diagnostic tests are simple implementations, and low frequency pump-probe experiments, while the greatest challenge, have been demonstrated with lower fluxes.

B2: Applications and Potential Outcomes to Australian Scientific Community

Applications and outcomes can be categorized by (i) ARC guidelines; (ii) new fields with new potential user groups; (iii) new problems which could then be solved.

(i) ARC Guidelines: Frontier Technologies for Building and Transforming Australian Industries:

Breakthrough Science: laboratory astrophysics; tests of Quantum Electro-dynamics and fundamental theory; plasma process modeling; dilute and driven systems; investigation of a wide range of charge states in atomic species; measurements of lifetimes and transition theory[18]; investigation of relativistic wavefunctions

Frontier technologies: high-accuracy X-ray and IR/UV spectroscopy; pump-probe resonance experiments with much higher brightness;

Advanced materials: quantum dot development

(ii) New fields and new potential user groups

The atomic physics and plasma physics communities are important for detector development, diagnostics development, monitoring and beam or machine studies at synchrotrons. These groups around Australia are often embedded in laser-optics spectroscopy, or high-energy particle investigations. The potential of this proposal to engage and encourage these large communities would be, for the synchrotron, both the engagement of new fields and large potential user groups. We note that the first experiment on the XFEL is an atomic physics pump-probe experiment, with a large series of potential developments. The group involved geared up to these experiments using specialized experiments (of a very different type) to great success on a beam-line at the APS. The Australian and regional communities would likely be encouraged by the existence of such facilities in the local context (i.e. in Australasia). This would also serve as a launching pad for possible physics or fundamental science-based projects at other FELs.

[18] Lifetime of the 1s2s 3S1 Metastable Level in He-like S14+ Measured with an Electron Beam Ion Trap, J. Crespo López-Uruttia, P. Beiersdorfer, and K. Widmann, Physical Review A 74, 012507 (2006)

In relation to fields, the pump-probe area is quite straightforward, as is the high-accuracy spectroscopy for e.g. physics, chemistry or applications.

B3: Match to Selection Criteria

Criterion 1 – Meet the demands of an identified group of users

Group 1: The plasma physics community might be one of the strongest beneficiaries[19]
Group 2: The atomic physics community, especially in relation to pump-probe experiments and the possibility of opportunities in relation to FELs, is a quite relevant community of interest
Group 3: The spectroscopy community, which might normally pursue laser-optical experiments in relation to physics, chemistry or applied sciences, but could now investigate a range of charge spectroscopy across new energy ranges
Group 4: Laboratory astrophysics is related to part of these, but addresses directly valence species of interest in solar physics, astrophysics and cosmology[20]
Group 5: Machine studies and diagnostics: these have a keen interest both in high energies, plasma processes and dynamics, and in diagnostics which can benefit from a *combined proposal*.

Criterion 2 – Take advantage of an existing third generation light source

Pump-probe experiments require high-brightness, and one of the key advantages of this proposal is that it uses this high brightness of the synchrotron for the first time.

A second key aspect is that this flux and brightness are key to the accuracy, calibration and transition probabilities of these categories of investigation.

Criterion 3 – Will position Australasian scientists at the leading edge of the field

This is clearly explained above. Most importantly, the local (synchrotron) and regional (Australian) groups will then have a clear advantage and opportunity for developing and establishing leadership in these areas, as is already evinced by the proponents, but in complementary and potentially quite different fields of research.

Criterion 4 – Can be demonstrated to be feasibly constructed in three years

As discussed above, this is a feasible proposal within a three year timeframe. Of course the timeline of this proposal submission does not lend itself to a complete detailed description but rather encourages the beginning of a dialogue and potential development program as called for very clearly and encouragingly by the synchrotron Roadshow a few weeks ago.

B4: Potential Users

---

[19] CH Skinner, Applications of EBIT to magnetic fusion diagnostics, Can. J. Phys. 86 (2008) 285-290
[20] Laboratory Astrophysics and Atomic Physics using the NASA/GSFC Microcalorimeter Spectrometers at the LLNL Electron Beam Ion Trap and Radiation Properties Facility
G. Brown, et al., NIM A 559, 623 (2006)

Does the project address a clearly identified need in the community? The need may be actual or potential.

Most of these identified needs exist in the worldwide and Australian communities, but it is fair to say that they are NOT traditional synchrotron groups, and in that sense this proposal clearly identifies large potential user groups and fields. All of these are established by literature reference, but the key aim is to encourage their involvement in synchrotron-related research and a growing user community. The other need lies with the plasma groups and the machine studies groups. Again these are real, existing and identified, and this proposal may well bring these large and disparate communities to a collegiate and coordinated whole.

For example, the Curtin University ITP group have recently addressed problems of plasma dynamics in EBITs especially relating to hydrogen-like ions as well as establishing quantum-mechanical foundations for plasma polarization spectroscopy in general. This is a developing field where more users from Australia are able to be involved in important and world-leading areas. Atomic spectral properties and collisions in hot and dense plasmas are an exciting area of direct relevance.

Case Studies:

1. New tests of Quantum Electro-Dynamics at a Synchrotron. Never achieved before, but methodology is extremely well documented. High profile. Quality. See J. D. Gillaspy, C. T. Chantler, D. Patterson, L. T. Hudson, F. G. Serpa, E. Takacs, 'First measurement of Lyman alpha x-ray lines in hydrogen-like vanadium: results and implications for precision wavelength metrology and tests of QED', J. Phys. B 2009, C. T. Chantler, J .M. Laming, J. D. Silver, D. D. Dietrich, P. H. Mokler, E. C. Finch, S. D. Rosner, 'The Hydrogenic Lamb Shift in Germanium, Ge^{31+} and fine structure Lamb shift,' Phys. Rev. A80 (2009) 022508. Requires high-accuracy calibration of sources.
2. Investigation of polarization in plasma sources. G.Csanak, D.P.Kilcrease, D.V.Fursa I. Bray Phys. Rev. A (2008) 062716. C.J. Bostock, D.V.Fursa, I.Bray Phys. Rev. A (2009) 052708 Also earlier work by T.Fujimoto,S.A.Kazantzev Plasma Phys.Control Fusion 39(1997)1267, Beiersdorfer et al., and Takacs et al. Methodology very well documented. High profile. Quality. Requires modest calibration of sources but careful calibration of polarization. Strong community in Australia and around the world, both on the synchrotron side and on the plasma science side.
3. A new possible measurement of the time variation of the fine structure constant and separately of parity violation. Flambaum, Dzuba, Ginges et al. The methodology is not so well developed, but the key scientific considerations are presented in Flambaum, Porsev Phys. Rev. A (2009) and Phys. Rev. A 80, 042503 (2009), Phys. Rev. A 77, 032119 (2008). Specifically requires the charged ions of an EBIT together with calibration and pump-probe investigation.
4. Detector development and diagnosis. Ryan et al., Rassool et al., Le Blanc et al. solid work and larger user community.
5. Plasma dynamics of excitation, ionization and recombination proceses. Relevant for tokamak, beam studies, laboratory astrophysics and related work. A mixture of high profile / quality and solid work and larger community.

6. IR pump-probe spectroscopy – investigation of near-degenerate levels and level crossings in relativistic quantum chemistry and theory. Methodology fairly straightforward.
7. Visible pump-probe spectroscopy – large Australian community of Optical Physicists. Methodology well-defined. See above references.
8. Quantum dot materials science and circuitboard development. Gillaspy et al. Potential user community of advanced materials, nanostructures, quantum computation and CPU companies. Funded in USA by IBM and related companies.
9. Laboratory Astrophysics. Recent critical investigations by astrophysical groups have been concerned with outer shell and inner shell transitions of Ti IV, Fe IV and a wide range of other transitions accessible by the proposal above but requiring an EBIT ion source, preferably a trap, a strong pump beam, preferably a synchrotron-based source, and good statistics and calibration.