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Application Details

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Applicant

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Area of Research

☐ Health ☑ Natural Sciences and / or Engineering ☐ Social Sciences and / or Humanities

Title of Research Proposal
Discovery and discrimination of models for new physics with combined terrestrial and astrophysical data

Host Institution

Institution	Faculty	Department
McGill University	FACULTY OF SCIENCE	DEPARTMENT OF PHYSICS

Supervisor

Surname	Given Name
Cline	James (Jim)

Institution	Department	Faculty
McGill University	Department of Physics	Faculty of Science

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McGill University

Lay title

The global search for dark matter and new symmetries of nature

Lay Abstract

Dark matter makes up over 80% of the matter in the Universe, but we still don't know what it actually is. Many theories predict that it is in some way associated with the Higgs boson, the origin of mass, and the existence of an as-yet-undiscovered symmetry about to be uncovered at the Large Hadron Collider (LHC). Using cutting-edge statistical techniques only developed in the last 5 years, this project will combine the results of searches for dark matter and new symmetries from a massive number of experiments, from the LHC to smaller accelerators, gamma-ray telescopes, cosmic antimatter probes, ultra-clean experiments in the world's deepest mines, and a neutrino telescope embedded in the Antarctic ice. The result will be the most comprehensive analysis yet of theories for dark matter and new physics. The statistical and computational tools developed in the process will serve the particle and astrophysics communities for decades to come.

Language in which proposal is written English

Keywords

dark matter, supersymmetry, particle theory beyond the standard model, cosmology, global fits, first stars, accelerator phenomenology, direct and indirect detection of dark matter, frequentist statistical methods, Bayesian statistical methods

Proposed Field of Study/Research

PHYS. & ASTRON.-PARTICLE PHYSICS

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Degree information

Degree Type:

- [x] PhD
- [ ] PhD Equivalent

Degree Name
Doctor of Philosophy in Theoretical Physics

Institution	Department
Stockholms Universitet	Department of Physics
Institution Country	**Date completed or expected(YYYY-MM)**
Sweden	2010-06-01

Lay abstract/Résumé non scientifique

Dark matter makes up over 80% of the matter in the Universe, but we still don't know what it actually is. Many theories predict that it is in some way associated with the Higgs boson, the origin of mass, and the existence of an as-yet-undiscovered symmetry about to be uncovered at the Large Hadron Collider (LHC). Using cutting-edge statistical techniques only developed in the last 5 years, this project will combine the results of searches for dark matter and new symmetries from a massive number of experiments, from the LHC to smaller accelerators, gamma-ray telescopes, cosmic antimatter probes, ultra-clean experiments in the world's deepest mines, and a neutrino telescope embedded in the Antarctic ice. The result will be the most comprehensive analysis yet of theories for dark matter and new physics. The statistical and computational tools developed in the process will serve the particle and astrophysics communities for decades to come.

My primary career goal has always been to perform cutting-edge research in astroparticle physics and particle phenomenology – to help discover and characterize new physics and symmetries of nature above the GeV scale, and their impacts upon astronomical observations.

I intend to pursue this goal via a series of nested subgoals. Ultimately, I wish to build and lead a large, strong and dedicated research group centred around the interface of particle physics and astronomy. I see this group focusing on the topics of dark matter and physics at or beyond the TeV scale. To achieve this goal, I must continue to extend my experience in the broad range of physics relevant to such a group, and gain the necessary professional experience to effectively build and lead it.

The first step in both these aspects is to obtain the scientific and professional experience necessary for me to become a junior faculty member. McGill offers fantastic opportunities in both these respects.

On the physics side, McGill offers an extremely broad range of experts, in virtually all the areas relevant to my research proposal. Jim Cline is foremost amongst these; his experience with supersymmetry, electroweak baryogenesis, and indirect and direct detection of dark matter covers large parts of the necessary phenomenology in my proposed global fits program. His input will be invaluable when I come to implement such models and observables in the fits. Within the theoretical high energy group, Robert Brandenberger will provide unique expertise in the theoretical cosmological aspects of the program, and Guy Moore will be available for consultation on all aspects of quantum field theory.

Ken Ragan and Dave Hanna, of the gamma-ray air Čerenkov telescope experiment VERITAS, provide a direct interface with the field of gamma-ray astronomy, essential in the indirect search for dark matter. Working with the VERITAS collaboration will allow me to directly include their gamma-ray data as constraints in the global fits. Both Ken and Dave have years of experience in experimental physics, so are also invaluable when it comes to advice on other experiments, such as direct searches for dark matter. Gil Holder is one of the world's foremost experts on the theory of the microwave background and reionization, and Matt Dobbs on their detection. The McGill ATLAS group plays a very prominent role in one of the two most important LHC accelerator experiments (the other being CMS). LHC data will have a massive impact on global fits in the near future, so their input will play an important role in my research program.

The proposal requires me to become an expert in every one of the specializations I have just listed, so the unique breadth of the skill base at McGill is an essential aspect. The collaborations I build at McGill, and the ground-work they enable, will provide a launching point for the rest of my career. *No other institute in Canada offers such a broad or in-depth combination of expert advice, so relevant to my proposal.*

Professionally, a Banting Fellowship at McGill with Jim Cline essentially offers the opportunity to train as a junior faculty member before obtaining such a position. A very important part of this is supervising students and teaching. Working with Jim makes it possible for me to already play a large role in the supervision of his PhD student Aaron Vincent, and in the future, his Master student Grace Dupuis. Similarly, collaborating with Robert Brandenberger has given me supervisory experience with his PhD student Wei Xue, and working with Gil Holder has allowed me to supervise his student Elinore Roebber. The two full-time years of research funding afforded by the award of a Banting Fellowship would keep me at McGill long enough to see out the supervision of these four students to the point of their graduation (or close to, in Elinore's case). This group of 4 students will play a pivotal role in the global fits research program, and effectively give me my first experience in directly managing my own research group.

The Department of Physics at McGill also offers virtually unparallelled postdoc teaching opportunities. Postdocs can (but do not have to) propose, create and lecture entire courses at the undergraduate or graduate level, gaining faculty-equivalent experience not offered elsewhere. This I did for the course *Practical Numerical Methods in Physics* in 2011, which was a very rewarding experience in terms of my professional development and recruitment of research students. With a Banting Fellowship, I will have the opportunity to teach the course again, providing an opportunity to reflect upon and improve my teaching, communication and research.

McGill and Jim offer all the material resources necessary to support my research: a minimum $10k p.a. travel budget, a dedicated computing cluster, and the CLUMEQ supercomputer. Computing resources are very important, as global fits can take days or weeks of runtime on a well-resourced cluster. Jim will also involve me in preparing his NSERC grant applications, providing grant-writing experience that would otherwise be inaccessible. Finally, Montreal is perfectly situated geographically, giving me equal access to the centres of activity in dark matter and particle phenomenology in Europe, California and the East Coast of the US.

McGill offers the perfect combination of expertise, facilities, professional opportunities and geographical location; I cannot imagine any other institute in Canada providing even a comparable fit for my research.

Discovery and discrimination of models for new physics with combined terrestrial and astrophysical data

Pat Scott

Core Research Questions

- What is the correct theory of matter beyond the Standard Model of particle physics?
- What is dark matter?
- What does simultaneous consideration of terrestrial and astrophysical data tell us about physics at the TeV energy scale?

Overview

The identity of dark matter and the nature of physics at the TeV energy scale are two of the most pressing and fundamental questions in modern physics. Despite constituting 80% of the matter in the Universe and having been discovered some 80-odd years ago, the true nature of dark matter (DM) remains a mystery. A TeV is the energy an electron gains when passing through an electric potential of 10^{12} volts; this is the energy scale at which the Higgs boson is thought to reside. With the recent turn-on of the Large Hadron Collider (LHC) and the construction of a bevy of high-energy astrophysics experiments, we currently stand on the doorstep of the TeV scale. Excitingly, many popular theories for physics beyond the standard model of particle physics (BSM – beyond the SM) include a DM candidate that is intrinsically linked to the appearance of new physics at the TeV scale [1–3]. Foremost amongst these is low-energy supersymmetry, in which a heavy 'superpartner' is postulated to exist for every SM particle.

A wealth of data exists in particle physics and astronomy that could in principle show signs of BSM physics. These complementary data include accelerator searches, neutrino masses and mixings, and direct and indirect searches for DM. Many experiments already show tantalizing hints of DM [4–8] or other TeV-scale BSM physics [9–14]. To make robust conclusions about the overall level of support for different BSM scenarios from such varied sources, a simultaneous statistical fit of all the data, fully taking into account all relevant uncertainties, assumptions and correlations is an absolute necessity. The same is true for determining the preferred regions of parameter space within a particular scenario. This is a highly non-trivial task, existing on the cusp of theory and experiment, astronomy and particle theory – and requiring excellent understanding not only of the theories and experiments involved, but also a raft of specialized statistical techniques and computer codes.

Whilst partial progress has recently been made in this direction (by various groups including myself and collaborators; [15–33]), the magnitude of the task and degree of technical difficulty have left it largely unexplored for the majority of theories and datasets. With the startup of the LHC, vast amounts of additional data are rapidly becoming available at the TeV scale, quickly making even the analyses that have been done in the past year obsolete. The research in this proposal will revolutionize this emerging field, by vastly expanding the scope of models and experiments to which it is applied, and providing essential tools for the explosion it will undergo in the coming years.

Objectives

- To combine data in a statistically consistent way, from a huge range of terrestrial and astrophysical experiments sensitive to BSM physics
- To use this data to constrain and discriminate between theories for the identity and microscopic properties of DM, and between theories for BSM physics at the TeV scale
- To develop appropriate software tools to enable the two objectives above

Significance

Identifying DM or discovering an additional fundamental symmetry beyond the SM would be of profound significance for our understanding of the natural world. Ruling out models that may have explained one or both of these mysteries is also a massive step forward, as it brings us ever closer to finding the correct model.

The 'global fit' research program I propose will result in far more complete and robust comparisons between experimental data and DM/BSM models than presently exists in the majority of the literature. Such holistic analyses exploit the synergy between different experimental approaches to its maximum potential, squeezing every last statistical drop of information possible from each source. Robust analysis of correlated signals, in a range of complementary experiments, is *essential* for claiming a credible discovery of DM or new physics at the TeV scale – and indeed, even for definitively excluding models.

Advancement of Knowledge and Existing Literature

The first statistically rigorous global fits for BSM physics analysis (not counting neutrino oscillations) were performed just 5 years ago [18, 19], in the context of very simple versions of the minimal supersymmetric standard model (MSSM). Subsequent analyses painstakingly improved the statistical and computational tools involved [20, 23, 34–36], examined small theoretical departures from the simplest models [37, 38], more general MSSM parameterizations [24], alternative supersymmetry-breaking schemes [25] or extensions of the MSSM [39], and added other astrophysical data to the fits [21, 26]. Recent efforts have focused on adding new data from the LHC [27–29], and from direct detection experiments [30, 31] hunting for nuclear scattering of DM on highly radio-pure target materials in deep underground labs, such as SNOLAB in Sudbury.

In all of these directions (observables, techniques and models), existing analyses are only just beginning to explore what can and must be done. On the observables side, I will investigate including searches for cosmic anti-deuterons from DM annihilation [40, 41] (with N. Karpenka, A. Putze and J. Edsjö), searches for DM annihilation in the Sun by IceCube (with the IceCube Collaboration, C. Savage and J. Edsjö), and combined searches for gamma rays from DM annihilation in all Milky Way dwarf satellite galaxies by *Fermi* (with the *Fermi* collaboration). I will also look into combined constraints on light DM models (*as implemented in DMBayes together with Jim Cline*), from *Fermi* observations of dwarf galaxies and multiple direct detection experiments. Together with R. Trotta, the other developers of DMBayes and the developers of GALPROP [42, 43], I will continue to develop a global fit analysis of *Fermi* data from the Galactic centre, in terms of simple effective DM models and highly detailed backgrounds. All of these will eventually feed into larger global fits, including a combination of gamma-ray data on DM searches by all existing telescopes, all the other observables just described, and further predictions previously developed by my collaborators and I [21, 26, 44].

Recent work [23, 34] has shown that fully-converged global fits are very challenging to compute, even for the simplest MSSM models. This applies whether one uses Markov Chain Monte Carlos, nested sampling or Genetic Algorithms. *With G. Holder and his student at McGill, E. Roebber*, and in collaboration with A. Putze, I will develop an alternative scanning code for BSM searches, based on the strategy of differential evolution.

A small number of studies [24, 45] have been performed to date with 19 or 20-parameter versions of the MSSM, but most have been done with 4-parameter subsets. I will investigate a much larger range of models, in combination with the greatly expanded set of observables, massively extending the existing phenomenological literature.

Research Framework/Methodology

The core methodology is that of a composite likelihood-based global fit (see e.g. [20, 21, 23]). One first chooses a BSM physics scenario with some model parameters, and then calculates predicted experimental signatures of the model for arbitrary parameter combinations (gamma-ray fluxes, event rates at the LHC, etc). Predictions are compared to experimental measurements, and a series of likelihood functions produced.

The likelihood describes the probability of obtaining the observed data if the BSM physics scenario is correct, given some combination of the model parameters. Each experimental dataset has an associated likelihood function. The individual likelihoods are multiplied to obtain a single combined likelihood. By sampling the likelihood function at a number of different parameter combina-

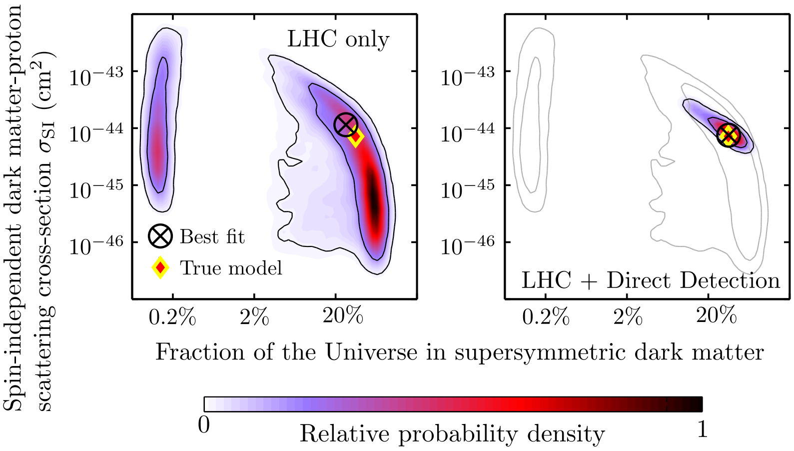

Figure 1: An example of how a global fit can exploit the synergy between different experiments in the search for BSM physics and DM. In the left panel, mock LHC data is used to try to identify an example supersymmetric model, in terms of the cosmological abundance of the DM and its scattering cross-section with protons. Two main parameter regions are compatible with the mock data. Shading indicates the relative probability of the different parts of the parameter space, and contours give 1σ and 2σ regions. In the right panel, mock data from a direct search for DM is added to the global fit, breaking the degeneracy and providing a highly accurate reconstruction. Here grey contours give the LHC-only result, for easy comparison. Based on results from [45].

tions, one can map the overall likelihood surface. This step is highly non-trivial and computationally intensive, even with sophisticated optimization algorithms [23, 34]; traditional grid and random scans are woefully inadequate even for simple versions of the MSSM. The samples are analysed with established statistical methods to produce likelihood maps and probability distributions for the different parameters and observables.

An example of the utility of the global fit approach is shown in Fig. 1. Here probability distributions for the amount of supersymmetric DM, and its scattering cross-section with protons, are shown for two parameter scans. In one scan (left), mock LHC data is used to try to 'find' a particular example point in the parameter space of the MSSM. Two broad regions of high probability exist, illustrating the model degeneracy with respect to LHC data alone. When data from a future direct search for DM are added (right), the degeneracy is lifted, and the correct result is reconstructed with high accuracy. Such analyses have the added advantage of being able to fully deal with uncertainties in modelling assumptions or standard input data, by including them as additional parameters in the fit. The entire exercise can be repeated for different BSM scenarios with different parameterizations, and the results compared to determine if the data strongly favour one scenario over another.

In my analyses, likelihood functions will come from far and wide: Higgs and supersymmetry searches at the LHC and its predecessors [9, 46–49], low-energy accelerators [12, 50–52], the magnetic moment of the muon [53], beam dump/fixed target searches for light bosons [54, 55], electroweak precision tests [56], DM direct detection experiments [4–6, 57–60], searches for antimatter in cosmic rays [8, 40, 41, 61–64], nuclear cosmic ray ratios [65], radio data [66, 67], effects of DM on reionisation [68, 69], recombination [70, 71] and helioseismology [72], the observed DM cosmological abundance [73], neutrino masses and mixings [13, 14, 74], and other indirect DM searches [21, 75–80]. The latter part of my analysis will benefit greatly from directly collaborating with experiments: the IceCube neutrino telescope (via M. Danninger, K. Hultqvist and J. Adams), the *Fermi* gamma-ray space telescope (via J. Conrad, T. Jeltema, et al), and the VERITAS (*via the McGill group of D. Hanna and K. Ragan*) and HESS/CTA (via J. Conrad, J. Ripken, et al) ground-based gamma-ray telescopes.

Not every dataset is relevant for all BSM scenarios. I will confront a number of phenomenological incarnations of the MSSM with the data mentioned above, as well as some based on specific supersymmetry-breaking schemes. DM-specific models will include simple effective DM, inert Higgs doublet models, asymmetric DM, inelastic/exciting models, isospin-violating DM and Sommerfeld enhanced models. Many of the latter will be best implemented *at McGill in close collaboration with Jim Cline*, as well as a global analysis of electroweak baryogenesis models and their implications for DM observables. *With a student at McGill (A. Vin-*

cent), I have also begun investigating combined impacts of solar physics and laboratory experiments on axion-like and magnetic DM models. Later (beyond the timeframe of this proposal), I intend to use global fit tools to investigate extensions to the MSSM, extra dimensional models, sterile neutrino DM, and left-right symmetric models.

This global fitting exercise will be done within the framework of three very large computer codes, designed to connect search algorithms, observable calculators and likelihood functions. For DM-specific models, I will use DMBayes, a dedicated DM global-fitting package presently being developed by myself, R. Trotta, R. Ruiz de Austri and others. Models with broader phenomenology will be analysed using SuperBayeS [18, 20, 81], a project on which I have also recently joined as an author, and later SUFit, a next-generation BSM global fit package I am developing in collaboration with others from the Oskar Klein Centre in Stockholm. A key feature of SUFit is that it will allow extreme flexibility in switching between different BSM scenarios, likelihoods and observable calculators; this will be a key component in facilitating the very ambitious program I have laid out in this proposal.

Dissemination, Impact Enhancement and Spin-off Science

I will disseminate the research by publishing it in top-tier journals like JCAP and JHEP, and presenting it at international conferences.

We intend to make the DMBayes, improved SuperBayeS and SUFit packages freely available to the community as open-source software. This will hugely enhance the value and impact of the research of this proposal. This includes the many instances of new and updated observable calculation routines contributing to the larger packages, many of which will see extensive use in the DM/phenomenology community outside the global fit arena. A prime example is the set of IceCube codes currently being developed for use with SuperBayeS and SUFit, but planned for inclusion in the public version of DarkSUSY [82]. Another example is the differential evolution algorithm discussed above, which will be released as a standalone public package.

Even after we fully characterize physics at the TeV scale, there will always be another energy frontier poorly constrained by data, as the TeV scale currently is. It is in this environment that the technical details of the statistical treatment of global fits are most crucial. The tools my collaborators and I develop for TeV-scale physics in the next few years, and the lessons we learn, will therefore also be directly applicable over the coming decades to the next era of particle physics. *Investment in this research program will therefore pay off not only in the cutting-edge research that it will produce in the two years of the fellowship, but for years to come.*

The research facilitated by the Banting Fellowship will also lead to substantial spin-off science. The differential evolution package will be equally useful for cosmological parameter estimation (linked to e.g. CosmoMC [83]), Galactic cosmic ray propagation (linked to e.g. USINE [84]) and planet searches. Our understanding of DM indirect detection places limits on the amplitude of cosmological perturbations via DM minihalos [85–87], which in turn constrains models of inflation. I intend to use the same techniques *together with R. Brandenberger at McGill* to place constraints on cosmic strings. Eventually, where such early-Universe models have other observable consequences, the constraints may prove useful as additional likelihood components in global fits. Similarly, one can use the global fit machinery to investigate inverse problems [44, 88]; one such problem is the ability of a SUSY detection at the LHC, coupled with the known cosmological abundance of DM, to constrain non-standard cosmologies and heavy moduli in the early Universe. This is an avenue I will pursue *with Wei Xue, a student at McGill.*

The IceCube and axion components of this proposal both depend upon the elemental composition of the Sun. Having substantial experience in this field, together with M. Asplund, N. Grevesse and J. Sauval [89–91], I will continue to help refine our knowledge of this crucial input data. I am also hopeful that the axion work might provide some clues as to why spectroscopy and helioseismology indicate different solar abundances. Finally, DM can have a significant impact on stellar evolution, so investigating so-called ‘dark stars’ [92–97] might also provide some complementary clues as to its identity. This work will lead to yet further spin-offs, relating to the DM velocity distribution in the Galactic Centre (with R. Church and M. Davies) and core condensation in helium white dwarfs (with R. Rosen [98, 99]).

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November 1st, 2011

Interdisciplinary Peer-review Committee and
Banting Postdoctoral Fellowships Program Selection Board

Dear Members of the Review Committee and Selection Board,

I write this letter to indicate the strong support of McGill University for the application submitted by **Dr. Pat Scott** for a Banting Postdoctoral Fellowship.

McGill places an extremely high priority on postdoctoral training. The University's 2006 strategic planning documents highlight strengthening of training programs and developing interdisciplinary areas of research as part of our objectives to enhance McGill as a research-intensive and student-centered university with the highest standards of achievement. We acknowledge the leading contribution made by postdoctoral fellows of Dr. Scott's calibre towards achieving these goals and our responsibility in providing them with the opportunities to achieve their full potential.

The university planning documents specify astrophysics as a priority research area for the future, and interdisciplinary science and emerging research areas as two of the University's key themes for enhancement. Dr. Scott's work cuts across astronomy, particle physics and theoretical physics in a highly interdisciplinary manner, and is therefore a perfect example of the research our University wishes to promote. Dark matter research, in particular, is an emerging research area of great current interest.

Expansion of astroparticle physics at McGill is also a strategic reinforcement of the strong investment recently made in establishing the Astrophysics group (6 faculty hires in 2000-2006), as the cross-disciplinary nature of astroparticle activities will solidify and expand the Astronomy group's role in the Department of Physics as a whole. Dr. Scott's research program is itself also a highly strategic and cost-effective investment, as it will produce novel, very high-impact science by drawing together data from a multitude of experiments across the globe, all of which are already funded.

.../2

Dr. Scott's research is catalytic to cross-disciplinary interactions between the extremely strong groups in theoretical particle physics, experimental particle physics, and most recently, astrophysics. His research is both innovative and timely, coinciding well with the turn on of major particle accelerator facilities such as the Large Hadron Collider, and will no doubt boost McGill's already leading research role on the national and international stage. The Department of Physics at McGill sees Dr. Scott's application for the Banting Fellowship as a means to leverage this diverse expertise in a way that enhances all three research programs, and further strengthens the synergy between them.

Dr. Scott is an exceptional candidate for the Banting Fellowship. He has repeatedly demonstrated an ability to produce outstanding research of international calibre, whilst at the same time making an invaluable contribution to the academic and professional environment of his host institution. Dr. Scott was selected by the University for recommendation for the Banting Fellowship through a two-stage competitive application process, at the departmental and institutional levels.

McGill's commitment to diversity, and specifically to gender equity, is clearly stated in our Employment Equity Policy and in the Handbook on Students' Rights and Responsibilities. At McGill, the Handbook officially applies to postdoctoral fellows. To ensure that McGill's commitment to gender equity has been honoured in the endorsement of candidates for the Banting Postdoctoral Fellowships, the Associate Provost (Policies, Procedures & Equity), Professor Lydia White, has participated in the Institutional review of applications, along with the Dean and Associate Deans of Graduate and Postdoctoral Studies and Associate Deans of the disciplinary faculties.

In conclusion, as Principal of McGill University, I join the Associate Provost (Graduate Education) and Dean of Graduate and Postdoctoral Studies, the Dean of the Faculty of Science, and the Chair of the Department of Physics in strongly endorsing Dr. Scott's proposal. We view the Banting Postdoctoral Fellowship program as a partner with McGill in developing Dr. Scott's potential as a world class researcher and leader in the community.

Sincerely,

Professor Heather Munroe-Blum

Supervision of the Proposal

A supervisor with versatile background and skills is needed to bring Dr. Scott's ambitious research proposal to fruition. My combination of expertise in theoretical cosmology and particle physics is the strongest reason Dr. Scott chose to come to McGill instead of four other competing institutions (including the offer of a named fellowship at the Harvard Center for Astrophysics). Dr. Scott's work is very much at the interface of these two fields. Although there are many potential supervisors who could lead on the astrophysics/cosmology front, the guidance of an eminent particle phenomenologist is also essential for the seminal aspect of his proposal: comparing predictions of broad classes of particle physics models for the identity of dark matter (DM).

My current research interests strongly overlap those of Dr. Scott, and I can provide essential guidance to him in the course of his research program. We have been intensively discussing the intricacies of DM model building during the planning stages of our collaboration, which we are now beginning in earnest. Much of the proposal relates to DM candidates from the Minimal Supersymmetric Standard Model (MSSM), which was the framework where I made formative contributions to the theory of electroweak baryogenesis [1]-[7] (656 citations). This work was carried out partly at CERN and tested to a great extent by the CERN LEP and Tevatron experiments, through their searches for the Higgs boson, light neutralinos, and top squarks. It kept my finger on the pulse of these experimental developments, which continue to unfold at CERN's Large Hadron Collider (LHC), and will undoubtedly play a key role in the global fits program that Dr. Scott is proposing. Part of his present proposal is to explore models that can accommodate both electroweak baryogenesis and DM, so my expertise will be indispensable in this aspect. Moreover, I have long-standing connections to the CERN theory group, which I am currently visiting, and where I have a been a Scientific Associate in 2002-2003 and 2010; these will facilitate Dr. Scott's accessibility to latest results from the LHC as they come (for example via the Collider Crosstalk forum), well in advance of the official publications. Further leadership on the particle theory side was demonstrated by my election to the council of the Institute for Particle Physics (Canada) for a three year term in 2006.

Since 2009, inspired by exciting experimental indications of indirect DM detection in our Galaxy, my research has focused primarily on the study of hidden sector DM models for explaining cosmic ray anomalies and hints of direct DM detection [8]-[16]. DM in this class of models has quite different properties from the MSSM DM candidates previously studied by Dr. Scott, and my experience here will be vital for extending the global fits programs to include these kinds of models, especially ones in which the DM has isospin-violating interactions with nuclei [15, 16]. I am also an expert on the possible effects of substructure in the DM halo [11, 14], which can be useful for understanding the constraining power of *Fermi*-LAT gamma-ray observations on these models, as well as relevant issues concerning the behaviour of the DM halo in the Galactic centre [10, 12]. A new collaboration with P. Martin of MPE, Munich will allow us to access 511 keV observations of the INTEGRAL/SPI experiment directly, and thus use this more effectively as one of the constraints we can impose on DM models in Dr. Scott's global analysis program.

My proficiency in theoretical cosmology has always been directed toward phenomenological issues, of relevance to Dr. Scott's proposal, such as understanding possible features in the cosmic microwave background (CMB) [17]-[20], and comparison of predictions of theoretical models of inflation to current data [21, 22]. The CMB provides crucial constraints on DM models, especially light DM, which can change the reionization history of the early Universe through its annihilation. These constraints figure prominently in Dr. Scott's proposal. I have been a principal organizer of cosmology conferences of international stature at the Aspen Center for Physics (2002) and the Banff International Research Station (2004). I was Principal Investigator for the FQRNT team grant on the Dark Energy of the Universe ($206k, 2005-2007). I was an invited speaker at the international conferences COSMO '08 (Madison) and The Dark Universe (Heidelberg, 2011). My accomplishments in these areas were recognized by the early award of full professor status in 2006, and a visiting scientist position with the cosmology and particle theory groups at Perimeter Institute during the latter half of 2010.

Departmental Synergy

Our department provides a remarkable synergy of research efforts that meaningfully overlap with Dr. Scott's research proposal. Within our group, we have the benefit of Robert Brandenberger's internationally recognized leadership in fundamental aspects of theoretical cosmology. In theoretical astrophysics, Gil Holder (with whom Dr. Scott and I have both collaborated) is extremely active in CMB physics, whose relevance to Dr. Scott's interests I already emphasized. Likewise in experimental astrophysics, Matt Dobbs is a leading figure on new experiments (the South Pole Telescope and POLARBEAR) to measure CMB polarization. In experimental high-energy astrophysics, David Hanna's and Ken Ragan's work on the VERITAS experiment provides another constraint on the properties of DM by its possible annihilation in nearby astrophysical objects, such as dwarf galaxies. Of course the postdocs and students working in these groups greatly multiply the opportunities for fruitful interactions.

Professional, Research and Career Support

Dr. Scott is already performing at an extremely high level for a postdoc at such an early stage of his career, and the extra research skills and connections that he can acquire with my assistance will help to assure his evolution toward a position of leadership at the highest levels. He is developing his grant-writing skills by giving me feedback on my own proposal for a renewal. He will more easily establish relationships at CERN and Perimeter Institute via my already existing links to those institutions. I can help him to obtain access to significant computational resources with CLUMEQ, a local research consortium for high performance computing. I will be able to mentor him during the process of interviewing for permanent positions, which could very well begin before the end of his tenure at McGill. I can also help him to hone his teaching skills, which will give him an edge in the keen competition for tenure-track jobs.

A very direct advantage that I am able to offer to Dr. Scott stems from my having a relatively large number of graduate students (six), some of whom are already well-versed in DM physics, others of whom are new to the field and eager to start learning and contributing. Ph.D. student A. Vincent has already been collaborating with him on a project about DM effects in the Sun, and M.Sc. student Grace Dupuis is starting work with Dr. Scott on DM annihilation in the Galactic centre. I will try to recruit one or two new students in the next year to compound these efforts. In addition to providing this manpower toward the realization of his ideas, we offer generous funding toward research expenses of $10k per year, including the expenses of visits by external collaborators. In short, we are quite fortunate to have Dr. Scott in our department, and I will continue to do all that is possible to further his development and research goals.

James M Cline

James M. Cline
Professor of Physics

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McGill University

McGill University is an internationally recognized, world-class research institute. It is currently ranked the top university in Canada and is among the top twenty universities in the world (according to the QS World University Rankings). The undergraduate population is exceptional, as manifested for example by the fact that several former McGill undergraduates were recently awarded Nobel Prizes. There are extensive funding resources for graduate students and postdoctoral fellows, fostering an active and stimulating research and academic environment for Dr. Scott.

The Department of Physics

McGill's Department of Physics is a well-established and world-renowned department within McGill. It is one of the oldest physics departments in Canada, and has a record of forefront research going back to Rutherford. It has produced numerous Nobel Laureates, and shown consistent commitment to research excellence.

In the past decade the McGill Physics Department has undergone an extensive faculty renewal. Currently, more than 60% of the Physics faculty are people who were hired since the year 2000. Without exception, these faculty members are very active in research. The research funding level per faculty is the highest of any Canadian Physics department. This has enabled the Physics Department to recruit a large number of graduate students and postdocs. There are close to 150 graduate students, and thus McGill has the highest ratio of graduate students to faculty among Canadian Physics departments. The number of physics majors is exceptionally high (more than 60 per year) and of excellent quality (as measured e.g. by the fraction who continue to graduate school and by how well they then perform in graduate school). All these factors provide Dr. Scott with an extremely stimulating research environment.

Personnel

In the year 2000, McGill decided to invest in a new astrophysics group and has provided all of the resources required for this group to grow and form a true centre of excellence. It currently consists of eight faculty members (six of whom were hired in the period between 2000 and 2006), eight postdocs and more than 20 graduate students. At least four of the faculty have close research overlap with Dr. Scott: two of the faculty (Hanna and Ragan) are playing a key role in the high energy gamma ray telescope VERITAS collaboration, Professor Dobbs is one of the leaders in several cosmic microwave (CMB) temperature and polarization experiments, and Professor Holder is an expert on theoretical aspects of CMB and cosmic reionization research.

In the years following 2000, McGill also hired three new faculty in experimental particle physics (currently playing an important role in the ATLAS collaboration at the Large Hadron Collider). In the same period, the High Energy Theory group underwent a renewal with the hiring of Profs. Brandenberger, Moore, Dasgupta, Maloney and Walcher. Three of these High Energy Theory faculty have close research overlaps with Dr. Scott. Foremost is Prof. Cline, who is currently working on dark matter models as his main research priority. Prof. Brandenberger is a world-renowned expert on both early Universe and late time cosmology, both of which constitute essential inputs to Dr. Scott's proposed program of global fits. Prof. Moore is an expert on quantum field theory at finite temperature and density, which is also highly relevant for physics of the early Universe.

One of the most special things about the current research environment in the McGill Physics Department is the close connection between all research groups with interests relevant to Dr. Scott's proposal. The High Energy Theory group interacts very closely with the Astrophysics Group, in particular concerning topics related to cosmology. Profs. Cline and Brandenberger are both directly collaborating with members of the Astrophysics Group. Members of the High Energy Theory group also maintain an active research collaboration with the Nuclear Theory group, led by Profs. Gale and Jeon. This particular resource will be especially valuable to Dr. Scott, because nuclear form factors are presently one of the largest uncertainties in the search for neutrinos from dark matter annihilation in the Sun, and in direct detection experiments. Thus, McGill provides Dr. Scott with a unique research environment, where all groups working on issues relevant to his research continuously collaborate and exchange ideas.

At McGill, Dr. Scott finds an ideal environment for the research program he plans to carry out. His research must draw on the expertise of people in quite varied areas: dark matter theory (Prof. Cline), indirect detection (Profs. Hanna and Ragan), cosmological aspects (Profs. Brandenberger and Holder from the theory side and Prof. Dobbs from the experimental side), collider constraints (Profs. Vachon, Warburton, Corriveau and Robertson from the ATLAS group), and quantum field theory (Professors Cline, Moore, Jeon and Gale). Experts on direct dark matter detection are located across Mt. Royal at the Université de Montréal (the PICASSO experiment). This unique combination of in house expertise and research strengths is extremely valuable for Dr. Scott (who turned down a postdoctoral fellowship at Harvard to come to McGill, specifically because he felt McGill offered a superior environment for his research program).

Likewise, McGill also has a special interest in having Dr. Scott here in Montreal. Dr. Scott is **THE** person who can provide the link between all of the research groups mentioned above. In particular, he is forging new links (e.g. a new seminar series) between particle physics, astrophysics and high energy theory.

At McGill Dr. Scott has the chance to work with many excellent graduate students, both from the High Energy Theory and the Astrophysics groups. He has already identified a core group of 4 students that would be heavily involved in the work he proposes here.

Facilities and Funding

Dr. Scott will have full access to a computer cluster recently purchased by the High Energy Theory group with applications to astrophysical and cosmological simulations in mind. The Astrophysics Group has a larger cluster used extensively for data analysis, which Dr. Scott will also have full access to. The Department provides two computer technicians who look after these computer clusters. Thus, there are excellent computational resources within the Department for Dr. Scott's research. McGill is a member of the CLUMEQ High Performance Computing network (linking several Quebec institutions), and the new director of CLUMEQ is a member of the Physics Department. Dr. Scott will also have access to all of CLUMEQ's facilities.

Dr. Scott will be provided with a $10k annual research budget, which can be used for travel, computing hardware or inviting collaborators. The Department has 5 full-time administrative staff, all of whom will be available to assist Dr. Scott in administering his Fellowship, whether regarding paperwork, travel, workshop/conference organization or hosting guests.

Professional Development: Dr Pat Scott, Banting Postdoctoral Fellowship 2011

In addition to being provided the best research experience, our postdoctoral fellows will be trained in the professional skills that will aid them in succeeding in their future endeavours and reaching their full potential. McGill's commitment to the overall professional development of our postdoctoral fellows is enshrined in the document Commitments of Postdoctoral Scholars and Supervisors and the accompanying Letter of Agreement for Postdoctoral Education that outlines the training objectives of the postdoc, an individualized training program to achieve those goals, and the responsibilities that define the working relationship between the supervisor and the postdoc to achieve those objectives. McGill's commitment to presenting a variety of opportunities to attain the full complement of professional skills provides an excellent environment to fulfil the aim of the Banting Postdoctoral Fellowships "to attract top-tier postdoctoral researchers...who will positively contribute to the country's economic, social and research-based growth".

McGill Graduate and Postdoctoral Studies, under the direction of the Graduate Education Officer, has formed partnerships with Teaching and Learning Services, Libraries, the Career Planning Office, and other units across the University to offer a comprehensive suite of workshops under the umbrella of *SKILLSETS: Professional Development Workshops for Graduate Students and Postdoctoral Fellows*. These workshops provide opportunities to attain general transitional/professional skill development under the nine basic themes of communication & interpersonal skills, research management & leadership, integrity & ethical conduct (responsible conduct of research), dissemination of research & knowledge translation, critical & creative thinking, career development, teaching competence, life skills, and societal & civic responsibilities. Postdoctoral fellows also are invited to take part in workshops organized for McGill professors to improve their teaching, supervisory and mentoring skills.

Other opportunities are available through McGill's Office of Technology Transfer, for guidance on technology transfer and intellectual property, and the Career Planning Service (CaPS), for help in maximizing employment opportunities, including coaching in interview skills and preparing curriculum vitae. Postdocs at McGill belong to the Postgraduate Students' Society and the affiliated Association of Postdoctoral Fellows, providing opportunities for networking and knowledge exchange with their colleagues across the university.

The research program proposed here will provide many opportunities for Dr. Scott to further develop his professional and academic skills. The research will be disseminated through articles in the leading high energy and astrophysics journals, and via presentations at international conferences. Dr. Scott will be the lead author and presenter, providing an excellent avenue for the improvement of his scientific writing and speaking. The wide variety of collaborators required for the success of the global fits program, both at McGill and beyond, will also extend his collaborative experience and communication abilities. He will obtain experience authoring and managing large public computer codes, by way of the SUFit, DMBayes and SuperBayeS packages outlined in the proposal. Grant-writing experience will be provided by participation in Prof. Cline's various grant applications, and in applying for startup funding for Dr. Scott's own group as the Banting Fellowship draws to a close.

Dr. Scott will gain invaluable teaching experience as course coordinator for the course *Practical Numerical Methods in Physics*, and a wealth of direct supervisory experience with 2 students of Prof. Cline's, and one each of Prof. Brandenberger and Prof. Holder. Dr. Scott will also gain experience in conference organization, as it is expected that he will be primarily responsible for arranging at least one workshop/meeting at McGill on the topic of the fellowship during its tenure (with the support of the Department and/or High Energy Theory and Astrophysics groups).

Summary: 22 refereed publications since 2006, 736 citations, h-index: 11
(Source: NASA Astrophysical Data System, Oct 14; see www.physics.mcgill.ca/~patscott/publications)

Phys. Rev. Lett.: Physical Review Letters
Phys. Rev. D: Physical Review D (Particles, Fields, Gravitation and Cosmology)
JCAP: Journal of Cosmology and Astroparticle Physics
JHEP: Journal of High Energy Physics
ARA&A: Annual Review of Astronomy and Astrophysics
ApJ: The Astrophysical Journal (including Letters)
A&A: Astronomy and Astrophysics
MNRAS: Monthly Notices of the Royal Astronomical Society
PoS: Proceedings of Science
Ap&SS: Astrophysics and Space Science
Can. J. Phys.: Canadian Journal of Physics

Part 1: List of Contributions

Articles published or accepted in refereed journals

[1] **P. Scott**, A. Venkatesan, E. Roebber, P. Gondolo, E. Pierpaoli, and G. Holder, *Impacts of Dark Stars on Reionization and Signatures in the Cosmic Microwave Background*, *ApJ* (2011) in press (accepted Aug 22), [arXiv:1107.1714].

[2] J. Ripken, J. Conrad, and **P. Scott**, *Implications for constrained supersymmetry of combined H.E.S.S. observations of dwarf galaxies, the Galactic halo and the Galactic centre*, *JCAP* (2011) in press (accepted Oct 17), [arXiv:1012.3939].

[3] Y. Akrami, C. Savage, **P. Scott**, J. Conrad, and J. Edsjö, *Statistical coverage for supersymmetric parameter estimation: a case study with direct detection of dark matter*, *JCAP* **7** (2011) 2, [arXiv:1011.4297].

[4] Y. Akrami, C. Savage, **P. Scott**, J. Conrad, and J. Edsjö, *How well will ton-scale dark matter direct detection experiments constrain minimal supersymmetry?*, *JCAP* **4** (2011) 12, [arXiv:1011.4318].

[5] E. Zackrisson, **P. Scott**, C.-E. Rydberg, F. Iocco, S. Sivertsson, G. Östlin, G. Mellema, I. T. Iliev, and P. R. Shapiro, *Observational constraints on supermassive dark stars*, *MNRAS* **407** (2010) L74–L78, [arXiv:1006.0481].

[6] E. Zackrisson, **P. Scott**, C.-E. Rydberg, F. Iocco, B. Edvardsson, G. Östlin, S. Sivertsson, A. Zitrin, T. Broadhurst, and P. Gondolo, *Finding High-redshift Dark Stars with the James Webb Space Telescope*, *ApJ* **717** (2010) 257–267, [arXiv:1002.3368].

[7] Y. Akrami, **P. Scott**, J. Edsjö, J. Conrad, and L. Bergström, *A profile likelihood analysis of the Constrained MSSM with genetic algorithms*, *JHEP* **4** (2010) 57, [arXiv:0910.3950].

[8] **P. Scott**, J. Conrad, J. Edsjö, L. Bergström, C. Farnier, and Y. Akrami, *Direct constraints on minimal supersymmetry from Fermi-LAT observations of the dwarf galaxy Segue 1*, *JCAP* **1** (2010) 31, [arXiv:0909.3300].

[9] M. Asplund, N. Grevesse, A. J. Sauval, and **P. Scott**, *The chemical composition of the Sun*, *ARA&A* **47** (2009) 481–522, [arXiv:0909.0948].

[10] **P. Scott** and S. Sivertsson, *Gamma rays from ultracompact primordial dark matter minihalos*, *Phys. Rev. Lett.* **103** (2009) 211301, [arXiv:0908.4082].

[11] **P. Scott**, M. Asplund, N. Grevesse, and A. J. Sauval, *On the Solar Nickel and Oxygen Abundances*, *ApJ* **691** (2009) L119–L122, [arXiv:0811.0815].

[12] **P. Scott**, M. Fairbairn, and J. Edsjö, *Dark stars at the Galactic Centre - the main sequence*, *MNRAS* **394** (2009) 82–104, [arXiv:0809.1871].

[13] M. Fairbairn, **P. Scott**, and J. Edsjö, *The zero age main sequence of WIMP burners*, *Phys. Rev. D* **77** (2008) 047301, [arXiv:0710.3396].

[14] **P. Scott**, M. Asplund, N. Grevesse, and A. J. Sauval, *Line formation in solar granulation. VII. CO lines and the solar C and O isotopic abundances*, *A&A* **456** (2006) 675–688, [arXiv:astro-ph/0605116].

Articles submitted to refereed journals

[15] T. Bringmann, **P. Scott**, and Y. Akrami, *Improved constraints on the primordial power spectrum at small scales from ultracompact minihalos*, *Phys. Rev. D* (2011), 21 pages, submitted Oct 28, [arXiv:1110.2484].

Other refereed contributions (proceedings)

[16] **P. Scott**, *Dark stars: structure, evolution and impacts upon the high-redshift Universe*, in *Cosmic Radiation Fields: Sources in the early Universe* (M. Raue, T. Kneiske, D. Horns, D. Elsaesser, & P. Hauschildt, ed.) (2011) *PoS*(**CRF 2010**)021, [arXiv:1101.1029].

[17] C. E. Rydberg, E. Zackrisson, and **P. Scott**, *Can the James Webb Space Telescope detect isolated population III stars?*, in *Cosmic Radiation Fields: Sources in the early Universe* (M. Raue, T. Kneiske, D. Horns, D. Elsaesser, & P. Hauschildt, ed.) (2011) *PoS*(**CRF 2010**)026, [arXiv:1103.1377].

[18] N. Grevesse, M. Asplund, A. J. Sauval, and **P. Scott**, *The New Solar Composition and the Solar Metallicity*, in *The Sun, the Solar Wind, and the Heliosphere* (M. P. Miralles and J. Sánchez Almeida, eds.), *IAGA Special Sopron Book Series* **4** (2011) 51–60.

[19] N. Grevesse, M. Asplund, A. Sauval, and **P. Scott**, *The chemical composition of the sun*, in *10th International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas*, *Can. J. Phys.* **89** (2011) 327–331.

[20] N. Grevesse, M. Asplund, A. J. Sauval, and **P. Scott**, *The chemical composition of the Sun*, in *Synergies between solar and stellar modelling*, *Ap&SS* **328** (2010) 179–183.

[21] **P. Scott**, J. Edsjö, and M. Fairbairn, *The DarkStars code: a publicly available dark stellar evolution package*, in *Dark Matter in Astroparticle and Particle Physics: Dark 2009* (H. V. Klapdor-Kleingrothaus & I. V. Krivosheina, ed.), World Scientific, Singapore (2010) 320–327, [arXiv:0904.2395].

[22] **P. Scott**, M. Fairbairn, and J. Edsjö, *Impacts of WIMP dark matter upon stellar evolution: main-sequence stars*, in *Identification of dark matter 2008* (2008) *PoS*(**idm2008**)073, [arXiv:0810.5560].

[23] **P. Scott**, J. Edsjö, and M. Fairbairn, *Low mass stellar evolution with WIMP capture and annihilation*, in *Dark Matter in Astroparticle and Particle Physics: Dark 2007* (H. K. Klapdor-Kleingrothaus and G. F. Lewis, eds.), World Scientific, Singapore (2008) 387–392, [arXiv:0711.0991].

Published Monographs

[24] **P. Scott**, *Searches for Particle Dark Matter: Dark stars, dark galaxies, dark halos and global supersymmetric fits.* Universitetsservice US-AB, Stockholm, ISBN 978-91-7447-031-4, 2010. PhD Thesis in Theoretical Physics, Stockholms Universitet, [arXiv:1110.2757]

Invited Presentations

[25] *Theoretical Astrophysics Seminar Series*, Fermilab, Batavia, USA, Sept., 2011, institutional.

[26] *Topics in Astroparticle and Underground Physics (TAUP) 2011*, Munich, Germany, Sept., 2011, international.

[27] *TeV Particle Astrophysics VII*, Stockholm, Sweden, Aug., 2011, international.

[28] *Weinberg Theory Group Seminar Series*, University of Texas, Austin, USA, Apr., 2011, institutional.

[29] *Cosmic Radiation Fields 2010: Sources in the Early Universe*, DESY Hamburg, Germany, Nov., 2010, international (plenary).

[30] *Nordic Astrophysics 2010*, Visby, Sweden, May, 2010, international.

[31] *Astroparticle Seminar Series*, Univeristy of Hamburg, Germany, May, 2010, institutional.

[32] *Astronomy & Theoretical Physics Colloquium*, Lund, Sweden, Mar., 2010, institutional.

[33] *Astronomy Colloquium*, Imperial College London, UK, Jan., 2010, institutional.

[34] *Searching for Dark Matter – A Multi-Disciplinary Approach*, University of Leicester, UK, Jan., 2010, international (plenary).

[35] *Mini Symposium on Dark Matter*, University of Hamburg, Germany, Dec., 2009, institutional.

[36] *Dark Stars Workshop*, Michigan Centre for Theoretical Physics, Ann Arbor, USA, Nov., 2009, international.

[37] *Extreme Astrophysics for All II*, Lund, Sweden, Feb., 2009, national.

[38] *SEAS Colloquium*, Max Planck Institute for Astrophysics, Garching, Germany, Dec., 2008, institutional.

[39] *Bok Prize Lecture, Astronomical Society of Australia Annual Scientific Meeting*, University of Sydney, Australia, July, 2005, national (plenary).

+41 contributed presentations not shown (see www.physics.mcgill.ca/~patscott/talks)

Part 2: Research Contributions

[8] **Scott**, Conrad, Edsjö, Bergström, Farnier & Akrami, *Direct constraints on minimal supersymmetry from Fermi-LAT observations of the dwarf galaxy Segue 1*, *JCAP* **1** (2010) 31.

37 citations

In this paper, we investigated the implications for supersymmetry of searches for gamma-rays from dark matter (DM) annihilation in the ultra-faint dwarf galaxy Segue 1, using the *Fermi* Large Area Telescope (LAT). This paper was the first to include results from either direct or indirect searches for dark matter in a global SUSY fit. It was also the first published dark matter result from the *Fermi*-LAT collaboration itself.

The work generated substantial interest from both the DM indirect detection and SUSY global-fit communities. Whilst the constraints on the parameter space were not especially strong, the paper demonstrated how DM searches could be used in SUSY global fits, without compromising on any of the technical aspects of the astronomical gamma-ray analysis. The community recongized (as evidenced in e.g. the referee's comments) that such analyses are indeed the way of the future for DM indirect detection. The paper continues to be well read and referenced, generating 37 citations to date in the ∼2 years since it was posted to the arXiv.

[9] Asplund, Grevesse, Sauval & **Scott** (AGSS09), *The chemical composition of the Sun*, *ARA&A* **47** (2009) 481–522.

452 citations

This article updated and compiled the present state of knowledge on the abundances of the chemical elements in the Sun, from Hydrogen up to and including Uranium ($Z = 92$). The composition of the Sun is a fundamental reference quantity in astrophysics, against which all other astronomical objects are measured. The article has found wide-ranging use in all parts of astronomy and astrophysics, from Galactic chemical evolution, planet searches and solar system physics to cosmology, extragalactic astrophysics and astroparticle physics. In just two years, AGSS09 (as it is known in the community) has generated over 450 citations, becoming one of the most highly cited articles of 2009.

This paper, published as an invited review article in the prestigious journal *Annual Reviews of Astronomy & Astrophysics*, in fact consisted almost entirely of original work. For no other article in my career where I was not first author have I ever done nearly as much work as for AGSS09. We reanalyzed the abundances of every element with identifiable lines in the solar spectrum. I was personally responsible for atomic data, line selection and abundance calculation for all elements from Na ($Z = 11$) to Zn ($Z = 30$). This was the first time anyone had published a homogeneous and complete analysis of elemental abundances in the Sun, using the same model atmosphere, spectra, line- and data-selection policies and treatment of errors for every element. We employed a new 3D hydrodynamic model of the solar atmosphere (the first time many elements had had their solar spectra analyzed in 3D), extremely discerning selections of atomic data and line lists, and in many cases, corrections for departures from local thermodynamic equilibrium in the atomic level populations. In a sense, the article was a 'pre-review' of a series of 7 papers we are currently finalizing for publication in *Astronomy & Astrophysics*, where all of the details of the results quoted in AGSS09 will be presented.

[12] **Scott**, Fairbairn & Edsjö, *Dark stars at the Galactic Centre - the main sequence*, *MNRAS* **394** (2009) 82–104.

33 citations

'Dark stars', stars whose structure and evolution are dictated more by dark matter annihilation in their cores than nuclear burning, have been a hot topic of research in recent years. This paper dealt with prospects for finding dark stars close to the Galactic centre. The paper was significant because it gave the full technical details and results of the most interesting investigations we discussed in earlier papers [13, 23]. This work was the first treatment of the effects of dark matter on the evolution of main-sequence stars (of any metallicity), using a full stellar evolution simulation. It was one of the initial 5-6 papers that really launched the recent run of ∼50 publications on dark stars. It also lead directly to the public 'dark stellar evolution' code DarkStars [21]. Aside from being interesting for the results it presented (showing that low-mass stars on elliptical orbits near the Galactic centre might be expected to exist as dark stars), the paper remains the most comprehensive and detailed exposition of the physics involved in simulating the structure and evolution of dark stars. It has thus become something of a standard reference work in the field, and has generated 33 citations to date.

Part 1: Leadership Activities

Participation on Committees

- Co-founder, McGill Astroparticle Seminar Series (to begin Jan 2012)
- Discussion session leader, *Dark Matter*, Northeast Cosmology Workshop 2011, Montreal
- Chair, Organizing Committee for Workshop *Dark Matter From Every Direction*, McGill University, April 1–3 2011, 27 attendees
- Associate member of the IceCube Collaboration (since April 2011)
- Co-chair, Organizing Committee for *PROSPECTS* Conference, Stockholm University, September 15–17 2010, 42 attendees
- Session chair, *Neutrinos*, Dark2009, NZ
- Affiliated member of the *Fermi* Large Area Telescope (LAT) collaboration (since 2008)
- Member of Stockholm U. Physics Departmental Computing Committee (2009-2010)

Participation as External Reviewer

- Referee for *JHEP* (3 articles), *JCAP* (2), *ApJ Lett.* (1), *Stat. Analysis & Data Mining* (1)

Participation in Training Activities

- Assistant Supervision (unofficial) of PhD students Yashar Akrami (Stockholm, 2010), Aaron Vincent, Wei Xue (both McGill, 2012), Natasha Karpenka (Stockholm, 2014), Elinore Roebber (McGill, 2015) and Master's student Hamish Silverwood (Canterbury, 2012).
- Lecturer, Tutor and Course Responsible, *PHYS606: Practical Numerical Methods in Physics*, Winter 2011, McGill University; 13 students, mixed graduate/undergraduate.
- Guest Lecture, *Stellar Evolution*, Spring 2011, San Francisco University (Lec: Aparna Venkatesan); $\sim$ 20 students, undergraduate.
- Tutor, *FK7025: Advanced Relativistic Quantum Field Theory*, Fall 2008, Stockholm University; 6 students, Master's level.
- Residential Tutor in Physics and Mathematics, Burgmann College, Australian National University, 2003; $\sim$ 20 students, undergraduate.

Participation in Scientific Outreach and Knowledge Mobilization

- Sole Author of DarkStars: a public computer package for calculating effects of dark matter on the evolution of stars
- Sole Author of FLATLib: a public package for fast convolution with *Fermi*-LAT instrumental response functions
- Development Author of SuperBayeS: a public package for performing SUSY global fits
- Authored *Med mörk materia som drivmedel* (English: Fuelled by dark matter) for Swedish magazine *Populär Astronomi* **3** (2008) 11
- Interview with *New Scientist* for the article "Dark matter makes galaxys stars live long and prosper" (2008)

Part 2: Details

PROSPECTS (PROblems in Statistical Parameter Estimation and ConsTraints for Supersymmetry) Conference 2010 – this conference brought together experts from every major group involved in SUSY global fits for the first time, to discuss methods, results and future plans. I co-headed the organization together with Are Raklev. A number of new papers and collaborations arose from the conference, and feedback from participants was overwhelmingly positive. I was personally able to meet and discuss my work and scientific opinions with all the leaders of the field, and firmly establish myself amongst them.

PHYS606: Practical Numerical Methods in Physics – I suggested, designed, lectured, graded and organized this course from scratch in the Winter Semester of 2011. The course gave graduate and advanced undergraduate students a solid practical background in the numerical methods required for doing everyday research in many areas of physics. It focused on understanding how to implement and effectively use the methods; assignments involved developing a personal library of numerical routines that students could use in their future research, as well as a seminar on an advanced topic. Part of my motivation for teaching the course was to find students interested in working on related projects with me, and endow them with the necessary skills for such collaborations. I have just begun supervising two of the students in exactly these projects (Wei Xue and Elinore Roebber), with one (Elinore) already having contributed some calculations to a paper that we recently had accepted at ApJ [1]. Teaching evaluations were stellar, and demand is strong for the course to run again.

McGill Astroparticle Seminar Series – this biweekly series of seminars by invited experts aims to foster an increased level of discussion and sense of shared community between the astro, hep-th and hep-ex groups at McGill, in line with the strategic aims of this fellowship proposal. This series has basic funding approval and will begin in January 2012; some small amount of the Banting funds will go toward funding additional speakers.

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CV BANTING

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Family Name	Given Name	Middle Initial(s)
Scott	Patrick	

Title

Dr. [X] Mr. [ ] Mrs. [ ] Ms. [ ] Prof. [ ]

Primary Affiliation Name	Mailing Address (If different from Primary Affiliation address)	Courier Address	Temporary Address
McGill University Start Date 10/2010 Primary Affiliation Address Department of Physics McGill University 3600 Rue University Montreal, Québec CANADA (H3A 2T8)		Department of Physics McGill University 3600 Rue University Montreal, Québec CANADA (H3A 2T8)	4444 Rue Drolet Montreal, Québec CANADA (H2W 2L8) Start Date 24/10/2011 End Date 09/01/2012

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Secondary: McGill Office Phone 1 (514) 398 5489		Web page address http://www.physics.mcgill.ca/~patscott
Temporary	Temporary	
Start Date / End Date	Start Date / End Date	

Citizenship	Permanent Residence in Canada
Canadian [ ] Other [X]	Permanent resident [ ]
Other Country of Citizenship: AUSTRALIA	Date of permanent residency status: (DD/MM/YYYY)

Correspondence Language

English [X] French [ ]

Gender

Male [X] Female [ ]

Date of Birth (DD/MM/YYYY)

21/06/1982

Language

	Read	Write	Speak	Understand
English (Yes or No)	Yes	Yes	Yes	Yes
French (Yes or No)	No	No	No	No

Other Languages: Swedish

AREA(S) OF EXPERTISE

Keywords

- astroparticle physics
- astrophysics
- cosmology
- particle physics
- theoretical physics
- dark matter
- supersymmetry
- statistical methods
- computational methods
- stellar and solar physics

Primary Discipline	Secondary Discipline
PHYSICS Particle Physics	ASTRONOMY AND ASTROPHYSICS Extra-galactic and Cosmology

ACADEMIC BACKGROUND

Indicate all university degrees obtained and those in progress (where applicable) starting with the most recent. If you hold a co-degree from more than one institution (e.g. under the Soutien aux cotutelles de thèse de doctorat agreement between Quebec and France) enter each institution separately. Do not enter honorary degrees here; they should be listed in the Distinctions section.

Also indicate research training, such as postdoctoral or fellowship training. Trainees only: also list undergraduate and graduate research training experience.

Degree Type	Degree Name Speciality	Institution/Department/ Institution Country	Degree Start Date (MM/YYYY)	Date Received or Expected (MM/YYYY)
Doctorate (PhD)	Doctor of Philosophy	Stockholms Universitet SWEDEN	10/2006	06/2010
Doctorate Equivalent (PhD)	Licentiate of Philosophy (intermediate between PhD and Master's)	Stockholms Universitet SWEDEN	10/2006	10/2008
Bachelor's, Honours	Bachelor of Science with Honours in Neuroscience	Australian National University AUSTRALIA	02/2001	11/2005
Bachelor's, Honours	Bachelor of Science with Honours in Astrophysics	Australian National University AUSTRALIA	02/2001	11/2004

WORK EXPERIENCE

Starting with the most recent, indicate your current position, where applicable, and other non-academic position(s) since the beginning of your university studies. For your current positions leave the end date blank. Additional pages will be accepted.

Position	Organization	Department/Division	Period (MM/YYYY to MM/YYYY)
Postdoctoral Research Fellow	McGill University	Physics Faculty of Science	10/2010 to
Doctoral Candidate and Teaching Assistant	Stockholms Universitet	Inst. of Theoretical Physics Oskar Klein Cent. f. Cosmoparticle Phys.	10/2006 to 09/2010
Consulting Software Engineer	Sound Safety Inc.		11/2001 to 02/2002
Casual Research Assistant	Australian Hearing		02/1999 to 09/2000
Casual Research Assistant	Northern Territory University	Institute of Advanced Studies Menzies School of Health Research	02/1996 to 02/1999

PATENTS AND COPYRIGHTS

OBTAINED			IN PROGRESS			TOTAL
Total Individual	Total Collective	Sub-Total	Total Individual	Total Collective	Sub-Total	
0	0	0	0	0	0	0

PUBLICATIONS AND PRESENTATIONS

Publications	Refereed Articles	Books and Monograms	Contributions to a Collective Work/ Book Chapters/ Proceeding	Abstracts/Notes	TOTAL
Already published	12	1	8	0	21
Accepted or in press	2	0	0	0	2
Presentations as guest speaker					15

DISTINCTIONS / AWARDS / CREDENTIALS

Starting with the most recent, indicate any recognition received, including awards, fellowships, scholarships, licenses, qualifications, professional designation or credentials. Do not include Academic Appointments here, as they are detailed under Work Experience. Maximum 20 entries.

Name/Title and Type	Organization Country	Effective Date to End Date (MM/YYYY)	Specialty	Total Amount
IPP Theory Fellowship Research award	Institute for Particle Physics CANADA	10/2010 to 09/2012	Theoretical Particle Physics	$60,000
Trottier Fellowship Research award	Trottier Family Foundation / McGill University CANADA	10/2010 to 09/2012	Astrophysics	$70,000
CfA Prize Fellowship (declined) Research award	Harvard-Smithsonian Centre for Astrophysics, Harvard University UNITED STATES	10/2010 to 09/2013		$228,000
The Sigrid Arrhenius Prize Distinction	Stockholm University SWEDEN	05/2010 to	Best Thesis in Natural Sciences during 2010	$10,000
G & E Kobbs Award Research award	G & E Kobbs Foundation / Stockholms Universitet SWEDEN	2009 to	Research Travel Award	$9,000
Helge Axelsson Johnsons Scholarship Research award	Helge Axelsson Johnsons Foundation SWEDEN	2009 to	Research Travel Scholarship	$2,400

DISTINCTIONS / AWARDS / CREDENTIALS

Name/Title and Type	Organization Country	Effective Date to End Date (MM/YYYY)	Specialty	Total Amount
CF Liljevalchs Scholarship Research award	Liljevalchs Foundation / Stockholms Universitet SWEDEN	2009 to	Research Travel Scholarship	$1,300
G & E Kobbs Award Research award	G & E Kobbs Foundation / Stockholms Universitet SWEDEN	2008 to	Research Travel Award	$2,500
Helge Axelsson Johnsons Scholarship Research award	Helge Axelsson Johnsons Foundation SWEDEN	2008 to	Research Travel Scholarship	$2,500
HEAC Doctoral Fellowship Research award	High Energy Astrophysics and Cosmology Centre (Stockholm University and Royal Technical Inst.; KTH) SWEDEN	10/2006 to 09/2010		$144,000
The University Medal Distinction	The Australian National University AUSTRALIA	06/2006 to	Neuroscience	
The Sir Grafton Elliot Smith Prize Distinction	The Australian Neuroscience Society AUSTRALIA	01/2006 to	Best Neuroscience Paper by a PhD/Honours Student	$1,000
The Bok Prize Distinction	The Astronomical Society of Australia AUSTRALIA	07/2005 to	Best Honours Thesis in Astronomy/Astroph ysics 2004	$500
The University Medal Distinction	The Australian National University AUSTRALIA	06/2005 to	Astrophysics	
Highest Overall Academic Achievement Award Distinction	Burgmann College, Australian National University AUSTRALIA	2003 to		$100
Winning Team Credential	Australian National Undergraduate Physics Competition AUSTRALIA	2003 to		
Summer Research Scholarship Research award	The Research School of Astronomy & Astrophysics, Australian National University AUSTRALIA	11/2003 to 01/2004	Cosmology	$5,000
National Undergraduate Scholarship Research award	The Australian National University AUSTRALIA	02/2001 to 11/2005		$50,000
The Distinguished Scholar Program Distinction	Faculty of Science, Australian National University AUSTRALIA	02/2001 to 11/2003		$1,800

DISTINCTIONS / AWARDS / CREDENTIALS

Name/Title and Type	Organization Country	Effective Date to End Date (MM/YYYY)	Specialty	Total Amount
Northern Territory Undergraduate Scholarship Research award	Government of The Northern Territory AUSTRALIA	02/2001 to 11/2004		$16,500

FUNDING AWARDED IN THE PAST 6 YEARS

Name of applicant and your role	Title of proposal, funding source and program name	Total Amount	Period (MM/YYYY to MM/YYYY)
Principal Applicant	Dark Matter From Every Direction (A 3-Day Workshop on Dark Matter at McGill University, April 1-3, 2011), Centre de recherches mathématiques (CRM),	$4,000	03/2011 to 04/2011
Principal Applicant	Dark Matter From Every Direction (A 3-Day Workshop on Dark Matter at McGill University, April 1-3, 2011), McGill University,	$1,000	03/2011 to 04/2011
Principal Applicant	Travel Funding for Collaborative Visit to CERN, European Union (EU) Research Directorate General, European Network f. Theoretical Astroparticle Phys. ILIAS/N6	$2,300	05/2008 to 06/2008
Principal Applicant	Travel Funding for Collaborative Visit to Mount Stromlo Observatory, International Astronomical Union (IAU), IAU Comission 46 - Exchange of Astronomers	$2,200	09/2007 to 12/2007

FUNDING APPLIED FOR (UNDER REVIEW)

Name of applicant and your role	Title of proposal, funding source and program name	Total Amount	Period (MM/YYYY to MM/YYYY)

FUNDING CURRENTLY HELD

Name of applicant and your role	Title of proposal, funding source and program name	Total Amount	Period (MM/YYYY to MM/YYYY)