Dr Patrick Scott

University Research Fellowship - 2013

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Applicant Career Summary

Statement of qualifications and career:

Qualification	Date
NSERC Banting Fellow, McGill University	Oct 2012 -
Trottier Astrophysics Fellow and Institute for Particle Physics (Canada) Theory Fellow, McGill University	Oct 2010 - Sep 2012
Postdoctoral Researcher, Stockholm University	May 2010 - Sep 2010
High Energy Astrophysics and Cosmology Centre (HEAC) Doctoral Fellow, Stockholm University	Oct 2006 - May 2010

Publications:

Personal Statement:

My overarching goal is to perform cutting-edge astroparticle research: to discover and characterise new physics and symmetries of nature, and their impacts upon astronomical observations. I ultimately wish to build and lead a large, strong and dedicated research group centred around the interface of particle physics and astronomy. This group will focus on dark matter and physics beyond the Standard Model of particle physics, with particular emphasis on quantitative, multi-messenger assessments of the leading theories of the day for new physics. To achieve this, I must continue to extend my experience in the extremely broad range of physics relevant to such a group, and gain the necessary professional experience to effectively build and lead it.

Next I must obtain the scientific and professional experience of a junior faculty member; a URF at Imperial offers an unparalleled opportunity to do this. The cosmological, statistical and astroparticle strengths of the Astronomy and Statistics groups, and the direct detection and collider expertise of the High Energy Physics group, provide an ideal environment in which to operate my independent research group. The URF will give me the opportunity to build this group, providing the stability to apply for further external funding to hire postdocs of my own, and take on students. This will allow me to take my leadership in astroparticle physics to the next level, and eventually run such a group in earnest as permanent faculty.

I have just under 3 years postdoctoral experience, 22 published or submitted articles in refereed journals, 10 refereed proceedings and 1214 citations. My work includes some of the most rigorous global fits for new particle theories to date with data from indirect dark matter searches [1,6,12 in publication list]. This work significantly improved constraints on supersymmetric dark matter, and was only possible through dedicated collaborations between myself and the relevant experiments: first with gamma-ray data from Fermi-LAT [12] and HESS [6], then with IceCube neutrino events [1]. I also played a pivotal role in the recent correction of the chemical composition of the Sun [13], which impacts many areas of astronomy and astroparticle physics.

I have been awarded multiple externally-funded research grants and fellowships: The Banting Fellowship from the Canadian Government, the CfA Fellowship from Harvard University (which I declined), two other major grants and 7 smaller competitive travel fellowships. I won The Arrhenius Prize at Stockholm University for the best PhD thesis in Science, the Bok Prize from the Astronomical Society of Australia for the best Honours/Master thesis in astrophysics, and two University Medals for my Honours research at the Australian National University.

I have given 66 talks (19 invited) at international conferences and institutions, chairing 5 sessions. I convened the Particle Astrophysics and Cosmology Track at the 2012 International Conference on High Energy Physics (ICHEP), organised 2 smaller conferences, and founded the McGill Astroparticle Seminar Series. I am an associate member of the IceCube Collaboration and an affiliated scientist of the Fermi Large Area Telescope (LAT). I have refereed for 6 top-tier journals and authored 4 public astroparticle software packages. I created and lectured an official McGill course in numerical methods, served on an external PhD defence committee, and have mentored 3 PhD and 5 Masters students.

Present Employer: McGill University

Present Department: Department of Physics

Present basic salary: GBP£45,000 pa (CAD$70,000 pa)

Present Salary (Enhancements): Exempt from Quebec provincial income tax; I pay only a flat rate of 10% in Canadian federal income tax.

Present Position End Date:	30/09/2014
Present Position Description:	Banting Fellow (funded by the Tri-Agency Research Councils of Canada; administered by the Natural Sciences and Engineering Research Council). Independent research fellow in Astro and Particle Physics
Is this position permanent?:	No
PhD Submitted Date:	13/04/2010
PhD Awarded Date:	14/05/2010
First Post-Doctorate Position Date:	15/05/2010
Pending Applications:	- Associate Professorship in Theoretical Physics at the Department of Physics, University of Oslo. Short-listed (ranked number 2 on shortlist). Interviews to be held Oct 2012. - STFC Rutherford Fellowship (with Imperial College) - Royal Society of New Zealand Marsden Fund (AI; J Adams PI. If successful, these funds will also be available to me as a Royal Society URF)
Where did you hear of this scheme?:	University sources
Existing grants:	Banting Fellowship (Natural Sciences and Engineering Research Council of Canada; begins Oct 2012) Trottier Fellowship in Astrophysics (Trottier Foundation and McGill University) Theory Fellowship (Institute for Particle Physics, Canada) None of these grants will continue if I take up a Royal Society URF.

Proposal

Subject:	Subject Group 02: Astronomy and physics, theoretical physics, and applied physics / Astrophysics
Project Title:	The astroparticle road to new physics
Keywords:	astroparticle physics, cosmology, dark matter, supersymmetry, particle theory beyond the standard model, direct detection of dark matter, indirect detection of dark matter, neutrinos, collider phenomenology, statistical methods
Research proposal:	
Scientific Abstract:	

Two questions dominate large parts of modern astroparticle physics: What is dark matter, and what is the nature of physics at the TeV scale? Dark matter accounts for approximately 80% of the matter budget of the Universe, yet its identity is unknown. Many theories for physics beyond the standard model of particle physics (BSM - beyond the SM), such as supersymmetry (SUSY), extra dimensions and phenomenological descriptions of weakly-interacting massive particles, involve a fundamental link between dark matter and the TeV scale. With the spectacular recent success of the Large Hadron Collider (LHC), particularly in uncovering the Higgs boson, and the construction of high-energy astrophysical experiments such as Fermi, IceCube and XENON, astroparticle physics is arriving at the TeV scale; the time to put these disparate pieces together into a cohesive and unified understanding of dark matter and TeV-scale physics is now.

Goals:
- Identify the correct theory behind dark matter and TeV-scale BSM physics
- Exclude large classes of other viable and popular dark matter and TeV-scale BSM theories
- Distinguish between areas of parameter space giving rise to distinct astroparticle phenomena within single BSM theories

Here I outline a cutting-edge 'global fit' research program designed to test a broad range of dark matter and BSM theories against a similarly large range of experimental datasets, with each theory to be simultaneously compared with every available dataset. The goal is to either uncover the identity of dark matter and carefully characterise it, or rule out and strongly constrain different BSM theories, drawing strongly on the synergies that exist between different experiments. This program of holistic analysis will result in far more complete and robust comparisons between experimental data and dark matter/BSM models than presently exists in the literature. My unique experience in bringing together theoretical, experimental and statistical techniques, as well as astronomical and particle perspectives, will be essential in the success of this endeavour.

I will employ as complete a set of experimental observables as possible (data from the LHC, Fermi, HESS, IceCube, PAMELA, XENON, CDMS, LUX and others), and consider a much broader range of dark matter and BSM models than have been subjected to such rigorous analysis to date (phenomenological and SUSY-breaking versions of the minimal supersymmetric SM, universal extra-dimensional, Two Higgs Doublet and effective dark matter models like Isospin-violating, Inelastic and Exciting Dark Matter). A crucial component of this project will be the development of a highly flexible 'second-generation' BSM global-fitting code, capable of operating at a degree of computational abstraction that would allow for very fast implementation of future models and datasets.

The research in this proposal will revolutionise the emerging field of BSM global fits, by producing rigorous global analyses of a vast number of BSM theories, and providing essential tools for the explosion it will undergo in the coming years.

Comply with Policy on use of Animals: Not applicable

Comply with Policy on use of Non-Human Primates: Not applicable

Lay Report:

Imagine living your life in a 5-person household where you don't know the names or faces of your 4 housemates. This is the situation astronomers and particle physicists find themselves in right now with the matter in our own Milky Way Galaxy. Dark matter makes up over 80% of the Milky Way, and the Universe as a whole, but we still don't know what it actually is.

Many theories predict that this mystery 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 unveiled at the Large Hadron Collider (LHC). My research aims to uncover the identity of dark matter, and the broader particle theory responsible for it.

Using cutting-edge statistical techniques only developed in the last few years, my research program will combine the results of searches for dark matter and new symmetries from a huge number of different experiments. These range from the LHC to smaller particle colliders, gamma-ray telescopes, cosmic antimatter probes, ultra-clean experiments in the world's deepest mines, and a neutrino telescope embedded in the Antarctic ice at the South Pole. The result will be the first truly comprehensive analysis of theories for dark matter and new physics, painting a much clearer picture of what dark matter is, and what it isn't. Excitingly, this research program may identify many more new, related particles than just dark matter, and give predictions for others to be discovered in the near future. The statistical and computational tools that I develop for this research program will also serve the broader particle and astrophysics communities during and beyond my fellowship, as they will be available as public, open source projects.

Justification for host organisation:

Imperial offers:
1. An ideal professional environment
2. Vast expertise relevant to my research
3. Priority access to a 4000+ core supercomputer

I will partake in decision-making and supervision in the Astrophysics group as if already a lecturer, and my career path will be factored into the group's long-term strategy. I will collaborate closely with Roberto Trotta, who has extensive experience in dark matter and global fits. My research program will enhance and benefit from the new Imperial Centre for Inference and Cosmology as I work with Heavens, van Dyk et al in optimising the numerical/statistical methods of my research. With Sumner and Araujo I will ensure that results of LUX and other direct detection experiments are correctly included in my global fits. I will draw on the Imperial CMS group in developing the collider likelihood modules. Trotta, Jaffe, Contaldi and Rajantie provide strong cosmological support (e.g. links to Planck), as do Duff and Kibble in quantum field theory.

Host department: Department of Physics

Financial Details

Financial Details:

Year	Payment type	Justification	Amount Requested
Year 1	Basic Salary		37,555.00
Year 1	On costs		0.00
Year 1	London Allowance		0.00
Year 1	Consumables		0.00
Year 1	Equipment		6,200.00
Year 1	Travel UK		500.00
Year 1	Travel International		6,000.00
Year 1	Other Expenses		300.00
Year 1	Estate Costs		0.00

Year	Payment type	Justification	Amount Requested
Year 1	Other		0.00
Year 1	Indirect Costs		0.00
Year 2	Basic Salary		38,682.00
Year 2	On costs		0.00
Year 2	London Allowance		0.00
Year 2	Consumables		0.00
Year 2	Equipment		3,000.00
Year 2	Travel UK		1,000.00
Year 2	Travel International		4,500.00
Year 2	Other Expenses		2,500.00
Year 2	Estate Costs		0.00
Year 2	Other		0.00
Year 2	Indirect Costs		0.00
Year 3	Basic Salary		39,842.00
Year 3	On costs		0.00
Year 3	London Allowance		0.00
Year 3	Consumables		0.00
Year 3	Equipment		0.00
Year 3	Travel UK		1,000.00
Year 3	Travel International		4,500.00
Year 3	Other Expenses		5,500.00
Year 3	Estate Costs		0.00
Year 3	Other		0.00
Year 3	Indirect Costs		0.00
Year 4	Basic Salary		41,037.00
Year 4	On costs		0.00
Year 4	London Allowance		0.00
Year 4	Consumables		0.00
Year 4	Equipment		2,500.00
Year 4	Travel UK		1,000.00
Year 4	Travel International		4,500.00
Year 4	Other Expenses		3,000.00
Year 4	Estate Costs		0.00
Year 4	Other		0.00
Year 4	Indirect Costs		0.00
Year 5	Basic Salary		42,268.00
Year 5	On costs		0.00
Year 5	London Allowance		0.00
Year 5	Consumables		0.00
Year 5	Equipment		3,700.00
Year 5	Travel UK		1,000.00
Year 5	Travel International		4,500.00
Year 5	Other Expenses		1,800.00
Year 5	Estate Costs		0.00
Year 5	Other		0.00
Year 5	Indirect Costs		0.00
Total			256,384.00

Start Date: 01/10/2013

Duration (Years): 5

Percentage Full Time: 100

Justification: Travel:

The highly internationalised nature of astroparticle physics, and the extremely interdisciplinary nature of the research program I propose will require extensive international travel, to present at conferences, attend Collaboration Meetings (both experimental and theoretical) and undertake direct visits to my collaborators' institutes. I will also need to host similar visits by collaborators to Imperial (although these costs are listed under 'Other Expenses').

In Year 1 I will incur costs of approximately GBP4000 in relocating from Montreal. The remaining GBP2000 for international travel will cover attendance at one European and one intercontinental conference, and the GBP500 a single domestic conference.

For years 2-5, I have allocated GBP4500 for my own international travel, corresponding to approximately two intercontinental trips and two continental European trips. I have also allocated GBP1000 for internal UK travel, which will cover two domestic trips per year.

Equipment:

Year 1: A new high-end laptop and peripherals (screen, keyboard, mouse; GBP2500) and corresponding enterprise-level desktop server (GBP3700) for developing and managing parallel global fit code.
Year 2: Two student laptops (GBP3000)
Year 3: none
Year 4: Replacement laptop and peripherals (GBP2500)
Year 5: Replacement server (GBP3700)

Other Expenses:

All years: Annual GitHub (or similar) hosting fees for global fit and related code repositories (GBP300 p.a.)
Year 2: Funding for visiting collaborators / students (GBP2200 = 1 intercontinental + 2 UK/continental guests)
Year 3: Funding to host a small meeting/workshop on global fits (GBP4000)
Funding for visiting collaborators / students (GBP1200 = 1 intercont. or 2 UK/cont. guests)
Year 4: Funding for visiting collaborators / students (GBP2700 = 2 intercont. + 1 UK/cont.)
Year 5: Funding for visiting collaborators / students (GBP1500 = 1 intercont. + 1 UK/cont.)

Pat Scott

List of Publications

Available from www.physics.mcgill.ca/~patscott/publications
Summary (Sep 5 2012, NASA ADS): 28 publications, 1214 citations, h-index: 13
(Two most siginficant papers are marked in bold and given an asterisk.)

Journal articles

[1] P. Scott, C. Savage, J. Edsjö, and the IceCube Collaboration: R. Abbasi et al., *Use of event-level neutrino telescope data in global fits for theories of new physics*, *JCAP* (2012) accepted, [arXiv:1207.0810].

[2] P. Scott, A. I. Cowan, and C. Stricker, *Quantifying impacts of short-term plasticity on neuronal information transfer*, *Phys. Rev. E* **85** (2012) 041921, [arXiv:1204.3270].

[3] C. Strege, R. Trotta, G. Bertone, A. H. G. Peter, and P. Scott, *Fundamental statistical limitations of future dark matter direct detection experiments*, *Phys. Rev. D* **86** (2012) 023507, [arXiv:1201.3631].

[4] T. Bringmann, P. Scott, and Y. Akrami, *Improved constraints on the primordial power spectrum at small scales from ultracompact minihalos*, *Phys. Rev. D* **85** (2012) 125027, [arXiv:1110.2484].

[5] 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* **742** (2011) 129, [arXiv:1107.1714].

[6] 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* **04** (2011) 012, [arXiv:1012.3939].

[7] 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].

[8] 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].

[9] 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].

[10] 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].

[11] 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].

[12] *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].

[13] *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].

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

[15] 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].

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

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

[18] 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, [astro-ph/0605116].

Other refereed contributions (proceedings)

[19] P. Scott, T. Bringmann, and Y. Akrami, *Constraints on small-scale cosmological perturbations from gamma-ray searches for dark matter*, in *Proceedings of TAUP 2011* (G. Raffelt et. al., ed.), *J. Phys. Conf. Series* **375** (2012) 032012, [arXiv:1205.1432].

[20] C. Blázas *et al.*, *DLHA: Dark Matter Les Houches Agreement*, in *Les Houches 2011: Physics at TeV Colliders New Physics Working Group Report* (Brooijmans, G. et. al., ed.) (2012) [arXiv:1203.1488].

[21] 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].

[22] 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].

[23] 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.

[24] 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.

[25] 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.

[26] 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].

[27] 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].

[28] 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].

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The astroparticle road to new physics

Vision

The identity of dark matter (DM) and the nature of physics at the TeV energy scale are two of the most pressing and fundamental questions in modern physics. DM constitutes 80% of the matter in the Universe and was discovered 80 years ago, but its composition remains a mystery. With the activation of the Large Hadron Collider (LHC), discovery of the Higgs boson and the construction of high-energy astrophysics experiments like Fermi, HESS-II, IceCube and SCDMS, we now stand on the doorstep of the TeV scale.

Excitingly, many popular DM candidates are intrinsically linked to the appearance of new physics at the TeV scale, beyond the Standard Model (BSM). A Higgs mass of 125 GeV itself even compels us to move beyond the SM: theoretically, this value should be orders of magnitude higher if the impact of SM virtual particles is taken into account, and if no other particles exist, then the very vacuum of our Universe is unstable, and might undergo a catastrophic energy transition at any moment. We also know that the SM is incomplete because it does not explain the excess of matter over antimatter in our Universe, nor that fact that neutrinos are massive.

Many different probes are sensitive to BSM physics: direct and indirect searches for DM, accelerator searches, and neutrino experiments. Experiments such as CRESST, Fermi and PAMELA may even already show tantalising hints of DM. 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. This ‘global fit’ approach is what I propose here. 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. This ‘win-win’ situation is a particular feature of a global fit analysis, as even non-detections provide crucial physical insight into which models and parameter regions are disfavoured.

This is an extremely demanding 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 many specialised statistical techniques and computer codes. I am uniquely placed to lead this endeavour, with the extensive cross-disciplinary background in astrophysics and particle physics, theory and experiment, DM phenomenology, statistical and numerical methods required to make this ambitious proposal a reality. Astroparticle experimental collaborations have so far carried out such global analyses only with my assistance: the examples to date have been my collaborations with Fermi [12 in publication list], HESS [6] and IceCube [1].

Whilst partial progress has recently been made (by various groups including Roberto Trotta at Imperial, myself, and our respective collaborators), the magnitude of the task and degree of technical difficulty have left global fits 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, making even the analyses that have been done in the past year obsolete. *Now* is precisely the time to invest in broadening the application and development of BSM global fits and their related computer codes, in order to deal with a greatly expanded range of models and datasets in a consistent and holistic way, in the near future.

Goals

- Identify the correct theory behind dark matter and TeV-scale BSM physics
- Exclude large classes of other viable and popular dark matter and TeV-scale BSM theories
- Distinguish between areas of parameter space giving rise to distinct astroparticle phenomena within single BSM theories

Research Framework/Methodology

An example of the utility of a global fit is shown in Fig. 1. Here probability distributions for the mass of supersymmetric DM, and its scattering cross-section with nucleons,

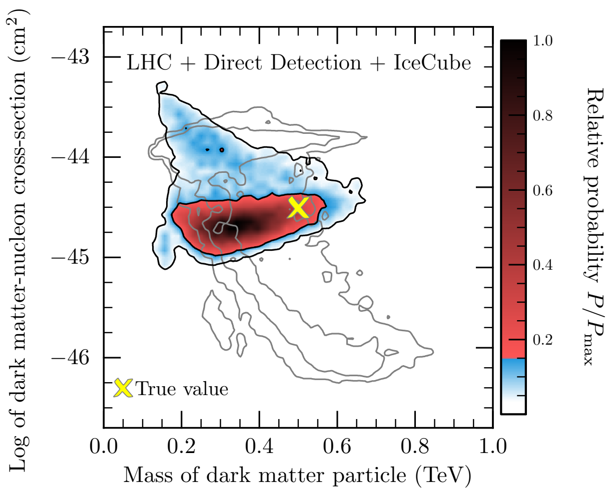

Figure 1: An example global fit exploiting the synergy between experiments in the search for BSM physics and DM. Grey contours show the result when LHC and XENON-100 direct detection data are used to constrain supersymmetry, in terms of the mass of the DM and its scattering cross-section with nucleons. Shading shows how the picture changes when a mock detection of DM by the IceCube Neutrino Telescope is considered, corresponding to a specific point in the parameter space. Shading gives the relative probability of the different parts of the parameter space, and contours give 1σ and 2σ regions. The fit with IceCube data zooms in markedly on the true point, determining the scattering cross-section with about a factor of 100 better accuracy than without IceCube (at 68% confidence level). Based on [1] in publication list.

are shown for two parameter scans. In one scan (grey), LHC and direct detection data are used to constrain an example supersymmetric theory. Two main regions of high probability exist: a horizontal region with large cross-sections, where the DM also has a large annihilation cross-section and its cosmological density it determined by DM-DM annihilation, and an almost vertical region extending to lower cross-sections, where the DM has a much lower annihilation cross-section and its cosmological density is determined mostly by co-annihilation of DM particle with other supersymmetric particles. With LHC and direct detection data alone, there is no way to determine which of these regions is favoured, and therefore what physical process is primarily responsible for determining the amount of DM in the Universe. When data from a future hypothetical detection of DM with the IceCube Neutrino Telescope are added (colour), the degeneracy is lifted, and the parameter space is constrained with high accuracy (a factor of 100 improvement in the cross-section).

The core methodology is that of a composite likelihood-based global fit. 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, LHC event rates, etc). Predictions are compared to experimental measurements, and a series of likelihood functions produced. 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 parameterisations, and the results compared to determine if the data strongly favour one scenario over another.

Core Research Fronts

Particle and astroparticle datasets: With Roberto Trotta and accelerator, direct detection and cosmic microwave background (CMB) experts at Imperial, I will include many new and updated observables in my global fits. BSM searches with CMS and ATLAS at the LHC are essential inclusions, but notoriously difficult in all but the simplest BSM models. In consultation with Tapper, Buchmüller and the Imperial CMS group, I plan to develop approximate but detailed LHC likelihood functions for use in global fits, initially based on the most constraining CMS searches for supersymmetry, including the 'razor' and 'MT2' analyses. Direct searches for DM like XENON-100, ZEPLIN and LUX will also play a pivotal role. In collaboration with Araujo and Sumner at Imperial (ZEPLIN) and the rest of the LUX collaboration, I will include full event-level data and detailed background models in the direct detection likelihoods of my global fits. With Jaffe I will include the impacts of DM annihilation on formation of the CMB seen by Planck.

I will leverage my contacts in *Fermi*, IceCube and AMS-02 to include searches for cosmic anti-deuterons from galactic DM annihilation with AMS-02, searches for DM annihilation in the Sun by IceCube, and combined searches for gamma rays from DM annihilation in all Milky Way dwarf satellite galaxies by *Fermi*. Together with the developers of the GALPROP cosmic ray propagation code, Trotta and I will develop a global fit analysis of *Fermi* data from the Galactic centre, utilising nested sampling, Bayesian object detection and detailed diffuse emission templates.

Theories: I will investigate the current leading candidates for new physics: 7-, 13-, 19- and 25-parameter phenomenological versions of the minimal supersymmetric standard model (MSSM), specific supersymmetry-breaking schemes such as Planck-scale-mediated, gauge-mediated, anomaly-mediated and gaugino-mediated scenarios, and models of extra dimensions. I will also derive global constraints on more effective DM models, including Effective WIMPs, Sommerfeld-enhanced models, Two Higgs Doublet Models, Asymmetric DM, Isospin-Violating DM, Inelastic and Exciting DM. This will allow me to test, refine and compare the viable regions of these models to a far greater extent than done previously.

Statistical & Numerical Methods: A core part of my URF is developing a second-generation BSM global-fitting software package, able to dynamically rewrite modules of its own code to implement new theories and adjust to new experimental datasets. This will allow a degree of flexibility not before seen in statistical analyses of BSM models, facilitating the analysis of vastly more models and experimental signatures than has been done to date. I intend to make this software, and its component physics codes, freely available to the community.

With the members of the new Imperial Centre for Inference and Cosmology (ICIC; Trotta, Jaffe, van Dyk et al), I will improve on the statistical and numerical aspects of global fit analyses. I have particular expertise in optimisation/scanning algorithms, with extensive experience in both Bayesian and frequentist scanning methods (e.g. genetic algorithms, nested sampling). I will leverage this expertise and the excellence of the ICIC to develop a new alternative scanning code for BSM searches, based on the strategy of differential evolution.

Additional synergies with my program exist within Imperial and the general London area. Ellis, Fairbairn and colleagues in High Energy Theory at King's College might contribute to phenomenological aspects of the BSM fit program. As I have shown previously, indirect DM detection also has cosmological implications, via consideration of ultracompact minihalos; my work in this direction would benefit from interaction with Jaffe and Contaldi (inflation and cosmological perturbations), and Rajantie (cosmic strings).

Timeline

Years 1–2 Develop core second-generation global fitting code, first LHC (few channels) and direct detection likelihood modules, differential evolution scanner
Year 3 Publish phenomenological MSSM global analyses with code; first public release of code
Year 4 Add/update observables (all LHC channels, cosmic rays, gamma-ray and neutrino telescope likelihoods) and theories (supersymmetry-breaking mediation models, extra dimensions, effective DM)
Year 5 Complete global analyses and extensive model comparison of supersymmetric, extra-dimensional and effective DM models