Netherlands Organisation for Scientific Research

Vernieuwingsimpuls / Innovational Research
Grant application form 2013 **Vidi scheme**
Please refer to Explanatory Notes when completing this form

Registration form (basic details)

1a. Details of applicant

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Use of extension clause (see Notes): No

1b. Title of research proposal

Probing the Genesis of Dark Matter

1c. Summary of research proposal (max. 300 words)

One of the central goals of fundamental physics and cosmology is the identification of the particle nature of dark matter (DM). DM makes up about 80% of the matter content in the Universe, but only its gravitational effects on the motion of celestial objects could be observed up to now. Theoretical models point towards scenarios where DM particles can self-annihilate. Self-annihilation would play a major role during the production of DM in the early Universe. Today, faint remnants of this self-annihilation could produce high-energy photons and charged particles at rates tantalizingly close to the sensitivity of current astronomical observations.

The goal of this project is to bring clear evidence for the existence of signals from DM annihilation, or otherwise provide the most stringent upper limits on the annihilation rates. To this end, I will perform a multi-messenger search for DM signals with radio, gamma- and cosmic-ray data. Firstly, I will scrutinize tentative signals for DM annihilation that I and others found in the gamma-ray measurements of the Fermi Large Area Telescope (LAT), investigate the cross-correlations of the high latitude diffuse emission with cosmic shear measurements, and make Fermi LAT results fruitful for future searches with the Cherenkov Telescope Array. Secondly, I will search for corroborating evidence for dark matter annihilation using cosmic-ray antimatter measurements from AMS-02, and investigate the existence of DM induced synchrotron emission with radio measurements by the Low Frequency Array LOFAR. Finally, I will combine my findings with complementary results from collider and direct searches, and investigate the impact on the most relevant models for particle DM.

The outcome of this project will be the most comprehensive combined analysis of gamma-ray, anti-matter and radio data to date, and strongly advance our understanding of DM and the history of the Universe.

1d. Key words (max. five keywords)

Dark Matter; Theoretical Physics; Astroparticle Physics

1e. Host institution (if known)

GRAPPA Institute, University of Amsterdam

1f. NWO Division (choose one)

Interdivisional*	
ALW	
CW	
EW	
GW	
MaGW	
ZonMw	
N	X
STW	

*** Elucidation of the interdivisional character of the proposal**
(only to be filled out if you have chosen to submit your proposal as interdivisional, 50-100 words)

1g. Main field of research (compulsory; see notes)
code + main field of research:

12.80.00 Theoretical Physics

If applicable: other fields of research, in order of relevance

Code	Other fields of research
12.10.00	Subatomic physics
17.90.00	Astrophysics

Research proposal

2a1 and 2a2. Description of the proposed research
(max. 4000 words on max. 8 pages, see Notes)

2a1. Overall aim and key objectives including:
- Scientific relevance and challenges
- Originality and innovative character
- Methods and techniques

2a2. Research plan including:
- Practical timetable/timeline over the grant period
- Local, national and international collaboration
- Workplan for requested personnel

2a1. Overall aim and key objectives

Background

The search for dark matter. Despite the enormous success of astrophysical and cosmological research over the last decades, about 80% of the matter content in the Universe remains unknown (Ade *et al.*, 2013). This unknown component was identified and dubbed *dark matter* (DM) already 80 years ago (Zwicky, 1933), and its existence is nowadays supported by a large array of gravitational observations from galactic to cosmological scales (Bergström, 2000). These observations provide detailed information about the phase-space distribution of DM, and – together with other probes – strongly suggest that DM is made of one or more new fundamental particles. However, the mass and interactions of these new particles remain largely unknown. The unambiguous identification of DM being made up by new fundamental particles is a central goal of contemporary astroparticle and fundamental physics. A successful identification would confirm the enormous importance of cosmology for our knowledge of the building blocks of nature. Currently, DM research is largely focused on the WIMP (Weakly Interacting Massive Particle) paradigm and its associated experimental signature (Bertone *et al.*, 2005). The next 5–10 years might be considered as the *moment of truth for WIMP dark matter* (Bertone, 2010): WIMPs will be either discovered, or they will become much less relevant as DM candidates and give way for new approaches and ideas.

Search strategies. If DM is made of WIMPs, they were in thermal equilibrium with the primordial plasma in the early hot Universe. After the temperature dropped below their mass (within the first nanosecond after the big bang) their abundance decreased exponentially due to efficient self-annihilation. At the same time, the expansion of the Universe resulted in rapidly decreasing densities, preventing a complete self-annihilation, and leaving behind the small relic density observed today (Jungman *et al.*, 1996). This is the thermal *freeze-out mechanism*. At a very small rate, this self-annihilation – as illustrated in Fig. 1 – would continue until today.

The different strategies to identify WIMP DM fall largely into three categories: Collider searches for new weakly interacting particles, direct searches for WIMP recoil off atomic nuclei in low-background detectors, and indirect searches that aim at identifying the self-annihilation products of WIMPs either in the cosmic rays or by their impact on astrophysical and cosmological observables. Thanks to bustling experimental developments, strong progress is expected to be made in all three branches of DM searches during the upcoming years. However, the unequivocal identification of a self-annihilation signal would be the most convincing test of the freeze-out scenario and the WIMP paradigm, and hence is of utmost importance.

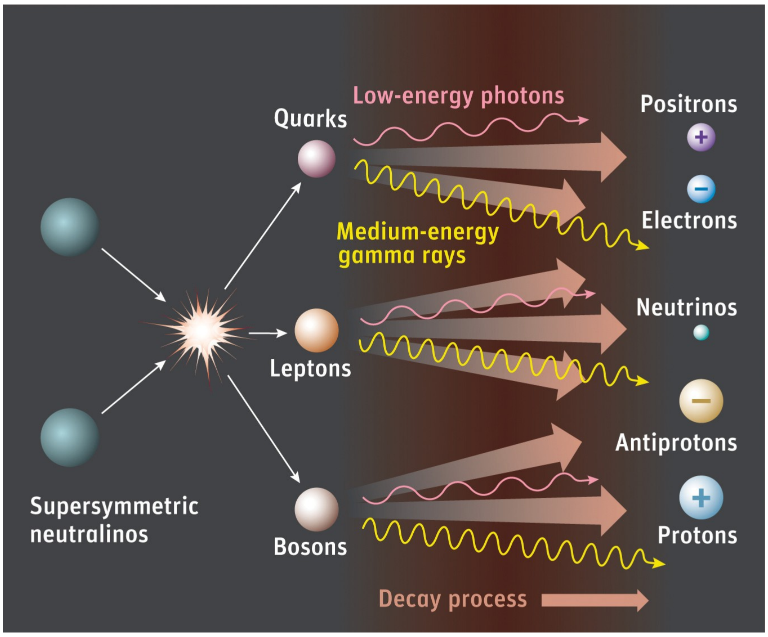

Figure 1: Illustration of the self-annihilation of WIMP DM (the most common candidate is the supersymmetric neutralino). This process determines the amount of DM that is present today. Observations of the annihilation products would be strong evidence for WIMP DM.

Indirect DM searches. The indirect detection of DM, and the exploration of its consequences, is the central goal of this proposal. Indirect searches for DM can draw on a large number of different messengers. Gamma rays play a pronounced role, as they propagate unperturbed through the Galaxy and the nearby Universe and directly point to their sources. Currently, the combined observation of dwarf spheroidal galaxies with the Fermi Large Area Telescope (LAT, Ackermann *et al.* (2011)) and Galactic centre observations with the Air Cherenkov Telescope (ACT) H.E.S.S. (Abramowski *et al.*, 2011) provide among the strongest and most robust constraints on the annihilation cross-section of DM.

A striking and unequivocal signature for DM annihilation would be the observation of a gamma-ray line emission from the Galactic centre (Bergström and Snellman, 1988), or of the similar emission from virtual internal Bremsstrahlung (VIB, Bringmann *et al.*, 2008), see Fig. 2. Last year, I found a candidate for such a gamma-ray line in the public data of the Fermi LAT (Bringmann *et al.*, 2012; Weniger, 2012), at energies around 130 GeV and with a local significance of 4.6 sigma. This was subsequently confirmed and critically discussed by several groups (Tempel *et al.*, 2012; Boyarsky *et al.*, 2012; Su and Finkbeiner, 2012 and others), and had a strong impact on the DM community. The existence of this feature in the data was recently investigated by the Fermi LAT collaboration (Ackermann *et al.*, 2013), who found that it becomes less significant when reprocessed or/and additional data is used (see also Weniger, 2013 for an earlier update). Its cause remains unclear: It could be a rare statistical fluke, have an instrumental cause (Finkbeiner *et al.*, 2013; Ackermann *et al.*, 2013; Whiteson, 2013), or in the best case turn out to be a real DM signal. In the first half of 2013, I led a proposal to change the survey strategy of the Fermi satellite in order to accelerate the collection of data from the Galactic centre and settle this question for good (Weniger *et al.*, 2013), which was positively reviewed by the Fermi mission and is likely to be adopted by December 2013.

Upcoming data. Fermi LAT will continue to survey the gamma-ray sky, most likely until the end of 2018. At higher energies, the existing ground-based ACTs H.E.S.S., VERITAS and MAGIC will continue to take data. A next next major step in high-energy gamma-ray astronomy is then the Cherenkov Telescope Array (CTA), which is planned to start taking data around 2018. In the radio regime, more data will come from Planck (polarization), and at low frequencies from instruments like the Low Frequency Array LOFAR. Further data releases relevant for indirect searches are expected from IceCube and later the planned KM3NeT (neutrinos), and from AMS-02 and the scheduled GAPS (cosmic-ray antimatter). Concerning *collider searches*, the Large Hadron Collider (LHC) will restart taking data close to its design energy in 2015, providing additional information on the production cross-section of DM particles. Results from *direct searches* are expected in the

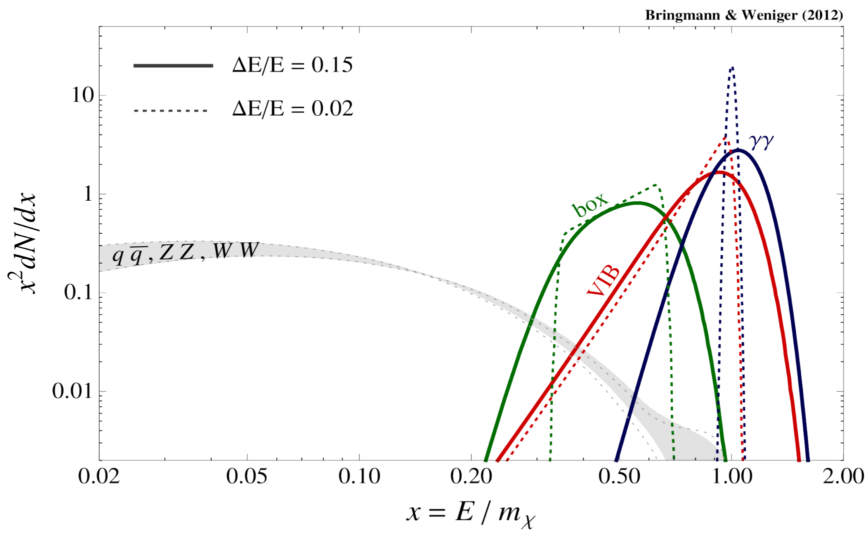

Figure 2: Different contributions to the energy spectrum of a gamma-ray annihilation signal, dN/dx, as function of energy divided by DM mass, $x = E/m_\chi$, with arbitrary normalization. In addition to continuum emission from annihilation into quarks and massive gauge bosons (gray band), different sharp spectral signatures can appear at the kinematic cutoff: gamma-ray lines (blue), virtual internal Bremsstrahlung (red), cascade decays (green). Observation of such sharp features in the gamma-ray sky would be a smoking-gun for DM annihilation. Solid and dotted lines correspond to different experimental energy resolutions. For experimental sensitivities to these features see e.g. Fig. 6 in Bringmann and Weniger (2012).

near future from a large number of experiments (CDMS, CoGeNT, LUX, XENON-1T and others), with a significant discovery potential if DM is made of WIMPs.

Research aims/approach

The goal of this project is to bring clear evidence for the existence of gamma-ray signature of annihilating DM, or otherwise provide very stringent upper limits on WIMP annihilation. To this end, I propose to

1. Perform a multi-messenger search for indirect DM signals with radio, gamma- and cosmic-ray observations.
2. Exploit the complementarity between indirect, direct and collider probes to determine the consequences of a detection or non-detection on WIMP DM models.

Subproject I: Gamma-ray searches

Specific aim: To scrutinize tentative DM signals in the Fermi LAT data and explore the potential of future observations.

I will continue to monitor the 130 GeV feature in the Fermi LAT data by making use of the latest data, and to search for instrumental causes for which worrisome but still inconclusive indications were found in Finkbeiner *et al.* (2013), Hektor *et al.* (2012) and Ackermann *et al.* (2013). A central question is whether the feature will reappear in a new trial-free measurement. If the feature is confirmed by Fermi LAT or HESS-II (Bergström *et al.*, 2012), I will significantly advance the current analyses by performing a combined analysis of multiple search regions, and by critically reassessing the validity of the template-based methods used in the recent literature (*e.g.* Su and Finkbeiner, 2012). I will derive the best constraints on the DM particle physics models giving rise to this excess, as well as the DM distribution towards the Galactic centre. If the feature disappears, I will use these techniques to obtain the most stringent limits on DM annihilation into line-like signatures.

Beside the 130 GeV feature, an excess of 1-5 GeV photons at the Galactic centre was investigated in a number of recent works (see *e.g.* Hooper and Linden, 2011; Boyarsky *et al.*, 2011; Abazajian and Kaplinghat, 2012; Gordon and Macias, 2013). Morphological and spectral analyses indicate that it is compatible with the annihilation of relatively light DM particles with masses between 10 and 50 GeV (*e.g.* Hooper and Slatyer, 2013; Abazajian and Kaplinghat, 2012). Other possible explanations range from milli-second pulsars to cosmic-ray interactions (Abazajian 2011; Hooper *et al.*, 2013), or contributions from improperly accounted for point sources (Boyarsky *et al.,* 2011). I will study the one-point fluctuations of gamma-ray fluxes (*e.g.* Malyshev and Hogg, 2011) close to the Galactic centre to determine whether the apparent excess emission is consistent with a diffuse DM signal or with unresolved point sources (*cp.* Carlson *et al.,* 2013). Furthermore, I will search for corroborating evidence for a DM signal by studying the cross-correlations between cosmic shear observations by the upcoming Dark Energy Survey (DES) and the extragalactic gamma-ray background, as discussed in Camera *et al.* (2013). Both approaches are new and were shown to be efficient for differentiating between a DM signal and astrophysical emission.

The upcoming CTA will soon probe DM masses far above one TeV, with sensitivities up to two orders of magnitude better than previous instruments (Wood *et al.*, 2013). The diffuse Galactic emission is an important background for such DM searches, but was neglected in previous sensitivity studies (Doro *et al.*, 2013; Wood *et al.*, 2013). In Bringmann *et al.* (2011) we showed that a careful treatment of spectral DM signatures can increase the discovery potential of CTA dramatically. I will use Fermi LAT data at high energies to construct templates for diffuse Galactic emission that can be used for CTA sensitivity studies. I will investigate in a combined analysis of Fermi LAT and simulated CTA data (using public information about the planned instrumental characteristics) how CTA can break the degeneracy between Galactic diffuse emission and a DM signal, and determine the most promising targets for DM searches with the CTA.

Subproject II: Radio and cosmic-ray antimatter searches

Specific aim: To search for corroborating evidence for DM annihilation in upcoming radio and cosmic-ray data.

LOFAR is a new radio interferometer with unprecedented sensitivity in the 10-240 MHz frequency range, and one of the key experiments of astroparticle physics in the Netherlands (van Haarlem *et al.*, 2013). I will use its unique capabilities to search for corroborating evidence for DM annihilation.

DM self-annihilation produces often a large number of energetic electrons and positrons with GeV energies (see Fig. 1), which give subsequently rise to synchrotron emission at radio frequencies. This synchrotron emission can be searched for at the Galactic centre (Bertone *et al.,* 2001; Laha *et al.*, 2013), nearby galaxies (*e.g.* Egorov and Pierpaoli, 2013) or galaxy clusters (Colafrancesco *et al.,* 2006; Storm *et al.*, 2013). I will systematically investigate which targets are most promising for DM searches with LOFAR. One challenge is the prediction of the DM signal flux, which depends on the details of cosmic-ray diffusion, the DM distribution and magnetic fields. Due to my previous work on cosmic-ray propagation in the Galaxy and galaxy clusters (Ibarra et al., 2010; Huang et al., 2012), I am well positioned to lead this analysis. I plan to make use of the large area LOFAR survey `Tier 1' to search for DM signals, and in case of a non-detection derive constraints on DM annihilation. Preliminary studies indicate that this approach is very promising to find corroborating evidence for both, the 130 GeV excess (Laha *et al.*, 2013) as well as the 1-5 GeV excess at the Galactic centre (see *e.g.* Egorov and Pierpaoli, 2013).

I demonstrated recently (Bergström et al., 2013) that a dedicated spectral analysis of the energy spectrum of the cosmic-ray positron fraction measured by AMS-02 is extremely powerful for searches for light DM with annihilation into leptonic final states. I will fully exploit the potential of this new and efficient approach to make it as reliable as the gamma-ray searches in dwarf spheroidal galaxies (Ackermann *et al.*, 2011). I will study the impact of solar modulation on the energy spectrum of DM signals (*e.g.* Gleeson and Axford, 1968; Maccione, 2013), and systematically marginalize over uncertainties associated with the local magnetic field, the interstellar radiation field, Galactic cosmic-ray diffusion and contributions from nearby pulsars (*e.g.* Cholis *et al.*, 2013), using a MCMC (Markov chain Monte Carlo) approach. Such a clean statistical analysis is essential for a clear identification of a DM signal in upcoming data, and will lead to the most robust constraints on DM annihilation into leptonic final states. It will provide important complementary information for the interpretation of gamma-ray and radio data.

Subproject III: Consequences for DM models

Specific aim: To explore the impact of my findings on the most relevant models for WIMP DM.

In this final part of the project, I will combine the results from gamma-ray, radio and cosmic-ray searches with collider and direct probes and study the impact on WIMP DM models. The exploration of different theoretical DM models will furthermore provide input for the above searches for DM signatures in form of annihilation energy spectra and annihilation rates.

The most common example for WIMP DM is the lightest neutralino of the Minimal Supersymmetric Standard Model (MSSM). Recent collider searches with the LHC push the mass of supersymmetric particles towards the TeV regime (though neutralino masses as low as 10 GeV are still not excluded, see *e.g.* Boehm et al. (2013)). I will make use of full scans over the MSSM-25 parameter space (Baer and Tata, 2006; see Silverwood *et al.*, 2013 for a recent example) including all recent experimental constraints and the effect of signal boosts from DM substructure (Bringmann, 2009), in order to investigate the consequences of a detection or non-detection of a DM signal on this prototypical WIMP scenario, and determine the discovery potential of the future CTA.

DM models compatible with the tentative DM signatures at the Galactic center, and accessible by *e.g.* LOFAR or AMS-02, require sufficiently large annihilation rates into Standard Model particles. This is often constrained by very stringent direct and collider limits (*e.g.* Bergström *et al*., 2011; Mambrini *et al.* 2012; Cline *et al.*, 2013). Though these constraints can be evaded if DM WIMPs couple primarily to leptons or photons, the relevant couplings to quarks can be regenerated at one-loop level (see *e.g.* Frandsen *et al.,* 2012 for a discussion in context of the 130 GeV feature). I will explore simplified models for DM with scalar and vector mediators between Standard Model and DM particles and evaluate the impact of these loop-induced couplings on the complementarity of direct, collider and indirect DM searches.

In light of the large amount of additional data expected from the LHC and different direct search experiments in the upcoming years, these projects are both timely and challenging. Due to my previous studies of the phenomenology of (non-)supersymmetric DM models (*e.g.* Ibarra *et al.*, 2009; Arina *et al.*, 2010; Schmidt *et al.*, 2010; Vertongen and Weniger, 2011; Bringmann *et al.*, 2012; Cline *et al.*, 2013), I am in a very good position to lead this work. Furthermore, I am strongly involved in the development of a new cutting-edge global fitting tool (GAMBIT, see *international collaborations* below), which will greatly facilitate the implementation and confrontation of results from collider, direct and indirect searches with DM models.

Originality and Relevance to Vidi Fellowship

The successful identification of a DM signature in non-gravitational experiments would be an extraordinary milestone in our understanding of the Universe. Indirect searches for DM are an extremely promising avenue to follow, since they directly probe the freeze-out mechanism, which is at the core of the currently leading hypothesis for particle DM.

The project will enter uncharted territory in a number of ways: The proposed multi-messenger search for corroborating evidence in gamma-ray, radio and cosmic-ray data is both original and timely, and it will provide the missing pieces that could turn the tentative signals in the gamma-ray sky in into a *bona fide* discovery of DM. The Dutch experiment LOFAR has an unprecedented sensitivity at the low radio frequencies which are relevant for DM searches, and with the first dedicated studies I will ensure that its discovery potential for DM is realized. If no clear signals are found, the combined limits on DM annihilation from gamma-ray, cosmic-ray and radio measurements will be the most stringent on a large number of DM models, and they will be crucial for falsifying wrong DM scenarios. As a researcher with a very strong background in the relevant theories of DM particles, as well being a hands-on user of the currently available data, I am well positioned to lead this project.

The recently founded GRAPPA initiative (Gravitation and Astroparticle Physics Amsterdam) is a *centre of excellence* at the University of Amsterdam (UvA), and aims at becoming the world leading research institute for astroparticle physics with a strong interest in DM. GRAPPA strongly supports my research, and recently promoted my 3-year GRAPPA fellowship to a 5-year staff position. The Vidi Fellowship will be an important additional support for my career development, and it will help to make the Netherlands in general, and GRAPPA in particular, one of leading places concerning the study of DM.

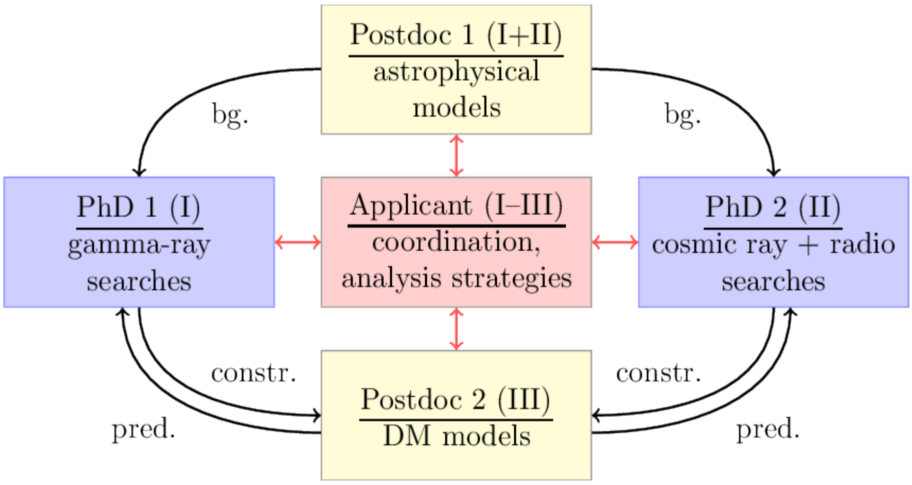

Figure 3: Interplay of requested personnel: PhD 1 and PhD 2 will respectively work on gamma-ray searches (subproject I) and radio/cosmic-ray searches (subproject II) for DM. To accomplish this task, postdoc 1 will provide the necessary models for various astrophysical backgrounds (bg.). Postdoc 2 will combine the DM constraints (constr.) obtained by PhD 1 and PhD 2 with collider and direct probes (subproject III) and explore the impact on WIMP DM models. Additionally, postdoc 2 will provide theoretical predictions (pred.) for the most relevant DM scenarios, which allow PhD 1 and PhD 2 to refine their analyses.

2a2. Research Plan

Local, national and international collaborations

I am junior staff at the GRAPPA Institute in Amsterdam. Together with the neighbouring IOP physics institutes at the UvA and the national institute for subatomic physics (NIKHEF), GRAPPA provides an excellent environment for the proposed research project. I intend to establish new and further strengthen existing collaborations with a number of people: Prof. Gianfranco Bertone (GRAPPA) is an internationally renowned key figure in the search for WIMP DM, and I will continue to collaborate with him on various fields. Prof. Shin'ichiro Ando (GRAPPA) is one of the pioneers of anisotropy probes for DM in the gamma-ray sky and will remain an important collaborator for the study of one-point and two-point functions. Prof. Patrick Decowski and Prof. Auke-Pieter Colijn (NIKHEF) are working on the worldwide leading direct search experiment XENON-100. Prof. David Berge (GRAPPA) and Prof. Paul de Jong (NIKHEF) are directly involved in DM searches and LHC data.

The Netherlands is one of the internationally most exciting places for DM research. With participation in key experiments like ANTARES, KM3NeT, XENON, LOFAR and the LHC, it provides an excellent ground for my career development and for leading a young research group. The close interaction with members of the LOFAR collaboration will be central for my proposed search for DM signals in radio data, for which I established contacts with Prof. Huub Rottgering (Leiden).

Internationally, I built up a strong network of collaborators (see *publication list* and *international activities*). I collaborated with people working in the US, Europe and Asia, including renowned experts in astronomy and particle physics like Prof. Tsutomu Yanagida (University of Tokyo), Prof. Lars Bergström (University of Stockholm) and Prof. Douglas Finkbeiner (Harvard University). I plan to strengthen the ties between my international contacts and my research group with frequent mutual short-term visits.

Finally, I am one of the founders and coordinators of the GAMBIT (Global And Modular Beyond-the-Standard-Model Inference Tool) collaboration. We are an international team of twenty-five experts (including members of AMS-02, ATLAS, CTA, DARWIN, Fermi-LAT, H.E.S.S. and IceCube) from all subfields of searches for beyond-the-Standard-Model physics with the goal to develop the world leading next-generation global fitting tool. I lead and coordinate the development of DM related codes for indirect,

direct and cosmological observables. GAMBIT will become extremely useful for the proposed comparison between indirect, direct and collider probes for DM.

Timetable

The individual subprojects described above will be worked out in a specific order to maximize the scientific output. I will closely supervise PhD students and postdocs to ensure that continuous progress is made during the five years. In the following I summarize the management plan for the project (illustrated in Fig. 3). All personnel will be based at the GRAPPA institute.

First year. Before the project starts, I will look out for excellent master students interested in gamma-ray astronomy and particle physics, and hire my first PhD student from that pool. PhD 1 will initially learn the basics about Galactic diffuse emission, statistical techniques, and the Fermi LAT data reduction pipeline. I will reassess template based techniques by comparison with existing diffuse models and develop the combined spectral analysis of multiple regions of interest. Milestones: Recruiting the best personnel.

Second year. I will hire postdoc 1 with strong expertise in the modelling of gamma-ray diffuse emission and cosmic-ray propagation, as well as PhD 2 with interest in radio astronomy and particle physics. With PhD 1, I will confirm or reject the existence of a 130 GeV feature using fresh Fermi LAT data. PhD 2 will interact with PhD 1 to learn the basics about cosmic-ray propagation. I will work with postdoc 1 on the refinement of diffuse gamma-ray and radio emission models. Milestones: Analysis of 130 GeV gamma-ray feature. Preparation of diffuse emission models.

Third year. PhD 1 will search for evidence that the extended 1-5 GeV gamma-ray excess at the Galactic centre is due to unresolved point sources, using the one-point function of the gamma-ray flux. I will search for corroborating evidence for the 1-5 GeV excess by analysing the cross-correlation between extragalactic emission and weak lensing measurements. PhD 2 will set up a MCMC analysis of cosmic-ray data, and together with postdoc 1 investigate what are the most promising Galactic and extragalactic sources for DM searches with LOFAR. Milestones: Analysis of 1-5 GeV gamma-ray excess. Selection of best LOFAR targets.

Fourth year. I will hire postdoc 2 with strong expertise in collider and/or direct searches. PhD 1 will use the information derived from Fermi LAT data to develop a combined analysis of Fermi LAT and simulated CTA data. PhD 2 will finalize the subproject on cosmic rays, and study the necessary details about the LOFAR data reduction pipeline. I will start with postdoc 2 to investigate the status of the MSSM and simplified DM models in light of the results from PhD 1 and PhD 2. Milestones: DM predictions for CTA in light of Fermi LAT. Analysis of cosmic-ray antimatter data.

Fifth year. PhD 2 will finalize the analysis of LOFAR data. Together with postdoc 2, I will combine the indirect search results from PhD 1 and PhD 2 and work out what they imply for the most relevant DM models. Milestones: Results from LOFAR. Combination of results from radio, gamma-ray and cosmic-ray data. Consequences for the MSSM-25 and simplified models of DM.

After five years, my research group will have brought clear evidence for the existence of gamma-ray signature of annihilating DM, or otherwise provide very stringent upper limits on WIMP annihilation. We will have searched for corroborating evidence in gamma-ray, radio and cosmic-ray channels, and explored the consequences of a detection or non-detection of a DM signal on the most relevant DM models. I plan to publish the results of this project in at least fifteen publications in high-impact journals.

2b. Knowledge utilisation

(max. 1000 words on max. 2 pages, see Notes)

- relevance of the results and/or new insights generated by the proposed research to current economic, societal, cultural, policy-related or technological problems and problems in other scientific disciplines, and probability that they will help to solve them;
- effectiveness and feasibility of the proposed approach to knowledge utilisation with respect to meeting the needs of third parties both within and outside the academic sector;
- the period over which potential knowledge utilisation is expected to occur;
- what, if anything, the researcher intends to do to bring about knowledge utilisation.

In the case of research that does not lend itself to knowledge utilisation, the researcher is requested to explain why he/she believes that knowledge utilisation is not applicable to the proposed research.

At the crossroad of elementary particle physics, astronomy and cosmology lies the key question of what is the particle nature of dark matter. Dark matter research rests on strong observational foundations, and a discovery of dark matter particles would extend our understanding of the fundamental forces and the particles in the Universe far beyond current borders. A detection of the annihilation signal from dark matter would in principle allow to survey the distribution of dark matter in the Universe; with important consequences for *e.g.* models for galaxy formation. Measuring the interactions of dark matter particles at the LHC would help to predict what happened within the first nanosecond after the big bang, possibly solving the puzzle of why matter dominates over anti-matter in the Universe. Measuring the recoil of dark matter particle in underground experiments would constrain the dark matter density and velocity distribution of dark matter particles in the vicinity of the solar system, helping to understand *e.g.* the merger history of the Milky Way. The development of increasingly sensitive low-background detectors leads to technologies and methods that will be useful to measure solar and atmospheric neutrinos. In short, the discovery of dark matter particles would likely have an enormous impact on cosmological and astronomical research. However, theoretical models for dark matter are right now necessarily of speculative nature, although very well motivated by natural extensions of the Standard Model. Until non-gravitational signatures of dark matter are unambiguously identified, it is difficult to predict whether a discovery of dark matter particles would finally lead to technological applications, or what specific implications it would have for other branches of science. An immediate way of knowledge utilization with cultural and societal impact can however be realized in *outreach programs* that emphasize fundamental research.

The quest for dark matter has all the ingredients of good fundamental research: compelling evidence for something that exceeds our knowledge, innovative theoretical ideas, challenging experiments, and a tremendous reward in case of a success. As such it is an excellent vehicle to transport the very ideas of scientific methods and the fascination that drives people who do fundamental research. The Institute of Physics at the University of Amsterdam, and the Delta-Institute for Theoretical Physics in context of the *Quantum Universe* initiative, both have a very active *outreach program*. This includes the organization of public lectures, and the offer for high-school students to do their high-school project (profielwerkstuk) on timely questions in the research field of physics. I have experience with public lectures and many interviews with popular journals. I am looking forward to further strengthen the existing activities at the University of Amsterdam during the five years of the Vidi Fellowship by providing public lectures on dark matter research and astroparticle physics in context of the *Quantum Universe* program, by contributing to the upcoming outreach website www.quantumuniverse.nl, and by offering inspiring high-school projects related to dark matter and the analysis of astronomical data.

2c. Number of words used: section 2a ______3985_____ (max. 4000 words)

Number of words used: section 2b _____486 _____ (max. 1000 words)

2d. Literature references

Abazajian, K. N., 2011, JCAP **1103**, 010.
Abazajian, K. N., and M. Kaplinghat, 2012, Phys. Rev. **D86**, 083511.
Abramowski, A., et al. (H.E.S.S. Collaboration), 2011, Phys. Rev. Lett. **106**, 161301.
Ackermann, M., et al. (Fermi-LAT Collaboration), 2011, Phys. Rev. Lett. **107**, 241302.
Ackermann, M., et al. (Fermi-LAT Collaboration), 2013, arXiv:1305.5597.
Ade, P., et al. (Planck Collaboration), 2013, arXiv:1303.5076.
Arina, C., T. Hambye, A. Ibarra, and C. Weniger, 2010, JCAP **1003**, 024.
Baer, H., and X. Tata, 2006, *Weak Scale Supersymmetry,* Cambridge University Press.
Bergström, L., 2000, Rept. Prog. Phys. **63**, 793.
Bergström, L., G. Bertone, J. Conrad, C. Farnier, and C. Weniger, 2012, JCAP **1211**, 025.
Bergström, L., T. Bringmann, I. Cholis, D. Hooper, and C. Weniger, 2013, to appear in Phys. Rev. Lett.
Bergström, L., T. Bringmann, and J. Edsjö, 2011, Phys. Rev. **D83**, 045024.
Bergström, L., and H. Snellman, 1988, Phys. Rev. **D37**, 3737.
Bertone, G., 2010, Nature **468**, 389.
Bertone, G., D. Hooper, and J. Silk, 2005, Phys. Rept. **405**, 279.
Bertone, G., G. Sigl, and J. Silk, 2001, Mon. Not. Roy. Astron. Soc. **326**, 799.
Boehm, C., P. S. B. Dev, A. Mazumdar, and E. Pukartas, 2013, JHEP **1306**, 113.
Boyarsky, A., D. Malyshev, and O. Ruchayskiy, 2011, Phys. Lett. **B705**, 165.
Boyarsky, A., D. Malyshev, and O. Ruchayskiy, 2012, Phys. Dark Univ. **2**, 90.
Bringmann, T., 2009, New J. Phys. **11**, 105027.
Bringmann, T., L. Bergström, and J. Edsjö, 2008, JHEP **0801**, 049.
Bringmann, T., F. Calore, G. Vertongen, and C. Weniger, 2011, Phys. Rev. **D84**, 103525.
Bringmann, T., X. Huang, A. Ibarra, S. Vogl, and C. Weniger, 2012, JCAP **1207**, 054.
Bringmann, T., and C. Weniger, 2012, Phys. Dark Univ. **1**, 194.
Camera, S., M. Fornasa, N. Fornengo, and M. Regis, 2013, Astrophys. J. **771**, L5.
Carlson, E., T. Linden, S. Profumo, and C. Weniger, 2013, Phys. Rev. **D88**, 043006.
Cholis, I. and D. Hooper, 2013, Phys. Rev. **D88**, 023013.
Cline, J. M., K. Kainulainen, P. Scott, and C. Weniger, 2013, Phys. Rev. **D88**, 055025.
Colafrancesco, S., S. Profumo, and P. Ullio, 2006, Astron. Astrophys. **455**, 21.
Doro, M., et al. (CTA collaboration), 2013, Astropart. Phys. **43**, 189.
Egorov, A., and E. Pierpaoli, 2013, Phys. Rev. **D88**, 023504.
Finkbeiner, D. P., M. Su, and C. Weniger, 2013, JCAP **1301**, 029.
Frandsen, M., U. Haisch, F. Kahlhoefer, P. Mertsch, and K. Schmidt-Hoberg, 2012, JCAP **1210**, 033.
Galli, S., F. Iocco, G. Bertone, and A. Melchiorri, 2009, Phys. Rev. **D80**, 023505.
Gleeson, L. J., and W. I. Axford, 1968, Astrophys. J. **154**, 1011.
Gordon, C. and O. Macias, 2013, arXiv:1306.5725.
van Haarlem, M., M. Wise, A. Gunst, G. Heald, J. McKean, et al., 2013, arXiv:1305.3550.
Hektor, A., M. Raidal, and E. Tempel, 2012, arXiv:1209.4548.
Hooper, D., I. Cholis, T. Linden, J. Siegal-Gaskins, and T. Slatyer, 2013, arXiv:1305.0830.
Hooper, D., and T. Linden, 2011, Phys. Rev. **D84**, 123005.
Hooper, D., and T. R. Slatyer, 2013, arXiv:1302.6589.
Huang, X., G. Vertongen, and C. Weniger, 2012, JCAP **1201**, 042.
Ibarra, A., A. Ringwald, and C. Weniger, 2009, JCAP **0901**, 003.
Ibarra, A., D. Tran, and C. Weniger, 2010, JCAP **1001**, 009.
Jungman, G., M. Kamionkowski, and K. Griest, 1996, Phys. Rept. **267**, 195.
Laha, R., K. C. Y. Ng, B. Dasgupta, and S. Horiuchi, 2013, Phys. Rev. **D87**, 043516.
Maccione, L., 2013, Phys. Rev. Lett. **110(8)**, 081101.
Malyshev, D. and D. W. Hogg, Astrophys. J. **738**, 181.
Mambrini, Y., M. Tytgat, and G. Zaharijas, 2012, JCAP **1211**, 038.
Pinzke, A., C. Pfrommer, and L. Bergström, 2011, Phys. Rev. **D84**, 123509.
Schmidt, J., C. Weniger, and T. T. Yanagida, 2010, Phys. Rev. **D82**, 103517.
Silverwood, H. et al, 2013, JCAP **1303**, 027.
Storm, E., T. E. Jeltema, S. Profumo, and L. Rudnick, 2013, Astrophys. J. **768**, 106.
Su, M., and D. P. Finkbeiner, 2012, arXiv:1206.1616.
Tempel, E., A. Hektor, and M. Raidal, 2012, JCAP **1209**, 032.
Vertongen, G., and C. Weniger, 2011, JCAP **1105**, 027.

Weniger, C., 2012, JCAP **1208**, 007.
Weniger, C., 2013, Proceedings 4th International Fermi Symposium, 28 Oct – 2 Nov 2012, Monterey.
Weniger, C., M. Su, D. P. Finkbeiner, T. Bringmann, and N. Mirabal, 2013, arXiv:1305.4710.
Whiteson, D., 2013, Phys. Rev. **D88**, 023530.
Wood, M., J. Buckley, S. Digel, S. Funk, D. Nieto, et al., 2013, arXiv:1305.0302.
Zwicky, F., 1933, Helv. Phys. Acta **6**, 110.

Cost estimates

3a. Budget

The maximum amount of a Vidi grant is € 800,000 spread over a period of 5 years. If the proposed research is of shorter duration, the maximum amount will be reduced accordingly.

Staff costs per project year in k€ incl. surcharge								
Scientific Staff	Intensity (fte)	Duration (months)	Project Year 1 k€	Project Year 2 k€	Project Year 3 k€	Project Year 4 k€	Project Year 5 k€	**TOTAL k€**
Applicant funded by Vidi grant	1,0	24				84,411	88,718	173,129
Applicant funded by institution	1,0	36	75,772	77,940	82,130			235,842
Postdoc 1	1,0	24		60,426	62,517			122,943
Postdoc 2	1,0	24				60,426	62,517	122,943
PhD student 1	1,0	48	39,958	46,557	49,982	52,381		188,878
PhD student 2	1,0	48		39,958	46,557	49,982	52,381	188,878
Sub total staff								**1032,613**
Non-staff costs in k€			Project Year 1 k€	Project Year 2 k€	Project Year 3 k€	Project Year 4 k€	Project Year 5 k€	**TOTAL k€**
Give a description of the non staff cost, as detailed as possible								
Domestic and international travel			6,000	11,000	11,000	11,000	9,000	48,000
Visitors			0,500	0,500	0,500	0,500	0,500	2,500
Books, publication charge			0,500	0,500	0,500	0,500	0,500	2,500
Sub total non-staff								**53,000**
TOTAL			122,730	236,881	253,186	259,200	213,616	**1085,613**
Total by Vidi grant								**800,000**

3b. Indicate the time (in fte) you will spend on the research (See Notes)
0,8 fte research; 0,2 fte teaching, organization and career development

3c. Intended starting date (See Notes)
1 October 2014

3d. Have you requested any additional grants for this project either from NWO or from any other institution? yes/no (if 'yes', see Notes)
No

3e. Has the same idea been submitted elsewhere? yes/no (if 'yes', see Notes)
No

Curriculum vitae

4a. Personal details

Title(s), initial(s), first name, surname: Dr., C, Christoph, Weniger
Gender: Male
Date and place of birth: 5 June 1980, Wuppertal, Germany
Nationality/ies: German
Birth country/ies of parents: Germany

4b. Master's ('Doctoraal')

University/College of Higher Education: University of Bonn, Germany
Date (dd/mm/yy): 11/10/2006
Studies: Theoretical Physics
Main subject: Condensed matter physics

4c. Doctorate

University/College of Higher Education: University of Hamburg
Starting date (dd/mm/yy): 01/11/2006
Completion date (dd/mm/yy): 03/02/2010
Supervisor ('promotor'): Dr. Andreas Ringwald
Title of thesis: "From SuperWIMPs to Decaying Dark Matter: Models, Bounds and Indirect Searches"

4d. Work experience since completing your PhD

Specify per appointment: number of fte, tenured term ('vast') / fixed-term ('tijdelijk').

From	To	Fte		Position	Institution
Mar 2010	Sep 2010	1,0	100% research	tijdelijk	DESY, Hamburg
Oct 2010	Sep 2012	1,0	100% research	tijdelijk	MPP, Munich
Oct 2012	Present	1,0	90% research, 10% education	tijdelijk (5 years), junior staff	Univ. Amsterdam

Months spent since completing your PhD (See notes for an example of the computation)

Experience	Number of months
Research activities	31*1,0*100% + 12*1,0*90% = 41.8 months
Education	12*1,0*10% = 1.2 months
Care or sick leave	0
Management tasks	0
Other, please specify	0

4e. Brief summary of your research over the last five years (max. 450 words)

[reference numbers as in 5a]

My research is driven by the question of what is the particle nature of dark matter (DM). To this end, I worked on a broad range of different subjects, including indirect and direct searches for DM, the analysis of astronomical data and the construction and phenomenological study of theories for DM.

Most recently, I concentrated on the analysis of gamma-ray data of the Fermi Large Area Telescope (LAT). I performed the first combined search for extended gamma-ray emission from nearby galaxy clusters, and investigated the impact of our results on gravitino DM [13]. I studied spectral features caused by monochromatic photons or virtual internal Bremsstrahlung, which are well-known smoking gun signatures for DM, and showed how a dedicated search can improve the sensitivity of Air Cherenkov Telescopes by an order of magnitude [14]. In Refs. [9, 10], I identified a sharp spectral feature at the Galactic center in the Fermi LAT gamma-ray data, with an energy around 130 GeV. This result was followed up by a large number of groups and generated a significant coverage in the international press. I showed that HESS-II has the potential to confirm or reject this signature in the near future [8], performed a comprehensive search for possible instrumental causes using Fermi LAT data [6], and studied the morphology and spectrum of the signature with a variety of innovative techniques [4, 7]. To date, it is unclear whether the feature is caused by an instrumental effect, a rare statistical fluke, or whether it is real. I proposed a modification of the LAT survey strategy in order to collect more data from the Galactic center and settle this question for good. This proposal was positively reviewed by the Fermi mission and will be likely adopted by December 2013. Lastly, I wrote a well-received review on gamma-ray searches for DM annihilation [7].

In Ref. [1], I showed that a spectral analysis of cosmic-ray positron data leads to extremely stringent limits on the annihilation of light DM particles. I demonstrated in Ref. [5] that hadronic final states give significant contribution to DM limits from the cosmic microwave background. In Refs. [17, 18] I found that light hidden sectors can solve the tension between thermal leptogenesis and primordial nucleosynthesis, in order to establish a consistent cosmology. I showed how classical Boltzmann dynamics follow from the Kadanoff-Baym equations that govern the dynamics of non-equilibrium quantum fields by adopting the Wentzel-Kramers-Brillouin approximation [11]. Lastly, I studied numerous (non-)supersymmetric particle physics models for DM, and their impact on structure formation, collider observables, indirect and direct searches [3, 7, 10, 12, 15, 16, 20, 23, 24].

4f. International activities (See Notes)
Activities since I obtained my Doctorate:

- Research visit at Institute for Physics and Mathematics of the Universe, Japan, March – May 2010 (Host: Prof. Hitoshi Murayama)
- Participant at "Dark matter underground and in the heavens" workshop, CERN, Geneva, Switzerland, July 2011
- Participant at "Dark matter and new physics" workshop at Kavli Institute for Theoretical Physics China, Beijing, September – October 2011
- Short-term research visit at Harvard-Smithsonian Institute for Astrophysics, Boston, March 2013 (Host: Prof. Douglas Finkbeiner)
- Short-term research visit at McGill University, Montreal, April 2013 (Host: Prof. Jim Cline)
- Short-term research visit at Fermilab, Chicago, April 2013 (Host: Prof. Dan Hooper)
- Participant at "Hunting for Dark Matter: Building a cross-disciplinary, multi-pronged approach" workshop at Kavli Institute for Theoretical Physics, Santa Barbara, United States, April – May 2013
- 20 invited seminars and colloquium talks: University of San Francisco (5/2013), Utah University (4/2013), Fermilab (4/2013), McGill University Montreal (4/2013), Harvard-Smithsonian Institute for Astrophysics (3/2013), University of Odense (2/2013), University of Padova (2/2013), APC Paris (2/2013), Oxford University (11/2012), University of Nottingham (11/2012), University of Basel (11/2012), SLAC Stanford (7/2012), UCSC California (7/2012), University of Montpellier (6/2012), CERN (4/2012), University of Brussels (3/2012), SISSA Trieste (3/2012), Stockholm University (1/2012), Madrid University (11/2011), IPMU, University of Tokyo (4/2010)
- 5 invited talks on international conferences and workshops: Workshop on the Future of Dark-Matter Astro-Particle Physics, Triest (scheduled 10/2013), Hunting for Dark Matter workshop, Santa Barbara (4/2013 and 5/2013), TeV Particle Astrophysics 2012, Mumbai (12/2012), Particle Physics and Cosmology 2012, Seoul (11/2012), 8th Patras Workshop on Axions, WIMPs and WISPs, Chicago (7/2012)
- 11 contributed talks at international conferences: 4th International Fermi Symposium, Monterey (11/2012), Cosmo 2012, Beijing (9/2012), Identification of Dark Matter 2012, Chicago (7/2012), 7th International Workshop on the Dark Side of the Universe, Beijing (9/2011), 12th International Conference on Topics in Astroparticle and Underground Physics, Munich (9/2011), TeV Particle Astrophysics 2011, Stockholm (8/2011), Fermi Symposium 2011, Rome (5/2011), 13th ICATPP Conference, Como (10/2010), 16th International Symposium on Particles, Strings and Cosmology, Valencia (7/2010), 5th Patras Workshop on Axions, WIMPs and WISPs, Durham (7/2009), 15th International Symposium on Particles, Strings and Cosmology (7/2009)
- more than 15 domestic (in Netherlands and Germany) invited/contributed talks and presentations

- I work with international collaborators from Belgium (Prof. Thomas Hambye, Université Libre de Bruxelles), Canada (Prof. Jim Cline, McGill University), France (Dr. Pasquale Serpico, Laboratoire d'Annecy-le-Vieux de Physique Théorique), Germany (Prof. Alejandro Ibarra, Technische Universität München and others), Japan (Prof. Tsutomu Yanagida, IPMU, Tokyo), Sweden (e.g. Prof. Lars Bergström, Stockholm University), United States (Prof. Douglas Finkbeiner, Harvard; Prof. Dan Hooper, Fermilab; Prof. Stefano Profumo, Satan Cruz)
- International press coverage includes Scientific American (9/2013), Scientific American (11/2012), Inside Science (11/2012), New Scientist (11/2012), Nature (11/2012), Physics World (4/2012), Scientific American (4/2012)
- I co-founded the GAMBIT (Global And Modular Beyond-the-Standard-Model Inference Tool) collaboration with about twenty-five international members from various fields of beyond-the-Standard-Model research. Our goal is to develop the world-leading next-generation software tool for *global scans*, which will allow to confront a large number of scenarios for physics beyond the SM (including various models for dark matter) with a combination of all relevant experimental results.

4g. Other academic activities (See Notes)

- Nov 2010 – Oct 2011: Supervision of exchange PhD student at MPP, Munich. Since Oct 2012: Supervision of one master and two PhD students at GRAPPA Institute.
- 29 June to 2 July 2013: Organization of the MITP Workshop "Cosmic-rays and photons from dark matter annihilation: Theoretical issues", together with Prof. Paolo Gondolo (Univ. of Utah).
- Referee for *Journal of Cosmology and Astroparticle Physics, Physics Letters B, Physical Review D, Monthly Notice of the Royal Astronomical Society, Nature.*
- Organization of a weekly journal club at the GRAPPA Institute, Univ. of Amsterdam, since June 2013.
- Workshops and lectures on indirect dark matter searches for undergraduate and graduate students at Univ. of Amsterdam (Nov 2012, Feb 2013, Jun 2013).

Academic staff supervised

PhDs	**Supervisor**	**Assistant supervisor**	
2 Ongoing	Prof. Gianfranco Bertone	Applicant	
1 Successfully completed	Prof. Xuelei Chen	Applicant	
			Subtotal **3**
Postdocs			
			Subtotal
Other			
			Subtotal

4h. Grants, scholarships and prizes

Grants

Grant Principal Investigator	**Amount**	**Year of award**
Subtotal		
Grant Co-Applicant		
Subtotal		

Scholarships

Scholarship Principal Investigator	**Amount**	**Year of award**
GRAPPA Fellowship	170 k€	2012
Subtotal	**170 k€**	
Scholarship Co-Applicant		
Subtotal		

Prizes

Prize Principal Investigator	**Amount**	**Year of award**
Ph.D. Prize 2010, awarded by "Association of the Friends and Supporters of DESY"	2 k€	2010
Best young researcher presentation at 9th International Conference "Identification of Dark Matter"	0,4 k€	2012
Subtotal	**2,4 k€**	
Prize Co-Applicant		
Subtotal		

List of publications

5a. Publications

Please number your publications consecutively and indicate the total number per category. Only mention those publications which have been published or have been accepted for publication starting with the most recent publication.

- **International (refereed) journals (25 articles)**
  author list is alphabetical by convention in most cases
  number of citations as of 26 Sep 2013 on http://inspirehep.net

1) *New limits on dark matter annihilation from AMS cosmic ray positron data*
   Lars Bergström, Torsten Bringmann, Ilias Cholis, Dan Hooper, Christoph Weniger
   Accepted for Physical Review Letters. (7 citations)

2) *Indirect Searches for Decaying Dark Matter*
   Alejandro Ibarra, David Tran, Christoph Weniger
   To appear in International Journal of Modern Physics A. (3 citations)

3) *Update on scalar singlet dark matter*
   James M. Cline, Kimmo Kainulainen, Pat Scott, Christoph Weniger
   Accepted for Physical Review D. (12 citations)

4) *A Clustering Analysis of the Morphology of the 130 GeV Gamma-Ray Feature*
   Eric Carlson, Tim Linden, Stefano Profumo, Christoph Weniger
   Physical Review **D88,** 043006 (2013). (2 citations)

5) *CMB bounds on dark matter annihilation: Nucleon energy-losses after recombination*
   Christoph Weniger, Pasquale D. Serpico, Fabio Iocco, Gianfranco Bertone
   Physical Review **D87**, 123008 (2013). (5 citations)

6) *Is the 130 GeV Line Real? A Search for Systematics in the Fermi-LAT Data*
   Douglas P. Finkbeiner, Meng Su, Christoph Weniger
   Journal of Cosmology and Astroparticle Physics **1301** (2013) 029. (42 citations)

7) *Gamma Ray Signals from Dark Matter: Concepts, Status and Prospects*
   Torsten Bringmann, Christoph Weniger
   Physics of the Dark Universe **1** (2012) 194-217. (47 citations)

8) *Investigating Gamma-Ray Lines from Dark Matter with Future Observatories*
   Lars Bergstrom, Gianfranco Bertone, Jan Conrad, Christian Farnier, Christoph Weniger
   Journal of Cosmology and Astroparticle Physics **1211** (2012) 025. (30 citations)

9) *A Tentative Gamma-Ray Line from Dark Matter Annihilation at the Fermi Large Area Telescope*
   Christoph Weniger
   Journal of Cosmology and Astroparticle Physics **1208** (2012) 007. (200 citations)

10) *Fermi LAT Search for Internal Bremsstrahlung Signatures from Dark Matter Annihilation*
    Torsten Bringmann, Xiaoyuan Huang, Alejandro Ibarra, Stefan Vogl, Christoph Weniger
    Journal of Cosmology and Astroparticle Physics **1207** (2012) 054. (168 citations)

11) *The Boltzmann Equation from Quantum Field Theory*
    Marco Drewes, Sebastian Mendizabal, Christoph Weniger
    Physics Letters **B718** (2013) 1119-1124. (10 citations)

12) *Indirect dark matter searches as a probe of degenerate particle spectra*
Masaki Asano, Torsten Bringmann, Christoph Weniger
Physics Letters **B709** (2012) 128-132. (19 citations)

13) *Probing Dark Matter Decay and Annihilation with Fermi LAT Observations of Nearby Galaxy Clusters*
Xiaoyuan Huang, Gilles Vertongen, Christoph Weniger
Journal of Cosmology and Astroparticle Physics **1201** (2012) 042. (35 citations)

14) *On the Relevance of Sharp Gamma-Ray Features for Indirect Dark Matter Searches*
Torsten Bringmann, Francesca Calore, Gilles Vertongen, Christoph Weniger
Physical Review **D84** (2011) 103525. (34 citations)

15) *Hunting Dark Matter Gamma-Ray Lines with the Fermi LAT*
Gilles Vertongen, Christoph Weniger
Journal of Cosmology and Astroparticle Physics **1105** (2011) 027. (61 citations)

16) *Gamma-Ray Lines from Radiative Dark Matter Decay*
Mathias Garny, Alejandro Ibarra, David Tran, Christoph Weniger
Journal of Cosmology and Astroparticle Physics **1101** (2011) 032. (23 citations)

17) *Dynamical Matter-Parity Breaking and Gravitino Dark Matter*
Jonas Schmidt, Christoph Weniger, Tsutomu T. Yanagida
Physical Review **D82** (2010) 103517. (7 citations)

18) *Supersymmetric Leptogenesis with a Light Hidden Sector*
Andrea De Simone, Mathias Garny, Alejandro Ibarra, Christoph Weniger
Journal of Cosmology and Astroparticle Physics **1007** (2010) 017. (13 citations)

19) *Constraining Decaying Dark Matter with Fermi LAT Gamma-rays*
Le Zhang, Christoph Weniger, Luca Maccione, Javier Redondo, Gunter Sigl
Journal of Cosmology and Astroparticle Physics **1006** (2010) 027. (31 citations)

20) *Intense Gamma-Ray Lines from Hidden Vector Dark Matter Decay*
Chiara Arina, Thomas Hambye, Alejandro Ibarra, Christoph Weniger
Journal of Cosmology and Astroparticle Physics **1003** (2010) 024. (37 citations)

21) *Detecting Gamma-Ray Anisotropies from Decaying Dark Matter: Prospects for Fermi LAT*
Alejandro Ibarra, David Tran, Christoph Weniger
Physical Review **D81** (2010) 023529. (41 citations)

22) *Decaying Dark Matter in Light of the PAMELA and Fermi LAT Data*
Alejandro Ibarra, David Tran, Christoph Weniger
Journal of Cosmology and Astroparticle Physics **1001** (2010) 009. (78 citations)

23) *Cosmic Rays from Leptophilic Dark Matter Decay via Kinetic Mixing*
Alejandro Ibarra, Andreas Ringwald, David Tran, Christoph Weniger
Journal of Cosmology and Astroparticle Physics **0908** (2009) 017. (59 citations)

24) *Hidden gauginos of an unbroken U(1): Cosmological constraints and phenomenological prospects*
Alejandro Ibarra, Andreas Ringwald, Christoph Weniger
Journal of Cosmology and Astroparticle Physics **0901** (2009) 003. (53 citations)

25) *Alpenglow - A Signature for Chameleons in Axion-Like Particle Search Experiments*
Markus Ahlers, Axel Lindner, Andreas Ringwald, Lily Schrempp, Christoph Weniger
Physical Review **D77** (2008) 015018. (46 citations)

- **National (refereed) journals**
- **Books**
- **Book chapters**
- **Patents**
- **Other**

Papers in preparation:

Cosmological bounds on mixed hot+cold dark matter
Meng Su, Christoph Weniger

The trial penalty for optimization on data
Christoph Weniger, Michael Gustafsson

Whitepapers / Proposals:

Closing in on the Fermi Line with a New Observation Strategy
Christoph Weniger, Meng Su, Douglas P. Finkbeiner, Torsten Bringmann, Nestor Mirabal
Whitepaper for change of the Fermi LAT survey strategy. Submitted to the Fermi mission.

Conference Proceedings:

Gamma-ray lines in the Fermi-LAT data?
Christoph Weniger
4th International Fermi Symposium. 28 Oct – 2 Nov 2012, Monterey, USA.

Tentative observation of a gamma-ray line at the Fermi LAT
Christoph Weniger
AIP Conf. Proc. **1505** (2012) 470-473.

Spectral cutoffs in indirect dark matter searches
Christoph Weniger, Torsten Bringmann, Francesca Calore, Gilles Vertongen
J. Phys. Conf. Ser. **375** (2012) 012034.

Galaxy Clusters and Gamma-Ray Lines: Probing Gravitino Dark Matter with the Fermi LAT
Xiaoyuan Huang, Gilles Vertongen, Christoph Weniger
2011 Fermi Symposium proceedings. 9-12 May 2011, Rome, Italy.

Supersymmetric leptogenesis and light hidden sectors
Christoph Weniger
J. Phys. Conf. Ser. **259** (2010) 012075.

Gamma-ray anisotropies from decaying dark matter
Christoph Weniger
Conference on Cosmic Rays for Particle and Astroparticle Physics. 7-8 Oct 2010, Como, Italy

Dark Matter Decay and Cosmic Rays
Christoph Weniger
5th Patras Workshop on Axions, WIMPs and WISPs. 13-17 Jul 2009, Durham, UK.

5b. Median impact factors for your own field

Compulsory for ZonMw-applications. For other NWO-divisions, this is only compulsory if you have mentioned impact factors of the journal under question 5a (See Notes).

5c. Top 5 publications (See Notes)

1) *A Tentative Gamma-Ray Line from Dark Matter Annihilation at the Fermi Large Area Telescope*
   Christoph Weniger
   Journal of Cosmology and Astroparticle Physics **1208** (2012) 007. (200 citations)

2) *Fermi LAT Search for Internal Bremsstrahlung Signatures from Dark Matter Annihilation*
   Torsten Bringmann, Xiaoyuan Huang, Alejandro Ibarra, Stefan Vogl, Christoph Weniger
   Journal of Cosmology and Astroparticle Physics **1207** (2012) 054. (168 citations)

3) *Decaying Dark Matter in Light of the PAMELA and Fermi LAT Data*
   Alejandro Ibarra, David Tran, Christoph Weniger
   Journal of Cosmology and Astroparticle Physics **1001** (2010) 009. (78 citations)

4) *Cosmic Rays from Leptophilic Dark Matter Decay via Kinetic Mixing*
   Alejandro Ibarra, Andreas Ringwald, David Tran, Christoph Weniger
   Journal of Cosmology and Astroparticle Physics **0908** (2009) 017. (59 citations)

5) *Hunting Dark Matter Gamma-Ray Lines with the Fermi LAT*
   Gilles Vertongen, Christoph Weniger
   Journal of Cosmology and Astroparticle Physics **1105** (2011) 027. (61 citations)

Statements by the applicant

Ethical aspects

	Not applicable	Not yet applied for	Applied for	Received
Approval from a recognised medical ethics review committee	x			
Approval from an animal experiments committee	x			
Permission for research with the population screening Act	x			

If applicable you need to send a copy of (one of) the aforementioned documents to NWO when your application has been granted and before your project can start.

By signing this form I endorse the code of conduct for laboratory animals and the code of conduct for biosecurity/possibility for dual use of the expected results and will act accordingly if applicable.

I have completed this form truthfully

Name: Christoph Weniger

Place: Amsterdam

Date: 4 Oct 2013

Please submit the application to NWO in electronic form (pdf format is required!) using the Iris system, which can be accessed via the NWO website (www.nwo.nl/vi). The only exception to this rule concerns applications within the Medical Sciences. The Medical Sciences division uses a similar system called ProjectNet, to which access is provided via the division's own website (www.zonmw.nl). For any technical questions regarding submission, please contact the Iris helpdesk (iris@nwo.nl).
