DOCUMENT 1

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MARIE SKŁODOWSKA-CURIE ACTIONS

Individual Fellowships (IF)
Call: H2020-MSCA-IF-2016

PART B

“TAcc-NeXB”

This proposal is to be evaluated as:

[Standard EF]

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In drafting PART B of the proposal, applicants must follow the structure outlined below.

DOCUMENT 1 (13-PAGE LIMIT APPLIED)

DOCUMENT 2 (NO OVERALL PAGE LIMIT APPLIED)

Please note that:

- *Applicants must ensure that document 1 does not exceed the total page limit of 13 pages. The Start Page must consist of 1 whole page. The Table of Contents must consist of 1 whole page. The List of Participating Organisations must consist of 1 whole page. Section 1 must start on page 4 of the document. Expert evaluators will be instructed to disregard any excess pages above the 10 page limit. Such excess pages will be watermarked.*
- *No reference to the outcome of previous evaluations of a similar proposal should be included in the text. Experts will be strictly instructed to disregard any such references.*

List of Participating Organisations

Please provide a list of all participating organisations (both beneficiaries and, where applicable, partner organisations[1]) indicating the legal entity, the department carrying out the work and the supervisor.

If a secondment in Europe is planned but the partner organisation is not yet known, as a minimum the type of organisation foreseen (academic/non-academic) must be stated.

For non-academic beneficiaries, please provide additional data as indicated in the table below.

Participating organisations	**Legal Entity Short Name**	**Academic**	**Non-academic**	**Country**	**Dept./ Division / Laboratory**	**Supervisor**	**Role of Partner Organisation[2]**
<u>Beneficiary</u>							
Katholieke Universiteit Leuven	KU Leuven	X		Belgium	CmPA, Dept. of Mathematics	Rony Keppens	
<u>Partner Organisation</u>							
- NAME							

Data for non-academic beneficiaries

Name	**Location of research premises (city / country)**	**Type of R&D activities**	**No. of full - time employees**	**No. of employees in R&D**	**Web site**	**Annual turnover (approx. in Euro)**	**Enterprise status (Yes/No)**	**SME status[3] (Yes/No)**

Please note that:

- Any inter-relationship between the participating organisation(s) or individuals and other entities/persons (e.g. family ties, shared premises or facilities, joint ownership, financial interest, overlapping staff or directors, etc.) **must** be declared and justified **in this part of the proposal**;
- The information in the table for non-academic beneficiaries **must be based on current data, not projections**.

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[1] All partner organisations should be listed here, including secondments

[2] For example hosting secondments, for GF hosting the outgoing phase, etc.

[3] As defined in Commission Recommendation 2003/361/EC.

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1. Excellence[4]

1.1 Quality and credibility of the research/innovation action (level of novelty, appropriate consideration of inter/multidisciplinary and gender aspects)

In the 2000's, simulations giving birth to wind-capture discs have been observed for symbiotic binaries, a family of binary systems where the two bodies are of stellar size and where the stellar wind is much slower than for massive stars (see eg Abate+13[5]). Since the accretor is much larger than in X-ray binaries (where we deal with a 10kms neutron star), the scale discrepancy is small enough to grasp both the shock and the accretor within the same simulation space. Those simulations brought insightful comments concerning the long-puzzling formation of barium stars, the shaping of planetary nebulae and the evolutionary path to the progenitors of Type Ia supernovae.

I want to carry on a similar investigation but in Supergiant X-ray Binaries (SgXB) hosting a neutron star (NS) where the scale discrepancy is way more important. In those systems, the mass transfer proceeds through the intense wind of the evolved OB Supergiant : it is called wind accretion. Several authors considered either an anomalously fast wind (Lora-Clavijo+13[6]) or an excessively large NS (Blondin+12[7]) to bypass this numerical obstacle but none has designed a consistent scheme to connect the orbital and accreting scales (resp. 10 billions of kilometres and 10 kilometres in realistic X-ray binaries). This multi-scales monitoring is a necessary condition to disentangle the phenomena responsible for the impressive time-variability we observe in those systems : is the stellar wind homogeneous? What is the influence of the X-ray radiative feedback on the shock? Is the shock stable? Does the flow form a disc around the accretor in spite of its low angular momentum? If not, what is the geometry of the accreted flow once it enters the NS magnetosphere? As we study those physical questions, we bring up hints about observational unexplained features such as the origin of the log-normal distribution in time of the X-ray luminosity in X-ray binaries, the correlations between the spectral and photometric time-variability or the evolutionary tracks over secular time scales of those systems.

My approach is to identify the dominant physical ingredients at each scale : from the ballistic wind at the orbital scale to the neighbourhood of the NS, dominated by its magnetic and gravitational fields (with departures from the non-relativistic theory), the computational algorithms we must rely on evolve a lot in complexity. For the last three years, I have managed to cover the orbital and intermediate scales. For the latter, I characterized a test-case planar hydrodynamical (HD) shock and the properties pertaining to mass accretion with Fabien Casse (APC, FR) in El Mellah & Casse 2015[8], using analytical predictions on the topology of the flow (Foglizzo+96[9]) as guidelines to ensure the robustness

[4] Literature should be listed in footnotes, font size 8 or 9. All literature references will count towards the page limit.
[5] Abate C., Pols O. R. et al 2013, A&A 552, A26
[6] Lora-Clavijo F. D. & Guzman F. S. 2013, MNRAS 429, 3144
[7] Blondin J. & Raymer E. 2012, AJ 752, 30
[8] El Mellah I. & Casse F. 2015, MNRAS 454, 2657
[9] Foglizzo T. & Ruffert M. 2013, A&A 361, 22

of our mesh-based code, MPI-AMRVAC (Porth+14[10]). This study has relied on a grid specifically designed to uniformly span up to 5 orders-of-magnitude in space, equivalent to 17 levels of refinement in AMR (Adaptive Mesh Refinement). At a larger scale, I identified the structure of the stellar wind in a SgXB, its likelihood to form a disc and the essential parameters it depends on (El Mellah & Casse 2016[11]) ; it enabled me to suggest self-consistent sets of observational parameters for several systems, such as the mass of the NS. The latter has been a long-standing question which connects to the still unknown equation-of-state of matter within those degenerated objects. Constrains on the maximum mass of a NS decide the viability of the models (relying on empirical coupling between General Relativity and Quantum Chromodynamics) and could lead to a major breakthrough in fundamental Physics.

I am now piping those results into 3D HD simulations of the NS vicinity to use physically-motivated sheared outer boundary conditions rather than a planar flow to monitor the accretion of angular momentum. Those demanding High Performance Computing (HPC) numerical simulations lie at the crossroad of :

- the modern international supercomputing facilities (organized in the PRACE – for Partnership for Advanced Computing in Europe),
- the on-going discoveries in Applied Mathematics (for the solving schemes of the underlying partial differential equations),
- the synthetic numerical models I design to save computing time while still retaining the essential physical features of the problem.

Since I was granted computing hours on the CINES supercomputers (part of the PRACE network) and that the MPI-ARMVAC code contains the most recent numerical solvers, the challenge is now to make an affordable numerical setup to address the flow within the shock. There, the flow (now a plasma due to photo-ionization) is likely to either form a disc or to couple to the NS magnetic field. To answer this question, I need to adapt the available magneto-HD (MHD) solvers to the multi-scales meshes I designed (see WP 3).

The plasma dynamics within the NS magnetosphere is a burning topic in high energy Astrophysics but the current numerical simulations focus on the innermost parts without coupling them with the upper scales, dominated by stellar physics. The approach I have undergone could enable to bridge the gap between the two communities and sparkle new interdisciplinary collaborations between high energy, stellar and plasma Astrophysics (the core domain of my host institution). In particular, I am willing to promote my results to the NS community and trace back the consequences of their fruitful though autonomous results to the orbital scale : given the coupling I will find between the scales, what is the expression at large scale of the instabilities they identified within the magnetosphere? How do they affect the flow upstream? Ultimately, this comprehensive sketch of wind accretion is prone to join the question of jet-launching conditions, a vastly explored and fertile ground of contemporary research with a wide range of career opportunities and applications (microquasars, active galactic nuclei, young stellar objects...).

[10] Porth O., Xia C. et al 2014, APJS 214, 4
[11] El Mellah I. & Casse F. 2016, being reviewed

1.2 Quality and appropriateness of the training and of the two way transfer of knowledge between the researcher and the host

Given its international renown, KU Leuven, and the Centre for mathematical Plasma Astrophysics (CmPA) in particular attract plenty of visiting scholars acknowledged for their major accomplishments. It is the occasion for many of them to provide advanced seminars and courses on specific techniques of direct use for my research. As an example, Prof. Paul Gibbon from the Jülich Supercomputing Centre, author of a reference book in plasma Physics[12], is expected to give several sessions on particle-based parallel programming in late 2017. These methods could bring me tools to extend the scope of my simulations to other burning topics such as cosmic rays acceleration at shocks (Spitkovsky08[13]) or Monte-Carlo monitoring of photons in optically thick environments (Commerçon+14[14]). The Flemish Supercomputer Centre (VSC) also offers dedicated trainings I plan to attend on HPC and coding (Message Passing Interface language, code performance analysis tools, etc).

In addition of those formal courses, I will take advantages of the specific expertise of the CmPA which hosts, among other Prof. Stefaan Poedts, author of two reference books on MHD[15,16]. The CmPA division is among world leading institutes which pay specific attention to HD and plasma physical processes that work across many spatial and temporal scales, ranging from those encountered in laboratory, magnetospheric, solar, or heliospheric gases and plasmas, all the way to the more exotic physics found in eg pulsar winds or in connection with active galactic nuclei. I am willing to reinforce the capacity of the team to consistently deal with several scales in three ways :

- A numerical one, by coupling the multi-scales meshes I developed with the dynamical AMR option of the MPI-AMRVAC code. I will also consider the possibility to implement Adaptive Time Stepping (ATS) to make this code the optimal tool to explore multi-scales phenomena on a non-Cartesian mesh, a long-awaited tool within the Astrophysics community[17].
- A computational one, by using the skills I have developed during my PhD to monitor CPU activity and optimize the computing performance of HPC simulations using advanced tools such as the Vampir profiler. Indeed, sophisticated hardware technologies require smart load balancing between processors and nodes to be used at their maximal capacity.
- A physical one, by identifying the relevant flow numbers and the self-similar scales and piping them to the scale-variant domains while still retaining the simple most physical framework. This skill I developed during my PhD already turned profitable when I proceeded in this way to design a synthetic model of wind accretion in SgXB (El Mellah & Casse 2016[11]).

[12] Short Pulse Laser Interactions with Matter : An Introduction, P. Gibbon, Imperial College Press
[13] Spitkovsky A. 2008, ApJ 682, 8
[14] Commerçon B., Debout V. & Teyssier R. 2014, A&A 563, 11
[15] Principles of MHD, Goedbloeb J. P. & Poedts S., 2004
[16] Advanced MHD, Goedbloeb J. P., Keppens R. & Poedts S., 2010
[17] Cosmologists have developed their own multi-scales Cartesian codes for the last decade (see eg the RAMSES code) but it does not fit the Astrophysical needs, where systems are generally centred and non-isotropic, contrary to the Universe.

1.3 Quality of the supervision and of the integration in the team/institution

The supervisor for this project, Prof. Rony Keppens, has extensive experience in computational solar and astrophysics, and in participating in and managing research projects. His international career includes PhD research at the National Centre for Atmospheric Research (1991-1994, High Altitude Observatory, Boulder, US), postdoc experience at the Kiepenheuer Institute for Solar Physics (Freiburg, GR) and group leadership (2001-2005) in Numerical Plasma Dynamics at the FOM Institute for Plasma Physics Rijnhuizen (currently DIFFER, Eindhoven, NL). He held full professor level appointments at Utrecht University (NL) and as Astronome at Observatoire de Paris (FR), and has been a tenured professor at KU Leuven since 2006. He received a concurrent professorship (2013-2016) at Nanjing University (CN), enhancing Belgian-Chinese research efforts in solar and plasma physics. At KU Leuven, he has chaired the CmPA (about 35 researchers with 5 permanent staff members) since 2009. He has been involved in many national and international interdisciplinary research projects, and currently coordinates an Inter-University Attraction Pole network with 7 partners (IUAP FP7/08 CHARM 2012-2017, 3 Meuro). He acted as promotor for 8 completed PhDs, and currently supervises 5 ongoing PhDs and 5 postdocs. He contributed to over 200 scientific publications (ADS search on 10/8/2016 yields 202 entries, 2652 citations, H-index 30), among which a Cambridge University Press book on Advanced MHD (2010).

He is contact point and co-developer for the open-source MPI-AMRVAC code, used for massively parallel, grid-adaptive computations. With his team, he is actively researching plasma dynamics in astrophysical jets and accretion discs, studies solar prominences, coronal rain, and space weather phenomena, and has expert know-how on MHD waves and instabilities in plasmas and on state-of-the-art numerical algorithmic approaches.

In the last decade, the CmPA has gained worldwide recognition for its pioneering role in HPC, with several PRACE funded projects running on Tier 0 platforms. A postdoctoral stay as a Marie Curie fellow at the KU Leuven CmPA will allow me to join and interact with the core developer team of the open source code effort MPI-AMRVAC. This software is ideally suited for high performance computing, and has a build-in versatility in its applications. This versatility has been key for my own PhD research, where I added functionalities that were not available in the public release such as customized user-defined grids. During my latest visit in April 2016 to the CmPA, we transferred this functionality to the public release, and can now fully exploit this feature in block grid-adaptive fashion. As a postdoc, I plan to make further improvements to the discretization schemes that are absolutely vital for my application on X-ray binary physics, such as encoding angular momentum conservation at machine precision, making Python tools for post-processing large data volumes, working with state-of-the-art visualization tools, etc.

The diversity in the plasma physical expertise of its 40 team members ranges from pure analytic modelling of wave and instabilities in especially solar contexts, to the study of winds and jets associated with massive stars or accreting configurations, over fundamental know-how on MHD descriptions of plasmas. The step to full scale MHD modelling of the X-ray binary accretion processes will thus fit seamlessly with the research ambitions of the division as whole, while it is as yet uncharted territory for the kind of numerical simulations I envision in this project. Close collaboration is foreseen with postdocs Chun Xia (general MPI-AMRVAC code development, specific attention to solar physics applications), Kirit Makwana (developing coupled fluid-kinetic treatments for reconnection physics), Matthieu Leroy (Hall-MHD applications, Earth magnetosphere physics) and Jannis Teunissen (FWO funded postdoc since summer 2016, focus on plasma discharges and coupled elliptic-hyperbolic problems on adaptive meshes).

1.4 Capacity of the researcher to reach or re-enforce a position of professional maturity/independence

My academic accomplishments as a student (Ecole Normale Supérieure, ranked 2nd in 1,409 candidates at the Agrégation) have shown my ability to develop a clear and rigorous reasoning to address challenging questions. My research experience at MIT (US) on stellar binaries (S. Rappaport et al, 2013[18]) and exoplanets (S. Rappaport et al 2012[19], R. Sanchis-Ojeda et al 2014[20]) has been a firm basis for my PhD that I have just finished and where I have taken the most of HPC simulations to tackle specific questions on X-ray binaries. I have delimited the two main regimes of mass transfer depending on the parameters of the system (El Mellah & Casse 2016[11]) and I had previously characterized the shock produced by a gravitationally beamed planar flow (El Mellah & Casse 2015[8]). I am now in a suitable position to pursue this journey towards the innermost regions of the accreted flow, in the neighbourhood of the compact object, provided I can join a team with the required numerical MHD skills. It is precisely the reason why I think the CmPA at KU Leuven is an ideal place to address the coupling between the plasma within the shocked region and the NS magnetosphere. Besides, the links with observers I have piled up during my year in the US can be reinforced thanks to the strong links of Rony Keppens with the astronomers of the Institute of Astronomy of KU Leuven (eg he co-supervises a postdoctoral position with Leen Decin).

2. Impact

2.1 *Enhancing the potential and future career prospects of the researcher*

The research project I want to carry on in Leuven will make the most of the leading-edge skills gathered and improved at the CmPA. Few places in the world are so firmly turned towards the use of numerical simulations as a proper reasoning step in a scientific discussion as the CmPA. I personally advocated in favour of the rise of a computational epistemology in the introduction of my PhD manuscript ; it still requires to push HPC simulations to the limit, in particular in extreme physical environments such as X-ray binaries, planetary magnetospheres or the stellar corona, three topics addressed by the staff at the CmPA.

The competences I will acquire in this team (see section 1.2 and 1.3) will make me a decisive asset to tackle the question brought up by the observations made

[18] Rappaport S., Deck K., Levine A., Borkovits T. et al 2013, ApJ 768, 33
[19] Rappaport S., Levine A., Chiang E., El Mellah I. et al 2012, ApJ 752, 1
[20] Sanchis-Ojeda R., Rappaport S., Winn J., Kotson M. et al 2014, ApJ 787, 47

by the current (FERMI, INTEGRAL) and future (SVOM, LOFT, ATHENA) generations of satellites. The evolution of the data available over the last decade suggests an incoming inflation of the number of X-ray binaries as the sensitivity of the instruments rise (Walter+15[21]). On the other hand, a selective pool of young numerical astrophysicists has been bred by a few precursors such as Rony Keppens. I am willing to fit my career into this promising track of explaining the plethora of available and incoming observational data with the numerical tool. If I was first introduced to HD and radiative simulations by Fabien Casse in Paris, I now plan to obtain reliable MHD simulations of the vicinity of a NS undergoing accretion thanks to Prof. Keppens' expertise. Since I characterized the large orbital scale during my PhD (El Mellah & Casse 2016[11]), it would make me one of the few able to bridge the gap between the stellar Physics which dominates the orbital dynamics and the NS magnetosphere. Teams such as Sera Markoff's (University of Amsterdam, NL) or Alexander Tchekhovskoy's (UC Berkeley, US) ones have been extensively exploring the latter and might take advantage of my unique profile to use a physically-motivated coupling with the large scale to orientate their research. I intend to set the conditions for this mutual feeding between NS studies and X-ray binaries models. On the other hand, the tools I will acquire thanks to my secondment will make it possible for me to characterize the instabilities and follow their growth (linear and non-linear), an ability more and more required as numerical simulations grow in complexity : being able to extract the physically meaningful information out of a seemingly cumbersome simulation is a precious prerequisite for the established instability community – Thierry Foglizzo (CEA, FR) and John Blondin (NC State University, US) for instance.

Aside of this core knowledge I wish to assimilate, the experience I will acquire in using the modern tools of HPC simulations analysis (eg parallel 3D visualization, selective post-processing to save memory) and communication tools (eg web interfaces as complimentary material to share results within the community, augmented reality in articles and posters) will boost my early career and highly participate in the multiplication of prospects I will be offered.

2.2 *Quality of the proposed measures to exploit and disseminate the action results*

The dissemination strategy for my technical deliverables (code development, simulation data, visualisation tools…) is twofold :

- as an active member of the MPI-AMRVAC code community, I follow the philosophy of the group which is to make the code and its annual updates free, open (with source files easy to access via GitLab) and well documented. A couple of my own code developments have been implemented in the official version (grid stretching and axisymmetric configurations)

- I also make my personal data and the Spyre web visualisation interface I developed available on demand or via my personal webpage to further explore the results I describe in my articles. Access and re-use of the data, in agreement with the Horizon 2020 prioritites, are guaranteed thanks to the storage policies of the supercomputing facilities I work on (see sections 3.2 and 3.3).

[21] Walter R., Lutovinov A., Bozzo E. & Tsygankov S. 2015, A&A Rev. 23, 2

Concerning the scientific conclusions I will draw from this raw material and technical tools, I will share different levels of details depending on the events I will attend and the documents I will rely on :

- two to three times a year, I will use the mobility grant of the Marie SKŁODOWSKA-CURIE EF to give seminars to specialists in the world leading laboratories in high energy and plasmas Astrophysics : Princeton University (US) with Jim Stone, UC Berkeley (US) with Eugene Chiang and Alexander Tchekhovskoy, the Max Planck Institutes for Astrophysics and Extreterrestrial Physics (DE) with Jason Dexter, the Niels Bohr Institute (DK) with Martin Pessah, the Observatory of Paris (FR) with Frédéric Vincent and the Observatory of Nice (FR) with Héloïse Méheut. During 30 to 50 minutes talks, I will discuss the precise aspects of the theoretical side of my research. On the other hand, I also intend, more sporadically, to present the sections of my work which are of direct use for observers such as Patrizia Romano's team at the Institute of Astrophysics of Palermo (IT). Because the observers' scientific interests orientate the fundings for new space missions, this step of my dissemination strategy will indirectly contribute to the technological innovation and economic growth at stake in any major Physics instrument.

- at an intermediate scale, I will attend local conferences and workshops to emphasize my main results to colleagues I still have to meet. It will be an occasion to enlarge my social scope and possibly to discover connected topics where my work could prove useful. In particular, I will be part of the InterUniversity Attraction Pole CHARM network (for Contemporary challenges for Heliospheric and AstRophysical Models) whose Prof. Keppens is a key member.

- to improve my visibility within the community as a whole, I will design oral presentations and posters for a broader audience. I will synthetize my results and apply to the main international conferences twice a year : the 44th European Physics Society conference on plasma Physics (June 2017, UK), the 29th Texas symposium on relativistic Astrophysics (December 2017, ZA), the 30th International Astronomical Union general assembly (August 2018, AT) and the 42nd COSPAR scientific assembly (2018).

2.3. Quality of the proposed measures to communicate the action activities to different target audiences

Beyond the communication of my results within the scientific community, I am willing to devote part of my working time (10 to 15%) to teaching and public outreach. For the latter, I will apply to the Planetarium of Brussels which shares privileged links with KU Leuven 20kms away through the Belgium Federal Science Policy Office (BELSPO). There, I could either support the development of an exhibition or give a public talk on high energy Astrophysics (possibly in French, my native tongue). Another possibility is to give seminars at the Cozmix, the public observatory of Bruges, very active in promoting Science to a large and indiscriminate audience. Finally, KU Leuven sponsors the yearly Flemish Science Week which aims at introducing middle and high school students to specific problematics. I wish to present the didactical material I developed to explain the Roche formalism (a Mathematica applet with 3D printed surfaces), as I did for the French Science festival in October 2015.

My academic accomplishments (see 1.4) and my experience (monitorat with ~100 hours per year during my PhD, private tutoring) have made me particularly fitted for higher education teaching. My future supervisor is in charge of two Master courses he is willing me to join as a teaching assistant :

- In the first semester, the course GOB30A – Computational Methods for Astrophysical application. Its aim is to introduce incoming graduate students to advanced numerical techniques to address problems of fluid dynamics, radiative transfers, etc. The second part of the course is made of hand-on sessions with the MPI-AMRVAC code.
- In the second semester, the course GOW48A – Research Projects in Theoretical Astrophysics (with Leen Decin from the Institute of Astronomy of KU Leuven). Students are driven in an investigation of an astrophysical contemporary problem through bibliographic work, reappropriation of the results and exploration of their own insights.

If the occasion presents, I would be glad to personally monitor an encouraging student for a pre-PhD internship over a few months.

3. Quality and Efficiency of the Implementation

3.1 Coherence and effectiveness of the work plan

Each of those WP will imply, as a main milestone, a submission to a peer-reviewed international journal (MNRAS, A&A, ApJ, etc).

<u>WP 1 : The shock</u>

The aim is to characterize the 3D structure of the shock around the accretor as a function of the Mach number of the incoming flow and to study its stability with Thierry Foglizzo (CEA, FR). In the 2000’s, T. Foglizzo et al showed that a resonant cavity can form between the shock and the sonic surface, the latter being typically 100 to 10,000 times closer from the accretor. The numerical study of this configuration has revealed how important this mechanism can be, with a possible application to the case of core-collapse supernovae. I plan to export this study to an axisymmetric configuration and monitor the non-linear growth and saturation of this advective-acoustic cycle. I also intend, with Allard Jan Van Marle (APC, FR), to evaluate the impact of self-ionization on the shock structure and the possibility for the shocked flow to form a disc-like structure around the accretor. The main deliverables are :

1. A first 3D multi-scales shock where numerical artefacts are under control.
2. X-ray luminosity diagram of the accreted flow, comparison to observations.
3. Characterization of a possible disc-like structure (poster).
4. Stability of the shock with respect to the advective-acoustic cycle and to the self-ionizing feedback.

<u>WP 2 : A clumpy wind</u>

The stellar wind itself is expected to display a certain level of inhomogeneity whose influence on the shock remains to be investigated. Ducci+2009[22] carried on a statistical study of its average influence on the accretion process and I intend to use their results to represent the "clumps" in the wind and follow them as they get accreted. The main deliverables are :

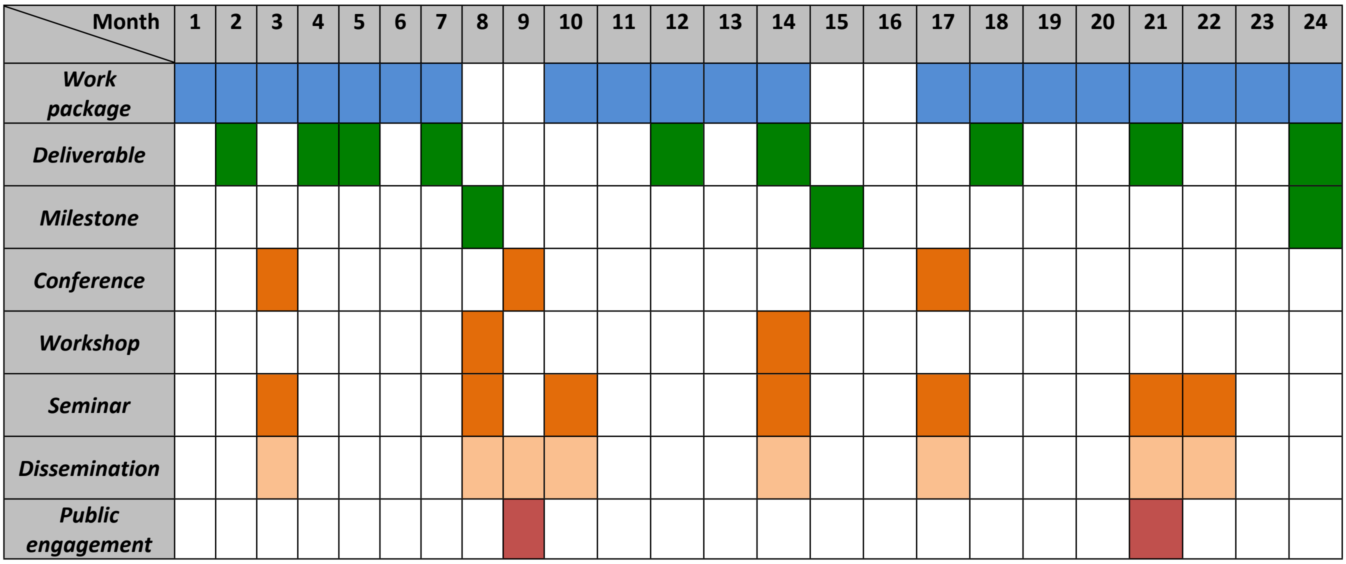
1. X-ray luminosity diagram of the accreted flow.
2. Evaluation of the influence of a clumpy wind on the stability of the shock.

WP 3 : The NS magnetosphere

With Zakaria Meliani (ObsPM, FR) and Rony Keppens, I want to implement a static dipolar field to represent the NS magnetosphere and study the coupling with the flow. The main deliverables are :

1. First simulation where the magnetic field divergence is controlled using the constrained transport module developed by Fabien Casse (APC, FR).
2. Validation of the compatibility of the MHD simulations with the stretched grids on test-cases.
3. Produce X-ray light curves and spectra of the cyclotron emission to compare to the observations.

Month#1 is fiducially set to April 2017. Deliverables are given in the order they are written in 3.1. Only the main international conferences have been specified (except the COSPAR scientific assembly whose date in 2018 is to be determined). The two-months periods in-between WP are to work on the communication and dissemination material (presentations, posters, web interfaces…), to write computing time proposals on supercomputers and to adapt to potential delays.



[22] Ducci L., Sidoli L. et al 2009, MNRAS 398, 2152

3.2. Appropriateness of the allocation of tasks and resources

I estimate the computing time (in CPU-hours) for the WP 1, 2 and 3 to respectively 500, 200 and 400 CPU-hours. The preliminary debugging work can be carried on local clusters at KU Leuven but the effective simulations must be performed on advanced facilities. Computing time is granted after applications are evaluated and I have been granted two times 300 CPU-hours on the national French supercomputer (CINES) for the last two years. I will participate again in the 2017 PRACE campaign to ask for 400 CPU-hours on the CINES and in parallel, I will ask 400 CPU-hours on the Jülich supercomputer, a privileged partner of the CmPA. It will cover my computing needs for the first year (600 CPU-hours) and I will repeat the applications for 2018.

In terms of working labour, I will be in the expert team for the code I use and I will be able to interact in a direct way on technical issues. For the physical problematics, Rony Keppens is acknowledged for his expertise in MHD and plasma Astrophysics (for the NS magnetosphere – WP 3) and Thierry Foglizzo is one of the world-leading experts in HD instabilities and shock Physics in Astrophysical context (for the study of the shock – WP 1).

3.3 Appropriateness of the management structure and procedures, **including risk management**

The environment of the CmPA is ideal for the scientific goals I set given its strongly interacting team composed of a core of 10 members whose Rony Keppens is a key-manager. Should an application to computing-time on the CINES or the Jülich supercomputer be discarded, I would apply to computing time on the Flemish VSC, use the local facilities and reapply to the mid-year offers.

3.4 Appropriateness of the institutional environment (infrastructure)

The beneficiary will grant me access to the CmPA facilities at KU Leuven. The facilities I need on a weekly-basis (desktop, Ethernet connection, registration to the main scientific reviews, storage space, computing facilities, personal website hosting…) will be managed by the local administration, technical teams, etc. It will also let me participate as a teaching assistant to the courses mentioned in 2.3 and I will attend advanced courses displayed in the local facilities. Finally, the beneficiary will bring me its support to apply to computing-time, submit papers to peer-reviewed journals, find complementary fundings for the communication and dissemination of my results, etc.

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DOCUMENT 2

4. CV of the Experienced Researcher

The CV is intrinsic to the evaluation of the whole proposal and is assessed throughout the 3 evaluation criteria by the expert evaluators.

This section should be limited to maximum 5 pages and should include **the standard academic and research record.** Any research career gaps and/or unconventional paths should be clearly explained so that this can be fairly assessed by the independent evaluators.

The *experienced researchers* must provide a list of achievements reflecting their track record, and this may include, if applicable:

1. **Publications** in **peer-reviewed scientific journals, peer-reviewed conference proceedings and/or monographs** of their respective research fields, indicating also the number of citations (excluding self-citations) they have attracted.
2. Granted **patent(s)**.
3. **Research monographs, chapters** in collective volumes and any translations thereof.
4. **Invited presentations** to peer-reviewed, internationally established conferences and/or international advanced schools.
5. **Research expeditions** that the *experienced researcher* has led.
6. **Organisation of International conferences** in the field of the researcher (membership in the steering and/or programme committee).
7. Examples **of participation in industrial innovation**.
8. **Prizes and Awards**.
9. Funding received so far
10. Supervising, mentoring activities, if applicable.

ILEYK EL MELLAH
born on 5th April, 1989
French citizen

+33 6 78 89 40 21
mailto:ileyk@apc.univ-paris7.fr
Personal webpage : here

EDUCATION

2016 - **PhD thesis supervised by Fabien Casse & Andrea Goldwurm on *Numerical simulations of wind accretion onto compact bodies.***
AstroParticule & Cosmology laboratory (APC) - Paris 7 Univ.

2013 - **Master degree in Astrophysics**
Observatory of Paris. Obtained with distinction

2010-12 – **Normalien at the Ecole Normale Supérieure of Cachan**

2011-12 – **Research internship and graduate courses**
MIT, Cambridge

2010-11 - **French Agrégation of Physics & Chemistry** - ENS of Cachan
Rank : 2nd in 1,409 candidates

2008-10 – **Bachelor degree in Fundamental Physics**-ENS/Paris 6 Univ.
Obtained with honours

2006-08 - **Preparatory classes to Grandes Ecoles**
Lycée Janson-de-Sailly, Paris

RESEARCH

2016 - **PhD thesis supervised by Fabien Casse & Andrea Goldwurm on *Numerical simulations of wind accretion onto compact bodies.***
AstroParticule & Cosmology laboratory (APC) - Paris 7 Univ.

2011-12 - **One-year internship supervised by Saul Rappaport on *Monitoring of close-in binary stars and short period exoplanets***
Data analysis and models of light curves from the Kepler satellite
Kavli Institute for Astrophysics - MIT

Ap-Ag 2010 – **Internship supervised by J.-F. Lestrade on *Gravitational perturbations of debris discs by a passing-by star***
LESIA - Paris Observatory

Jn-Jl 2009 – **Internship supervised by G. Belmont & P. Robert on *Resampling of the CLUSTER satellites data***
Plasma Physics Laboratory - Vélizy

COMMUNICATION

Peer-reviewed publications

[1] I. El Mellah & F. Casse. *A numerical investigation of wind accretion in persistent Supergiant X-ray Binaries. I - Structure of the flow at the orbital scale* (2016) - under reviewing

[2] I. El Mellah & F. Casse. *A Numerical simulations of axisymmetric hydrodynamical Bondi-Hoyle accretion on to a compact object* (2015) - MNRAS 454 (3): 2657-2667

[3] R. Sanchis-Ojeda, S. Rappaport, J. Winn, M. Kotson, A. Levine, I. El Mellah. *The Shortest-period Planets Found with Kepler* (2014) - ApJ, vol. 787:1 18pp - 29 cit.

[4] S. Rappaport, K. Deck, A. Levine, T. Borkovits, J. Carter, I. El Mellah, R. Sanchis-Ojeda, B. Kalomeni. *Triple-star Candidates among the Kepler Binaries* (2013) - ApJ, vol. 768:1 18pp - 57 cit.

[5] S. Rappaport, A. Levine, E. Chiang, I. El Mellah, J. Jenkins, B. Kalomeni, E. S. Kite, M. Kotson, L. Nelson, L. Rousseau-Nepton, K. Tran. *Possible Disintegrating Short-Period Super-Mercury Orbiting KIC 12557548* (2012) ApJ, vol. 752:1 13pp - 72 cit.

Main oral contributions

Sp 2016 - **Super-Eddington accretion on compact objects**

Arbatax conference center - 20’ talk

Ag 2016 - **Monthly Astrophysics seminar**

Department of Physics and Astronomy, Aarhus University - 50’ invited talk

Ap 2016 - **Weekly High Energy Astrophysics seminar**

APC laboratory - 40’ invited talk

Ap 2016 - **Monthly CmPA seminar**

KU Leuven, Center for mathematical Plasma Astrophysics - 50’ invited talk

Oc 2015 - **Monthly Computational Astrophysics seminar**

CEA Saclay, SAp, AIM laboratory - 50’ invited talk

Jn 2015 - **Journées de la SF2A** - Toulouse - 20’ talk

The proceedings of the 2015 Journées de la SF2A

Mr 2015 - **Ecole des Houches : Turbulence, magnetic fields and self organization in laboratory and astrophysical plasmas** - 20’ talk

TEACHING

2014-15 - **Classical Mechanics, 1st year** – Paris 7 Univ.

2013 – **Physics for Medical studies, 1st year** - Paris 7 Univ.

2013 – **Deterministic systems & signals, 4th year** - Paris 7 Univ.

2012-13 – **Private lessons with the company *Cours Thalès*** – Paris

2011 – **French Agrégation of Physics & Chemistry**

2009-10 – **Teaching assistant at the high school Eiffel** - Cachan

OUTREACH

Ap-Nv 2015 – **Community manager of the Young Physicists Meeting**

Oc 2015 – **Festival of Science** - Paris 7 Univ.

Sp 2015 - **Wolfram demonstration on the ballistic motion in a Roche potential and 3D-printing of the corresponding surfaces** – APC

2013 - **Java applet on Turing's theory of morphogenesis**
Paris Observatory

GRANTS & AWARDS

2016 - Computing time on the CINES clusters : 300 kh·cpu

2015 - Computing time on the CINES clusters : 300 kh·cpu

2013 - 3-years PhD fellowship from the ENS of Cachan

2013 - 3-years teaching assistant grant from the Paris 7 University

2012 - 1-week observing time at the Mont Mégantic Observatory (Canada)

2011 - French Agrégation of Physics and Chemistry - Rank : 2nd / 1,409

2010 - 2-years fellowship from the ENS of Cachan as a normalien

CONFERENCES & SCHOOLS

Sp 2016 - Super-Eddington accretion on compact objects - Arbatax, IT
Talk

My 2016 - 6th Les Houches school in Numerical Physics - Les Houches, FR
Poster

Dc 2015 - 28th Texas symposium on relativistic Astrophysics - Geneva, SW
Poster

Jn 2015 - Journées de la Société française d'astronomie et d'astrophysique
Toulouse, FR - 20' talk

Mr 2015 - Ecole des Houches : Turbulence, magnetic fields and self organization in laboratory and astrophysical plasmas
Les Houches, FR - 20' talk

Nv 2014 - Magnetic fields from the Sun to black holes, in memory of Jean Heyvaerts - Paris, FR – Poster

Sp 2014 - The many faces of compact stars, the newComp star school
Barcelona, SP

Jn 2014 – Journées de la SF2A – Paris, FR

My 2013 – International Cargese school on cosmic accelerators
Cargese, FR

SELECTED SKILLS

Programming languages

Fortran, C, C++, Python, Idl, Java, Perl, XML, Csh, Bash, HTML, css, JavaScript, CoffeeScript, HTML5

Codes & softwares

MPI-AMRVAC, Mathematica, VisIt, Paraview, Vampir, VampirTrace, Atom, Emacs, Pyke, Inkscape, Gnuplot, DS9

Data analysis

Extended Fourier and wavelet analysis, resampling and interpolation of time/space series (cubic spline and Whittaker-Shannon interpolations)

Languages

French (native), English (fluent)

5. Capacity of the Participating Organisations

Beneficiary: Katholieke Universiteit Leuven	
General Description	*KU Leuven has a large tradition on education and research that dates back six centuries. It is the largest university of Belgium in terms or research funding and expenditure. KU Leuven employs about 7000 researchers (annual report 2015) and has extensive experience in coordinating and participating in EU-funded research, and was ranked 6th in acquired European FP7 projects (April 2016). The Centre for mathematical Plasma Astrophysics (CmPA) was founded in 1992 and concentrates research on the dynamical interaction between plasmas – the most abundant state of known matter in our universe – and magnetic fields. It participated/coordinated various EC projects (Swiff, Soteria, eHeroes, DEEP-ER, SOLSPANET, ...).*
Role and Commitment of key persons (supervisor)	*Prof. dr. Rony Keppens (Full professor, Division Chair for CmPA) will closely collaborate with the applicant, provide expert advice on numerical aspects and ensure access to High Performance Computing (HPC) platforms. He coordinates a team of 10 researchers, and safeguards their complementarity and cross-fertilization.*
Key Research Facilities, Infrastructure and Equipment	*KU Leuven is a large university with lively scientific activity. The CmPA has 35 researchers and 5 staff members, and owns a suite of powerful multi-core parallel desktops. The CmPA has gained significant expertise in HPC, exploiting the Flemish Supercomputing Centre (VSC , see www.vscentrum.be, for Tier-1 and Tier-2) and the European Funded PRACE (www.prace-ri.eu, for Tier-0 access).*
Independent research premises?	*Access to VSC facilities is possible for all researchers in Flemish universities. Tier-1 access is through FWO-reviewed project applications, and Tier-2 infrastructure can be funded from ongoing research projects. PRACE access is handled by project applications at European level, with active CmPA participation.*
Previous Involvement in Research and Training Programmes	*Prof. Keppens has been involved in many national and international interdisciplinary research projects during his career (e.g. Solaire Marie Curie RTN 2006-2011; EC FP7 SWIFF work package leader 2012-2014; COST action MP0905, 2010-2014). He was co-investigator in a KU Leuven project on `Solar and space plasma physics' from 2008-2013, as well as in an interdisciplinary project on `Exo-planet atmosphere modeling' (2012-2015). He promoted 8 PhDs and has 5 PhDs ongoing.*
Current involvement in Research and Training Programmes	*Prof. Keppens currently coordinates a national, BELSPO funded Intra-University Attraction Pole network (CHARM, IAP P7-08, 2012-2017, 3 Meuro), with 7 partners. He supervises several PhD and postdoc fellows funded by FWO and BELSPO.*
Relevant Publications and/or research/innovation products	`Formation and plasma circulation of solar prominences', *C. Xia & R. Keppens, 2016, ApJ* ***833****, 22.* `Pinwheels in the sky, with dust: 3D modelling of the Wolf-Rayet 98a environment', *T. Hendrix, R. Keppens, A.J. van Marle, P. Camps, M. Baes & Z. Meliani, 2016, MNRAS* ***460****, 3975-3991.* `The SS433 jet from subparsec to parsec scales', *R. Monceau-Baroux, O. Porth, Z. Meliani, & R. Keppens, 2015, Astron. & Astrophys.* ***574****, A143.* `Interacting tilt and kink instabilities in repelling current channels', *R. Keppens, O. Porth, & C. Xia, 2014, ApJ* ***795****, 77.* `Parallel, grid-adaptive approaches for relativistic hydro and magnetohydrodynamics', *R. Keppens, Z. Meliani, A.J. van Marle, P. Delmont, A. Vlasis, & B. van der Holst, 2012, JCP* ***231****, 718-744.* ***(with the MPI-AMRVAC open source community code).***

Partner Organisation Y	
General description	
Key Persons and Expertise (supervisor)	
Key Research facilities, infrastructure and equipment	
Previous and Current Involvement in Research and Training Programmes	
Relevant Publications and/or research/innovation product	*(Max 3)*

6. Ethical Issues

Compliance with the relevant ethics provisions is essential from the beginning to the end of the action and is an integral part of research funded by the European Union within Horizon 2020.

Applicants submitting research proposals for funding within Marie Skłodowska-Curie actions in Horizon 2020 should demonstrate proactively to the REA that they are aware of and will comply with European and national legislation and fundamental ethical principles, including those reflected in the Charter of Fundamental Rights of the European Union[1] and the European Convention on Human Rights and its Supplementary Protocols[2].

Please be aware that it is the applicants' responsibility to identify any potential ethical issue, to handle the ethical aspects of the proposal and to detail how these aspects will be addressed.

The Ethics Review Procedure in Horizon 2020

All proposals above threshold and considered for funding will undergo an Ethics Review carried out by independent ethics experts. When submitting a proposal to Horizon 2020, all applicants are required to complete an "**Ethics Issues Table (EIT)**" in the Part A of the proposal. Applicants who flag ethical issues in the EIT have to also complete a more in depth **Ethics Self-Assessment in Part B**.

The ethics self-assessment will become part of the Grant Agreement and may thus lead to binding obligations that may later on be checked during ethics checks, reviews and audits.

For more details, please refer to the H2020 **"How to complete your Ethics Self- Assessment"** guide[3].

[1] The Charter of Fundamental Rights of the European Union: http://www.europarl.europa.eu/charter/pdf/text_en.pdf

[2] http://www.echr.coe.int/Documents/Convention_ENG.pdf

[3] http://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/ethics/h2020_hi_ethics-self-assess_en.pdf

http://ec.europa.eu/research/participants/docs/h2020-funding-guide/cross-cutting-issues/ethics_en.htm

Ethics Self-Assessment (Part B)

The Ethics Self-Assessment must:

1) Describe how the proposal meets the EU and national legal and ethics requirements of the country/countries where the task raising ethical issues is to be carried out.

For more information on how to deal with Third Countries please see Article 34 of the Annotated Model Grant Agreement[4], as well as the following link:

http://ec.europa.eu/justice/data-protection/international-transfers/adequacy/index_en.htm

Please list the documents provided with their expiry date.

Ensure early compliance of the proposed research with EU and national legislation on ethics in research. Should your proposal be selected for funding, you will be required to provide as soon as possible the following documents (if applicable):

- an opinion from an Ethics Committee/Authority, required under national law;
- any other ethics-related documents mandatory under EU or national legislation;

If you have not already applied for/received the ethics approval/required ethics documents when submitting the proposal, please indicate in this section the approximate date when you will provide the missing approval/any other ethics documents, to the REA (scanned copy). Please state explicitly that you will not proceed with any research with ethical implications before the REA has received a scanned copy of all documents proving compliance with existing EU/national legislation on ethics.

If these documents are not issued in English, you are encouraged to submit also an English summary (containing in particular, if available, the conclusions of the Committee or Ethics Authority concerned). *If you plan to request these ethics documents specifically for your proposed* action*, your request must contain an explicit reference to the* action*'s title.*

2) Explain in detail how you intend to address the ethical issues flagged, in particular with regard to:

- the research **objectives** (e.g. study of vulnerable populations, cooperation with a Third Country, etc.);
- the research **methodology** (e.g. clinical trials, involvement of children and related information and consent/assent procedures, data protection and privacy issues related to data collected, etc.);

[4] http://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/amga/h2020-amga_en.pdf

- the potential **impact** of the research (e.g. dual use issues, environmental damage, malevolent use, etc.).
-

7. Letters of Commitment (GF only)

Please use this section only for the Global Fellowships to insert **scanned copies** of the required **Letters of Commitment from the partner organisations in TC.** Minimum requirements for the letter of commitment:

- heading or stamp from the institution;
- up-to-date (i.e. issued after the call publication date, 12 April 2016);
- the text must demonstrate the will to actively participate in the proposed action and the precise role;
- signed by the legal representative.

Please note that proposals failing to comply with the above-mentioned requirements will be declared inadmissible.

ENDPAGE

MARIE SKŁODOWSKA-CURIE ACTIONS

Individual Fellowships (IF)
Call: H2020-MSCA-IF-2016

PART B

“TAcc-NeXB”

This proposal is to be evaluated as:

[Standard EF]