CONCOURS ASTRONOME-ADJOINT 2019 – FICHE RÉCAPITULATIVE

NOM, Prénom : EL MELLAH, Ileyk
Date de naissance : 5 Avril 1989
Nombre de candidatures antérieures : 0
Interruption(s) d'activité(s) : -

Établissement et équipe d'accueil demandés :
Institut de recherche en astrophysique et planétologie de Toulouse
Equipe galaxies, astrophysique des hautes énergies et cosmologie

Post-doctorats et situation actuelle :
Mai 2017 - Juin 2020 | Bourse FWO [Pegasus]^2 Marie Skłodowska-Curie | 3 ans | KU Leuven
Octobre 2016 - Mai 2017 | Contrat postdoctoral | 8 mois | KU Leuven

Thèse : *Wind accretion onto compact objects*, supervisée par F. Casse & A. Goldwurm à l'APC (Paris 7, équipe High Energy Astrophysics), soutenue le 7 Septembre 2016 (après 3 ans).

Thèmes des recherches effectuées : Compact objects (CO): neutron star (NS), black hole (BH) - Roche lobe overflow (RLOF), wind accretion - High mass (HMXB) and low mass X-ray binaries - Stellar and disc outflows, line-driven winds - Ultra-luminous X-ray sources (ULX)

Méthodologies : Théorie – Modélisation – Simulations

Tâches de service effectuées et/ou envisagées :
ANO2 SVOM - Bertrand Cordier (CEA) - Avec Jean-Luc Atteia et Olivier Godet (IRAP), caractérisation de la réponse instrumentale d'ECLAIRs et développement d'outils d'analyse de la performance de l'instrument pour le segment sol et l'*ECLAIRs Instrument Center* pour produire les fichiers auxiliaires de calibration nécessaires au traitement des données.

Enseignements effectués :

2018-19	Computational methods for Astrophysics	40h cours	5th year	KU Leuven
2017-18	Linear Algebra	30h TD	1st year	KU Leuven
2016-17	Computational methods for Astrophysics	60h TD	5th year	KU Leuven
2014-16	Classical Mechanics	128h TD	1st year	Paris 7
2013	Physics for Medical studies	32h TD	1st year	Paris 7
2013	Deterministic systems and signals	32h TP	4th year	Paris 7
2009-10	Teaching assistant	16h cours	high school	Gustave Eiffel

Résultats principaux :
2019: I proved that discs could be formed around a CO in a HMXB by capture of the wind, without RLOF, with dramatic consequences on the spinning up/down of the accretor. I also proposed a new mechanism for mass transfer in ULX. 2018: overdense regions form in the wind of hot stars (clumps). I showed that the serendipitous capture of these clumps by an orbiting CO does not account for the time variability of the mass accretion rate we observed in Vela X-1 with Chandra, contrary to previously thought. Additional instabilities in the immediate vicinity of the BH or in the NS magnetosphere are required. 2015-17: characterization of the structure of the bow shock formed as a CO moves through an ambient medium (mass accretion rate, stability, topology of the inner sonic surface), for instance the wind of a stellar companion.

Programme de recherche : Mergers between a NS and a BH or another NS can lead to the formation of a an accretion disc around the remnant. 1. Study of the parameters of this disc and of its evolution as it undergoes accretion onto the remnant at high mass accretion rates (above the Eddington limit). 2. Analysis of the neutrino-driven and subsequent line-driven outflow from this disc and its interaction with the surrounding ejecta responsible for the kilonova.

Compétences acquises et points forts de votre candidature : Wide expertise in Computational Astrophysics (e.g. MHD approximate Riemann solvers and flux-limited diffusion for radiative transfer). Improvements of `MPI-AMRVAC`, a finite volume code to numerically solve the equations of MHD, on an adaptive grid whose geometry can be adapted to the needs of a physical problem. I also gained experience in adjacent domains such as visualization, high performance computing, hardware, cluster and data management, profiling and code optimization.

Publications

Nombre de publications de rang A publiées et sous presse: 11

Nombre de publications de rang A soumises: 0

Nombre de communications et/ou de posters présentés à des conférences: 14

Autres (participation à des ouvrages, rapports techniques, codes, logiciels, sites web, etc...) :

2013-18	Developer for the MHD code `MPI-AMRVAC`
2017	Radio show *Faconde* on scientific outreach (Radio Campus, Bruxelles)
2016	PhD manuscript
2015	Festival of Sciences (Paris 7) and 3D-printing of Roche potentials
2015	Personal webpage
2015	Website of the *Rencontres des Jeunes Physiciens 2015*
2015	Community manager of the *Rencontres des Jeunes Physiciens 2015*
2015	Wolfram demonstration *Trajectory of a Test Mass in a Roche Potential*

Liste des 5 publications de rang A, par ordre d'importance, qui illustrent le mieux votre travail et vos compétences (avec liens) :

[1] **El Mellah I.**, Sander A. A. C., Sundqvist J. O. & Keppens R.
Formation of wind-captured discs in Supergiant X-ray binaries : consequences for Vela X-1 and Cygnus X-1 (2019) - A&A

[2] **El Mellah I.**, Sundqvist J. O. & Keppens R.
Accretion from a clumpy massive-star wind in Supergiant X-ray binaries (2017) - MNRAS

[3] **El Mellah I.**, Sundqvist J. O. & Keppens R.
Wind Roche lobe overflow in high mass X-ray binaries : a possible mass transfer mechanism for Ultraluminous X-ray sources (2018) - A&A

[4] **El Mellah I.** & Casse F.
A numerical simulations of axisymmetric hydrodynamical Bondi-Hoyle accretion on to a compact object (2015) - MNRAS

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

January 21st, 2019

To the members of the CNAP committee,

I am a [Pegasus]^2 Marie Skłodowska-Curie fellow in KU Leuven, at the Center for mathematical Plasma Astrophysics (CmPA), working in Computational Astrophysics with Rony Keppens. I joined the CmPA in October 2016 after defending my PhD on *Wind accretion onto compact objects*, under the supervision of Andrea Goldwurm and Fabien Casse. I apply to the position of *Astronome-adjoint* at the IRAP, in the GAHEC team, for I believe my profile could match the expected requirements and since it would be a valuable support to pursue and develop further my emerging academic career. I wish to be assigned to the ANO2, *Instrumentation des grands observatoires au sol et spatiaux*, in the SNO *Astronomie Astrophysique*.

After my undergraduate studies at the Ecole Normale Supérieure, I volunteered to join the Kepler satellite data analysis effort under Saul Rappaport's lead at MIT. There, I was introduced to stellar evolution and binary systems and took an active part in the discovery and characterization of the first disintegrating exoplanet in 2012. My involvement also contributed to the identification of 30 new triple star systems and to a detailed analysis of the shortest-period exoplanets, those right in the spotlight of their host star. This seminal long term experience in Research laid the foundations of my scientific program : a better understanding of stellar objects and remnants in interaction with their environment.

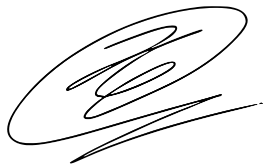
As I started my PhD, I turned to numerical tools to complement the analytical skills I had acquired during the previous years and model the turbulent twilight of binary systems, the X-ray binaries. I got familiar with advanced techniques such as solvers for hyperbolic partial differential equations and parallel computing, in the context of the finite volume MHD code `MPI-AMRVAC`. With several successful proposals on Tier-1 clusters and the code development I carried out, I could run the widest dynamics simulations of wind accretion onto compact objects.

By the end of my first postdoctoral year in KU Leuven, I was granted a 3-years [Pegasus]^2 Marie Skłodowska-Curie fellowship. I also joined an ISSI sponsored collaboration led by Silvia Martínez-Núñez (IFCA) and Peter Kretschmar (ESAC) to gather observers and theoreticians from the X-ray binaries and massive stars winds communities. It enabled me to design and confront simulations of the accretion process in Supergiant X-ray binaries to the most recent observations of Vela X-1. Thanks to Jon Sundqvist and collaborators' simulations of the internal shocks in the wind of isolated massive stars, we could evaluate the impact of the wind micro-structure on the time variability of the mass accretion rate onto the neutron star.

I am now willing to extend my investigations to the accretion/ejection process in the disc formed by the merging of a neutron star with another neutron star or a black hole. The expertise already available at the IRAP in the domain of accretion at high rates on compact objects would be a decisive asset to pursue this goal. May you judge my application admissible, I remain fully available to bring further information you might need.

Sincerely,

Ileyk El Mellah



Ileyk El Mellah

http://homes.esat.kuleuven.be/~ileyk

Research

Since 2016 **FWO [Pegasus]^2 Marie Skłodowska-Curie fellowship with Rony Keppens**
Center for mathematical Plasma Astrophysics – KU Leuven

2013-16 **PhD with Fabien Casse & Andrea Goldwurm**
Wind accretion onto compact bodies – APC, Paris Diderot University

2011-12 **One-year volunteer internship supervised by Saul Rappaport on**
Monitoring of close-in binaries and short period exoplanets with Kepler
Kavli Institute for Astrophysics – MIT

Ap-Ag 2010 **BSc internship supervised by Jean-François Lestrade on**
Gravitational perturbations of debris discs by a passing-by star
LESIA – Paris Observatory

Jn-Jl 2009 **BSc internship supervised by Gérard Belmont & Patrick Robert on**
Resampling of the CLUSTER satellites data
Plasma Physics Laboratory – Paris

Education

2013-16 **PhD with Fabien Casse & Andrea Goldwurm** – Paris Diderot University
Wind accretion onto compact bodies

2012-13 **Master degree in Astrophysics, with distinction** – Paris Observatory

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, FR
Rank : 2nd in 1,409 candidates

2008-10 **Bachelor degree in Fundamental Physics, with honours** – ENS

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

Grants & awards

2016	3-years FWO [Pegasus]^2 Marie Skłodowska-Curie fellowship
2013-16	3-years PhD fellowship from the Ecole Normale Supérieure of Cachan
2013-16	3-years teaching assistant grant from the Université of Paris 7 Diderot
2011	French *Agrégation* of Physics and Chemistry
2010-12	2-years *normalien* study fellowship from the ENS of Cachan

Computing & observing time

2018	XMM-Newton proposal *Mapping the wind and accretion in Vela X-1* (co-I.)
2017-18	Computing time on the Flemish Tier-1 VSC cluster : 2.5 Mh·CPU
2015-16	Computing time on the French CINES Tier-1 cluster : 600 kh·CPU
2012	1-week observing time at the Mont Mégantic Observatory (Canada)

Supervision & teaching

Supervision

2018-...	Co-supervisor with Jon Sundqvist of a graduate student, Nicolas Moens
2018-...	Member of the supervisory committee of a graduate student, Luka Poniatowski
2018	Reader for Florian Driessen's Master thesis supervised by Jon Sundqvist
2018	Reader for Prem Kumar Bulusu's Master thesis supervised by Hugues Sana

Teaching

2018-19	Lecturer in Computational methods for Astrophysics, 5th year - KU Leuven
2017-18	Teaching assistant (TA) Linear Algebra, 1st year - KU Leuven
2016-17	TA Computational methods for Astrophysics, 5th year - KU Leuven
2014-16	TA Classical Mechanics, 1st year - Univ. of Paris 7 Diderot
2013	TA Physics for Medical studies, 1st year - Univ. of Paris 7 Diderot
2013	TA Deterministic systems and signals, 4th year - Univ. of Paris 7 Diderot
2012-13	Private lessons with the company *Cours Thalès* - Paris
2011	French *Agrégation* of Physics & Chemistry
2009-10	High school Gustave Eiffel - Cachan

Community service

Reviewing

2019	Reviewer for Astronomy & Astrophysics
2018	Reviewer for The Astrophysical Journal
2018	Reviewer for DiRAC High Performance Computing Tier-1

Outreach

Oc 2017	1h30 radio interview on scientific communication in *Faconde* - Brussels
Nv 2015	Community manager and webmaster of the Young Physicists Meeting - Paris
Oc 2015	Festival of Science - Paris Diderot University
Sp 2015	3D-printed models and Wolfram interactive applet for the Roche potential
2013	Java applet on Turing theory of morphogenesis - Paris Observatory

RESEARCH PROFILE AND CONTEXT

Most massive stars were born in multi-star systems but only a fraction ends up in a compact objects binary due to their agitated evolution. With the discovery of the first gravitational wave (GW) signal in 2015 by the LIGO/Virgo consortium, we now feel the pressing need to understand the details of this evolution. Binarity introduces new effects compared to the evolution of isolated stars such as mass and angular momentum transfer. My work addresses these questions at a key stage in massive binary evolution, in high mass X-ray binaries (HMXB) where a neutron star (NS) or a black hole (BH) orbits a high mass donor star and captures part of its stellar wind. As matter is accreted onto the compact object, the X-rays we observe are emitted.

Semi-analytical models of the accretion process in HMXBs highlighted the need for solving the complex dynamics of the wind (Ducci et al., 2009). Using full three-dimensional simulations spanning up to five orders of magnitude in space, I derived the structure of the accreted flow in these systems, first in an idealized case in[1] El Mellah & Casse (2015)[1] and then in more realistic configurations in El Mellah, Sundqvist & Keppens (2018)[2] and El Mellah, Sander, Sundqvist & Keppens (2019)[5]. These results arouse the interest of the European X-wind collaboration which gathers experts of X-ray binaries (e.g. Felix Fürst from ESAC Madrid) and of massive stars outflows (e.g. Lida Oskinova from the University of Potsdam). I was invited to join this common effort in 2017 to provide theoretical and numerical support and help to draw a comprehensive view suitable to bridge the gap between the two communities. To do so, I developed a model of absorption by the dense stellar wind to interpret X-ray Chandra data of Vela X-1 in Grinberg, Hell, El Mellah et al. (2017)[3]. Following previous suggestions (Martínez-Núñez et al., 2017), we used the orbiting NS as an X-ray probe moving in the wind of its donor star to bring unprecedented constrains on the micro-structure of the winds of massive stars. Applied to observations from the future X-ray missions XRISM (JAXA, 2021) and Athena (ESA, 2030), these models will considerably enlarge the scope of our knowledge on the progenitors of the compact objects mergers observed with the incoming GW observatories.

Binarity adds new parameters in the stellar evolutionary models such as the mass ratio or the orbital period (Sana et al., 2012). To compute accurate mass and angular momentum transfer rates in each case, I wrote an open-source code adapted to an exhaustive study of the impact of binarity on the structure of the stellar wind (e.g. spiral shocks and compression in the orbital plane). I applied it to HMXBs to identify typical behaviors in El Mellah & Casse (2017)[4]. Thanks to this versatile tool, I designed and validated a new scenario in El Mellah, Sundqvist & Keppens (2019)[6] to explain how mass is transferred in some Ultra-luminous X-ray sources (ULXs), extra-galactic X-ray sources among which the brightest might contain an accreting intermediate mass black hole (Webb et al., 2014). Most interestingly, I extended this code to cool stars and brought the formal proof that the two cool evolved stars we observed in Decin et al. (2019)[7] were orbited by a previously unnoticed companion. The corrected mass loss rates we derived accounting for binary interaction solved long-standing inconsistencies in the prediction of the evolution of this type of stars (Renzini, 1981).

I not only used but also co-developed a sophisticated code, `MPI-AMRVAC` (for Message Passing Interface - Adaptive Mesh Refinement Versatile Advection Code), which solves the equations of magneto-hydrodynamics (MHD) on a multi-dimensional grid with higher resolution in places where small scale structures need to be resolved. We reported on the new features we implemented in Xia, Teunissen, El Mellah et al. (2018)[8]. I now aspire to take part in the blossoming of Computational Astrophysics in France by making the most of the available supercomputers and training new generations of astrophysicists with a strong numerical expertise.

[1]The indexes in brackets refer to the publications I co-authored, given in the research summary.

Selected skills

Astrophysics

- Binary systems : Roche dynamics, mass and angular momentum transfer, secular evolution
- Radiative hydrodynamics (HD) : line-driven winds, optically thin and thick cooling/heating
- MHD : NS or white dwarf magnetosphere, resistive MHD

Computational Fluid Dynamics

- Godunov finite volume methods for conservation equations : approximate Riemann solvers, high order techniques (e.g. slope limiters)
- Radiative transfer : forward-time central-space, multi-grid solvers, alternating direction implicit, Monte Carlo
- High Performance Computing (HPC) : parallelization, multithreading, scaling tests, Tier-1 supercomputers

Data analysis

- Python : NumPy, SciPy, Pandas, Bokeh, Plotly, Jupyter, yt
- 3D data visualization softwares : VisIt, Paraview, Tecplot
- Graphical User Interface (GUI) : applets (with Wolfram language and Spyre framework)
- Signal analysis : Fourier, wavelets, spectral energy distribution

Code development

- advanced Fortran 2003 programming : procedure pointers
- Perl and bash scripting : pre-processors, serial job runs
- parallel code debugging : Allinea Forge's DDT
- parallel code profiling and optimization : VampirTrace
- interactive and responsive web design : HTML5, CSS and Javascript
- version control : GIT

RESEARCH SUMMARY

In Supergiant X-ray binaries (SgXBs), a sub-family of HMXBs, a NS or a BH orbits a supergiant O/B star and captures part of its stellar wind. SgXBs are thought to be the progenitors of the double compact object binaries whose final merger produces flares of gravitational waves similar to the ones first observed by the LIGO/Virgo collaboration in 2015. So as to make the most of the data from these merging compact objects, we need to look at their evolution and wonder how binarity has affected their properties. In simulations of secular long-term evolution (Tauris et al., 2006), proxies are used to deduce a mass and angular momentum transfer rate from elementary parameters such as the mass ratio, but the efficiency of accretion onto the compact companion and of the associated spin-up from mass transfer is still highly uncertain. This flaw hampers our capacity to interpret the gravitational wave observations and to predict accurate merging rates. On the other hand, the observing X-ray facilities in orbit tell us about the short term variability of SgXBs, within the reach of a mission lifetime (Fürst et al., 2018). Numerical models of the accretion flow provide the missing link between the two and have brought unprecedented insights on the geometry of these unresolved objects (Blondin et al., 1991).

In this context, I have used and developed state-of-the-art MHD codes in an attempt to follow the flow from the Dantean stellar surface down to the magnetic vicinity of the NS or the relativistic surroundings of the BH. I have laid the foundations of a **consistent representation of the accretion process in SgXBs** by isolating the appropriate physics at stake at each scale, accounting for the complexity of the flow geometry (accretion tail in the wake of the compact object, photoionized and shocked regions, etc) and neatly linking the scales together. My work has helped to interpret observations of the **time variability we observed in Vela X-1** with the Chandra X-ray observatory. It brought new insights on the accretion process and the mass and angular momentum transfer mechanism which shapes the secular evolution of massive binaries and determines their final fate. **In agreement with observations of Cygnus X-1 and the ULX M101 ULX-1**, I have shown that **wind-captured discs could form around a wind-fed accretor**, without Roche lobe overflow of the donor star. For accreting NSs, where the applied torques on the magnetosphere depend strongly on the geometry of the accreting flow, **the implications for the spinning up/down of the NS might be consequent**. Finally, the versatility of the numerical setups I have designed enabled me to look at a totally different type of binaries. Around two Asymptotic Giant Branch (AGB) stars, I contributed to the **discovery of the imprints left in the stellar wind by the presence of a previously unseen orbiting companion**, with dramatic consequences on the measured maximum mass loss rate of this type of stars.

Time variability in Supergiant X-ray binaries

[1] ***Axisymmetric hydrodynamical Bondi-Hoyle accretion onto a compact object***
El Mellah & Casse, MNRAS 2015
[2] ***Accretion from a clumpy massive-star wind in Supergiant X-ray binaries***
El Mellah, Sundqvist & Keppens, MNRAS 2018
[3] ***The clumpy absorber in the high mass X-ray binary Vela X-1***
Grinberg, Hell, El Mellah et al., A&A 2017

Continuous monitoring of SgXBs has revealed an incredible time variability (e.g. off-states and flares) which could shed light on the micro-structure of the stellar wind. Using the orbiting X-ray source as a backlight, we could evaluate the degree of inhomogeneity or "clumpiness" of the wind. Since clumpiness systematically alters the values of the mass loss rates we derive from observations, improved constrains on the wind clumpiness would be of tremendous importance to predict the properties of the compact remnants massive stars eventually collapse into, for instance their mass distribution.

During my PhD, I developed a HD representation of the ideal wind accretion configuration, where a compact object captures material from a planar homogeneous supersonic wind (upper right insert in the left panel in Figure 1). I implemented semi-analytic boundary conditions to avoid spurious reflections of acoustic waves at the inner boundary and enable the computation to numerically relax. Since the scale at which the flow is significantly perturbed by the presence of the accretor (the accretion radius) is orders of magnitude larger than the compact object for realistic wind speeds, we designed, with my PhD advisor Fabien Casse (APC) a stretched self-similar spherical grid centered on the accretor. We then characterized the structure of the bow shock and the accretion tail which form as the flow is beamed towards the compact accretor, but also the actual mass accretion rate onto the compact object and the dependence on the Mach number of the incoming flow [1].

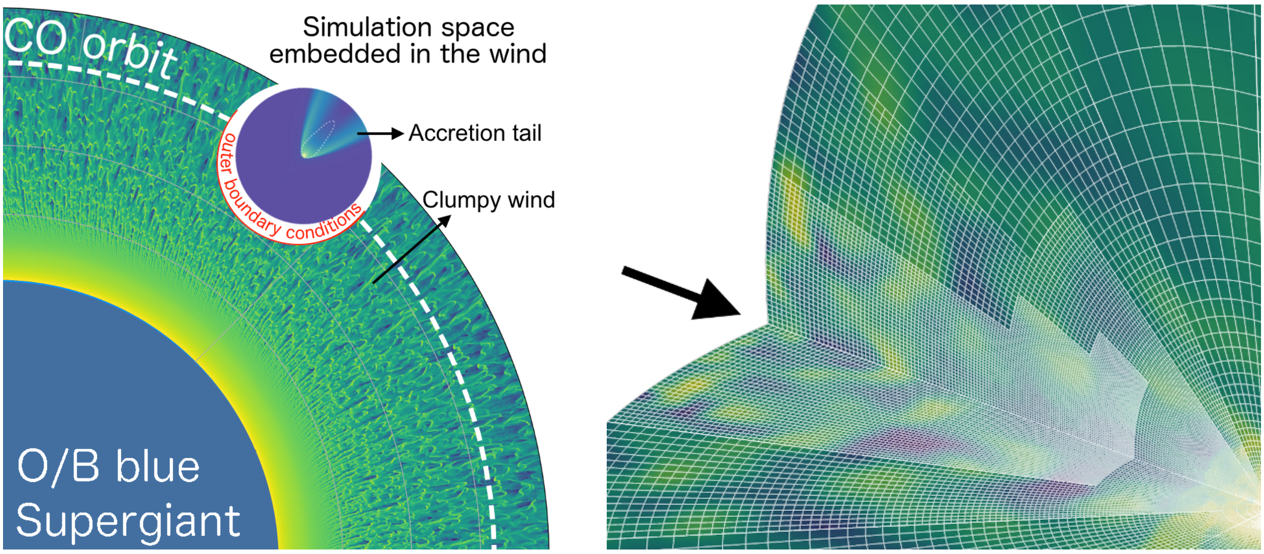


Figure 1: (*left*) Simulations where the multi-dimensional micro-structure of the wind of the hot donor star is for the first time resolved and followed as it is accreted by the compact object (CO). (*right*) The clumps enter the simulation, perturb the shock and form transient disc-like structures around the accretor in the bottom right corner (see Figure 2). The 3D mesh illustrates how the coupling between a radially stretched grid and the adaptive mesh refinement algorithm enables us to monitor all the flow at once up to five orders of magnitude.

During my first postdoctoral year, this setup served as a reference to study the effect of the clumps formed by internal shocks in the line-driven winds of hot stars. For long, it was proposed that the observed flares in a SgXB like Vela X-1 could be provoked by the serendipitous capture of a clump. However, with Rony Keppens and Jon Sundqvist (KU Leuven), we showed in [2] that realistic clumps computed from radiative-HD simulations do not undergo direct accretion (Figure 1). For the first time, we characterized how the material redistributes after the clumps impact the shock. The induced flares do not directly relate to individual clumps but are rather triggered by instantaneous angular momentum cancellation within the shocked region. Our results drove the community into exploring additional instabilities at the outer rim of the NS magnetosphere to reproduce the observed variability in SgXBs (Bozzo et al., 2008).

In [3], we reported coherent absorption events in Vela X-1. I was responsible for the interpretation and showed that these events could only be due to unaccreted clumps passing by the line-of-sight, provided the clumps were larger and the wind slower than expected. This result inspired the second part of my work on enhanced wind accretion.

Enhanced accretion, wind-captured discs and orbital compression

[4] ***A numerical investigation of wind accretion in persistent Supergiant X-ray binaries***
El Mellah & Casse, MNRAS 2017
[5] ***Formation of wind-captured discs in SgXBs: consequences for Vela X-1 & Cygnus X-1***
El Mellah, Sanders, Sundqvist & Keppens, A&A 2019
[6] ***Wind Roche lobe overflow in HMXBs: a mass transfer mechanism for ULXs***
El Mellah, Sundqvist & Keppens, A&A 2019
[7] ***Reduced maximum mass loss rates of OH/IR stars due to unnoticed binary interaction***
Decin et al., Nature Astronomy 2019

In my last year of PhD, I designed a model to study how the coupling between stellar, wind, orbital and accretion parameters in SgXBs could provide reliable estimates of the amount of angular momentum captured by the compact object [4]. I identified the configurations suitable to accrete enough angular momentum to form disc-like structures within the Roche lobe of the accretor. It seemed to require stringent conditions on the speed of the wind, which had to be very low compared to what was considered at that time in the literature. However, refined observations and stellar atmosphere computations later on suggested that line-driven acceleration might be more progressive than initially thought, leading to low speeds at the orbital separation. It drove me into performing full 3D HD simulations with the appropriate sets of parameters I had found in [4]. In [5], I showed that, below a certain ratio of wind speed by the orbital speed and provided radiative cooling was accounted for, a centrifugally-maintained structure could form between the shock and the NS magnetosphere below which the disc is truncated (see Figure 2 Ghosh et al., 1979).

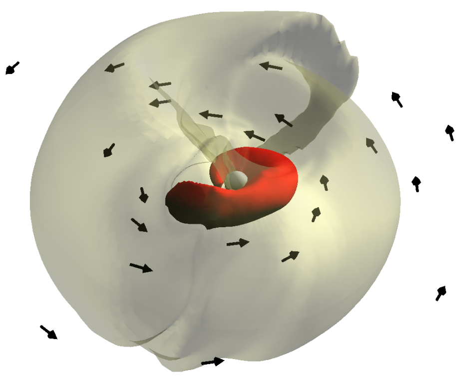


Figure 2: In simulations of wind accretion in SgXBs, I discovered a wind-captured geometrically thick disc around the central NS, while this type of flow was previously thought to be spherical. It was made possible by the five orders of magnitude spanned by these simulations, from the orbital scale down to the magnetosphere.

With these simulations, I noticed that this regime known as wind - Roche lobe overflow (Mohamed et al., 2011) was also associated to a surge of the rate at which mass is transferred due to the compression of the wind into the orbital plane. Therefore, I proposed a new mechanism for mass transfer in Ultra-luminous X-ray sources which, because it does not require Roche lobe overflow, explains how a small donor star like in M101 ULX-1 can feed a compact object accreting at a super-Eddington rate [6].

In [7], we invoked binarity to solve the controversy on the existence of a superwind phase which was claimed to end the life of cool giant stars such as AGB stars : the orbital density enhancement of the wind induced by the presence of a previously unseen companion is large and leads to significant overestimates of the mass loss rate when the wind is wrongly assumed to be isotropic. In ALMA observations of molecular lines around two OH/IR stars, a subclass of AGB stars, we detected spiral structures identifying them as wide binary systems. In this paper, I adapted the codes I had developed for SgXBs to show that for realistic parameters, the wind of the OH/IR stars was strongly compressed into the orbital plane due to the presence of this previously undetected binary companion. It showed that the reported OH/IR star mass loss rates assuming an isolated star had been overestimated by a factor of a few to a few 10, depending on the binary orbit parameters, which has important consequences for the secular evolution of these objects.

Code development & Kepler data analysis

[8] *MPI-AMRVAC 2.0 for Solar and Astrophysical Applications*
Xia, Teunissen, El Mellah et al., ApJS 2018
[9] *A study of the shortest-period planets found with Kepler*, Sanchis-Ojeda et al., ApJ 2014
[10] *Triple-star candidates among the Kepler binaries*, Rappaport et al., ApJ 2013
[11] *Possible disintegrating short-period super-Mercury orbiting KIC 12557548*
Rappaport, Levine, Chiang, El Mellah et al., ApJ 2012

For the last years, I have extensively developed the MHD finite volume code `MPI-AMRVAC`. I implemented an angular momentum preserving scheme to guarantee the conservation of angular momentum to machine precision. This step was decisive to insure the robustness of the disc properties I reported on in [5]. I designed a radially stretched spherical grid and coupled it to an adaptive mesh refinement algorithm to monitor the accretion flow over several orders of magnitude at an affordable computational cost (see Figure 1, right panel). I made this new functionality public, documented its usage and validated it on the classic 1D Bondi spherical accretion in a paper describing new numerical techniques we developed for `MPI-AMRVAC 2.0` [8]. I also wrote a conservative scheme to handle viscosity as a flux term and apply the slope-limiting methods which enable us to combine high-order accuracy and stability in the solvers we use. On my own, I coded a ballistic integrator adapted to explore the effects of binarity on different types of winds (e.g. from O/B supergiant stars or AGB stars) that I used in [5], [6] and [7].

Finally, I volunteered to join the Kavli Institute for Astrophysics and Space Research (MIT) from September 2011 to July 2012 and took an active part in the Kepler satellite data analysis effort under the supervision of Saul Rappaport. I used a prospective method to measure masses of very low mass stars in orbit around an F/G companion by using the Doppler boosting of light to get a photometric access to the radial velocity. Using the PyKE data reduction pipeline, I filtered thousands of Kepler light curves before Fourier transform to highlight potential short orbital period signatures. I would then fold and bin the data at the identified period, and that is how I ran into the peculiar transits of Kepler-1520b, the first disintegrating and super-Mercury exoplanet that we characterized in [11]. I also developed a pipeline to systematically look for eclipse timing variations, typical of the presence of a perturbing third body. It contributed to the identification of 30 new hierarchical triple star systems which could not have been detected with the transit method [10] and to a detailed analysis of the shortest-period exoplanets [9]. This seminal experience in Research laid the foundations of my scientific program : a better understanding of stellar bodies and remnants in interaction with their environment.

RESEARCH PROJECT

Fall-back accretion following NS-NS/BH-NS mergers

What it tells us about the ultimate moments of merging compact objects

The discovery of the first GW signal three years ago marked the dawn of a new astronomy (The LIGO/Virgo Collaboration, 2016). Four decades after the indirect GW detection by Hulse and Taylor in an inspiralling pulsar binary (Hulse et al., 1974), we are now fully able to capture the very last moments of the epic life of massive stars through the burst of GW emitted when the compact remnants eventually merge. If the first detections were interpreted as merging BHs, without any electromagnetic counterpart, a GW signal from two merging NSs was observed last year in association with a **short GRB** and a subsequent **luminous blue kilonova** (The LIGO/Virgo Collaboration, 2017). The crossed analysis of these three signals can unearth invaluable information on a multitude of aspects : the equation-of-state (EOS) of condensed matter in NSs, the nucleosynthesis of the heaviest elements and new constrains on gravity in the strong field regime are only a few examples of the promising breakthroughs ahead.

Short GRBs are intense non-repeating flares of 10^{51} ergs released as gamma-rays over less than two seconds (Berger, 2014). Of cosmological origin, they have long been thought to be powered by the **accretion of a massive remnant disc onto the compact object** formed after a NS-NS/BH-NS merger (Eichler et al., 1989). The interplay between **accretion and rapid rotation of the central engine can drive a magnetically-collimated ultra-relativistic outflow** (Piran, 2005), similar to the ones observed in X-ray binaries and extensively modeled by Julien Malzac at IRAP (Toulouse). In France, GRBs lie at the core of the models developed by Frédéric Daigne (IAP, Paris) and his collaborators and they are the main targets of the incoming French-Chinese multi-wavelength *SVOM* mission in which IRAP is playing a major role (see *Tâche de service*). Furthermore, mid-January 2019, a rapid follow-up of the GRB *GRB-190114C* detected by Swift/BAT led to the first sub-TeV detection of a GRB from the ground thanks to the MAGIC Cherenkov telescopes. Although the origin and properties of this GRB are still unclear, it opens a new door to ground-based gamma-ray Astronomy with the incoming CTA (*Cherenkov Telescope Array*), an instrument for which IRAP develops data analysis softwares.

Kilonovae are week-long supernovae-like transients found in association with short GRBs, with a spectral peak ranging from near infrared to optical and a peak luminosity at 10^{40-41}erg·s^{-1} reached after a few days (Tanaka, 2016; Metzger, 2017). They are thought to be produced by neutron-rich material ejected during a NS-NS/BH-NS merger : as the mildly relativistic cocoon expands, it is **heated by** radioactive decay (Li et al., 1998) but also by **fall-back accretion onto the central body** (Rosswog, 2007). A simplified sketch of the different components is displayed in Figure 3.

Consequently, the accretion disc plays a key role in the accretion/ejection mechanism which connects the different components and eventually produces the photonic counterpart emission we observe. The main scientific questions I want to address with this research proposal are :

1. under which conditions a disc is formed and which are its initial properties?
2. how do disc outflows develop and how does fall-back accretion proceed?

1 Accretion disc formed by NS tidal disruption

When two NSs merge, a fraction of the material is tidally disrupted and can form a disc (Baiotti et al., 2017), while magnetic field rearrangement occurs (Crinquand et al., 2018). When a NS

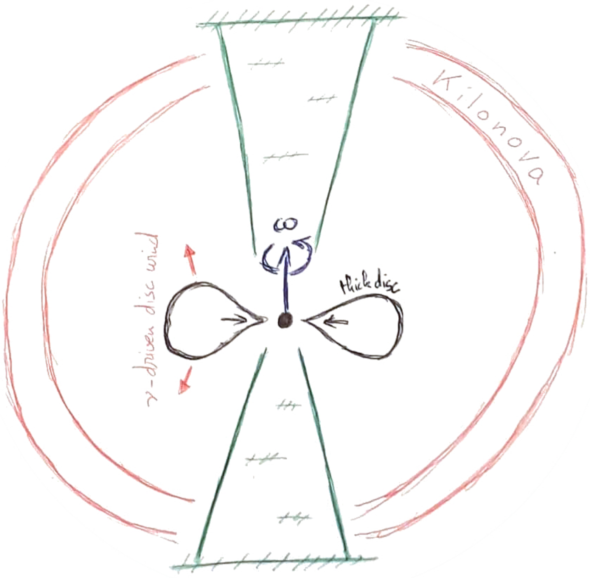


Figure 3: Simplified sketch of the different physical components. The central black dot stands for the merger remnant. If it is a BH, a neutrino ("ν") driven disc wind is first expected before the disc (in black) gets geometrically thick. From the disc, jets (in green) responsible for the short GRB are thought to be launched, here represented in green (with double lines indicating internal and external shocks). The kilonova (in red) comes from outflowing material (both the dynamical ejecta and the disc wind). The details of these pictures depend strongly on the initial merger and the nature of the remnant.

merges with a BH, the situation is different : a disc can only be formed provided the tidal disruption of the NS occurs before the innermost stable circular orbit (ISCO), a critical distance below which the amount of angular momentum is too low to maintain a circular orbit. The constrain set by the presence of the ISCO has been shown to be very stringent. In Figure 4, I represented in fully opaque green the zone where the tidal disruption of a $1.4M_{\odot}$ NS would lead to the formation of a disc (based on arguments inspired from Foucart, 2012). This preliminary approach seems to indicate that only mergers of NSs with low mass BHs ($\lesssim 5M_{\odot}$) could lead to the formation of a disc but the result depends strongly on the BH spin and the redistribution of angular momentum between the ejected material and the inspiralling NS.

I wish to make use of the angular momentum preserving scheme I developed for `MPI-AMRVAC` (see Research summary) to monitor the disc formation in NS-NS/BH-NS mergers with numerical simulations. Depending on the properties of the NS material disrupted during the merger (e.g. its cooling mechanism and its content in neutrons), the discs formed will be different. The major numerical obstacle to overcome to solve the dynamics of the flow is the radiative transfer. In this type of dense and opaque environments, optically thick, radiation couples to matter and advanced numerical schemes are required to solve the new terms which appear in the conservation equations. Furthermore, the emission from this early phase is strongly connected to radiative and kinetic processes in highly magnetized relativistic plasmas, a topic widely addressed in France by Renaud Belmont at IRAP but also by Guillaume Dubus (IPAG), Jérôme Pétri (Strasbourg Observatory) and Fabrice Mottez (LUTh).

During my postdoctoral years, I have worked on different schemes to solve the radiative transfer equations and understand how matter couples to radiation in radiation-dominated environments such as geometrically thick discs : methods inspired from long characteristics with Jon Sundqvist (KU Leuven), flux-limited diffusion and an alternating directional implicit scheme with Nicolas Moens (a PhD student I co-supervise with Jon Sundqvist) and multi-grid solvers with Jannis Teunissen (CWI Amsterdam). I am now in a position to apply these tools to the numerical study of the disc formation following the merger and to contribute to improve our understanding.

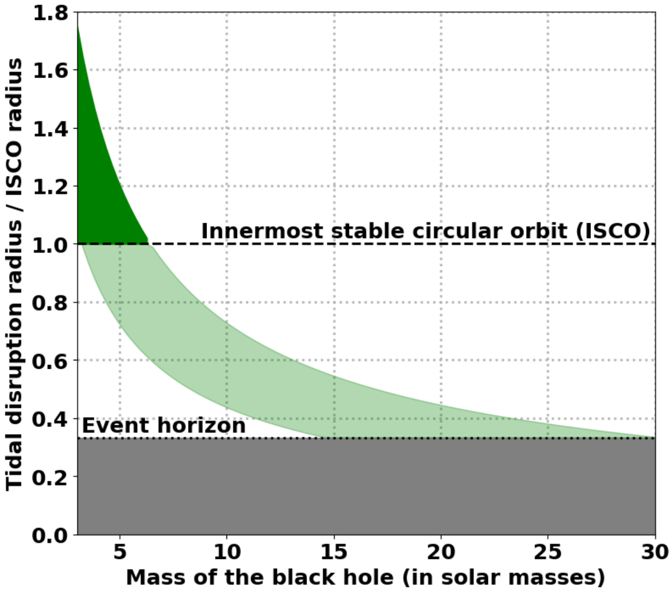


Figure 4: Ratio of the tidal disruption radius of a $1.4M_{\odot}$ NS by the radius of the ISCO of a non-rotating BH, as a function of the mass of the BH. The green shaded region shows the estimated tidal disruption radius for a NS radius between 9kms (lower limit, high compacity, soft EOS) and 15kms (upper limit, low compacity, stiff EOS). The tidal disruption radius needs to be larger than the ISCO radius to form a disc (fully opaque green shaded region).

2 Accretion/ejection in geometrically thick discs

Beyond the question of the structure of the disc, it is necessary to understand how the surrounding kilonova produced by the ejecta can be impacted by the disc, both through disc outflow and radiation. Since the heating rate of the kilonova due to fall-back accretion can be of the same orders of magnitude as radioactive decay, the interpretation of the kilonova light curves observed after a merger will require an accurate understanding of this connection.

During the first seconds following the merger, when the disc is a proficient source of neutrinos, disc outflows can rival or even dominate the dynamical ejecta i.e. the mass ejected from the contact interface between the colliding NS. Although physical differences exist between neutrinos and photons, the numerical treatment of neutrinos transport share many common points with the aforementioned radiative transfer problem. Simulations of neutrino-driven winds would quantify the amount of mass and energy reinjected in the kilonova by the disc outflow. As neutrino-cooling becomes inefficient, the disc transitions to a geometrically thick regime. The hot surface of the disc acts like a stellar photosphere and the wind launching mechanism is similar to the one of line-driven winds of massive stars (Castor et al., 1975), a topic I extensively studied for the last three years, using numerical techniques such as periodic long characteristics in Cartesian slabs and effective acceleration inhibition distance. I could extend these methods to model the specificities of this type of discs.

Fall-back accretion is expected to occur at a rate leading to a luminosity above the Eddington limit of the compact remnant. The Eddington limit is a maximum luminosity, depending only on the mass of the accretor, above which accretion is self-regulated because the spherical outward radiation pressure on free electrons is so high that it compensates the gravitational field. Models of super-Eddington accreting compact objects have blossomed since 2014, when we realized that several ULXs were powered by NSs accreting much above their Eddington limit (Bachetti et al., 2014). Although ULXs are different types of systems, we could now adapt the results obtained for these objects to the accretion disc formed after a NS-NS or a NS-BH merger. The strong expertise of Natalie Webb (IRAP) and Olivier Godet (IRAP), who have carried out pioneering observations of ULXs since the late 2000's, would be a decisive asset to guide my theoretical and numerical modeling of this exotic accretion regime.

To conclude, the accomplishments achieved by multi-messengers Astronomy are impressive but the efforts which were made will be wasted if observers can not rely on robust numerical setups to put their data into perspectives. Typically, the bias introduced by the inclination of the mergers with respect to our line-of-sight can be alleviated in the incoming years, provided we carry out full 3D numerical simulations. I propose to make use of `MPI-AMRVAC`, the code I have been using and developing, to characterize the geometry of the different components.

During the last decade, numerical simulations have revolutionized the field of core-collapse supernovae and provided an inestimable support to understand long GRBs. They showed how important 3D dynamics and micro-physics (e.g. neutrino heating) could be to solve the old conundrum of the stalling shock. Now that compact object mergers are directly within our reach, it is time to deploy the same efforts for short GRBs. High performance computing facilities such as the ones I daily use already exist at the national (e.g. CINES in France and VSC in Flanders) and European levels to carry out this computational investigation, and so do the massively parallel codes. `MPI-AMRVAC` provides a versatile environment to solve the equations of MHD in their conservative form, in a classical or a relativistic framework.

I am willing to take part in this collective effort at IRAP, in the GAHEC team, and to bring a complementary numerical expertise suitable to the problems tackled by its members. As my supervision record indicates, I would try to attract excellent Master and PhD candidates to support this effort. Thanks to the Pegasus Marie Skłodowska-Curie grant I received in 2017, I am also in an ideal position to apply for ERC grants in the following years, in an attempt to provide the necessary momentum to the field of short GRBs in France.

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Tâche de service SVOM/ECLAIRs

Type (ANO1 à ANO6)	ANO2
Nom du service	SO2 - Instrumentation spatiale
Nom de la tâche	SVOM/ECLAIRs
Labellisation	oui
Nom du responsable scientifique correspondant	Bertrand Cordier
Laboratoire et OSU dont elle relève	IRAP - OMP

Les sursauts gamma comptent parmi les phénomènes les plus lumineux dans l'Univers. Observés à des distances cosmologiques depuis les années 60, ils sont probablement associés au lancement d'un jet ultra-relativiste depuis le voisinage immédiat d'un objet compact nouvellement formé. Outre qu'ils nous renseignent sur la première génération d'étoiles, les sursauts longs sondent l'Univers primordial et l'époque de la réionisation et pourraient un jour servir comme chandelles standards jusqu'à des distances bien plus importantes que les supernovae Ia, apportant ainsi de nouvelles contraintes sur les paramètres cosmologiques et la nature de l'énergie noire. Les sursauts courts ont connu un regain d'intérêt en 2017 après la détection d'un signal d'onde gravitationnelle produit par la coalescence de deux étoiles à neutrons dans l'Univers local : pour la première fois, la détection s'est accompagnée d'une contrepartie photonique avec un sursaut gamma court suivi d'une kilonova. Les découvertes à venir grâce à cette nouvelle astronomie multi-messager sont considérables, parmi lesquelles la structure interne des étoiles à neutrons et leur équation d'état, le mécanisme de formation des trous noirs et de lancement des jets ou encore la nucléosynthèse des éléments les plus riches en neutrons.

Au cours des 15 dernières années, le satellite *Swift* a détecté plus d'un millier de sursauts gamma dont seulement un tiers ont une mesure de décalage vers le rouge. Avec la détection de nombreuses sources transitoires à venir grâce au LSST (*Large Synoptic Survey Telescope*) et à SKA (*Square Kilometre Array*), un satellite agile et multi-longueurs d'onde capable de fournir rapidement et de façon automatique les positions précises de ces sources (notamment des sursauts gamma) afin de mesurer leur distance est indispensable à l'essor de l'astronomie multi-messagers pour la prochaine décennie. **Le satellite multi-longeurs d'onde sino-français SVOM** (*Space-borne multi-band Variable Object Monitor*), dont le lancement est prévu pour 2021, intègre à la fois des instruments de détection à grand champ de vue (entre 4keV et 5MeV) pour une localisation préliminaire de la source, et des instruments à petit champ de vue pour affiner la boîte d'erreur et assurer le suivi temporel de la contrepartie du visible aux rayons X. Ce dispositif spatial sera complété par un réseau de télescopes robotiques au sol.

La présente tâche de service porte essentiellement sur 2 composantes sous la responsabilité scientifique de l'IRAP : **le télescope grand champ X et gamma ECLAIRs** embarqué sur SVOM, semblable à l'instrument BAT (*Burst Alert Telescope*) sur Swift, et **le segment sol associé, l'EIC** (*ECLAIRs Instrument Center*). Le plan de détection développé à l'IRAP doit être livré au CNES début 2020 pour intégration à l'instrument complet ECLAIRs, **ce qui nécessite dès maintenant l'étalonnage du plan de détection et le développement des outils numériques pour ce faire**, afin d'assurer la réussite scientifique de l'instrument. Je me propose de participer à la préparation des essais menés sur le modèle de vol du plan de détection, au développement logiciel, notamment en contribuant à **étalonner le modèle numérique des réponses spectrale et temporelle de l'instrument ECLAIRs** à partir de données expérimentales, et à la validation des performances scientifiques d'ECLAIRs. Au sein de l'EIC, je prendrai part au **développement des fichiers auxiliaires de calibration requis pour l'analyse des données d'ECLAIRs** et aux **activités scientifiques d'avocat sursaut sous la responsabilité du FSC** (*French Scientific Center*).

1 SVOM : charge utile et segment sol

La mission SVOM rassemble un satellite éponyme et un segment sol composé de télescopes robotiques de suivi au sol et d'un réseau d'antennes radio au sol VHF (*Very High Frequency*) pour assurer le relai avec le satellite et communiquer à la communauté scientifique les informations nécessaires au suivi au sol en moins d'une minute. Le satellite comporte plusieurs instruments :

- Développé par l'IRAP, l'IRFU et l'APC et sous maîtrise d'œuvre du CNES, **l'imageur grand champ X durs / gamma ECLAIRs** est doté d'un masque codé qui surplombe un plan focal de détection DPIX, une plaque refroidie à -20°C sur laquelle sont disposés 6400 détecteurs en tellurure de Cadmium. Le flux des sources dans le champ de vue passe par le masque et active les détecteurs du DPIX. Ce dispositif confère à ECLAIRs à la fois un large champ de vue et une résolution angulaire suffisamment bonne pour apporter une localisation préliminaire de la source ($\lesssim$ 13 minutes d'arc). Une unité de gestion et de traitement scientifique embarquée, l'UGTS (*Unit for detector manaGement, Triggering and Scientific processing*) scanne en temps réel le ciel à la recherche de nouveaux signaux transitoires apparaissant dans son champ de vue de manière autonome. Dès qu'une détection est confirmée et qu'une position a pu être calculée, ECLAIRs envoie cette information à la plateforme pour initier la séquence d'alerte: certains paramètres de la source (e.g. position et flux) sont immédiatement communiquées via les antennes VHF tandis que la plateforme calcule l'itinéraire le plus rapide permettant de pointer les instruments à petits champs de vue vers la position identifiée par ECLAIRs (en moins de cinq minutes dans 50% des cas).
- Un premier instrument à petit champ de vue (un degré carré), le **télescope X MXT** (*Micro-channel X-ray Telescope*, 0.2-10keV), doté d'une meilleure résolution angulaire qu'ECLAIRs, de l'ordre de quelques secondes d'arc.
- Un second instrument à petit champ de vue, **le télescope VT** (*Visible Telescope*), qui apportera une localisation encore meilleure, inférieure à l'arcseconde dans le visible.
- Enfin, **le GRM** (*Gamma Ray Burst Monitor*) dont les 3 détecteurs permettront la localisation grossière de la source par triangulation dans un champ de vue plus large que celui d'ECLAIRs et la mesure du spectre de l'émission prompte jusqu'à 5 MeV, en particulier pour les sursauts gamma courts.

2 Contenu et équipe d'accueil

L'IRAP est considérablement impliqué (i) dans le développement de l'instrument ECLAIRs (conception du plan de détection DPIX et de ses électroniques de lecture, et étalonnage scientifique) dont le laboratoire est PI avec son responsable scientifique Jean-Luc Atteia et (ii) dans le segment sol via l'EIC sous la responsabilité d'Olivier Godet. L'EIC représente 20 personnels scientifiques équivalent temps plein sur la période 2017-2022 et apporte un support scientifique et technique sous différentes formes : préparation du commissionnement de l'instrument (vérification des performances après le lancement et ajustement), surveillance de l'état et de la calibration de l'instrument en vol, suivi de l'évolution des performances de l'instrument, mise à jour des fichiers de configuration pour le bord (opérabilité de la caméra) et auxiliaires (pour le traitement et l'analyse des données), maintenance du logiciel de bord et gestion des alarmes.

Afin d'assurer la livraison du modèle de vol du plan de détecteurs DPIX au CNES début 2020 puis de l'instrument ECLAIRs en Chine pour intégration au satellite fin 2020, il est impératif d'effectuer au plus vite une série de mesures de performance instrumentale. Pour étalonner les **modèles numériques de la réponse spectrale d'ECLAIRs**, je me propose de prendre comme référence des spectres de sources radioactives simulés par le code Geant4 et de les comparer à ceux mesurés. Je développerai les outils logiciels d'analyse nécessaires pour mener à bien cet étalonnage et pour **calculer certaines tables de configuration pour le bord** telles que les tables des seuils bas des ASICs (*Application-Specific Integrated Circuit*), d'efficacité, de gain, d'offset ou de pixels bruyants/morts. **Le contrôle du bruit** intrinsèque et propagé introduit par les ASICs du DPIX est un enjeu majeur pour éviter que de fausses alertes ne soient déclenchées. Je caractériserai la **réponse temporelle** d'ECLAIRs en calculant les temps morts des détecteurs afin d'en évaluer l'impact sur les flux mesurés. Dans un second temps, ces outils seront en partie intégrés à l'EIC pour **construire les fichiers de calibration en vol**.

3 Evolution de la tâche de service

Dans un second temps se posera la question du legs de la mission avec **l'archivage des données SVOM et leur mise à la disposition** de la communauté scientifique mais aussi des étudiants et du public, du ressort d'une tâche de service ANO5 (Centres de traitement, d'archivage et de diffusion de données). Je souhaiterais participer de deux manières : (i) en développant des outils numériques pour **constituer un catalogue et détecter a posteriori de nouvelles sources**, et (ii) **en organisant les données issues de SVOM dans des formats qui respectent les standards de l'IVOA** (*International Virtual Observatory Alliance*), de façon semblable à ce qui a été réalisé à l'Observatoire de Paris-Meudon par Zakaria Meliani, Franck Le Petit et leurs collaborateurs pour des données de simulation.

A plus long terme, je souhaite mettre à profit l'expérience que j'aurai accumulée avec SVOM pour contribuer à **l'instrument X-IFU** (*X-ray Integral Field Unit*; PI: Didier Barret, IRAP) du satellite Athena (*Advanced Telescope for High ENergy Astrophysics*, Agence Spatiale Européenne) dont le lancement est prévu après 2030. Présentement, Edoardo Cucchetti (IRAP), Etienne Pointecouteau (IRAP) et leurs collaborateurs produisent des observations synthétiques à partir de simulations cosmologiques hydrodynamiques et du simulateur de télescopes X *Sixte*. A terme, le simulateur *end-to-end* d'X-IFU et les outils d'analyse bénéficieront de ceux développés pour la mission SVOM.

4 Compétences pour la tâche de service

Mon activité scientifique ces cinq dernières années a été résolument tournée vers la programmation de modules destinés à produire et analyser des données de simulation en tout point semblables à celles issues des expériences que j'ai menées à bien pendant mon cursus (en particulier pendant l'année de préparation à l'Agrégation). La gestion en temps réel de données volumineuses est un problème que je résous régulièrement en recourant à des méthodes de parallélisation des tâches allouées à différents processeurs (e.g. avec le protocole de communication MPI et l'interface pour architectures à mémoire partagée OpenMP). J'ai su m'adapter à des environnements de travail pré-existants tels que des packages et des codes particulièrement sophistiqués dont la documentation n'était pas toujours exhaustive. J'ai appris à développer rapidement en équipe des ensembles de scripts complexes, documentés en détail (e.g. avec Doxygen) et robustes en me servant des systèmes de contrôle de versions et de partage des tâches (e.g. Git), une qualité précieuse pour garantir la livraison d'ECLAIRs dans les temps. Ma versatilité numérique garantit que je pourrai être opérationnel dès mon affectation, quels que soient les langages et conventions au sein de l'équipe d'accueil.

Pendant mon cursus, j'ai aussi acquis les connaissances théoriques et pratiques pour caractériser la réponse spectrale d'une matrice de pixels. Lors des dix jours d'observation qui m'ont été alloués à l'Observatoire du Mont Mégantic (Canada) par exemple, j'ai réalisé des mesures de vitesses radiales sur des systèmes binaires d'étoiles en recourant à une caméra CCD que j'ai d'abord dû calibrer.

ENSEIGNEMENT

Après une première expérience d'enseignement dans le cadre de mes études à l'ENS de Cachan, j'ai passé l'Agrégation de Physique en 2011 où j'ai été classé second. La diversité des sujets abordés pendant cette année, ainsi que la nécessité de se les réapproprier pour pouvoir les restituer en un cours construit, ont considérablement renforcé ma culture en Physique générale et mon souhait de participer aux activités d'enseignement supérieur.

Durant la 1^{e} année de mon monitorat de thèse, ma mission d'enseignement s'est déroulée pour moitié (32h TD) en Première Année Commune aux Etudes de Santé (PACES) sous la direction d'Isabelle Grenier (AIM, Paris 7). J'y étais responsable de 2 groupes de TD d'environ 40 étudiants chacun. Le programme de Physique de PACES porte sur un vaste panel de problèmes, de la mécanique des fluides aux intéractions rayonnement-matière. J'encadrais ensuite les travaux pratiques du cours de M1 "Traitement du signal - Signaux déterministes" de Laurent Daudet (Institut Langevin, PSL), à hauteur de 32h TD (signaux discrets, analyse de Fourier, convolutions, spectre de puissance, filtrage, etc).

En 2^{e} et 3^{e} année de thèse, j'ai rejoint l'équipe de Cécile Roucelle (APC, Paris 7) où j'ai encadré les TDs de Mécanique du point au niveau L1. Durant les 128h qui m'ont été assignées, j'ai participé à la rédaction des sujets d'exercice et formé des étudiants néophytes aux spécificités du raisonnement physique. A mon sens, la 1^{e} année d'études supérieures représente un moment charnière dans le cursus des étudiants et requiert donc un encadrement étroit et exigeant pour éviter que les étudiants ne perdent un temps précieux.

En 1^{e} année de contrat postdoctoral à Leuven, j'ai encadré des projets scientifiques de Master dans l'unité d'enseignement *Computational Methods for Astrophysical Applications* dirigée par Rony Keppens ($\sim$60h TD au cours de ma première année de postdoctorat). En 2^{e} année, je me suis porté volontaire pour encadrer deux groupes de TD d'étudiants en 1^{e} année de Génie biologique, dans le cadre d'un cours d'Algèbre linéaire. Cette année, je remplace Rony Keppens comme co-responsable du cours de Master *Computational Methods for Astrophysical Applications* à l'occasion de son départ en année sabatique. La préparation du cours ($\sim$40h) m'a demandé de formaliser des connaissances en Astrophysique numérique que j'avais acquises de façon empirique depuis le début de ma thèse et de replacer les outils que j'utilise au quotidien dans une perspective plus didactique. L'organisation logistique de l'enseignement, en mettant en place un réseau de machines virtuelles accessibles aux étudiants, a aussi été une composante importante, à garder à l'esprit lorsque l'on souhaite intégrer la dimension numérique à l'enseignement.

L'outil numérique offre de nouvelles opportunités pour l'activité scientifique, à condition de s'assurer que les étudiants qui seront amenés à la porter dans les années à venir aient pleinement conscience de sa centralité. Il s'agit de rendre l'Informatique familière aux étudiants dès leur première année afin qu'elle nourrisse leur réflexion scientifique au lieu d'apparaître comme une contrainte à laquelle ils seraient obligés de se soumettre. Au quotidien, la recherche en Physique ne peut pas plus se passer de compétences avancées en Informatique qu'en Mathématiques. C'est pourquoi je souhaite soumettre aux étudiants dès la Licence une base de donnée de sujets numériques d'exercices. Ils seraient écrits de façon à encourager le déploiement de compétences telle que la mise en ligne d'exposés intéractifs de leurs réponses via la programmation d'applets.

Compte tenu de mon parcours, j'ai donc toutes les compétences pour enseigner à l'Université Toulouse III Paul Sabatier où je souhaiterais intervenir en Licence de Physique fondamentale (TD, TP et CM) ainsi qu'en M1 Science de l'Univers et Technologies Spatiale (SUTS, encadré par Gabriel Fruit) et en M2 SUTS parcours Astrophysique, Science de l'Espace et Planétologie (ASEP, encadré par Natalie Webb). En particulier en M2, je souhaiterais initier les étudiants aux techniques modernes de calcul intensif (parallélisation, optimisation, visualisation et stockage des données, etc), indispensables tant pour l'analyse de données que pour la résolution numérique de problèmes physiques.

RESPONSABILITÉS

L'an dernier, j'ai co-encadré avec Rony Keppens et Jon Sundqvist la thèse de M2 de Nicolas Moens sur les vents d'étoiles massives. Avec mon aide, il a implémenté avec succès des modèles physiques de lancement dit "radiatif" de ces vents dans le code de résolution sur grille des systèmes d'équations hyperboliques, `MPI-AMRVAC`. De son propre chef, il s'est ensuite attelé à la création d'un nouveau module de transport radiatif basé sur un algorithme de flux-limité diffusif qui permet maintenant à `MPI-AMRVAC` de traiter le refroidissement dans les environnements optiquement épais. Suite à cette expérience fructueuse, Nicolas a commencé en Octobre 2018 une thèse sous la direction conjointe de Jon Sundqvist et moi-même au département de Physique et d'Astronomie de KU Leuven.

Aux côtés de Leen Decin (KU Leuven), Stanley Owocki (University of Delaware), Alex de Koter (University of Amsterdam) et Hugues Sana (KU Leuven), je suis membre du comité de suivi de thèse de Luka Poniatowski (encadré par Jon Sundqvist). J'ai aussi été rapporteur en Juin 2018 pour les thèses de Florian Driessen (*First empirical constraints on the low Hα mass-loss rates of magnetic O-stars*) et Prem Kumar Bulusu (*XMM-Newton observations of the highly eccentric binary system HD 93129A towards its periastron passage*).

A la suite de sollicitations, j'ai référé des articles pour *The Astrophysical Journal* et *Astronomy & Astrophysics*. Une désignation comme expert compétent par un·e membre de la communauté m'a amené à évaluer une demande de temps de calcul sur le supercalculateur britannique DiRAC.

Afin de tisser des liens forts entre jeunes chercheurs, la Société Française de Physique a initié en 2013, sous l'égide de Samuel Guibal (MPQ, Paris 7), un évènement annuel intitulé les Rencontres Jeunes Physiciens (RJP). En deuxième année de thèse, je me suis engagé au sein du comité d'organisation des RJP 2015 en tant que community manager. Mon rôle était d'assurer aux RJP une visibilité médiatique maximum, tant sur les réseaux sociaux qu'à travers sa principale vitrine, son site Web, dont j'ai adapté la mise en page et le contenu. Pour garantir la pérennité des RJP, j'ai aussi procédé, avec l'aide du personnel du Conservatoire National des Arts et Métiers où se déroulait l'évènement, à la captation audio et vidéo des interventions orales qui rythmaient la journée, ainsi qu'à leur traitement puis à leur diffusion. L'évènement, qui a rassemblé quelque 200 doctorants et post-doctorants d'Ile-de-France, a reçu le soutien de nombreuses universités, écoles doctorales et institutions. Grâce à elles, nous avons pu rassembler près de 15k€, qui nous ont permis de faire de cette journée un temps fort de la vie sociale des jeunes physiciens et physiciennes d'Ile-de-France. En tant que membre du comité d'organisation, j'ai aussi participé à la sélection des 16 interventions orales parmi la quarantaine de résumés qui nous avaient été soumis.

Dans mon laboratoire de thèse, l'APC, j'ai animé des Présentations hebdomadaires des Doctorants (ou *PhD*) dévolues à des aspects méthodologiques de l'activité scientifique telles que les éditeurs de codes, la veille bibliographique ou encore la gestion de versions avec des outils comme Git. Afin de s'assurer que chaque doctorant soit opérationnel à l'issue de ces présentations, nous organisions des ateliers d'une durée de 3h où chacun ramenait sa propre machine de travail sur laquelle avaient été installés au préalable les outils nécessaires à la session. Moins formels et plus spécialisés que les ateliers de formation génériques proposés à tous les doctorants de l'université, ces sessions permettaient de partager rapidement et efficacement des méthodes de travail qui apportent des gains de temps considérables.

DIFFUSION DES CONNAISSANCES

En Novembre 2017, j'ai participé à une émission radiophonique, la Faconde, sur la radio universitaire de l'Université Libre de Bruxelles. J'y ai discuté de la communication scientifique et promu sa composante sensible et esthétique, par opposition à la transmission mécanique de résultats scientifiques formatés qui désenchante et, in fine, suscite un détachement et un relativisme généralisé au sein de la population.

Dans une perspective plus pédagogique, j'ai animé un atelier sur la notion de potentiel en mécanique à destination d'élèves de lycée en Octobre 2016, à l'occasion de la Fête de la Science. Pour ce faire, j'ai mis à profit des maquettes de potentiels de Roche que j'ai pu imprimées en 3D grâce à l'assistance technique de Hubert Halloin et Marco Agnan et à un financement DIM ACAV[1]. En parallèle, j'ai produit une application intéractive en ligne qui permet d'appréhender empiriquement la notion de potentiel lorsqu'elle est utilisée conjointement avec la maquette suscitée : la maquette sert à visualiser le potentiel en 3D pour un paramètre donné (le rapport de masse entre les deux corps), alors que l'application en ligne permet de modifier ce paramètre à souhait et de visualiser les trajectoires associées.

Pendant ma thèse, j'ai aussi publié une page personnelle à même de rendre compte de mes travaux au sein de la communauté scientifique mais aussi auprès du grand public.

[1] Domaine d'Intérêt Majeur en Astrophysique et Conditions d'Apparition de la Vie.

Peer-reviewed publications[1]

[1]* **El Mellah I.**, Sundqvist J. O., & Keppens R.
Wind Roche lobe overflow in high mass X-ray binaries : A possible mass transfer mechanism for Ultraluminous X-ray sources - A&A 2019

[2]* Decin L., Homan W., Danilovich T., de Koter A., Engels D., Waters L. B. F. M., Muller S., Gielen C., García-Hernández D. A., Stancliffe R. J., Van de Sande M., Molenberghs G., Kerschbaum F., Zijlstra A. A., **El Mellah I.**
Reduced mass-loss rate of OH/IR stars due to binary interaction - Nature Astronomy 2019

[3]* **El Mellah I.**, Sander A. A. C., Sundqvist J. O., & Keppens R.
Formation of wind-captured discs in Supergiant X-ray binaries : consequences for Vela X-1 and Cygnus X-1 - A&A 2019

[4]* **El Mellah I.**, Sundqvist J. O., & Keppens R.
Accretion from a clumpy massive-star wind in Supergiant X-ray binaries - MNRAS 2018

[5]* Xia C., Teunissen J., **El Mellah I.**, Chané E. & Keppens R.
MPI-AMRVAC 2.0 for solar and astrophysical applications - ApJS 2018

[6]* Grinberg V., Hell N., **El Mellah I.**, Neilsen J., Sander A. A. C., Leutenegger M. A., Fürst F., Huenemoerder D. P., Kretschmar P., Kühnel M., Martínez-Núñez S., Niu S., Pottschmidt K., Schulz N. S., Wilms J. & Nowak M. A.
The clumpy absorber in the high mass X-ray binary Vela X-1 - A&A 2017

[7]* **El Mellah I.** & Casse F.
A numerical investigation of wind accretion in persistent Supergiant X-ray Binaries I - Structure of the flow at the orbital scale - MNRAS 2017

[8]* **El Mellah I.** & Casse F.
Numerical simulations of axisymmetric hydrodynamical Bondi-Hoyle accretion on to a compact object - MNRAS 2015

[9] Sanchis-Ojeda R., Rappaport S., Winn J., Kotson M., Levine A., **El Mellah I.**
A Study of the Shortest-period Planets Found with Kepler - ApJ 2014

[10] Rappaport S., Deck K., Levine A., Borkovits T., Carter J., **El Mellah I.**, Sanchis-Ojeda R., Kalomeni B.
Triple-star Candidates among the Kepler Binaries - ApJ 2013

[11]* Rappaport S., Levine A., Chiang E., **El Mellah I.**, Jenkins J., Kalomeni B., Kite E. S., Kotson M., Nelson L., Rousseau-Nepton L., Tran K.
Possible Disintegrating Short-Period Super-Mercury Orbiting KIC 12557548 - ApJ 2012

[1] The stars indicate the papers in which I made a major contribution.

Proceedings

[12] **El Mellah I.**, Sundqvist J. O., & Keppens R.
Wind-captured discs in Supergiant X-ray binaries
IAU Vienna 2018

[13] Fürst F., Kretschmar P., Grinberg V., Pottschmidt Katja, Wilms J., Kühnel M.,**El Mellah I.**, Martínez-Núñez S.
Variability in High Mass X-ray Binaries
XMM-Newton workshop 2018

[14] **El Mellah I.**, Sundqvist J. O., & Keppens R.
Clumpy wind accretion in Supergiant X-ray Binaries
Journées de la Société Française d'Astronomie et d'Astrophysique 2017

[15] **El Mellah I.**, Casse F.
Numerical simulations of axisymmetric Bondi-Hoyle accretion onto a compact object
Journées de la Société Française d'Astronomie et d'Astrophysique 2015

Conferences & workshops

Fb 2019	12th INTEGRAL conference – Geneva, (SW)
Oc 2018	Stellar Winds in Massive X-ray Binaries workshop – Santander (SP) – **invited**
Oc 2018	Leuven-Amsterdam-Bonn massive stars meeting – Leuven (BE)
Ag 2018	IAU General Assembly – High Mass X-ray Binaries symposium – Vienna, AT
Jn 2018	Belgium FNRS meeting – Brussels, BE
Sp 2017	Frontiers of Astrophysical Modeling – KU Leuven (BE)
Ag 2017	Numerical techniques in MHD simulations – Köln (GE)
Jl 2017	Journées de la SF2A – Paris (FR)
Mr 2017	CHARM meeting – Brussels (BE)
Mr 2017	Stellar winds in massive X-ray binaries (ISSI workshop) – Bern (SW) – **invited**
Sp 2016	Super-Eddington accretion on compact objects – Arbatax (IT)
Mr 2015	International school of Computational Astrophysics – Les Houches (FR)
Jn 2015	Journées de la SF2A – Toulouse (FR)
Mr 2015	Turbulence, magnetic fields and self organization – Les Houches (FR)

Seminars

Fb 2019	APC Paris 7 Diderot (FR)
Nv 2018	IRAP Toulouse (FR)
Jl 2018	TAPIR Caltech (US)
Fb 2018	LUPM Montpellier (FR)
Dc 2017	Radboud University Nijmegen (NL)
Nv 2017	ESAC, Madrid (SP)
Sp 2017	LUTh, Observatory of Paris (FR)

Sp 2016	Aarhus University (DN)
Ap 2016	APC, Paris 7 University (FR)
Ap 2016	CmPA, KU Leuven (BE)
Oc 2015	AIM, CEA (FR)

Posters

Jl 2018	Clumpy wind accretion in Supergiant X-ray binaries, COSPAR Pasadena (US)
Jn 2017	Clumpy wind accretion in Supergiant X-ray binaries, EWASS, Prague (CZ)
Dc 2015	Wind accretion onto compact objects, Texas symposium, Geneva (SW)
Nv 2014	Wind accretion undergoing flip-flop instability, IAP, Paris (FR)

Diverse communications

El Mellah I.
Wind accretion onto compact objects
PhD manuscript 2016

El Mellah I.
3D-printed models and Wolfram interactive applet for the Roche potential
2015

1h30 radio interview on scientific communication in Faconde
Brussels 2017

Auteurs lettres de recommandation

Fabien Casse
Rony Keppens
Natalie Webb / Olivier Godet