DOSSIER DE CANDIDATURE AAP 2026 DIM ORIGINES

ALLOCATIONS DOCTORALES

Acronyme du projet : **SpiralsMatter**

Nom - Prénom du porteur du projet : **Pichon Christophe**

Laboratoire : **Institut d'astrophysique de Paris/LUX Observatoire de Paris**

Spirals Matter: The emergence of Galactic Morphology & Scaling Laws

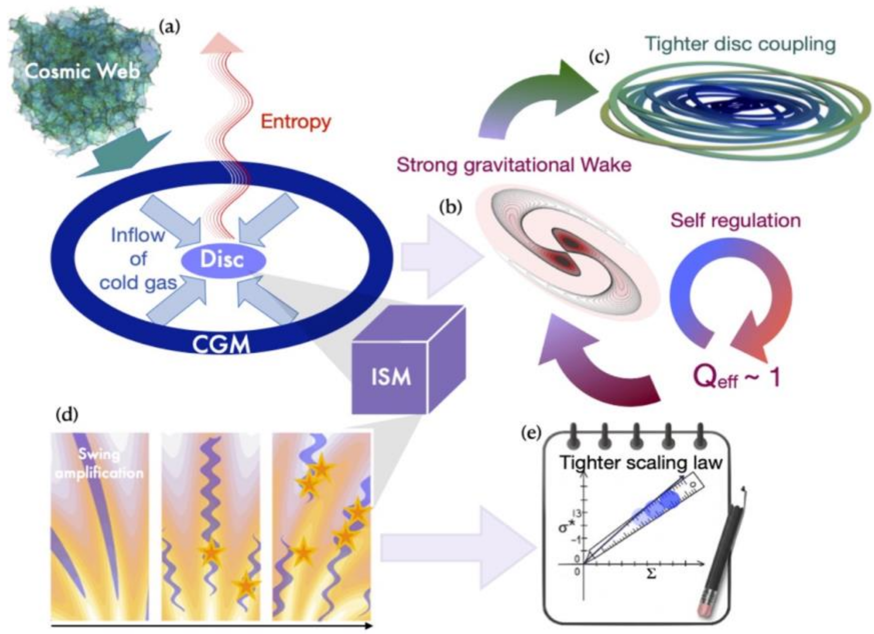

Figure 1. Illustration of the self-regulating control loop motivating the resilience and robustness of disc emergence. External and internal perturbations (heating/diffusion) are amplified by the system's collective response, which in turn drives a powerful cooling (reaction) process, robustly maintaining the system in a state of homeostasis near marginal stability. The interplay between three co-evolving galactic components (a), the interstellar medium (purple), the disc (light blue) and the circum-galactic medium (dark blue), sets up an emerging dissipative machine (b), which, through wakes, achieves both self-regulation and stiffening, (c). Inflowing cold gas lowers the disc's effective temperature, hence triggers wakes, which sources the turbulent cascade in the ISM through sequences of stellar swing amplifications, (d), leading to recurrent star formation. The thin disc inherits the coherence of the cosmic web's steadiness, (a), through gravitationally-driven top-down causation, but the link is not finely tuned, thanks to the co-induced homeostasis towards stellar marginal stability. The net effect of the induced attractor is to "glue" baryonic and dynamical properties together, explaining the ubiquity of tight scaling laws, (e). Stellar or AGN feedback are not fine-tuned to reach bottom-up baryonic regulation, because it is achieved by the dominant stellar component.

I Dossier Scientifique https://spiralsmatter.com

Spirals are not ornaments: they are signatures of an emergent process that arises spontaneously when the collision-less dynamics of stars couples with collisional physics of cold gas. It yields a robust gravity-driven attractor which controls star formation and morphology: no fine tuning is required.

For billions of years, vast stellar discs, seemingly fragile structures, have demonstrated remarkable robustness, resisting disruption and maintaining a highly ordered state. This persistence is explained with difficulty by conventional models that rely on fine-tuned, localized parameters.

The PhD candidate will posit that galactic discs are archetypal examples of emergent systems. Their resilience does not stem from a delicate balance but from a robust, self-regulating feedback loop driven by the universal force of gravity. In this framework, perturbations that "heat" the system by increasing orbital disorder trigger a powerful gravitational response, which in turn drives cooling processes (star formation on ordered orbits) that challenge stability. The galaxy is naturally drawn to an attractor state of marginal stability, allowing it to absorb perturbations and persist over cosmic timescales. In turn this attractor closely links the *global* properties of the galaxy to its *local* star formation efficiency, as traced by various observed scaling laws. Its very existence allows for a **theory for galactic morphology**.

Astrophysical Context

The persistence of thin discs and their tight scaling laws is central to precision cosmology, since surveys such as Euclid and LSST rely heavily on galaxy morphology and luminosity. A long-standing paradox remains unresolved: in ΛCDM, galaxies evolve within a perturbed environment with continuous inflow and satellite interactions, yet observations reveal structurally fragile but long-lived discs. JWST has strengthened this tension by showing that such discs already exist at high redshift. This PhD will test whether a top-down spiral-driven form of self-regulation resolves this paradox. The hypothesis is that multi-scale gravitational response, gas inflow, and turbulent star formation set up a self-organised feedback loop that maintains discs near marginal stability. This loop simultaneously explains their resilience and the emergence of tight scaling laws: internal disorder induced by perturbations is counterbalanced by cold-gas-driven cooling processes that rebuild ordered orbits. The resulting attractor glues baryonic properties (star formation, gas fraction, metallicity) to dynamical ones (halo mass, angular momentum distribution), reducing intrinsic scatter in relationships relating these quantities: **spirals matter**! Understanding this homeostatic behaviour is crucial for interpreting morphology and luminosity-dependent biases in cosmological inference.
While our recent work strongly hints that self-regulation near marginal stability underlies the tightness of galactic scaling laws, this remains a working hypothesis that has **not** yet been fully demonstrated from first principles nor systematically tested against cosmological simulations and observations. Whatever the answer, clarifying whether spiral-driven self-regulation can or cannot resolve the paradox of the resilience of thin star-forming discs will have significant impact on our understanding of galaxies and on precision cosmology.

Method

Two recent advances now make it possible to model disc evolution perturbatively rather than relying on expensive simulations: i) the validation of kinetic-theory formalisms capturing disc heating through

orbital diffusion (Roule+24); ii) new developments in large deviation theory describing fluctuations and morphological diversity beyond mean-field evolution (Feliachi+24). The PhD will extend these tools to formulate a dissipative, self-consistent quasi-linear ("dressed") **reaction-diffusion equation** for galactic discs. The diffusion term will capture stochastic gravitational heating driven by internal and external fluctuations. The reaction term will describe the cooling supplied by cold gas inflow and the formation of stars on ordered orbits. The collective gravitational response ("dressing") will encode spiral swing amplification and determine how perturbations are boosted or suppressed depending on the discs state. Large deviation theory will predict the observed spread in scaling laws.
The PhD is deliberately multi-modal, combining analytical development of a dressed reaction–diffusion formalism with targeted numerical experiments, controlled extractions from cosmological simulations and explicit confrontation to observations. This strategy ensures that conceptual progress on the physics of self-regulation is firmly anchored in data, realistic galactic environments, while avoiding an exclusive reliance on costly ab initio simulations.

Relying on the expertise of both institutes, LUX and IAP, the student will explore stationary solutions, bifurcations, and thresholds for disc survival or failure, using perturbative models and targeted numerical experiments. The formalism will be confronted with survey data to quantify environment-dependent resilience and its imprint on scaling-law scatter. When completed, the student will have demonstrated how gravity provides top-down causation across scales, from cosmic-web inflows to ISM turbulence within spiral arms, and why thin discs remain coherent over billions of years. She will also quantify the induced biases in cosmological measurements and propose ways to marginalize over them. The timing of this PhD is optimal: JWST now routinely resolves discs and scaling relations out to high redshift, while Euclid, LSST and DESI are beginning to deliver unprecedented statistics on morphology-dependent clustering and dynamics.
This PhD project is designed to interpret these new data within a physically motivated framework of spiral-driven self-regulation, rather than relying on purely empirical parameterisations. The PhD student will seek to provide a first principles explanation for the emergence and small scatter of galactic scaling laws, or, if the hypothesis fails, to delineate precisely where simple gravitational self-regulation breaks down, and which additional physical ingredients must be invoked. In both cases, the outcome will influence how scaling laws are used in cosmology and galaxy-evolution modelling.

II Plan de recherche et calendrier :

Framework The PhD will be co-supervised by Christophe Pichon (IAP, Paris) and Damien Le Borgne (IAP, expert in super spirals, star formation), in close interaction with Philippe Salomé (LUX Obs Paris, expert in ISM turbulence, feedback, baryon cycle) and Maxime Trebitsch (LUX Obs Paris, expert in Cluster environment, cosmological simulations) as part of the GALBAR ANR (**https://www.secular-bars.org**). Our established **collaborations** (20+ papers, over 3000 citations) will benefit from complementary synergies on observational, theoretical and numerical astrophysics: our team has expertise in galactic dynamics, secular evolution, spiral structure, interstellar physics and scaling laws, as evidenced by successful PhD projects on related topics (orbital diffusion, bar formation, disc settling, super spirals, large-deviation modelling). The student will thus benefit from this environment.

Goals and milestones: The PhD student will aim to:

- Demonstrate how gravity-driven baryonic processes establish a self-regulating loop that maintains disc marginal stability and tightens galactic scaling laws.

- Develop a theory for galactic morphology based on dissipative, open kinetic-theory models (reaction-diffusion, large deviation) to follow disc thinning and resilience over secular timescales.
- Predict observables (disc thickness, bar/bulge/super spiral fractions, scatter in scaling relations (bTF/RAR/KS/metallicity-kinematics) as a function of environment and redshift, for comparison with current (JWST, Euclid) and upcoming facilities (with Trebitsch & Le Borgne).
- Identify environmentally-driven thresholds where self-regulation fails, leading to secular quenching or bar formation, or conversely when it persists, leading to super spirals (with Salomé & Le Borgne).
- Quantify morphology-induced biases in cosmological surveys and provide physically motivated corrections.

To achieve these goals, the PhD candidate will aim for the following set of milestones:
1rd semester/ She will develop a novel mathematical framework for resilience in the gravitational context. She will formulate and solve a "dressed" reaction-diffusion equation derived from first-principles kinetic theory. This master equation will describe the secular evolution of the disk's distribution function, capturing the balance between disorder-inducing perturbations (diffusion) and order-restoring feedback (reaction), mediated by the system's own long-range gravity.
2nd semester/ Using large deviation theory, she will understand how, while the discs settle, the scaling laws tighten, reflecting the modulation of both orbital diffusion *and* star formation by the same confounding factor, proximity of galaxies to marginal stability, which acts like an attractor (with Le Borgne). With Trebitsch, she will in parallel quantify the mean field, the actions and the distribution function of the galactic disks extracted from our cosmological simulations in order to carry out ensemble averages comparable to the theory. She will in particular characterize the spectral properties of the galactic cosmic environment (power spectrum of the fluctuations in the force field and fluxes at the two boundaries: interstellar medium-disc, disc-circumgalactic medium). The induced orbital scattering will be quantified independently in simulations.
3rd semester/ She will identify the universal parameters and thresholds that govern the cosmological robustness of galactic discs. Using this analytical framework, she will explore the system's behaviour under a range of conditions (e.g., varying the intensity and nature of external noise, the efficiency of the cooling term). With Trebitsch, her goal will be to identify the critical thresholds where self-regulation fails, leading to a catastrophic phase transition and morphological transformation (i.e., the 'death' of the disc). Doing so, she will quantitatively assess the extent of the resilience of galactic discs.
4th semester/ Beyond this threshold, together with Salomé, she will quantify (using instantons) how the disc chooses another path to sustain the stress imposed by its environment, and quantify how this impacts morphological diversity (ellipticals, bars, spirals and super-spirals resp.) across redshift. She will then produce tools to marginalize morphology-induced biases in the inference of cosmological parameters.
5th semester/ Together with Salomé and Le Borgne, the student will finally test against observational data from major cosmic surveys (Euclid, LSST, DESI, JWST) the predictions of the framework -- such as the tightness of scaling laws, the system's stability as a function of cosmic environment, and the epoch of spontaneous emergence.
6th semester/ Thesis production and viva.

Feasibility, timeliness and importance: This PhD proposal is an exploratory and challenging but *feasible* project: it involves addressing a central tenet in long-term galactic evolution, using novel theoretical and numerical developments involving perturbative theory and stochastic methods. •The basic theoretical building blocks (quasi-linear kinetics, orbital diffusion in self-gravitating discs, large-deviation theory) have already been developed and tested in closely related contexts (theses by Fouvry, Rozier, Roule, Tep, Ko). The characterisation of super-spirals was achieved by Cologni under the joint supervision of Le Borgne, Guillard and Salomé.

•The required cosmological simulations (field, NewHorizon, Megatron, and cluster NewCluster, Obelix produced by Trebitsch) already exist; the task is to extract and analyse the force fields from them; this reduces the risk of depending on new, computationally heavy simulations.

•The PhD plan is designed in an incremental way: each milestone is based on a testable model of increasing complexity, which makes it possible to readjust the level of ambition according to the student's actual progress.

•Theorists (Pichon, Trebitsch) are complemented by observers (Le Borgne, Salomé) who have direct access to unique data sets (noticeably super spirals). Trebitsch's expertise will also be critical to help the student develop the computational algorithms to follow the thinning of discs over cosmic times, and measure the ingredients entering extended kinetic theories.

Impact sociétal : Understanding emergence, a fairly universal process (snowflakes, hurricanes, life, etc) in the context of such a simple system (where gravity drives the show) is clearly of general societal interest, because it can be studied both at a microscopic (the stars) and mesoscopic (the homeostatic machine obeying open kinetic theory) level. Sharing this knowledge has proven popular with the general public, e.g. during the "Nuit de l'Astronomie". This aspect of the work will therefore continue to be advertised (such as in this public lecture, or that one, the RER-B exhibit below, or online https://www.cosmic-evolution.org/). We will also present our simulations in 3D in the La Villette planetarium (in collaboration with A. Riazuelo). All aspects of this work are of course open science. Note that this line of research also provides means of studying the long-term evolution of galaxies without relying exclusively on energy intensive simulations.

Impact économique : The economic implications of this line of work are indirect yet significant for both institutes (IAP and LUX). Self-regulation operates throughout many aspects of robotics and automation, hence understanding how and when it occurs spontaneously in nature is of interest, if only to understand how robust a given system can be. Galactic disc's cosmic resilience provides a specific simplified playground where the nature and limitation of self-regulation can be studied in details to address generic questions such as "*when and why does the self-regulation break down?*", "*how to anticipate the corresponding phase transition?*". Emergence generically operates near phase transition, as the result of non-trivial solutions to reaction-diffusion processes. The mathematics of such processes has tight connection to chaos theory, instantons, and is of interest in the context of modeling complex systems (solid state physics, electronics, climate change, cybernetics, etc). As such, the mid-term economic impact of the applicant's work will be significant.

CV du directeur de thèse :

CHRISTOPHE PICHON

Born: 7 May 1968 (57 years old) http://www.iap.fr/users/pichon

http://cncpichon.github.io ORCID: 0000-0003-0695-6735

Pichon has published 222 refereed publications (150 in the last 10 years), 50 of which have over 100 citations. His papers have over 25 000 citations (H=70).

EDUCATION

2008 Habilitation: Gravitational structuration mechanisms : theory and estimation.
1994 PhD : *Dynamics of self gravitating disc* with D. Lynden-Bell, Cambridge, UK

CURRENT & PREVIOUS POSITION(S)

2021- Research director, first class, CNRS, UMR 7095, Institut d'astrophysique de Paris, Fr.
2011-2020 Research director, 2nd class, CNRS, UMR 7095, Institut d'astrophysique de Paris, Fr.
2015-2025 (First astronomy) KIAS Scholar, Korean Institute of Advanced Studies, Seoul, Korea.
2018 Sabbatical at Institute for Astronomy, Royal Observatory of Edinburgh, UK.
2015 Sabbatical at Churchill College, Institute of Astronomy, University of Cambridge, UK.
2010 Sabbatical at Merton College, Astrophysics, Department of Physics, Oxford, UK.

FELLOWSHIPS AND AWARDS

2025 Kyung Hee Eminent scholar Korea.
2018 Scottish University Physics Alliance distinguished visitor Edinburg.
2015 Korean Institute of Advanced Studies Scholarship Seoul.
2014 Churchill College-CNRS fellowship, University of Cambridge.
2013 Sackler visiting fellowship, University of Cambridge.
2010 Merton College visiting Professorship, University of Oxford.
2009 Leverhulme Professorship, University of Oxford.
1992 Knight Prize * University of Cambridge.

SUPERVISION OF GRADUATE STUDENTS AND POSTDOCTORAL FELLOWS

I have (co-)supervised 19 PhD students (one ongoing), ***eleven*** of whom have now permanent positions in astronomy.

E. Ko : "Dynamical Heating by Superbubbles" 2023-
M. Roule : *"Kinetic theory of self-gravitating stellar systems"* with J.B. Fouvry, 2024, Paris,
K. Tep : *"Secular evolution of stellar clusters"* with J.B. Fouvry, 2023, Paris,
S. Rozier : *"Linear Stability of Rotating Stellar Clusters"* with J.B. Fouvry, 2020, Paris,
C. Cadiou* : "*The impact of the LSS on dark matter halo and galaxy formation*",with Y. Dubois 2019,
C. Gouin* : "Lensing probing the mass content of the Universe" with R. Gavazzi, 2018, Paris
C. Laigle* : "*Constraints on galaxy evolution*" with H.J. McCraken, 2016, Paris.
J.B. Fouvry*: "*Secular evolution of self-gravitating systems*", with J. Binney, 2016, Paris.
C. Welker* : "*Gas inflows and mergers shape galaxies*" with J. Devriendt, 2015, Paris.
S. Codis* : "*Que nous apprennent les grandes structures de l'Univers?*"with D. Pogosyan, 2015.
C. Gay : "*L'évolution cosmique du squelette de l'Univers*", with D. Pogosyan, 2011, Paris.
J. Thiébaut : "*Reconstruction de champs magnétiques*" with S. Prunet, 2011, Paris.
T. Sousbie* : "*Le Squelette de l'univers*" with H. Courtois, 2009, Lyon.
S. Caucci : "*La topologie du Milieu intergalactique*" with P. Petitjean, 2009, Paris.
B. Aracil : "*Étude du milieu intergalactique*" with P. Petitjean, 2007, Paris.
E. Rollinde*: "*La physique du milieu intergalactique*" with P. Petitjean, 2006, Paris.
D. Aubert* : "*Étude des flux cosmologiques au travers de la sphère du viriel Galactique*", 2004, Paris.
P. Ocvirk* : "*Évolution spectro-dynamique des disques galactiques*"with A. Lançon, 2004,Strasbourg.

A. Siebert* : "*Structure et dynamique des disques de la Galaxie*" with O. Bienaymé, 2003, Strasbourg.

MEMBERSHIPS OF SCIENTIFIC SOCIETIES & COLLABORATIONS

2026 –2030 CoI of ANR The formation of galactic bars (590k€) ANR-25-CE31-4684.
2020 –2025 PI of ANR Secular evolution of galaxies Fr (550k€) ANR-19-CE31-0017.
2014 –2018 PI of ANR Cosmic origin of Hubble sequence Fr (550k€) ANR-13-BS05-0005 .

CV du co-directeur de thèse :

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Positions

- 2021 - now — Maitre de conférences HC, HDR, Sorbonne Université; IAP; ED 127
- Sept 2018 - Sept 2020 — Invited researcher at Leibniz Institute for Astrophysics Potsdam (AIP)
- Sept 2019-- Sept 2020 — CNRS delegation
- Sept. 2008 - now — Maître de conférences section 34, Sorbonne Université, IAP ; ED 127
- 2005- 2008 — Postoctoral researcher, Service d'Astrophysique, CEA Saclay, France
- 2003- 2005 — Postoctoral researcher, University of Toronto, Canada
- 2000-2003 — Teaching duties at Ecole Polytechnique (192h)

Academic Cursus

- 2025 — HDR, Sorbonne Université
- 2000 - 2004 — PhD Doctoral school ED127 1999 – 2000
- 1998 - 2000 — Ecole Supérieure d'Electricité (Supélec) Engineering School

Research

- Topics : Galaxies formation and evolution / Large spectroscopic surveys; / Star-formation histories / Cosmological simulations / Galaxy morphology
- Publications: 61 rang A (11782 citations, h=41).

Projects

- Co-I of the ANRs "iMAGE" (2022-now), "SPINE" (2013-2018) and "HUGE" (2009-2013)
- 2012 - now : Member of the scientific teams of the Maunakea Spectroscopic Explore
- 2015 - now : Member of the scientific teams of SVOM
- 2011-2015 : Member fo the GDRE « Gamma Ray Bursts »
- 2008-2013 : Co-I of the OT key project "GOODS-Herschel"
- 2014-2018 : co-I for the Horizon and Horizon-AGN simulations GENCI proposals

Teaching and supervision

- 192 hours/year at Sorbonne Université at all levels from L1 to M2.
- Various lectures on "Mechanics" (L1), "Thermodynamics" (L1, L2), "Statistical Methods and Data Analysis" (M2 AAIS) (Lecture + TP), etc.

- 3 PhDs : Florian Livet (2018-2021) ; Sébastien Carrassou (2014-2017); Romane Cologni (2023-)
- 1 Postdoc : Yuko Kakazu (2008-2010)

Diffusion

- Co-chair, SOC and LOC : 2013 IAP International conference "Origin of the Hubble Sequence"
- LOC : 2010 IAP international conference "Progenitors and environments of stellar explosions"

Responsabilities

- 2021-now : Deputy director of the Institut d'Astrophysique de Paris
- 2022-2025 : Master 2 AAIS Executive Office ("Bureau") representative for Sorbonne
- 2015-2019 : Member of the CNU section 34

2015-now : Member of the Steering Commitee for the ANOs GAZPAR and ASPIC

CV d'un candidat possible :

Mara's past internship with us has demonstrated a strong interest in theoretical astrophysics, analytical modelling, and numerical experimentation. Her current training in the world leading team in kinetic field theory makes her the ideal candidate for this PhD. She has expressed a strong interest.

Mara-Andreea Iancu

E-mail address: mara-andreea.iancu@stud.uni-heidelberg.de

Education

Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany — 10/2024 – Present
Master of Science in Physics — *Current GPA: 1.5*

École Polytechnique, Palaiseau, France — 09/2021 – 07/2024
Bachelor of Science in Physics and Mathematics, with Chemistry minor — *Final GPA: 3.65/4.30*

"Tudor Vianu" National High School of Computer Science, Bucharest, Romania — 09/2017 – 07/2021
High school diploma — *Final grade: 9.8/10.0*

Experience

Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg | *Intern* — 10/2025 – Present
- Master's thesis on kinetic field theory (KFT) for cosmic structure formation
- Study of the time coordinate choice in KFT that optimizes free particle trajectories against the interaction term between trajectories

Institut d'Astrophysique de Paris | *Intern* — 01/2024 – 03/2024
- Bachelor's thesis on the large-scale structure of the Universe
- Statistical modeling of filaments through Gaussian random fields in 2D and 3D
- Validation of the local skeleton theoretical algorithm with simulation data

Laboratoire Leprince-Ringuet, École Polytechnique | *Intern* — 09/2023 – 12/2023
- Data collection from an ^{90}Sr source with an electromagnetic calorimeter prototype for particle colliders
- Noise level determination and fit of functions to entry distributions in the detector using the ROOT C++ framework

Centre de Physique Théorique, École Polytechnique | *Intern* — 06/2023 – 07/2023
- Reading project on introductory cosmology: derivation of Friedmann equations from the Einstein field equations, the ΛCDM model

Laboratoire d'Optique Appliquée, École Polytechnique | *Intern* — 07/2022 – 08/2022
- Computation of electromagnetic fields generated by ultra-relativistic electron beams analytically and with numpy
- Study of electromagnetic field reflection at the boundary of a plasma

Projects

PhysiX - Bachelor Physics Committee | *Board member* — 2022 – 2023
- Hosted meetings and presented various topics to fellow physics students
- Proposed and graded problems for the annual Bachelor physics competition

Bachelor Physics Seminar | *Organizer and speaker* — 2022 – 2023
- Organized weekly undergraduate physics seminars, presented by students who were supervised by professors
- Delivered a talk focused on explaining hidden variables theories and a Greenberger–Horne–Zeilinger experiment, to highlight the contrast between results of classical and quantum theories

Skills

Programming languages: C/C++, Python, Wolfram Language
Software: LaTeX, ROOT data analysis framework, Mathematica, Linux

Languages

Romanian: native language
English: full professional proficiency
French: limited working proficiency
German: elementary proficiency

Liste des publications les plus pertinentes : 1 page maximum

- Binney, J., & Lacey, C. 1988 MNRAS, 230 (4), 597–627
- Bournaud, F., et al. 2007, ApJ, 670, 237
- Domez T., et al. 2023, MNRAS, 527, 2139
- Fouvry, J.-B., et al. 2015, A&A, 584, A129
- Fouvry, J.-B., et al. 2015, MNRAS, 449, 1967
- Fouvry, J.-B., et al. 2015, MNRAS, 449, 1982
- Fouvry, J.-B., et al. 2017, MNRAS, 471, 2642
- Fouvry, J.-B., et al. 2021, MNRAS, 508, 2210
- Feliachi O, et al. 2022 Stat.186
- Hopkins, P. F., et al. 2014, MNRAS, 445, 581
- Julian, W. H., & Toomre, A. 1966, ApJ, 146, 810
- Kormendy, J., & Kennicutt, R. C. Jr. 2004, ARA&A, 42, 603
- Kraljic, K., et al. 2018, MNRAS, 474, 547
- Kraljic, K., et al. 2020, MNRAS, 493, 362
- Vega-Ferrero, J. et al 2024 ApJ 961 51
- Lelli, F., et al. 2019, MNRAS, 484, 3267
- Leroy, A. K., et al. 2008, AJ, 136, 2782
- Lian, J., & Luo, L. 2024, ApJL, 960, L8
- McGaugh, S. S. 2012, AJ, 143, 40
- Michikoshi, S., & Kokubo, E. 2016, ApJ, 821, 35
- Papastergis, E., et al. 2016, A&A, 593, A39
- Park, M., et al. 2021, MNRAS, 530, 4378
- Pichon, C., Aubert, D. 2006 MNRAS, v368, 1657-1694
- Pogosyan, D., et al. 2009, MNRAS, 396, 635
- Ristea, A., et al. 2024, MNRAS, 527, 7438
- Robertson, B., et al. 2006, ApJ, 645, 986
- Romeo, A. B., et al. 2010, MNRAS, 407, 1223
- Roule, M., et al. 2022, PRE, 106, 044118
- Roule, M., et al. 2025, A&A, 699, A140
- Rozier, S., et al. 2019, MNRAS, 487, 711
- Sellwood, J Carlberg, 1984 ApJ 282, 61
- Tep, K., et al. 2022, MNRAS, 514, 875
- Toomre, A. 1964, ApJ, 139, 1217
- Tumlinson, J., Peeples, M., & Werk, J. K. 2017, ARA&A, 55, 389
- Vogelsberger, M., et al. 2020, MNRAS, 492, 5167
- Weinberg, M. ApJ, 2001, 328, 321

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