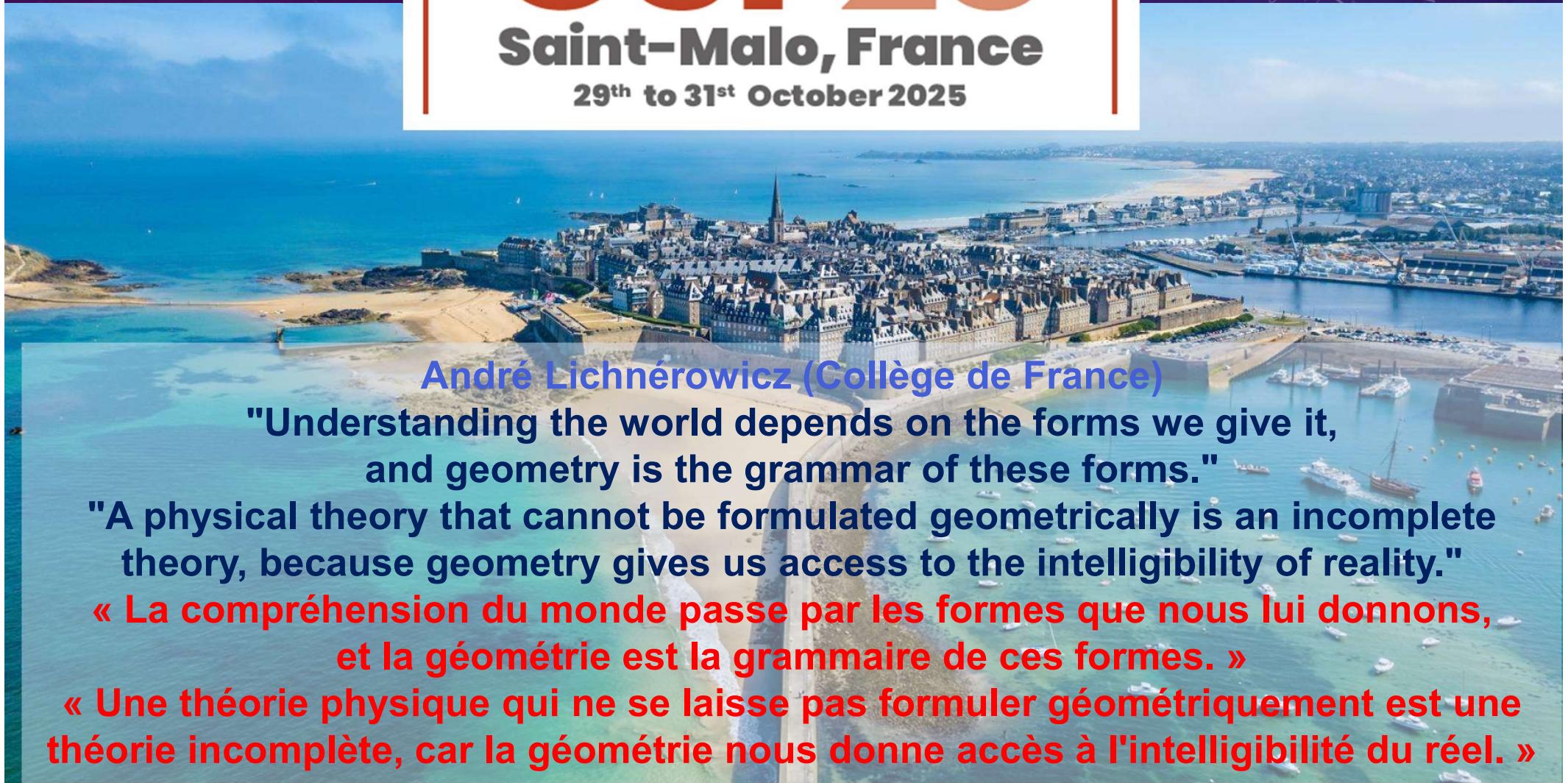


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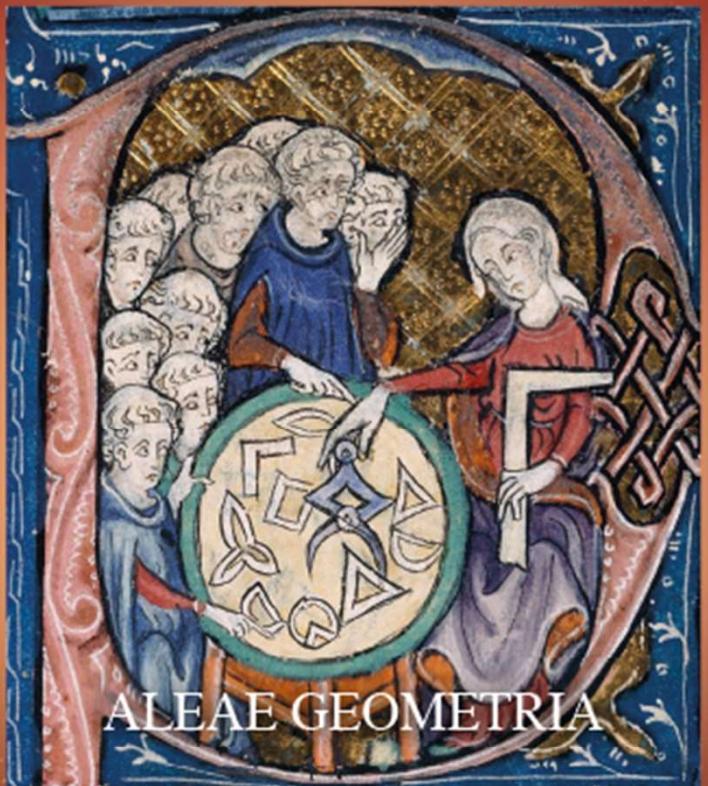
7<sup>th</sup> International Conference on  
**GEOMETRIC SCIENCE  
OF INFORMATION**  
**GSI'25**  
**Saint-Malo, France**  
**29<sup>th</sup> to 31<sup>st</sup> October 2025**



7<sup>th</sup> Conference on the  
**Geometric Science  
of Information**  
**GSI'25**

Geometric Structures of Statistical & Quantum Physics,  
Information Geometry, and Machine Learning

Saint-Malo, 29<sup>th</sup> to 31<sup>st</sup> October 2025



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## OPENING SESSION

# 7<sup>th</sup> International Conference on **GEOMETRIC SCIENCE OF INFORMATION** **GSI'25**

## Saint-Malo, France

29<sup>th</sup> to 31<sup>st</sup> October 2025

### | GSI 2025 General Co-Chairs |



**Frédéric Barbaresco**  
(THALES)

[www.thalesgroup.com/en/speakers-bureau/  
frederic-barbaresco](http://www.thalesgroup.com/en/speakers-bureau/frederic-barbaresco)



**Frank Nielsen**  
(Sony Computer Science Laboratories Inc.)  
[www.sonycls.co.jp/member/tokyo/164/](http://www.sonycls.co.jp/member/tokyo/164/)

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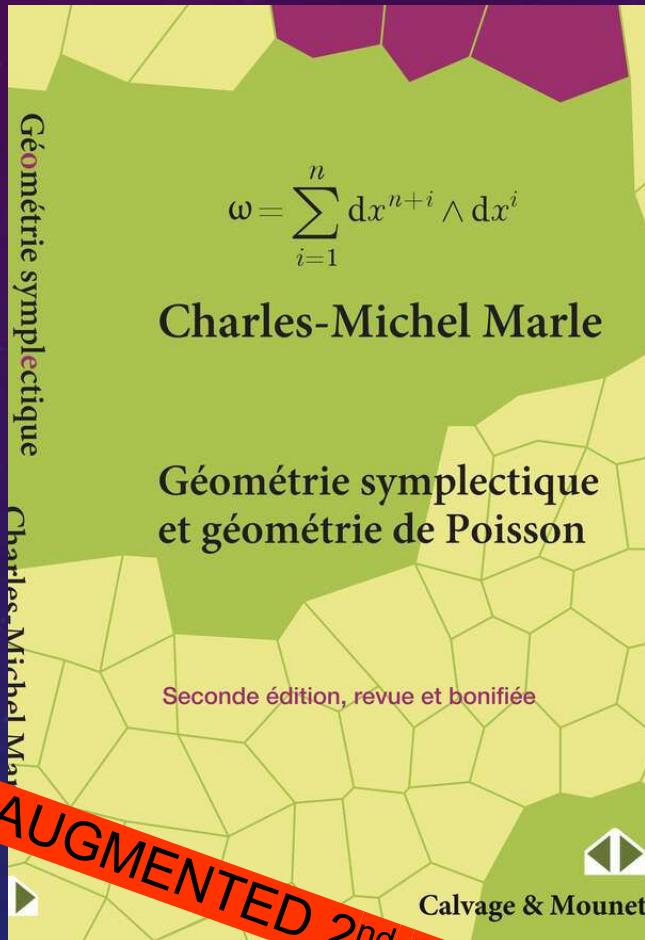
THE GSI'23 CONFERENCE WAS  
DEDICATED TO THE MEMORY OF  
MADEMOISELLE PAULETTE LIBERMANN,  
GEOMETER STUDENT OF ELIE CARTAN  
AND ANDRÉ LICHNEROWICZ, PHD  
STUDENT OF CHARLES EHRESMANN  
AND FAMILIAR WITH THE EMERALD  
COAST OF FRENCH BRITTANY.



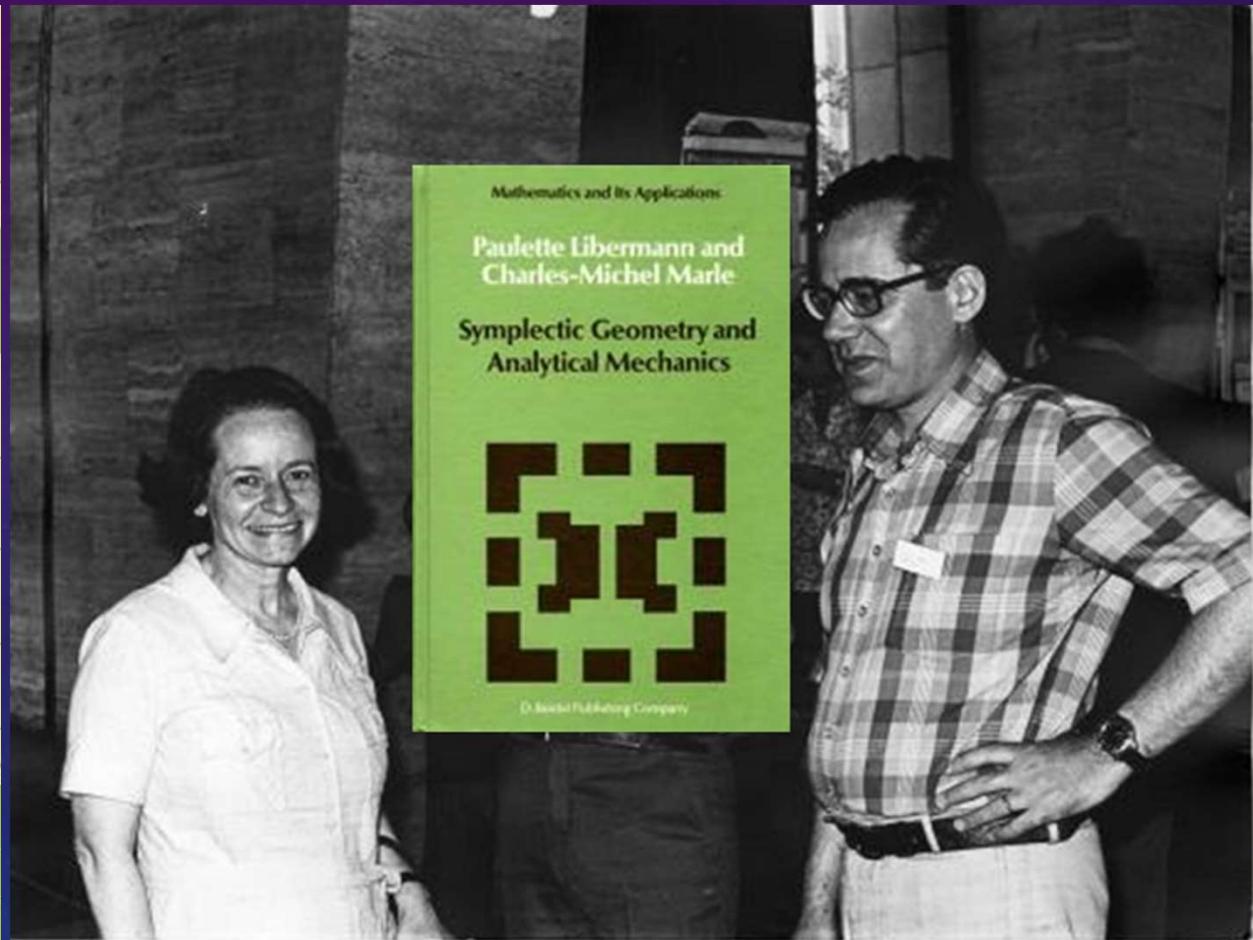
Paulette Libermann  
on Dinard Beach in Front  
of Saint-Malo



# PAULETTE LIBERMANN & CHARLES-MICHEL MARLE BOOKS



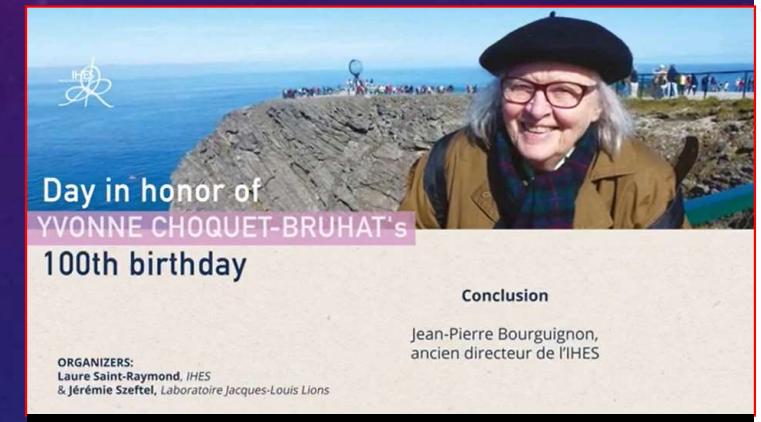
► NEW AUGMENTED 2<sup>nd</sup> EDITION



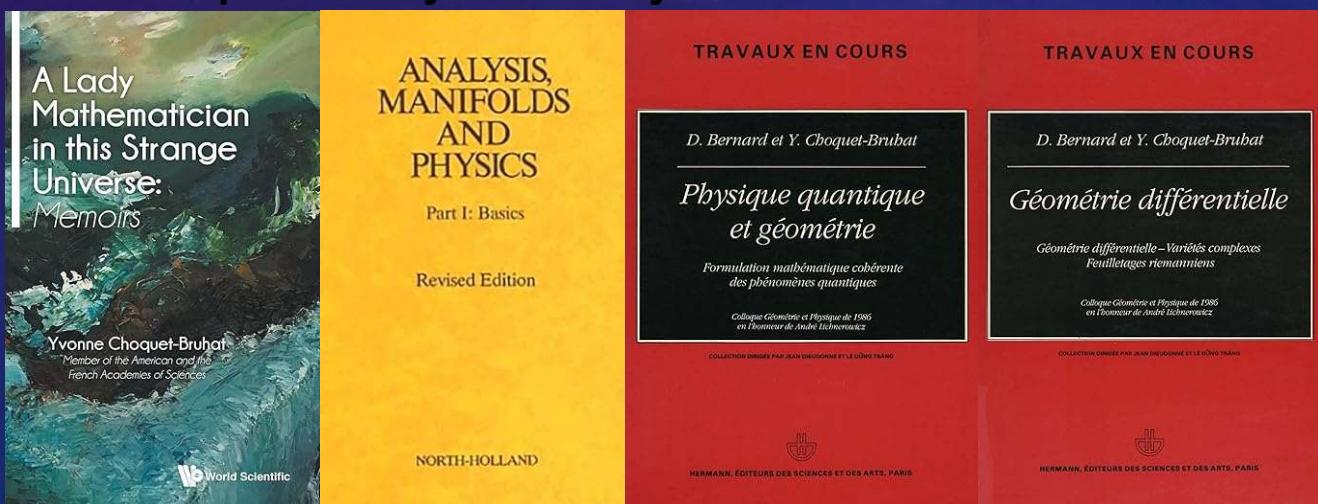
GSI'25 IS DEDICATED TO YVONNE CHOQUET-BRUHAT WHO PASSED AWAY AT 101 YEARS OLD IN 2025.

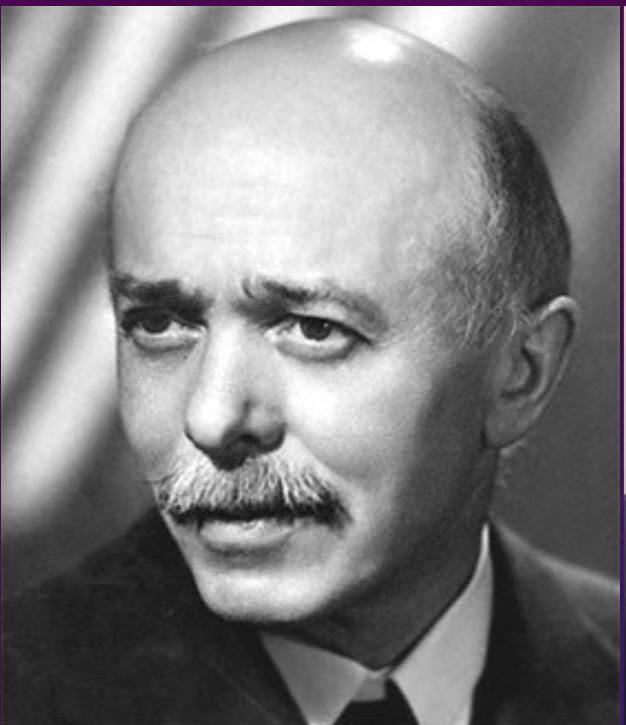
## TOPICAL CONTRIBUTIONS TO GEOMETRY IN PHYSICS (FIRST WOMAN ELECTED AT THE FRENCH ACADEMY OF SCIENCE IN 1979)

<https://www.dailymotion.com/video/x5knapi>

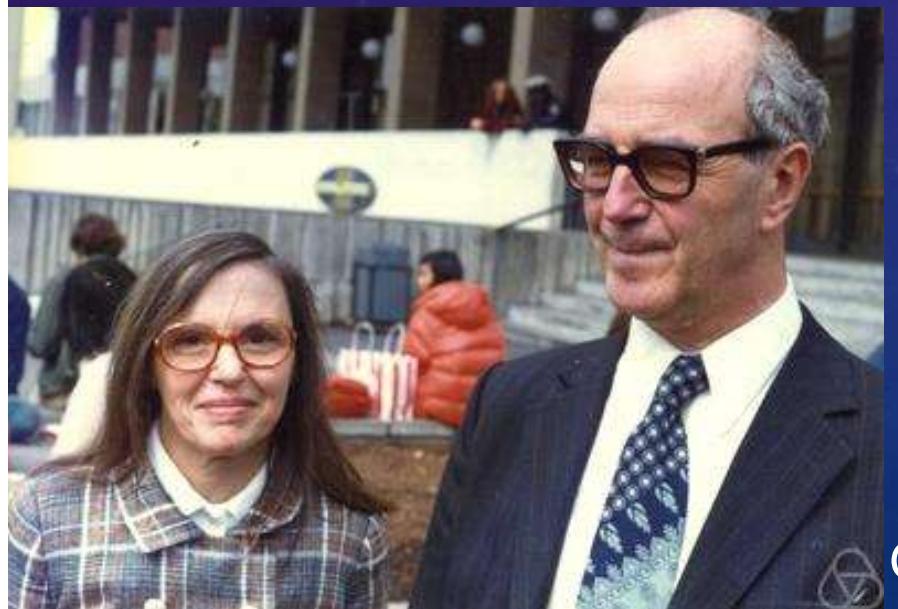


PhD supervised by Jean Leray and André Lichnérowicz





Her Father GEORGES  
BRUHAT  
Physics Teacher at ENS



Her First Husband  
GUSTAVE CHOQUET

## YVONNE CHOQUET-BRUHAT

Her work lies at the intersection of differential geometry and physics. It covers a broad spectrum, from the discovery of the first mathematical proof of Einstein's theory of relativity to the study of the conversion of electromagnetic waves into gravitational waves in the vicinity of a black hole. In particular, she has developed new mathematical methods that allow the study of several theories: general relativity, supergravity, and non-Abelian gauges. Her reformulation of Einstein's theory of gravitation has led to major scientific advances in numerical relativity. They have enabled the advancement of the VIRGO and LIGO projects, which focus on the detection of gravitational waves.

# PROBLÈME DE CAUCHY GLOBAL EN RELATIVITÉ GÉNÉRALE

par Yvonne CHOQUET-BRUHAT

## INTRODUCTION

Je me propose d'exposer ici un théorème global d'unicité géométrique pour les solutions des équations d'Einstein, dû à R. Geroch et moi-même [8]. Un énoncé plus faible avait été obtenu précédemment (cf. [8]).

### 3. THÉORÈMES SEMI-LOCAUX D'EXISTENCE ET D'UNICITÉ

**THÉORÈME I.** Toute donnée initiale  $\bar{g}$  admet un développement M.

La démonstration consiste à recouvrir  $\Sigma$  par un atlas  $(\Sigma_a, \varphi_a)$  et à résoudre dans un ouvert de  $R^4$  un problème de Cauchy sur  $\varphi_a(\Sigma_a)$ . Les données de Cauchy  $g_{\alpha\beta}, \partial_\gamma g_{\alpha\beta}$  sont déterminées par l'image par  $\varphi_a$  de  $\bar{g}$  et K et des conditions de coordonnées, on résoud ce problème pour les équations d'Einstein en coordonnées harmoniques qui sont un système de type classique :

$$(3.1) \quad g^{\lambda\mu} \partial_{\lambda\mu}^2 g^{\alpha\beta} + H_{\alpha\beta} (\partial_\gamma g^{\lambda\mu}, g^{\lambda\mu}) = 0$$

qui a une solution unique si  $(V_2^\mu$  espace de Sobolev, cf. Leray-Dionne pour  $V_2^\mu$ )

$$g^{\lambda\mu}|_{x^0=0} \in W_2^\mu \quad \partial_\lambda g^{\mu\nu}|_{x^0=0} \in V_2^{\mu-1}, \quad \mu \geq 5$$

$g^{\lambda\mu}$  uniformément hyperbolique sur  $x^0 = 0$ , et  $x^0 = 0$  uniformément spatial.

On montre qu'une solution de (3.1), avec les hypothèses faites sur les données initiales, vérifie

$$R_{\alpha\beta} = 0.$$

Yvonne Choquet-Bruhat attended classes with [Jean Leray](#), a renowned French mathematician who invited her to work with him as his assistant when he moved to Princeton, in the United States. There she met [Albert Einstein](#) in 1951: "He asked me to present my thesis, based on his theory of general relativity, in French, telling me that he would respond in English. At the end of my presentation, he told me that I could come and see him whenever I wanted. Albert Einstein was a truly kind man."

Une variété munie d'une métrique riemannienne hyperbolique, à orientation temporelle, est dite globalement hyperbolique si l'ensemble des chemins temporels joignant deux points  $x$  et  $y$  est compact (dans la topologie (2.1) de l'espace des chemins).

On montre (Hawking) que cette définition est équivalente à :

- 1) il n'y a pas de chemin temporel fermé ;
- 2)  $\varepsilon_x^+ \cap \varepsilon_y^-$  est compact pour tous  $x, y \in V_n$ .

J'ai démontré d'autre part qu'elle impliquait la "forte causalité" de Penrose-Hawking (il n'y a pas de chemins temporels fermés ni presque fermés).

Le théorème suivant, énoncé par J. Leray, fournit de nombreux exemples de variétés globalement hyperboliques :

**THÉORÈME.** Une condition nécessaire et suffisante pour que  $(V_n, g)$  soit globalement hyperbolique est que, dans une métrique proprement riemannienne complète, sur  $V_n$ , tous les chemins temporels joignant deux points  $x$  et  $y$  aient une longueur bornée.



Jean Leray - Parc de Sceaux (1985)



# KYOTO PRIZE

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## The 2025 Kyoto Prize Kyoto Prize Laureates



**Shun-ichi Amari** / Mathematical Engineer

### Lecture topics

My Life Has Been Lucky!

### Abstract of the lecture

I entered the University of Tokyo and proceeded to a newly established Mathematical Engineering course at the Faculty of Engineering, which accepted only five students. That was the beginning of my fortunate journey. In that course, the professors were passionately striving to explore their research fields in mathematical engineering toward new academic frontiers. Observing their great efforts, I learned the art of pursuing my own research freely without any constraint by conventional frameworks.

After earning a Ph.D., I started to contemplate the mechanisms of the brain and the nature of information at Kyushu University. At that time, I never imagined that my early study on machine learning there would in future lead to research connected to a Nobel Prize in Physics and grow into a major trend in artificial intelligence. The core of my research focused on artificial intelligence, mathematical neuroscience, and information geometry, all of which took ten or even twenty years until finally gaining worldwide recognition.

The greatest fortune in my life was being in such an environment to enjoy the freedom to fully immerse myself in unconstrained research driven solely by my own curiosity.



<https://www.kyotoprize.org/en/lectures/2025>

# Congratulatory Message to Professor Shun-ichi Amari on Being Awarded the 2025 Kyoto Prize in Information Science

Frédéric Barbaresco<sup>1</sup>  and Frank Nielsen<sup>2</sup> 

<sup>1</sup> Thales, 91120 Palaiseau, France

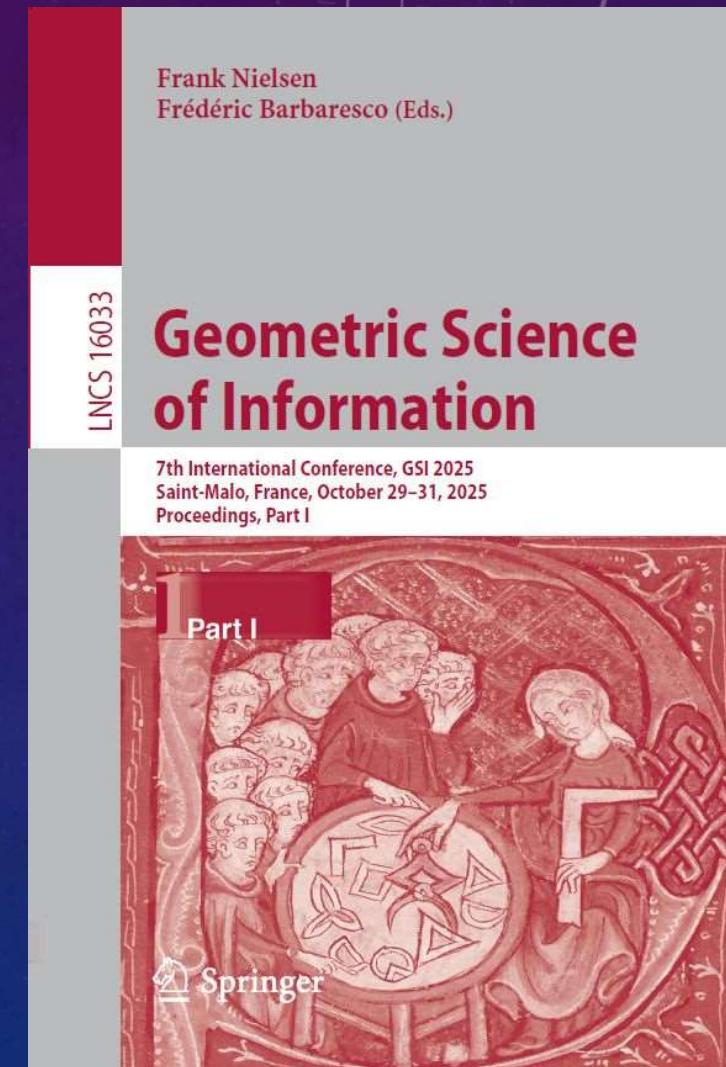
<sup>2</sup> Sony Computer Science Laboratories Inc., Tokyo, Japan

The Geometric Science of Information (GSI) community heartily congratulates Professor Shun-ichi Amari on being awarded the 2025 Kyoto Prize in information science. Professor Amari is recognized for his “pioneering contributions to opening up theoretical foundations of artificial intelligence and establishment of information geometry.”

Frank Nielsen first invited Professor Amari to the computer science department colloquium of École Polytechnique entitled ‘Emerging Trends in Visual Computing: LIX Fall Colloquium’ (ETVC 2008), which was held in École Polytechnique, Palaiseau, France, during November 18–20, 2008. The revised papers and invited papers were published in [7], and Professor Amari contributed to an invited article entitled “Information Geometry and Its Applications: Convex Function and Dually Flat Manifold” [1]. His video lecture is available online.



Fig. 1. Group photo of GSI 2013 with Professor Shun-ichi Amari.





# KYOTO PRIZE

## 1985

### Claude E. Shannon



Commemorative Lectures

#### DEVELOPMENT OF COMMUNICATION AND COMPUTING, AND MY HOBBY

**Claude E. Shannon**

Thank you very much. It is a very great honor to receive this Kyoto Prize, and Mrs. Shannon and I are finding much pleasure in visiting Japan for the first time. When we began to plan our journey, Betty brought home four books relating to the culture and customs of Japan. I am not sure how reliable these were, since they were all written by Americans. One thing they had in common was telling a Japanese proverb — The nail that sticks up gets hammered down. It occurred to me that in receiving this Inamori Prize I was just such a nail, and standing up here I don't see any hammers over my head at the moment.

I don't know how history is taught here in Japan, but in the United States in my college days, most of the time was spent on the study of political leaders and wars — Caesars, Napoleons and Hitlers. I think this is totally wrong. The important people and events of history are the thinkers and innovators, the Darwins, Newtons and Beethovens whose work continues to grow in influence in a positive fashion.





DOWNTOWN  
KYOTO CITY

# GSI'13 (ECOLE DES MINES): S.I. AMARI WITH JEAN-Louis KOSZUL & HIROHIKO SHIMA



# GSI'15 (ECOLE POLYTECHNIQUE)



Shun-ichi Amari, Takeru Matsuda:

Wasserstein Statistics in One-Dimensional Location-Scale Models. GSI 2021: 499-506

Ryo Karakida, Shun-ichi Amari:

Information Geometry of Wasserstein Divergence. GSI 2017: 119-126

John Armstrong, Shun-ichi Amari:

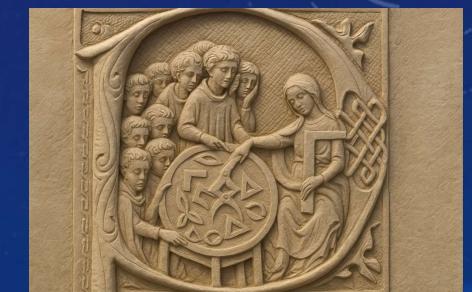
The Pontryagin Forms of Hessian Manifolds. GSI 2015: 240-247

Shun-ichi Amari, Nihat Ay:

Standard Divergence in Manifold of Dual Affine Connections. GSI 2015: 320-325

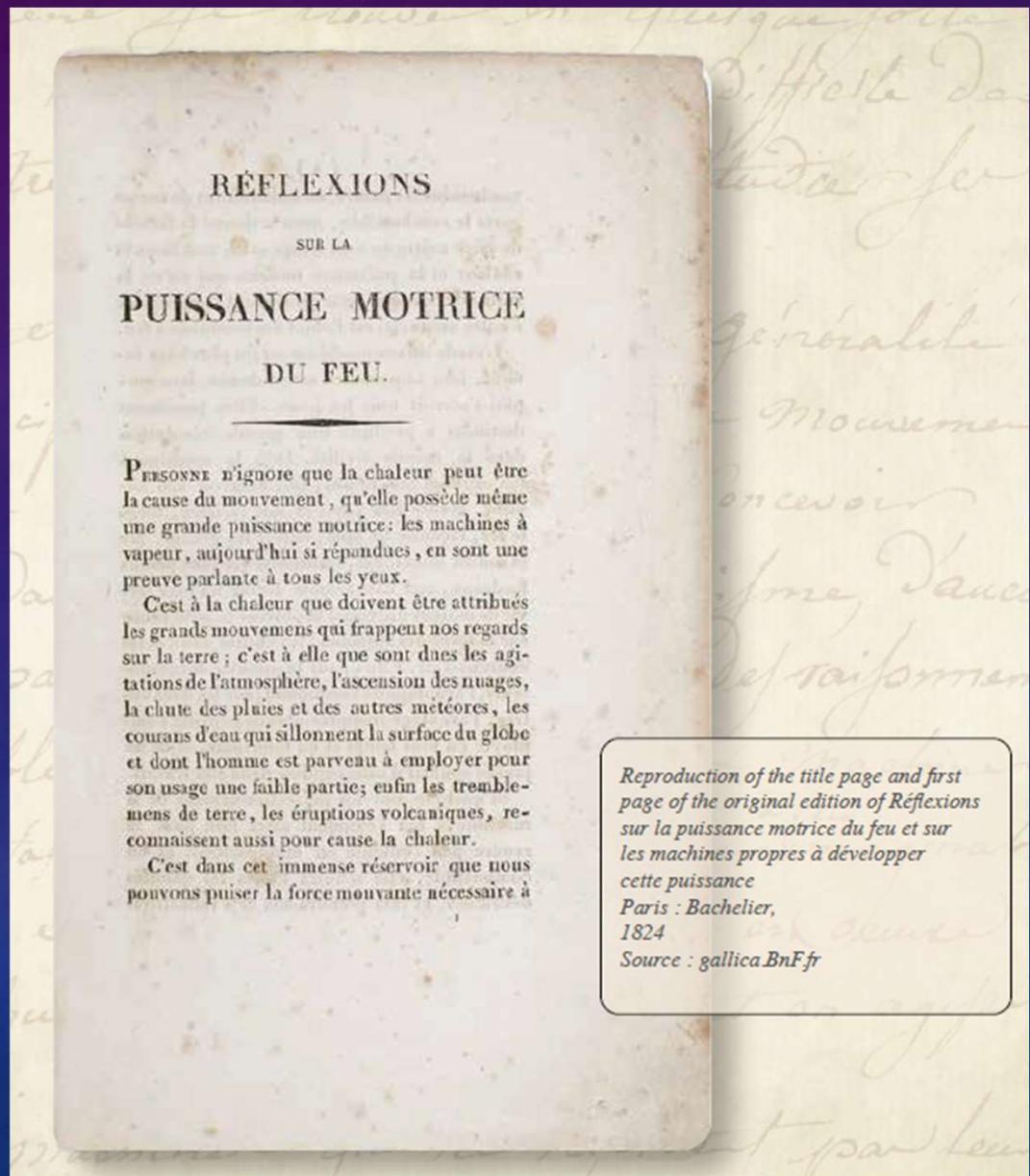
Shun-ichi Amari:

Information Geometry and Its Applications: Survey. GSI 2013: 3



But also keynote talk at ETVC 2008@Ecole Polytechnique

GSI'25 IS DEDICATED TO BICENTENARY OF SADI CARNOT'S BOOK  
« RÉFLEXIONS SUR LA PUISSANCE MOTRICE DU FEU » (1824)



Reproduction of the title page and first page of the original edition of *Réflexions sur la puissance motrice du feu et sur les machines propres à développer cette puissance*

Paris : Bachelier,  
1824

Source : gallica.BnF.fr

PERSONNE n'ignore que la chaleur peut être la cause du mouvement, qu'elle possède même une grande puissance motrice: les machines à vapeur, aujourd'hui si répandues, en sont une preuve parlante à tous les yeux.

C'est à la chaleur que doivent être attribués les grands mouvements qui frappent nos regards sur la terre; c'est à elle que sont dues les agitations de l'atmosphère, l'ascension des nuages, la chute des pluies et des autres météores, les courans d'eau qui sillonnent la surface du globe et dont l'homme est parvenu à employer pour son usage une faible partie; enfin les tremblements de terre, les éruptions volcaniques, reconnaissent aussi pour cause la chaleur.

C'est dans cet immense réservoir que nous pouvons puiser la force mouvante nécessaire à

# 1824-2024 – BICENTENARY OF SADI CARNOT'S BOOK « RÉFLEXIONS SUR LA PUISSANCE MOTRICE DU FEU »



**1824**

## *Réflexions sur la puissance motrice du feu*

pages 1 – 8

Introduction: why the subject is important, presentation of the issues addressed below, choice of a fundamental approach. (panel 2)

pages 9 – 13

Vision of the thermal machine: the "caloric fall" from hot to cold generates the motive power; steam is one way inter alia to realise this power. (panel 3)

pages 14 – 15

Rephrasing the original questions in the formalism that was to follow.

pages 16 – 19

A reversible engine is a heat pump running in reverse (panel 6). Introduction of a first cycle with change of state (Rankine) between two thermostats. (panel 5)

pages 20 – 25

Maximum efficiency reached for a reversible transformation (Panel 7); the effects of reversibility on the machine's operating conditions.

pages 25 – 27

Improvement of the demonstration using a differential method.

page 28

Rephrasing the initial questions.

pages 29 – 38

Generalisation of the earlier results by applying the same reasoning to a cycle with no change of state (Carnot Cycle). Statement of Carnot's Theorem. (panel 8)

pages 39 – 68

Statement of five properties of "aeriform fluids" (gases), verification with experimental data published in the scientific literature. (panel 9)

pages 69 – 73

Relation between the efficiency and temperatures of thermostats. (panel 8)  
Analytical development in footnote.

pages 74 – 89

Theoretical calculation of the efficiency for an infinitesimal transformation carried out with air, water vapour and vapour of alcohol. (panel 11)

pages 90 – 97

Practical considerations for designing and engineering thermal machines. (panel 11)

pages 97 – 107

The value of high-pressure machines does not lie in the pressure itself, but in the operating temperature. Analyse de Machines Commerciales (Watt, Trevithick & Vivian).

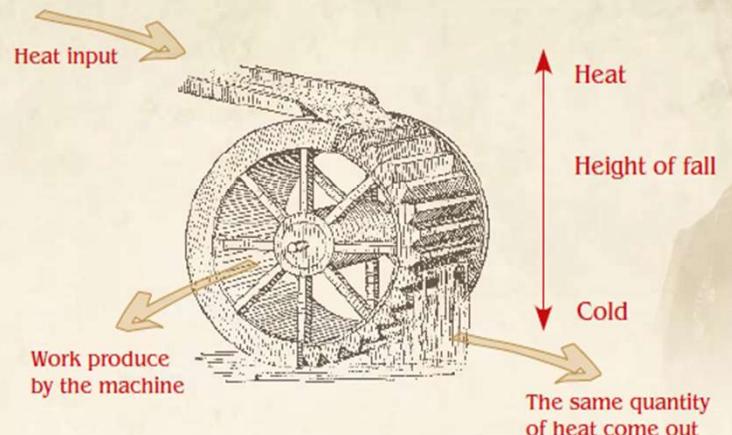
pages 107 – 113

Practical considerations regarding the choice of working fluid (air, water vapour or other).

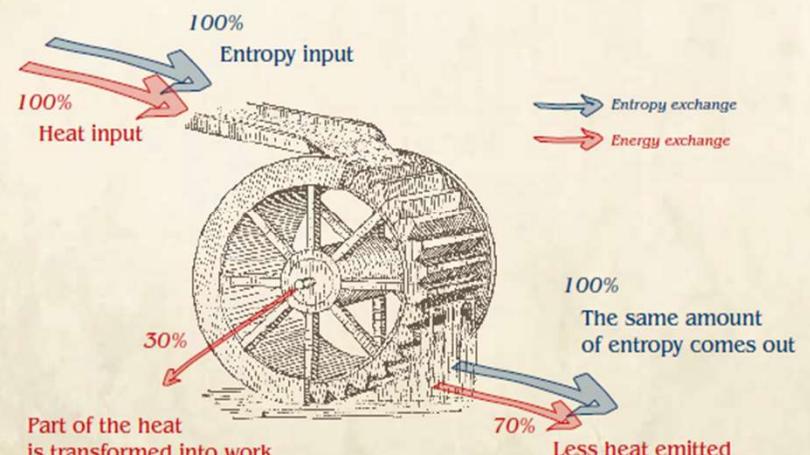
pages 113 – 118

Comparison between the theoretical maximum efficiency and the performance of today's machines in order to underline the room for progress. (panel 11)

Sadi Carnot's view



Modern view



In 1824, the French physicist Sadi Carnot stated the second law of thermodynamics, one of the most important laws of physics: the qualitative degradation of work energy into heat. The first law of thermodynamics was also found in his notes: the qualitative conservation of energy.



Fermat's  
Principle  
of Optical  
Least Time



d'Alembert's  
Principle  
of Mechanical  
Work



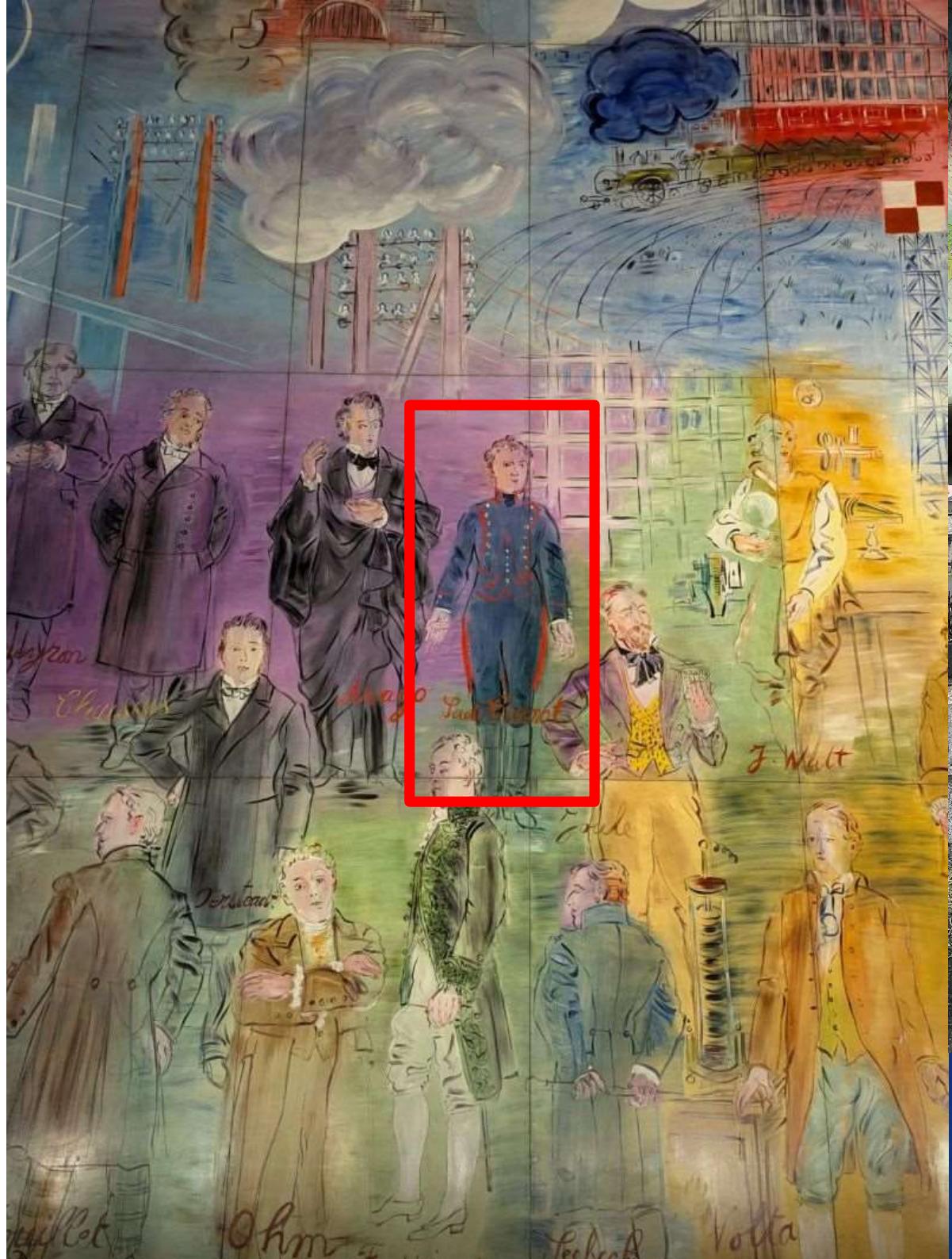
Maupertuis's  
Principle  
of Mechanical  
Least Action



Carnot's 2<sup>nd</sup>  
Principle  
of Thermo  
-dynamics



Souriau's  
Maxwell  
Principle of  
Mechanics



# La Fée Électricité (Raoul Dufy) (Exposition Universelle Paris 1937)



Sadi Carnot  
died in Ivry-  
sur-Seine in  
the private  
insane  
asylum  
“Esquirol”



LILLE CARNOT 2024 (BY RAFFAELE PISANO)

[HTTPS://CARNOTLILLE2024.SCIENCESCONF.ORG/](https://carnotlille2024.sciencesconf.org/)



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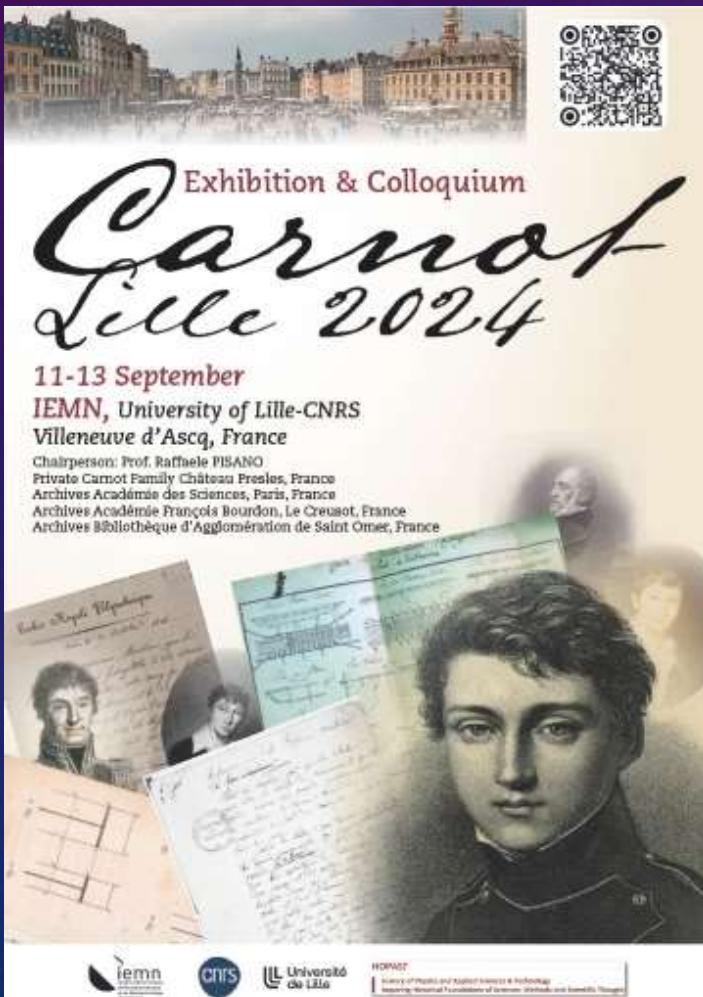
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1824-2024 BICENTENARY OF THERMODYNAMICS INVENTION BY SADI CARNOT

RAFFAELE PISANO (BOOK EDITED BY SPRINGER)

BOOK OF ABSTRACT:

[HTTPS://CARNOTLILLE2024.SCIENCESCONF.ORG/DATA/PAGES/BOOK\\_ABSTRACTS\\_CARNOT\\_LILLE2024\\_EN\\_6\\_SEPT2024.PDF](https://CARNOTLILLE2024.SCIENCESCONF.ORG/DATA/PAGES/BOOK_ABSTRACTS_CARNOT_LILLE2024_EN_6_SEPT2024.PDF)



# SADI CARNOT – BIRTH OF A CYCLE EXHIBITION AT ECOLE POLYTECHNIQUE

## Sadi Carnot Birth of a cycle

Exhibition  
booklet

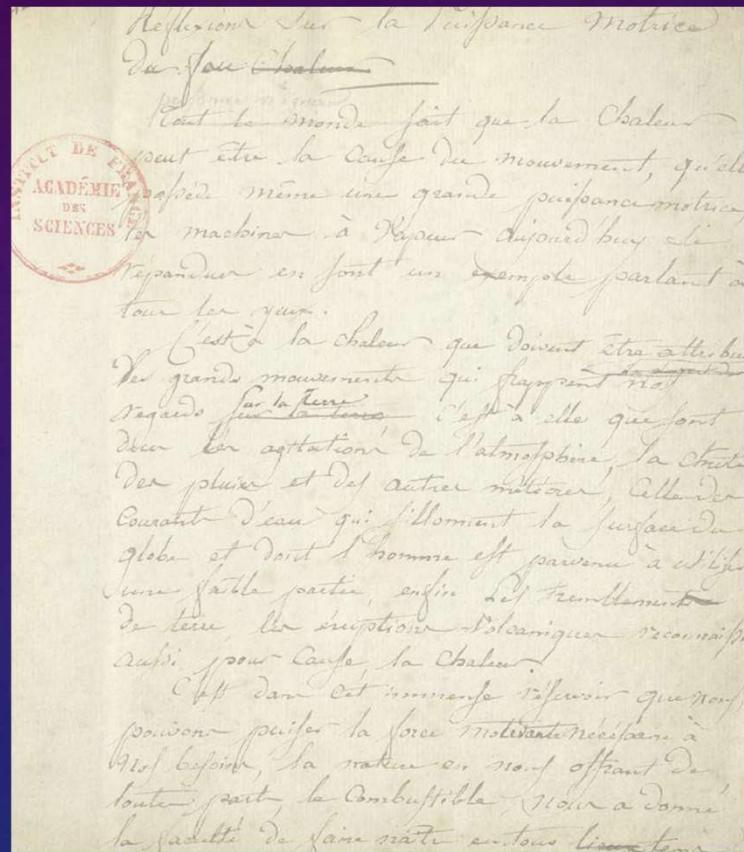
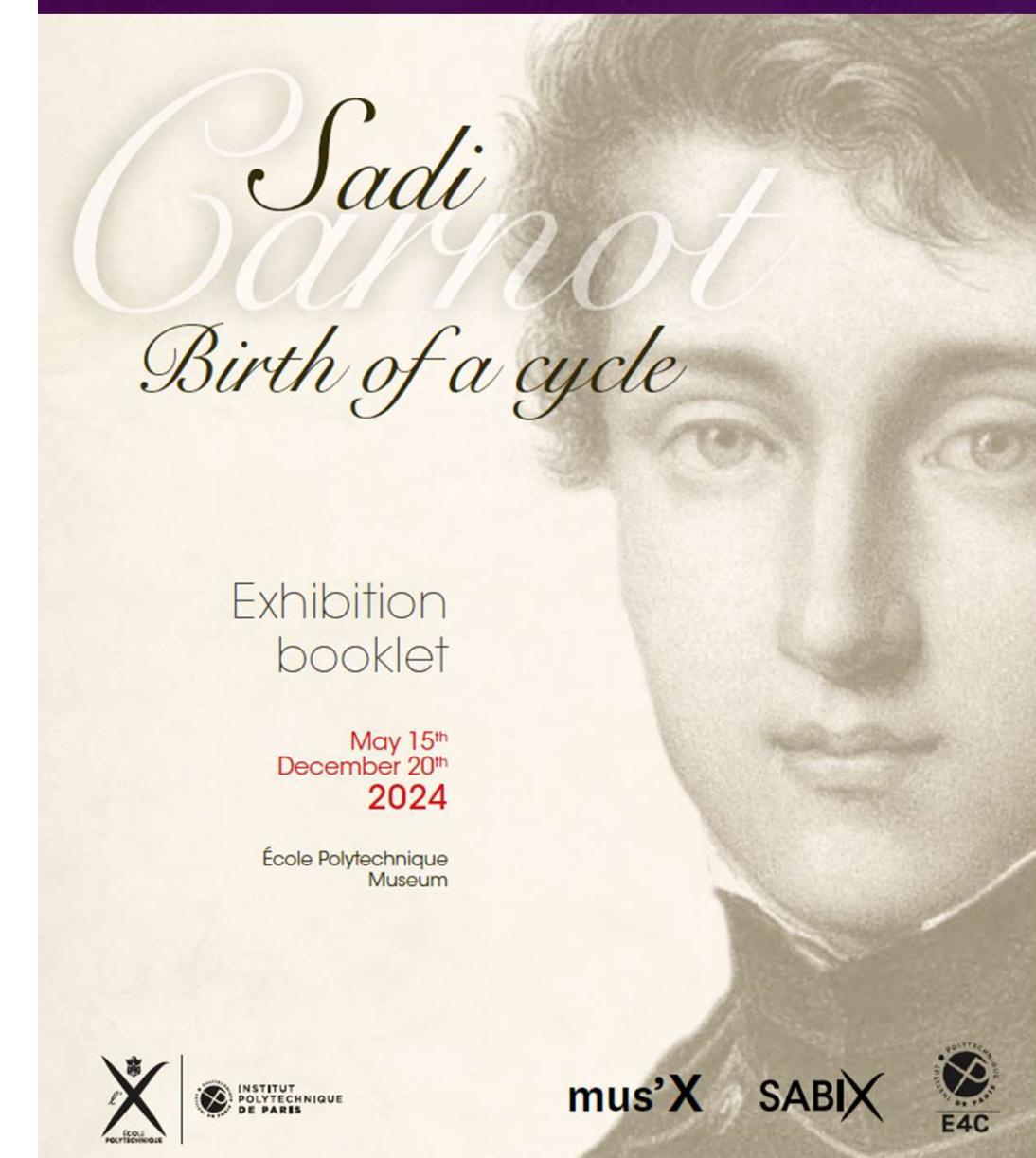
May 15<sup>th</sup>  
December 20<sup>th</sup>  
**2024**

École Polytechnique  
Museum



mus'X

SABIX



\* "By providing us with fuel from all sides, nature has given us the ability to generate heat and the driving force that follows it at all times and in all places."

"To give rise to motive power, it is not enough to produce heat: cold must also be obtained; without it, heat would be useless."

<https://gargantua.polytechnique.fr/siatel-web/app/linkto/S3pkKzBLTE9abjJja2kwSm5qMWF5OG43eUNlejg5OVVLbDIObDg0cE1pdmF3UlIpFZXR0OXFWZmpmV09DUmdCdUrhVG14TGVZNU84PQ>

[https://www.youtube.com/playlist?list=PLKYO-j4\\_wQb7GdT2a-hTfcdt8Nv2O9jhD](https://www.youtube.com/playlist?list=PLKYO-j4_wQb7GdT2a-hTfcdt8Nv2O9jhD)

[https://www.youtube.com/playlist?list=PLKYO-j4\\_wQb6GRbVNH2\\_RuDFwaeP4](https://www.youtube.com/playlist?list=PLKYO-j4_wQb6GRbVNH2_RuDFwaeP4) VOD

# ECOLE POLYTECHNIQUE: SADI CARNOT'S LEGACY: [HTTPS://CARNOT-LEGACY.SCIENCESCONF.ORG/](https://carnot-legacy.sciencesconf.org/)

September  
16<sup>th</sup>-18<sup>th</sup>  
2024

École polytechnique  
Palaiseau, France

## Sadi Carnot's Legacy

*Celebrating the 200<sup>th</sup> anniversary  
of the 2<sup>nd</sup> law of thermodynamics*



### **SADI CARNOT'S LEGACY - "CELEBRATING THE 200TH ANNIVERSARY OF THE 2ND LAW OF THERMODYNAMICS"**

When Sadi Carnot published his "Reflections on the motive power of fire" in 1824, there was no sign that one of the greatest scientific revolutions was about to take place, in a world then dominated by mechanics and optics. Yet, by bringing a conceptual analysis to the practical problem of the steam engine, Sadi Carnot wrote the birth certificate of thermodynamics, and, in particular, its second principle.

Today, thermodynamics has branched out into a multitude of fields and applications, from industrial processes to microscopic systems, and continues to renew our view of science.

Since its origins, thermodynamics has raised as many questions as it has answered.

To celebrate the bicentenary of the "Réflexions", this colloquium aims to bring together members of the thermodynamics community and to invite them to take a critical look at modern thermodynamics and the open questions it raises. The colloquium will be structured around pedagogical presentations introducing the various fields of the discipline. Poster sessions will allow participants to share their work.

# SADI CARNOT'S LEGACY GALA DINNER

September  
16<sup>th</sup>-18<sup>th</sup>  
2024

École polytechnique  
Palaiseau, France

## Sadi Carnot's Legacy

*Celebrating the 200<sup>th</sup> anniversary  
of the 2<sup>nd</sup> law of thermodynamics*





Projet Nicolas Léonard  
Sadi Carnot au Panthéon

1824 - 2024 : 200 ans de l'ouvrage *Réflexions sur la puissance motrice du feu et sur les machines propres à développer cette puissance*

<https://sadi-carnot-physicien.fr/>



# CARNOT'S FAMILY PROJECT TO PLACE SADI CARNOT IN PANTHÉON BETWEEN HIS FATHER LAZARE CARNOT AND HIS NEPHEW SADI CARNOT, THE FRENCH REPUBLIC PRESIDENT



# ENERGY, POWER, ENVIRONMENT. A SYMPOSIUM ON THE OCCASION OF THE BICENTENARY OF THE PUBLICATION OF SADI CARNOT'S 'RÉFLEXIONS SUR LA PUISSANCE MOTRICE DU FEU'



## Maison Française d'Oxford

Institut français de recherche à l'étranger



Convened by **Robert Fox** (University of Oxford)

In his *Réflexions sur la puissance motrice du feu*, a modest volume published in 1824, Sadi Carnot laid some of the most important foundations of modern thermodynamics and power technology. In certain respects, the book was not an easy read, and it had faults. The result was a masterpiece, though arguably a flawed one, and it remained almost unread until it was discovered and reconfigured by William Thomson (the future Lord Kelvin) and Rudolf Clausius from the late 1840s. Given the importance that physical scientists and engineers now attach to such fundamental ideas as the Carnot cycle, the second principle of thermodynamics, and the notion of entropy – all of which have roots in Carnot's thinking – why was the *Réflexions* neglected for so long? The contributions to this workshop explore the origins, content, and long-term impact of Carnot's ideas, including the legacy of debates about energy sources and implications for climate change that continue to engage us today.

<https://mfo.web.ox.ac.uk/event/energy-power-environment-symposium-occasion-bicentenary-publication-sadi-carnots-reflexions>

**Pascal Marty** (Maison française d'Oxford). Introduction and welcome

*First session.* Chair: **Maxine Berg** (University of Warwick)  
**Raffaele Pisano** (University of Lille): 'Reading Lazare & Sadi

Carnot's manuscripts: a foundational programme for mechanical and heat machines'

**Robert Fox** (University of Oxford): 'The technological environment of Sadi Carnot'

**Crosbie Smith** (University of Kent): 'Interpretations of the Réflexions by William Thomson and Rudolf Clausius'

*Second session.* Chair: **Erica Charters** (University of Oxford)

**Ben Marsden** (University of Aberdeen): 'Reflections on perpetual motion, alternatives to steam power, and energy physics'

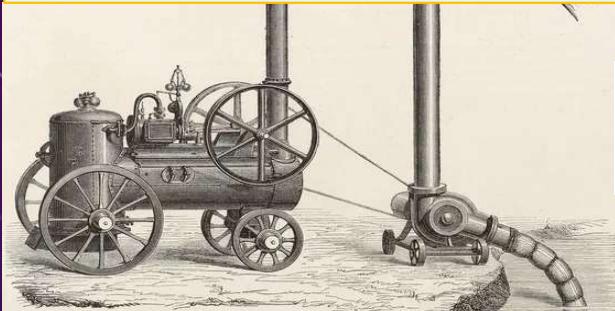
**Iwan Morus** (Aberystwyth University): '"That vast granary of force": how to power an imperial future'

**Jean-Baptiste Fressoz** (Ecole des Hautes Études en Sciences Sociales-Centre de Recherches Historiques): 'No transition: a new history of energy'

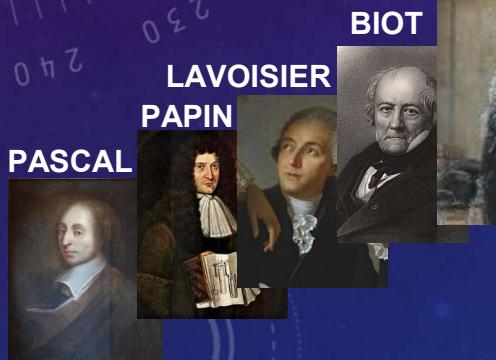
**Rob Iliffe** (University of Oxford) Concluding remarks

# From Steam Engine To Quantum Computer Qubits Regulation & TINN

## Steam Engine Revolution



## Classical Thermodynamics



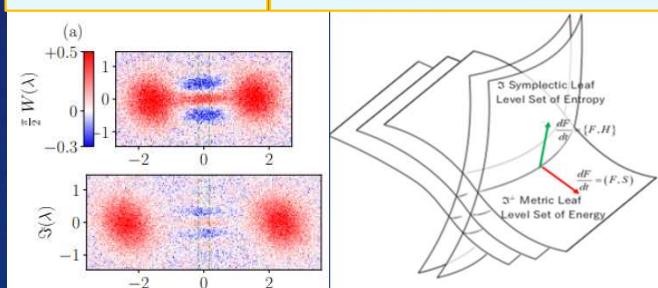
Carnot 2<sup>nd</sup>  
Principle  
(Carnot Cycle)



## Quantum Computing Revolution

Lindblad  
Equation  
(Metriplectic  
Equation)

## Thermodynamics Informed ML Revolution

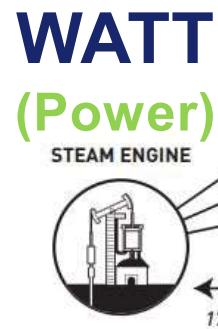


## Quantum & Lie-Groups Thermodynamics

# PHILIPPE AGHION NOBEL PRIZE 2025FOR « THE THEORY OF SUSTAINED GROWTH THROUGH CREATIVE DESTRUCTION »



**Sadi Carnot**  
Classical Thermodynamics  
Engineer-Scientist  
19th Century



GDP per person

United Kingdom — Sweden

**WATT-HOUR**

(Energy)

40,000

30,000

20,000

10,000

0

1712 →

1825 →

**GFLOPS**  
(Entropy)

ARTIFICIAL  
INTELLIGENCE

**GFLOPS/WATT**

(Dissipation)

QUANTUM  
ENGINEERING

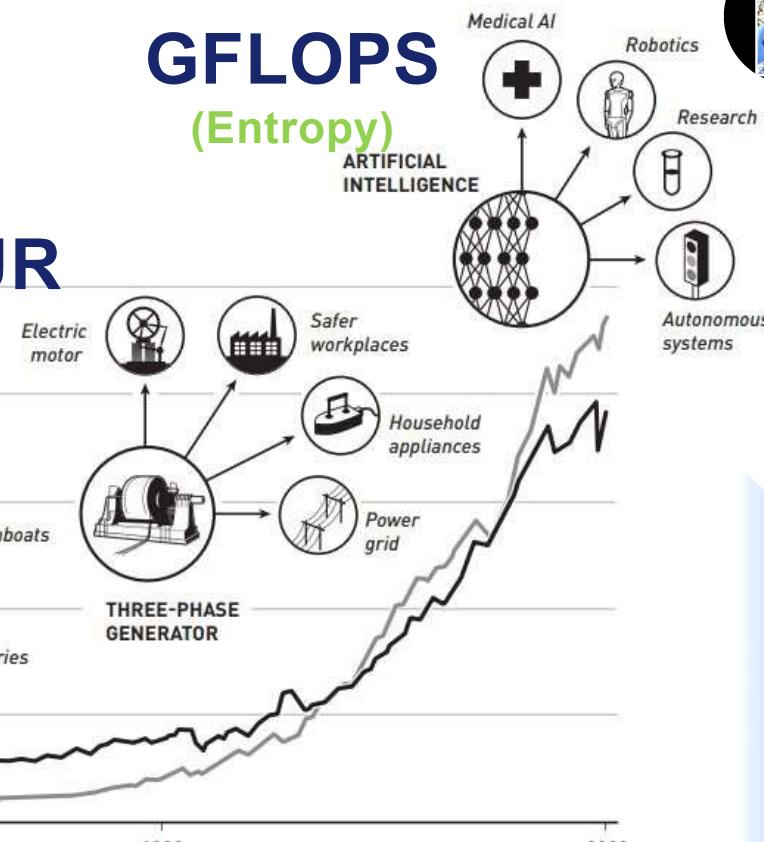
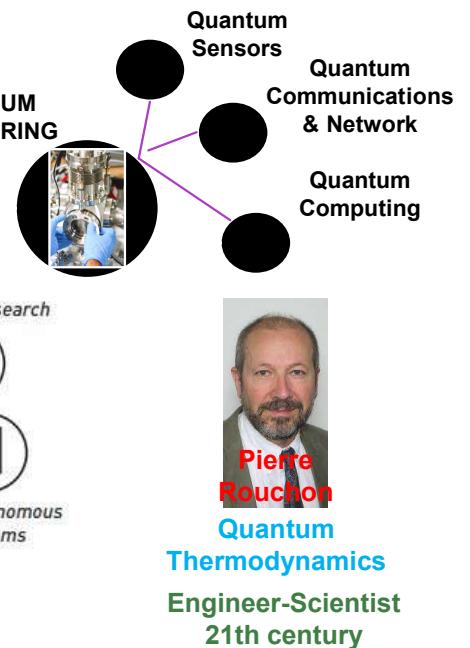


Figure 4. Over the past 200 years, annual growth has been around 1.5 per cent in Sweden and the United Kingdom. Technological innovations and scientific progress have built upon each other in an endless cycle. Data: Maddison Project Database 2023 with underlying sources from Broadberry et al. [2015], Krantz [2017], Schön and Krantz [2015].



**Pierre Rouchon**  
Quantum Thermodynamics  
Engineer-Scientist  
21st century

*Sadi Carnot,  
archetype  
of the French  
scientist-  
engineer*

# SADI CARNOT « THE LEGEND »



**Sadi Carnot by Michel Serres**  
« Brûler » in « La légende des Sciences »  
[La Légende des Sciences – Brûler](#)  
<https://www.youtube.com/watch?v=J5JSWebXms0>

**"La Théorie du Feu" Hommage à Sadi Carnot**  
<https://www.youtube.com/watch?v=uNRGDYDygt4>

**(Couplet 1)**

Il naquit à Paris, un jour de juin,  
Sadi Carnot, au destin incertain.  
Fils d'un révolutionnaire, grand mathématicien,  
Le feu dans le cœur, la science en chemin.

À vingt-sept ans, il écrit son grand livre,  
Des machines à vapeur, il voulait le livre.  
"Réflexions sur le feu, la chaleur, le moteur",  
Ses idées jaillissent comme une lueur.

**(Refrain)**

Thermodynamique, il en est le pionnier,  
Avant même que le terme soit inventé.  
Un moteur thermique, voilà ce qu'il a tracé,  
Les bases d'une science pour l'avenir, gravées.



# NEW 2024 EDITION OF « ACADEMIE FRANÇAISE » DICTIONNARY



MOT À RECHERCHER



1<sup>re</sup>

2<sup>e</sup>

3<sup>e</sup>

4<sup>e</sup>

5<sup>e</sup>

6<sup>e</sup>

7<sup>e</sup>

8<sup>e</sup>

9<sup>e</sup> édition

1694

1718

1740

1762

1798

1835

1878

1935

ACTUELLE

Dictionnaire de l'Académie française, 9<sup>e</sup> édition (actuelle)



thermodynamique

## THERMODYNAMIQUE nom féminin et adjectif

XIX<sup>e</sup> siècle. Composé de *thermo-* et de *dynamique*.

1. **N. f.** Partie de la physique étudiant les systèmes macroscopiques du point de vue énergétique lorsqu'ils sont à l'état d'équilibre ou connaissent une évolution, que celle-ci soit spontanée ou causée par des échanges d'énergie ou de matière avec le milieu extérieur. *En étudiant le lien entre la chaleur et la production de travail mécanique, Nicolas Sadi Carnot posa les bases de la thermodynamique.*

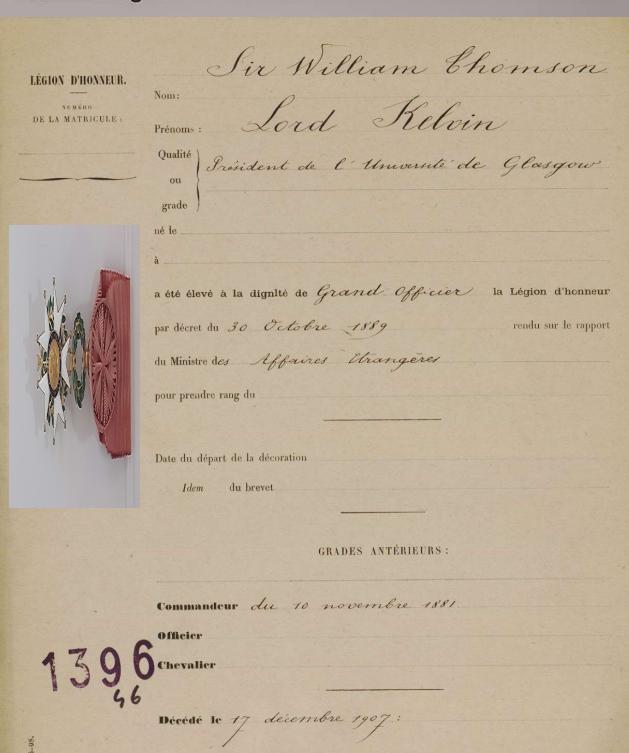
# LORD KELVIN 200<sup>TH</sup> BIRTHDAY IN GLASGOW 2024

[HTTPS://WWW.GLA.AC.UK/EXPLORE/LORDKELVIN200/](https://www.gla.ac.uk/explore/lordkelvin200/)



France Legion of Honour Commander's badge 1881

France Legion of Honour Grand Officer's star 1889



## Special Issue

# 200 Years Anniversary of “Sadi Carnot, Réflexions Sur La Puissance Motrice Du Feu”; Bachelier: Paris, France, 1824

### Message from the Guest Editors

The 1824 book by Sadi Carnot was no less than the cradle of thermodynamics. It has influenced different disciplines, including physics, chemistry, biology, geology, engineering and materials science. Thermodynamics provides the framework for a generalized dynamics covering all kind of energy conversion in the living and non-living world, including metabolic pathways, chemical reactions, thermoelectricity and Hamiltonian mechanics. In harmonized appearance, all balance equations for extensive quantities (e.g. mass, momentum, angular momentum, entropy, electric charge, chemical substance, energy) follow the same format and reflect the uniformity in the basic principles. Thermodynamics covers both equilibrium and non-equilibrium systems. It is compatible with relativistic theory and field theories and, when complemented by statistical concepts, it comprises phenomena that traditionally fall in the domain of quantum mechanics. Thermodynamics is widely viewed as one of the sound standing and far-reaching concepts in science, technology, engineering and mathematics (STEM). Contributions addressing any of these issues are very welcome.

---

### Guest Editors

Prof. Dr. Armin Feldhoff

Prof. Dr. Christophe Goupid

Prof. Dr. Pascal Boulet

Prof. Dr. Marle-Christine Record

Dr. Eric Herbert

Dr. Gaël Giraud

et al.

---

Deadline for manuscript submissions

closed (31 March 2025)



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- Entropy, Carnot Cycle and Information Theory, Part 2 by Mario Martinelli
- Near-Horizon Carnot Engines Beyond Schwarzschild: Exploring Black Brane Thermodynamics by Lotte Mertens and Jasper van Wezel
- Rethinking Economic Measurement Using Statistical Ensembles by Cal Abel
- Three Optima of Thermoelectric Conversion: Insights from the Constant Property Model by Paul Raux, Christophe Goupil and Gatien Verley
- Temperature Gradients as a Data Storage Principle by Jeroen Schoenmaker, Pâmella Gonçalves Martins and Julio Carlos Teixeira
- The Gibbs Fundamental Relation as a Tool for Relativity by Friedrich Herrmann and Michael Pohlig
- Fundamental Limits of an Irreversible Heat Engine by Rui Fu
- Carnot and the Archetype of Waterfalls by Hans U. Fuchs, Elisabeth Dumont and Federico Corni
- Exploring the Thermodynamic Uncertainty Constant: Insights from a Quasi-Ideal Nano-Gas Model by Giorgio Sonnino
- A Contemporary View on Carnot’s Réflexions by Jan-Peter Meyn
- Phase Space Spin-Entropy by Davi Geiger
- Testing the Minimum System Entropy and the Quantum of Entropy by Uwe Hohm and Christoph Schiller
- Jean-Marie Souriau’s Symplectic Foliation Model of Sadi Carnot’s Thermodynamics by Frédéric Barbaresco

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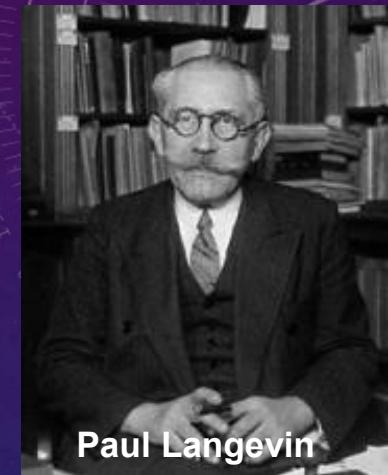


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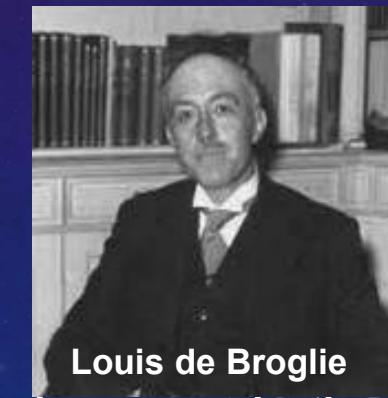


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- Organizes conferences and seminars
- Initiates/attracts International Conferences in France
- Institutional French member of IFAC and IFIP
- Awards (Glavieux/Brillouin Prize, Général Ferrié Prize, Néel Prize, Jerphagnon Prize, Blanc-Lapierre Prize, Thévenin Prize), grades and medals (Blondel, Ampère)
- Publishes 3 periodical publications (REE, ...) & 3 monographs each year
- Web: <http://www.see.asso.fr> and LinkedIn SEE group
- SEE Presidents: Louis de Broglie, Paul Langevin, ...



Paul Langevin



Louis de Broglie

1883-2023: From SIE & SFE to SEE: 142 years of Sciences

Société de l'électricité, de l'électronique et des technologies de l'information et de la communication



1881

Exposition Internationale d'Electricité



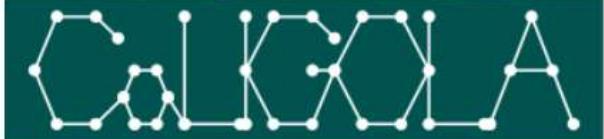
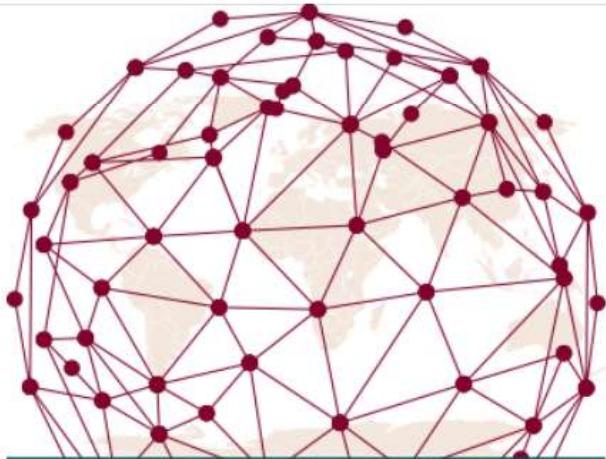
1883: SIE  
Société  
Internationale  
des Electriciens



1886: SFE  
Société  
Française  
des Electriciens



2025: SEE  
17 rue de l'Amiral Hamelin  
75783 Paris Cedex 16



## WP5: The geometry of Deep Learning

### Main research themes:

- Lie groups thermodynamics
- Persistent Homology and Genoos
- The geometry of (Geometric) Deep Learning

### Key People:

Rita Fioresi  
(UNIBO)

Frédéric Barbaresco  
(Thales)

## CaLIGOLA

Cartan geometry, Lie and representation theory, Integrable Systems, quantum Groups and quantum computing towards the understanding of the geometry of deep Learning and its Applications

Programme: Horizon Europe Framework Programme (HORIZON)

Call: MSCA Staff Exchanges 2021 (HORIZON-MSCA-2021-SE-01)

Project ID: 101086123

[details](#)

CaLIGOLA aims at advancing the research in Cartan Geometry, Lie Theory, Integrable Systems and Quantum Groups to provide insight into a variety of multidisciplinary fields oriented towards the applications with a special interest in machine learning and quantum computing. Sound mathematical models for quantum computing, vision and more generally machine learning are a priority for Horizon Europe and strategic to include Europe among the leading actors in such fields. Through the theory of symmetric spaces from the Cartan Geometric and Lie theoretic point of view, we shall implement the Erlangen philosophy for mathematical and physical questions (integrable systems and SUSY gauge field theory), but also for more applied themes including Quantum Computing and (geometric) Deep Learning. Quantum symmetric spaces and quantum representations will be the key to approach the questions of fault tolerant quantum algorithms in topological quantum computing and quantum information geometry on homogeneous spaces. With the language of Cartan geometry and Quantum Groups, we shall reformulate group invariant neural network models. Persistent homology and topological data analysis will take a step forward towards a metric theory on the space of observers. With the help of Lie group thermodynamic, we shall push the understanding of symmetries at a deeper level. Overall, the new algorithms of Deep Learning and Geometric Deep Learning will find a better modeling and understanding towards a comprehensive theory of dimensionality reduction of parameter space via group equivariance.



ALMA MATER STUDIORUM  
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Funded by  
the European Union



## WG4: Vision models

### VISION

In this WG we focus on the study of new models to advance in our understanding of vision in the framework of the new techniques as deep learning (DL), geometric deep learning (GDL).

### CONTACTS

Jesus Angulo

MINES Paris, France

[Write an e-mail](#)

### Goals and Tasks:

- G4.1: Provide a new understanding of the interplay between the Geneo theory (in TDA) and the new machine learning algorithms coming from geometric deep learning with group equivariance.
- G4.2: Provide new models for vision via Cartan Geometry, understand its application in DL, GDL.
- T4.1: Enhance the Geneo approach to machine learning vision applications, beyond topological data analysis, towards the applications to concrete problems (molecular dynamics, material science).
- T4.2: Reframe the GDL approach via symmetric space theories developed in Cartan geometry.
- T4.3: Interpret SGD and the metric structure of the model space with Souriau Lie Thermodynamics. Interpret the coadjoint orbits of the symmetry group action as level set of entropy; exploit their symplectic structure to construct further symmetries (group equivariant GDL).

### Aims of the Project

Symmetry is a central unifying theme in mathematics and physics.

In this project we focus our attention on symmetries realized through Lie groups and Lie algebras.

In addition to the spectacular achievements in representation theory, and differential geometry, Lie theory is also exceptionally important for the formalization of fundamental physical theories.

CaLISTA aims to advance cutting-edge research in mathematics and physics through a systematic application of the ideas and philosophy of Cartan geometry, a thoroughly Lie theoretic approach to differential geometry.

In addition to making major progress in Cartan geometry itself, CaLISTA aims to develop crucial applications to integrable systems and supersymmetric gauge theories.

Quantum groups and their quantum homogeneous spaces come into the play as a bridge between these topics: quantum groups stem originally from the R-matrix formulation in integrable systems, and their homogeneous spaces offer prototypical examples of noncommutative parabolic geometries.

Parabolic geometry is the first and possibly the most important example of Cartan geometry, and one of the main aims of CaLISTA is to obtain a quantum generalization.

Surprisingly, Lie theory and Cartan geometry play a role in an exciting new interpretation of the differential structure, and related dynamics, of models for popular algorithms of vision like Deep Learning and the more recent Geometric Deep Learning.

CaLISTA aims to investigate and improve on these techniques. CaLISTA will provide essential mathematical models with far-reaching applications, placing Europe among the leading actors in these innovative research areas.

EU COST Action CaLIGOLA:  
<https://site.unibo.it/calista/en>

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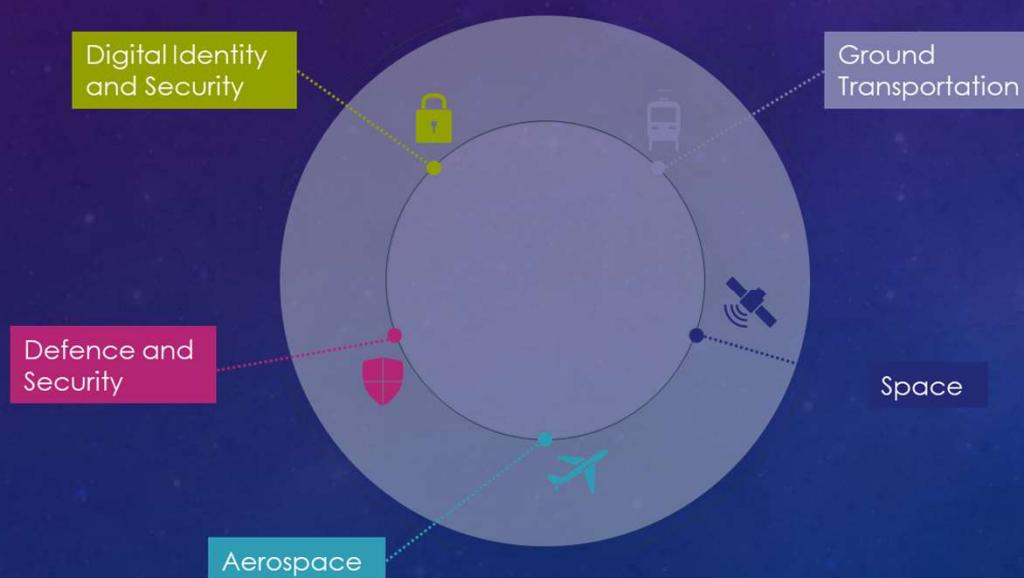


**Albert Fert**

Scientific director of the CNRS/Thales joint physics unit and winner of the **2007 Nobel prize in physics**.



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# GSI'25 Figures

- *GSI'25 Registrations: 190 participants*
- *GSI'25 Program*
  - *6 Keynote Speakers*
  - *125 talks in 27 Oral sessions*
  - *19 Posters in 1 Poster session*
- *Papers Acceptance Rate of 85% based on 133 reviewers (minimum of 2 reviews per paper)*
- *Papers Origin: France, Germany, USA, Japan , UK, Denmark , Netherlands, Australia, Austria, Belgium, Canada, Norway, Portugal, Romania, Spain, Sweden, Switzerland, ...*

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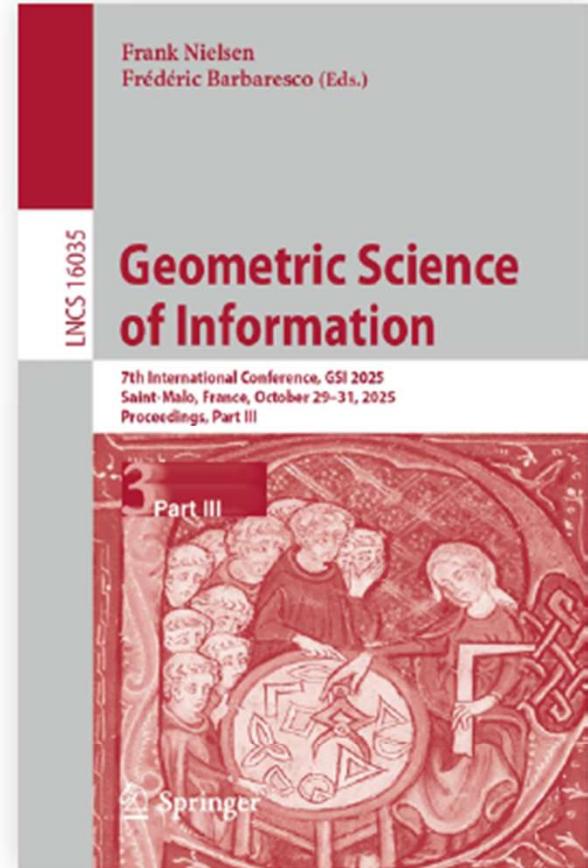
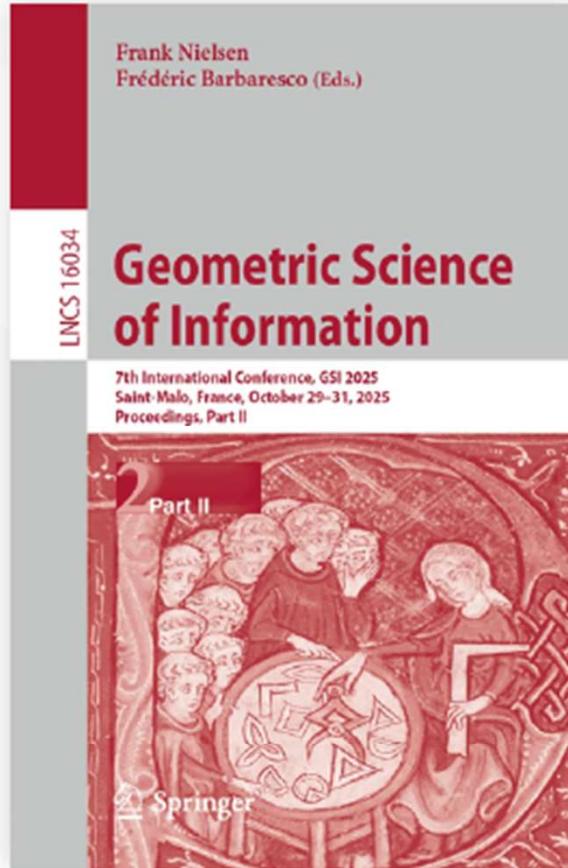
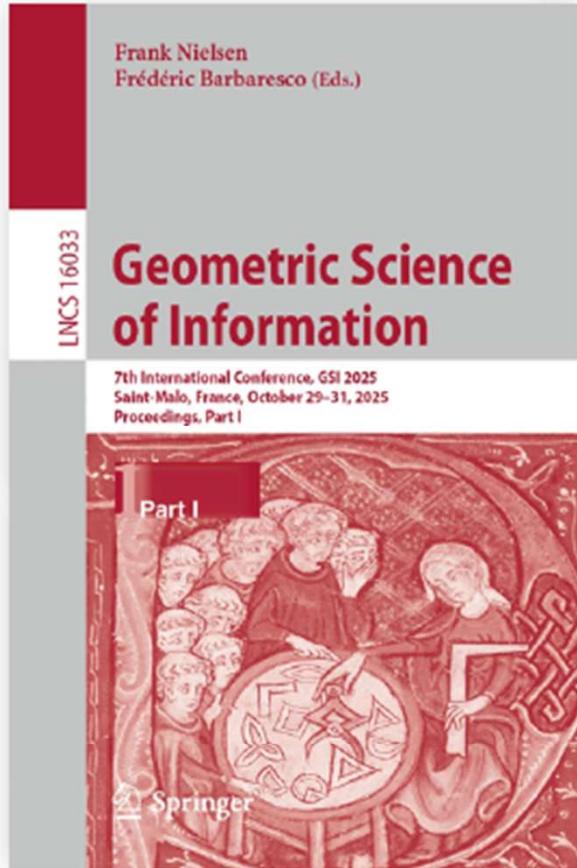
• **Jun Zhang**, University of Michigan, Ann Arbor, USA

# | GSI'25 Proceedings |

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# | GSI'25 Special Issue INGE |



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*This special issue of Information Geometry (INGE) will include selected refereed papers presented at the 7<sup>th</sup> international conference on Geometric Science of Information (GSI'25) held in Saint-Malo, France, from 28th to 31st October 2025.*

*All papers will be refereed according to the high standards of INGE.*

*Paper Submission: Authors should submit their work to Information Geometry via the online platform: <https://link.springer.com/journal/41884/submit/mission-guidelines>*

**Frederic Barbaresco and Frank Nielsen**



# GSI'25 MDPI Special Issue: Methods from Differential Topology and Differential Geometry in Information Geometry

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## Special Issue

### Methods from Differential Topology and Differential Geometry in Information Geometry

#### Message from the Guest Editors

This Special Issue was created as a parallel publication associated with the Geometric Science of Information 2025 Conference, which will be held at the Palais du Grand Large, Saint-Malo, France, in October 2025. This conference aims to bring together mathematicians, physicists, and engineers with a shared interest in geometric tools and their applications in information analysis and learning. Emphasizing the active participation of young researchers, GSI fosters collaboration and discussion on emerging topics in this interdisciplinary field. GSI'25 focuses on the theme: From Classical to Quantum Information Geometry: Geometric Structures of Statistical & Quantum Physics, Information Geometry, and Machine Learning.

---

#### Guest Editors

Dr. Stéphane Puechmorel

Prof. Dr. Frank Nielsen

Dr. Frédéric Barbaresco

---

#### Deadline for manuscript submissions

31 March 2026



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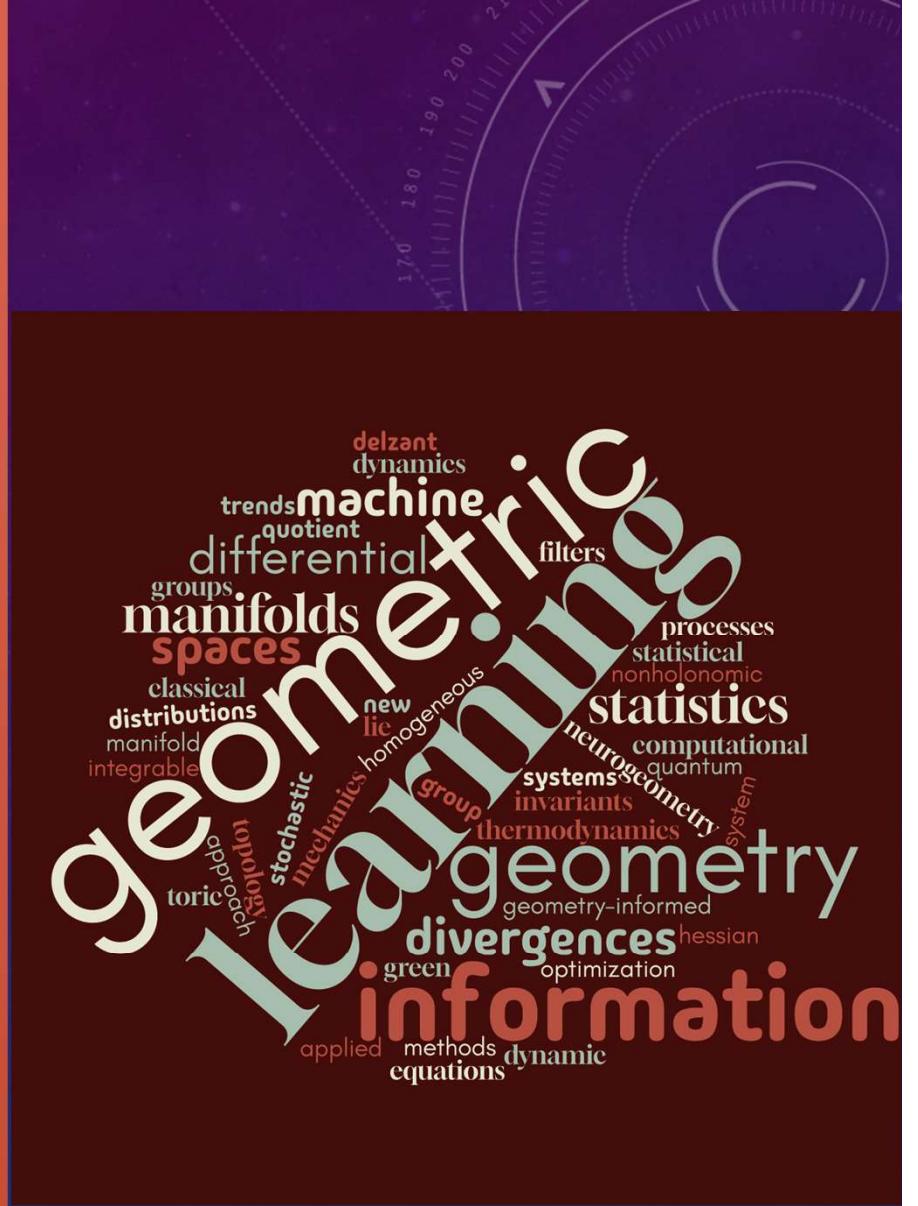
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**The GSI'25 conference was structured in 18 sessions of more than 120 papers:**

1. Geometric Learning and Differential Invariants on Homogeneous Spaces
  2. Statistical Manifolds and Hessian information geometry
  3. Applied Geometry-Informed Machine Learning
  4. Geometric Green Learning on Groups and Quotient Spaces
  5. Divergences in Statistics and Machine Learning
  6. Geometric Statistics
  7. Computational Information Geometry and Divergences
  8. Geometric Methods in Thermodynamics
  9. Classical & Quantum Information, Geometry and Topology
  10. Geometric Mechanics
  11. Stochastic Geometric Dynamics
  12. New trends in Nonholonomic Systems
  13. Learning of Dynamic Processes
  14. Optimization and learning on manifolds
  15. Neurogeometry
  16. Lie Group in Learning Distributions & in Filters
  17. A geometric approach to differential equations
  18. Information Geometry, Delzant Toric Manifold & Integrable System



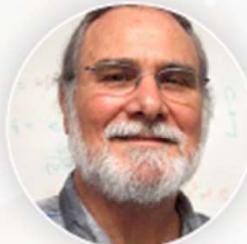
# GSI'25 keynote speakers

## KEYNOTES:



**Prof. Nina MIOLANE**

Assistant Professor, AI, UC Santa Barbara.  
Co-Director, AI Center, Bowers Women's Brain  
Health Initiative. Affiliate, Stanford SLAC  
*Topological Deep Learning: Unlocking  
the Structure of Relational Systems*



**Philip J. MORRISON**

The University of Texas at Austin,  
Physics Department

*Metriplectic Dynamics: A Geometrical Framework for  
Thermodynamically Consistent Dynamical Systems*



**Mário A.T. FIGUEIREDO**

Instituto de Telecomunicações and Instituto Superior  
Técnico Universidade de Lisboa, Portugal

*Extended Variational Learning  
via Fenchel-Young Losses*



**Rita FIORESI**

FaBiT, University of Bologna, Italy

*A Noncommutative perspective of Graph Neural  
Networks*



**Alice LEBRIGANT**

Université Paris 1 Panthéon-Sorbonne

*The  $L^p$  Fisher-Rao metrics a  
nd the alpha-connections*



**Frédéric BARBARESCO**

THALES, Campus de Paris-Saclay, Palaiseau, France

*Bicentenary of Thermodynamics and Sadi Carnot's  
Seminal Work: From Constantin Carathéodory's  
Contact Geometry Model to Jean-Marie Souriau's  
Symplectic Foliation Structure*

# 29<sup>th</sup> October 09:30

## Prof. Nina MIOLANE

Assistant Professor, AI, UC Santa Barbara.  
Co-Director, AI Center, Bowers Women's Brain  
Health Initiative. Affiliate, Stanford SLAC



## TOPOLOGICAL DEEP LEARNING: UNLOCKING THE STRUCTURE OF RELATIONAL SYSTEMS

**Abstract:** The natural world is full of complex systems characterized by intricate relations between their components: from social interactions between individuals in a social network to electrostatic interactions between atoms in a protein. Topological Deep Learning (TDL) provides a framework to process and extract knowledge from data associated with these systems, such as predicting the social community to which an individual belongs or

predicting whether a protein can be a reasonable target for drug development. By extending beyond traditional graph-based methods, TDL incorporates higher-order relational structures, providing a new lens to tackle challenges in applied sciences and beyond. This talk will introduce the core principles of TDL and provide a comprehensive review of its rapidly growing literature, with a particular focus on neural network architectures and their performance across various domains. I will present open-source implementations that make TDL methods more accessible and practical for real-world applications. All in all, this talk will showcase how TDL models can effectively capture and reason about the complexity of real-world systems, while highlighting the remaining challenges and exciting opportunities for future advancements in the field.

### References:

1. Hajij, M., Papillon, M., Frantzen, F., Agerberg, J., Aljabea, I., Ballester, R., ... & Miolane, N. (2024). TopoX: a suite of Python packages for machine learning on topological domains. *Journal of Machine Learning Research*, 25(374), 1-8.
2. Papamarkou, T., Bldal, T., Bronstein, M. M., Carlsson, G. E., Curry, J., Gao, Y., ... & Zamzmi, G. (2024). Position: Topological Deep Learning is the New Frontier for Relational Learning. In Forty-first International Conference on Machine Learning.
3. Papillon, M., Bernárdez, G., Battiloro, C., & Miolane, N. (2024). TopoTune: A Framework for Generalized Combinatorial Complex Neural Networks. arXiv preprint arXiv:2410.06530.
4. Papillon, M., Sanborn, S., Hajij, M., & Miolane, N. (2023). Architectures of Topological Deep Learning: A Survey of Message-Passing Topological Neural Networks. arXiv preprint arXiv:2304.10031.
5. Hajij, M., Zamzmi, G., Papamarkou, T., Miolane, N., Guzmán-Sáenz, A., Ramamurthy, K. N., ... & Schaub, M. T. (2022). Topological deep learning: Going beyond graph data. arXiv preprint arXiv:2206.00606.

# 29<sup>th</sup> October 14:00

Alice LE BRIGANT

Université Paris 1 Panthéon-Sorbonne



## THE L^P FISHER-RAO METRICS AND THE ALPHA-CONNECTIONS

**Abstract:** The information geometry of parametric statistical models is built around two central constructions: the Fisher-Rao metric and the family of dual\alpha-connections. Both have non-parametric counterparts, which we discuss in this talk. We introduce the  $L^p$ -Fisher-Rao metrics, a family of Finsler metrics that generalize the Fisher-Rao metric, and study their links with the \alpha-connections. We show that their

geodesics coincide on the space of smooth densities, for  $p=2/(1-\alpha)$ , while they differ on the space of probability densities. This gives a new variational interpretation of\alpha-geodesics as being energy minimizing curves. Joint work with Martin Bauer, Yuxiu Lu and Cy Maor.

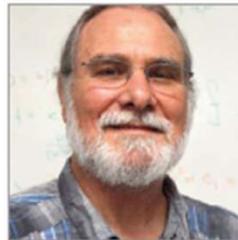
### References:

1. M. Bauer, A. Le Brigant, Y. Lu and C. Maor.  
« The  $L^p$ -Fisher-Rao metric and Amari-Cencov  $\alpha$ -Connections. » Calculus of Variations and Partial Differential Equations 63.2 (2024): 56.

# 30<sup>th</sup> October 09:00

## Philip J. MORRISON

The University of Texas at Austin , Physics Department



### METRIPLECTIC DYNAMICS: A GEOMETRICAL FRAMEWORK FOR THERMODYNAMICALLY CONSISTENT DYNAMICAL SYSTEMS

**Abstract:** Classical descriptions of matter present many fluid mechanical and kinetic theory dynamical systems. These include, e.g., the Navier-Stokes-Fourier system, the Cahn-Hilliard-Navier-Stokes system for multiphase fluid flow, and various types of

collisional kinetic theories for gaseous and plasma modeling. A desirable feature of such modeling is thermodynamic consistency, i.e., conservation of energy and production of entropy, in agreement with the first and second laws of thermodynamics. Metriplectic dynamics is a kind of dynamical system (finite or infinite) that encapsulates in a geometrical formalism such thermodynamic consistency. An algorithmic procedure for building such theories is based on the metriplectic 4-bracket, a bracket akin to the Poisson bracket that maps phase space functions to another. However, the 4-bracket maps 4 such functions and has algebraic curvature symmetries. Metriplectic 4-brackets can be constructed using the Kulkarni-Nomizu product or via a pure Lie algebraic formalism based on the Koszul connection. The formalism algorithmically produces many known and new dynamical systems, and it provides a pathway for constructing structure preserving numerical algorithms.

### References:

1. P. J. Morrison and M. Updike, « Inclusive Curvature-Like Framework for Describing Dissipation: Metriplectic 4-Bracket Dynamics, » *Physical Review E* 109, 045202 (22pp) (2024).
2. A. Zaldnl, P. J. Morrison, and S. Benjelloun, « Thermodynamically Consistent Cahn-Hilliard-Navier-Stokes Equations using the Metriplectic Dynamics Formalism, » *Physica D* 468, 134303 (11pp) (2024).
3. N. Sato and P. J. Morrison, « A Collision Operator for Describing Dissipation in Noncanonical Phase Space, » *Fundamental Plasma Physics* 10, 100054 (18pp) (2024)
4. W. Barham, P. J. Morrison, A. Zaldnl, « A thermodynamically consistent discretization of 1D thermal-fluid models using their metriplectic 4-bracket structure, » *arXiv:2410.11045v2 [physics.comp-ph]* 19 Oct 2024.
5. A. Zaldnl, P. J. Morrison, « Metriplectic 4-bracket algorithm for constructing thermodynamically consistent dynamical systems, » *arXiv:2501.00159v1 [physics.flu-dyn]* 30 Dec 2024.

Frédéric BARBARESCO

THALES, Campus de Paris-Saclay, Palaiseau,  
France



## BICENTENARY OF THERMODYNAMICS AND SADI CARNOT'S SEMINAL WORK: FROM CONSTANTIN CARATHÉODORY'S CONTACT GEOMETRY MODEL TO JEAN-MARIE SOURIAU'S SYMPLECTIC FOLIATION STRUCTURE

**Abstract:** Sadi Carnot stands as a symbol of the "Ingénieur-Savant" who have profoundly enriched the fertile ground of French innovation. The discipline of thermodynamics, which he founded, today underpins information theory, the development of future quantum computers, and artificial intelligence, as well as climate science, pillars upon which rest both our industrial policies and the future of our societies. Sadi Carnot formulated the second law of thermodynamics in his treatise, "Reflections on the Motive Power of Fire" (1824), that initially received little

attention, but emerged from obscurity years later thanks to the works of Émile Clapeyron, William Thomson (later Lord Kelvin), and Rudolf Clausius. Sadi Carnot drew upon a remarkably wide range of knowledge, nourished by an eclectic and inquisitive mind. Taken by illness only a few years after publishing his *Reflections*, he remains forever preserved in the brilliance of his genius. The explanation of thermodynamics through geometric models was initiated by seminal figures such as Gibbs, Reeb, Carathéodory and Souriau. We shall trace the narrative of the geometric models, from Carathéodory (1909) to Souriau (1969), that have sought to re-establish Sadi Carnot's thermodynamics upon new foundational variational principles. As observed by Vladimir Arnold, "Every mathematician knows it is impossible to understand an elementary course in thermodynamics. The reason is that thermodynamics is based, as Gibbs has explicitly proclaimed, on a rather complicated mathematical theory, on the contact geometry". A seminal contribution of Carathéodory lies in the introduction of a differential equation that governs the infinitesimal changes in state functions as the system undergoes infinitesimal transitions between states. This equation is of paramount importance as it embodies the first and second laws of thermodynamics in a single, unified mathematical expression. Carathéodory's axiomatization is intricately linked with the language of differential geometry, later interpreted as contact geometry and has greatly influenced Misha Gromov geometer who introduced the concept of Carnot-Carathéodory spaces. One of the pivotal results of Carathéodory's axiomatization is his theorem, which asserts that, given certain conditions the second law of thermodynamics, as formulated by Clausius, can be derived directly from the fundamental thermodynamic relation. While Carnot thermodynamics was primarily concerned with systems in equilibrium, Carathéodory's axiomatization extends far beyond this, offering a more general framework that accommodates systems in non-equilibrium states. Only recently, however, has the Souriau's Symplectic Foliation Model,

introduced within the domain of geometric statistical mechanics, provided a geometric definition of entropy as an invariant Casimir function on symplectic leaves, specifically, the coadjoint orbits of the Lie group acting on the system, where these orbits are interpreted as level sets of entropy. We present a symplectic foliation interpretation of thermodynamics, based on Jean-Marie Souriau's Lie Groups Thermodynamics. This model offers a Lie algebra cohomological characterisation of entropy, viewed as an invariant Casimir function in the coadjoint representation.

### References:

1. Carnot Sadi (1824) *Réflexions sur la Puissance Motrice du Feu et sur les Machines propres à développer cette Puissance*, Bachelier, Paris.
2. Carathéodory Constantin (1909) Untersuchungen über die Grundlagen der Thermodynamik. *Mathematische Annalen* 67:355–386.
3. Massieu François (1869) Sur les Fonctions caractéristiques des divers fluides. *Comptes Rendus de l'Académie des Sciences Paris* 69:858–862.
4. Souriau Jean-Marie (1974) Mécanique statistique, groupes de Lie et cosmologie. In : Souriau JM (eds). *Colloque International du CNRS Géométrie symplectique et physique Mathématique*, CNRS, Marseille.
5. Callen Herbert Bernard (1974) Thermodynamics as a Science of Symmetry. *Foundations of Physics* 4(4):423–443.
6. Balian Roger & Valentin Patrick (2001) Hamiltonian structure of thermodynamics with gauge. *The European Physical Journal B, Condensed Matter and Complex Systems* 21:269–282.
7. Barbaresco Frédéric (2025) Jean-Marie Souriau's Symplectic Foliation Model of Sadi Carnot's Thermodynamics. *MDPI Entropy*, special issue on 200 Years Anniversary of "Sadi Carnot, Réflexions Sur La Puissance Motrice Du Feu"; Bachelier: Paris, France, 1824.
8. Projet Nicolas Léonard Sadi Carnot au Panthéon 1824–2024 : <https://sadi-carnot-physicien.fr/>

# 31<sup>st</sup> October 08:30

Rita FIORESI  
FaBIT, University of Bologna, Italy



## A NONCOMMUTATIVE PERSPECTIVE OF GRAPH NEURAL NETWORKS

**Abstract:** In this talk we show how the merging of different languages pertaining to K-theory, algebraic geometry, noncommutative geometry and gauge field theory can be fruitfully integrated to give a unified version of discrete differential geometry on graphs.

### References:

1. E. J. Beggs, S. Majid, Quantum Riemannian Geometry, Springer, 2020.
2. Bodnar, C., Di Giovanni, F., Chamberlain, B. P., Lio, P., et Bronstein, M. M., Neural Sheaf Diffusion: A Topological Perspective on Heterophily and Oversmoothing in GNNs, ICLR 2022.
3. M. Bronstein, J. Bruna, T. Cohen, et P. Veličković, Geometric Deep Learning: Grids, Groups, Graphs, Geodesics, and Gauges, ArXiv:2104.13478, 2021.
4. Theo Braune, Yiyi Tong, François

# 31<sup>st</sup> October 14:50

## Mário A.T. FIGUEIREDO

Instituto de Telecomunicações and Instituto Superior Técnico Universidade de Lisboa, Portugal



## EXTENDED VARIATIONAL LEARNING VIA FENCHEL-YOUNG LOSSES

**Abstract:** Many statistical learning and inference methods, from Bayesian inference to empirical risk minimization, can be unified through a variational perspective that balances empirical risk and prior knowledge. We introduce a new, general class of variational methods based on Fenchel-Young (FY) losses. These losses, derived using Fenchel conjugation (a central tool of convex analysis), generalize the Kullback-Leibler divergence and encompass Bayesian as well as classical variational learning. This FY framework provides generalized notions of free energy, evidence, evidence lower bound, and posterior, while still enabling standard optimization techniques like alternating minimization and gradient backpropagation. This allows learning a broader class of models than previous variational formulations. This talk will review FY losses and then detail this new generalized variational inference approach to machine learning.

### References:

1. Blondel, A. Martins, V. Niculae, « Learning with Fenchel-Young losses », Journal of Machine Learning Research, vol. 21, pp. 1532-4435, 2020.
2. Martins, M. Treviso, A. Farinhas, P. Aguiar, M. Figueiredo, M. Blondel, V. Niculae, « Sparse continuous distributions and Fenchel-Young losses », Journal of Machine Learning Research, vol. 23, pp. 1–74, 2022.
3. A. Martins, A. Farinhas, M. Treviso, V. Niculae, P. Aguiar, M. Figueiredo, « Sparse and Continuous Attention Mechanisms », Neural Information Processing Systems (NeurIPS), 2020
4. Sklaviadis, S. Agrawal, A. Farinhas, A. Martins, M. Figueiredo, « Fenchel-Young Variational Learning », arXiv:2502.10295, 2025.

# Program at Glance

## | Program at glance |

### DAY 1 - OCTOBER 29<sup>TH</sup>

Time	Auditorium Maupertuis	Room Vauban 1	Room Vauban 2
09:00	"Conference Opening Session Rédéric Barbaresco & Frank Nielsen (GSI'25 General Chairs)"		
09:30	'Topological Deep Learning: Unlocking the Structure of Relational Systems Nina Miolane (UC Santa Barbara, USA)"		
10:30	Coffee Break + GSI'25 Posters Session		
11:00-12:20	"Geometric Statistics (Session 1) Chairmen: Xavier Pennec, Stefan Sommer, Benjamin Eitzner"	"A geometric approach to differential equations (Session 1) Chairman: Javier de Lucas Araujo"	"Lie Group In Learning Distributions & In Filters (Session 1) Chairmen: Eren M. Kiral, Kolchi Tojo, Ha Q. Minh"
12:20-12:40	Lunch break + GSI'25 Posters Session		
14:00	'The Lp Fisher-Rao metrics and the alpha-connections Alice Le Brigant (Université Paris 1 Panthéon-Sorbonne, France)"		
15:00-16:00	"Geometric Statistics (Session 2) Chairmen: Xavier Pennec, Stefan Sommer, Benjamin Eitzner"	"A geometric approach to differential equations (Session 2) Chairman: Bartosz Zawora"	"Lie Group In Learning Distributions & In Filters (Session 2) Chairmen: Eren M. Kiral, Kolchi Tojo, Ha Q. Minh"
16:00-16:30	Coffee Break + GSI'25 Posters Session		
16:30-17:50	"Neurogeometry Chairmen: Alessandro Sarti, Giovanna Citti, Giovanni Petrì"	"New trends in Nonholonomic Systems Chairmen: Manuel de Leon, Leonardo Colombo"	"Learning of Dynamic Processes Chairman: Stéphane Chrétien"
18:45	Conference Group Photo		
19:00	Cocktail		

### DAY 2 - OCTOBER 30<sup>TH</sup>

Time	Auditorium Maupertuis	Room Vauban 1	Room Vauban 2
09:00	Metriplectic Dynamics: A Geometrical Framework for Thermodynamically Consistent Dynamical Systems - Philip J. Morrison (The University of Texas at Austin, USA)		
10:00	"Geometric Methods in Thermodynamics (Session 1) Chairman: François GAY-BALMAZ, Hiroaki YOSHIMURA"	"Stochastic Geometric Dynamics Chairman: Ana Bela CRUZEIRO, Jean-Claude ZAMBRINI, Stefania UGOLINI"	"Optimization and learning on manifolds (Session 1) Chairman: Cyrus MOSTAJERAN, Salem SAID"
11:20	Coffee Break + GSI'25 Posters Session (Chair: Rita FIORESI)		
11:50	"Geometric Methods in Thermodynamics (Session 2) Chairman : François GAY-BALMAZ, Hiroaki YOSHIMURA"	"Classical & Quantum Information, Geometry and Topology Chairman : Florio M. CIAGLIA, FABIO DI COSMO, Pierre BAUDOT and Grégoire SERGEANT-PERTHUIS"	"Optimization and learning on manifolds (Session 2) Chairman : Cyrus MOSTAJERAN, Salem SAID"
13:30	Lunch Break + GSI'25 Posters Session (Chair: Rita FIORESI)		
15:00	Bicentenary of Thermodynamics and Sadi Carnot's Seminar Work: From Constantin Carathéodory's Contact Geometry Model to Jean-Marie Souriau's Symplectic Foliation Structure - Frédéric BARBARESCO (THALES, France)		
16:00	Coffee Break + GSI'25 Posters Session (Chair Rita FIORESI)		
16:30-18:30	"Information Geometry, Delzant Toric Manifold & Integrable System Chairman : Mathieu MOUTOR, Hajime FUJITA, Daisuke TARAMA and Frédéric BARBARESCO"	"Geometric Green Learning on Groups and Quotient Spaces Chairman : Alice Barbara TUMPACH, Diarra FALL and Levin MAIER"	"Applied Geometry-Informed Machine Learning (Session 1) Chairman : Pierre-Yves LAGRAVE, Santiago VALASCO FORERO and Teodora PETRISOR"
19:30	Conference Group Photo at Maison du Corsaire		
20:00	Gala Dinner at Maison du Corsaire		

### DAY 3 - OCTOBER 31<sup>ST</sup>

Time	Auditorium Maupertuis	Room Vauban 1	Room Vauban 2
08:30	A Noncommutative perspective of Graph Neural Networks - Rita FIORESI (University of Bologna, Italy)		
09:30	"Geometric Mechanics (Session 1) Chairman : Géry de SAXCE, Zdravko TERZE, François DUBOIS"	"Computational Information Geometry and Divergences (session 1) Chairman : Frank NIELSEN and Olivier RIOLU"	"Statistical Manifolds and Hessian Information geometry (Session 1) Chairman : Michel NGUIFFO BOYOM, Stéphane PUECHMOREL"
11:10 - 11:40	Coffee Break + GSI'25 Posters Session		
11:40	"Geometric Mechanics (Session 2) Chairman : Géry de SAXCE, Zdravko TERZE, François DUBOIS"	"Computational Information Geometry and Divergences (session 2) Chairman : Frank NIELSEN and Olivier RIOLU"	"Applied Geometry-Informed Machine Learning (Session 2) Chairman : Pierre-Yves LAGRAVE, Santiago VALASCO-FORERO and Teodora PETRISOR"
13:20 - 14:50	Lunch Break + GSI'25 Posters Session		
14:50	Extended Variational Learning via Fenchel-Young Losses - Mário A.T. FIGUEIREDO (Universidade de Lisboa, Portugal)		
15:50	"Divergences in Statistics and Machine Learning Chairman : Michel BRONIATOWSKI and Wolfgang STUMMER"	"Statistical Manifolds and Hessian Information geometry (Session 2) Chairman : Michel NGUIFFO BOYOM, Stéphane PUECHMOREL"	"Geometric Learning and Differential Invariants on Homogeneous Spaces Chairman : Remco DUTTS, Erik BEKKERS"
17:50	Closing Session (Paper Awards)		

Group Photo



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## GSI 2025

October 29<sup>th</sup>-31<sup>st</sup> 2025  
Saint-Malo, France

# The 7<sup>th</sup> international conference on Geometric Science of Information

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## GSI 2025

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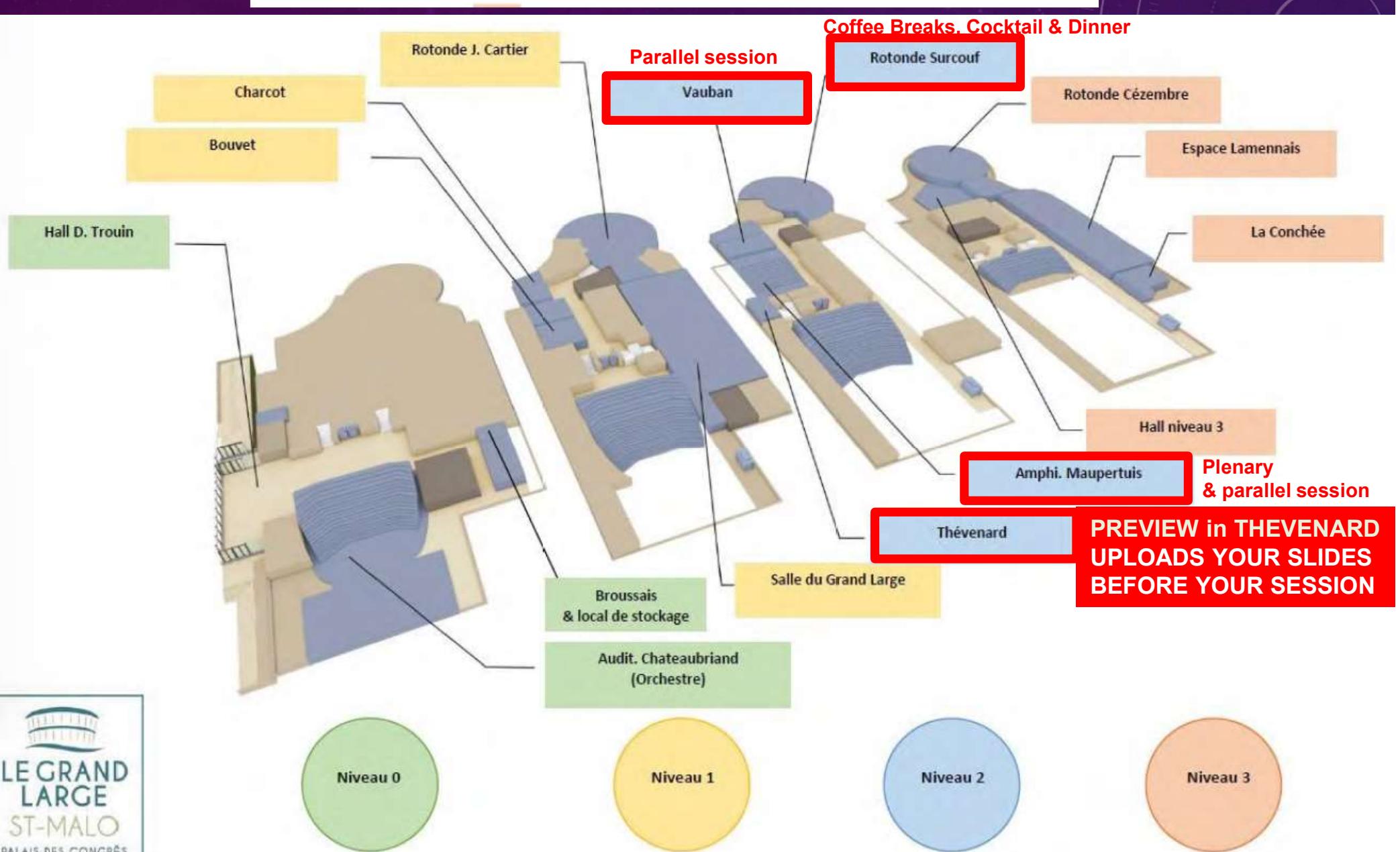
Frank Nielsen  
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# Palais du Grand-Large Map





**Room Maupertuis (2<sup>nd</sup> floor)**  
Plenary Sessions & Parallel Sessions



**Welcome Desk (Ground Floor)**  
Registration & Badges



**Room Vauban 1&2 (2<sup>nd</sup> floor)**  
Parallel Sessions



**Rotonde Surcouf (2<sup>nd</sup> floor)**  
Coffee Breaks & Posters Session

## | WiFi Access |



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## Welcome Cocktail

The Welcome Cocktail Reception will take place on  
**October 29<sup>th</sup> at 19.00pm In La Rotonde Surcouf.**  
Same floor than Maupertuis Plenary Session Room.



## Gala Dinner

The Gala Dinner will take place on  
**October 30<sup>th</sup> at 20.00 pm In La Demeure de Corsaire.  
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The gala dinner is included in the full registrations only.



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Service continu	
7 – Ô de Mer	02 99 40 15 04
8 – Le Cambusier	02 99 20 18 42
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12 – Le Cairn	02 90 10 17 53
13 – Fidelis	02 99 40 97 27
14 – DOMA	02 99 40 97 52

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17 – Récit de Voyages	02 99 80 66 99
18 – Bergamote	02 99 40 97 27



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Leon Brillouin  
Seminar  
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SÉMINAIRE LÉON BRILLOUIN

SCIENCES GÉOMÉTRIQUES  
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Marc Arnaudon (IMB, Bordeaux)

Un algorithme stochastique pour trouver  
les moyennes généralisées  
sur les variétés compactes.

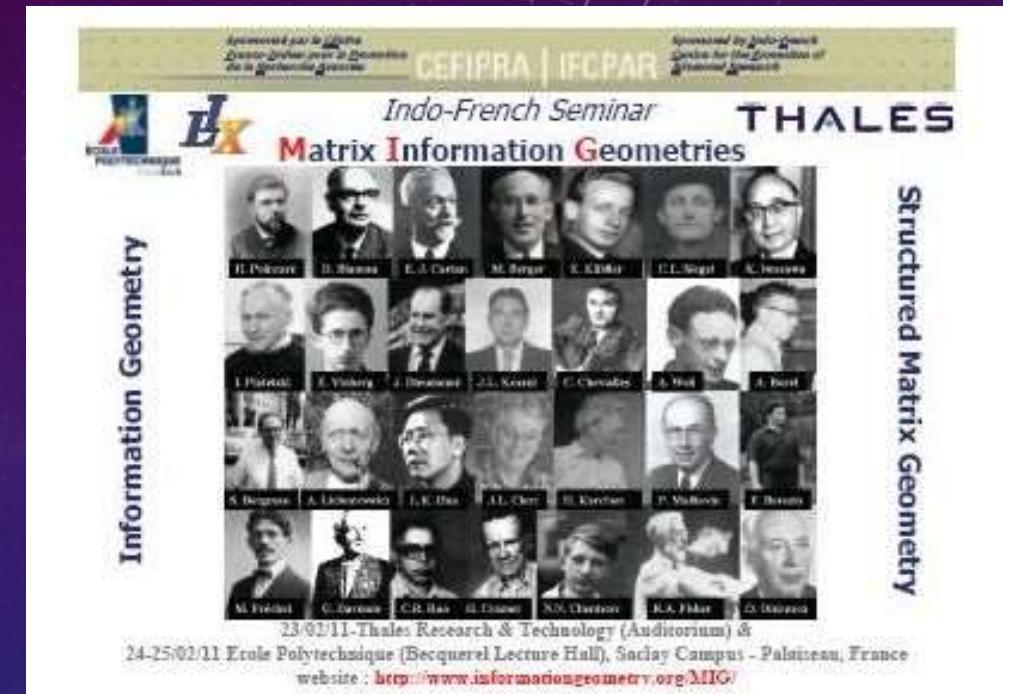
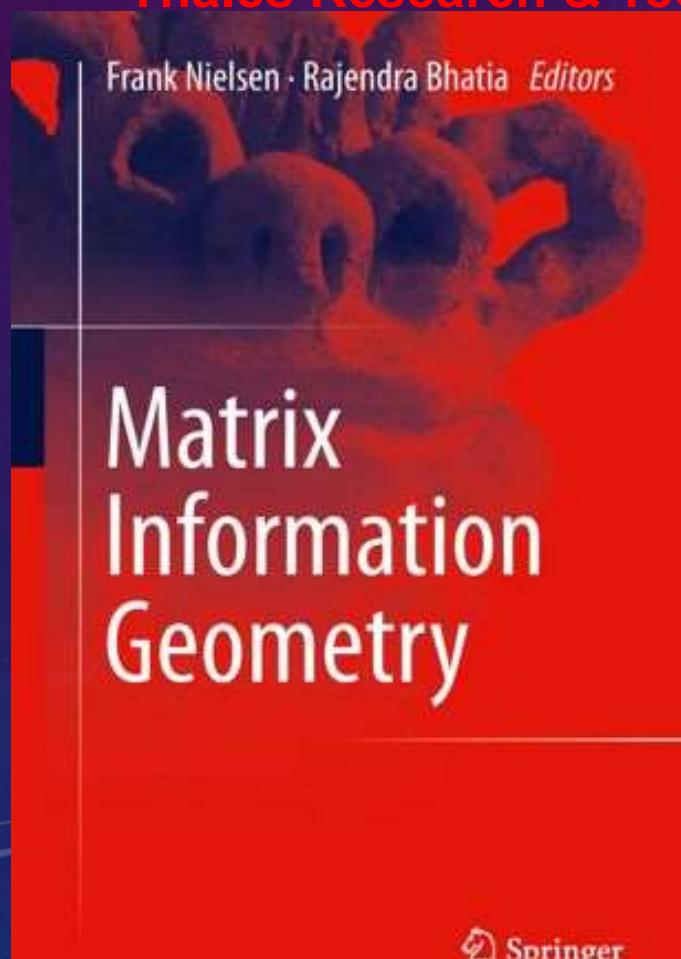
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# GSI conferences ancestors INDO-FRENCH MIG'11 Matrix Information Geometry Workshop

(Ecole Polytechnique &  
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# GSI biannual conferences

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GSI'13 Mines ParisTech



GSI'15 Ecole Polytechnique



GSI'17 Mines ParisTech



GSI'19 ENAC



GSI'21 Sorbonne University



GSI'23 Saint-Malo

# GSI LNCS Proceedings

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Hirohiko Shima  
Jean-Louis Koszul



Roger Balian



GSI'13 Mines ParisTech



GSI'15 Polytechnique



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Marle



Daniel  
Bennequin



Gérard  
Letac

Elena  
Celledoni

GSI'19 ENAC

Jean-Michel Bismut &  
Yann Ollivier

# GSI'21 Souvenirs



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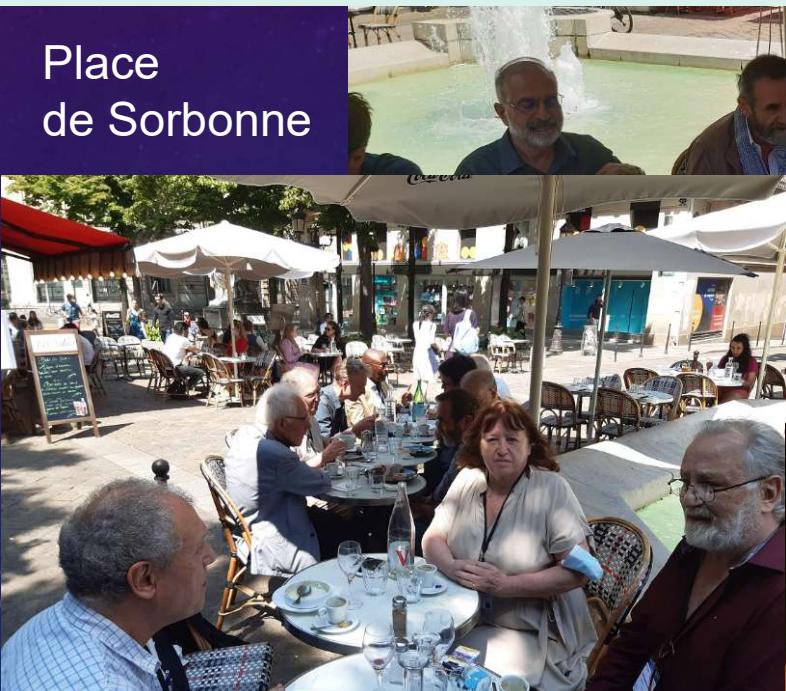


Maurice de Gosson

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Gazeau & M & Mme de Gosson



Longo,  
Bennequin  
& Marle



Jean Petitot & Daniel Bennequin  
5<sup>th</sup> Conference on Geometric  
Science of Information



Michel Broniatowski



Max Welling

# GSI'23 Souvenirs

## 10 Years Birthday



# Other GSI events

<https://franknielsen.github.io/GSI/>



TGSI'17 CIRM



FGSI'19 IMAG



GRETSI'19 PEYRESQ



SPIGL'20 LES HOUCHES



MAXENT'22



# CaLISTA Workshop Geometry-Informed Machine Learning

at Mines Paris (France)

**02/09 - Maxplus Algebra, Tropical Geometry and Mathematical Morphology in Deep Learning**, chaired by Jesus Angulo

**03/09 - Symplectic Model of Lie Groups Thermodynamics & Physics-Informed Neural Network (200<sup>th</sup> Birthday of Sadi Carnot Book)**, chaired by Frédéric Barbaresco

**04/09 - Symmetry and equivariance in Deep Learning**, chaired by Santiago Velasco-Forero

**05/09 - Geometric Deep Learning & Graph Neural Network**, chaired by Maurizio Parton

**Web Site:** <https://sites.google.com/view/calistaworkshop2024paris/home>  
**Videos:** <https://www.youtube.com/@CalistaWorkshopParis2024>



Elie CARTAN



Jean-Marie SOURIAU



Georges MATHERON

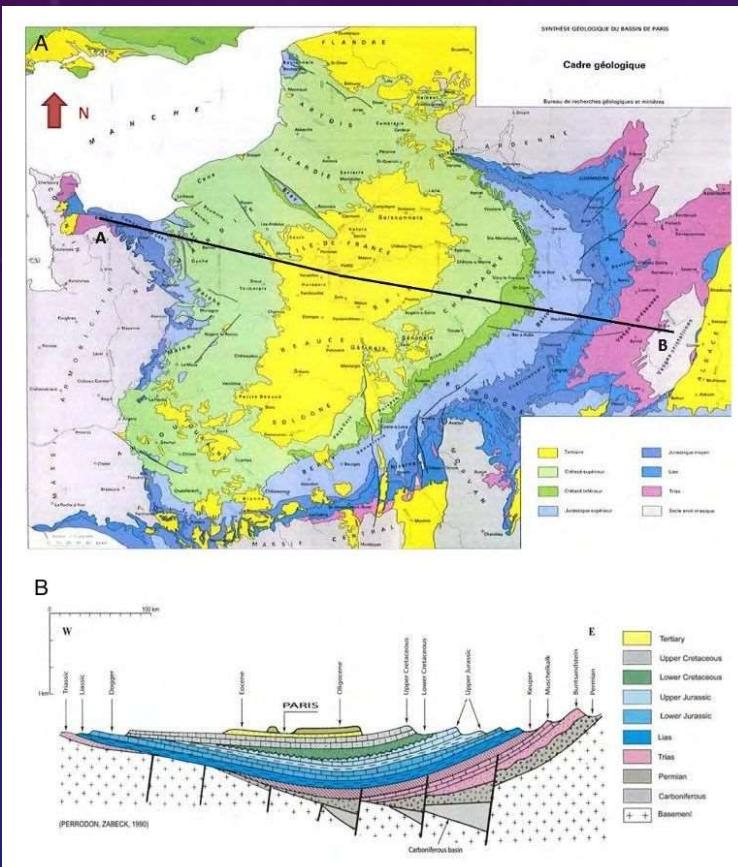


Tullio LEVI-CIVITA

# « NORD-BASSIN PARISIEN » SEMINAR ON « GEOMETRIC STRUCTURES OF DISSIPATION »

« Nord-Bassin Parisien » Seminar 2020's

➤ Paris-Metz-Valenciennes-Lille-Louvain-Liège-Bruxelles



« Sud-Rhodanien » Seminar 1980's

> Lyon, Marseille, Montpellier



**Forgetting and memory are also inventive.  
L'oubli et la mémoire sont également inventifs**  
**J. L. Borges, Le Rapport de Brodie**

**Special Issue: "Dynamics Beyond the Hamiltonian: Dissipation in Classical Metriplectic Systems and Quantum Non-Unitary Systems"**

- **Guest Editor:** Dr. Massimo Materassi and Dr. Frédéric Barbaresco
- **Submission deadline:** 31 December 2025



[mdpi.com/si/229747](https://mdpi.com/si/229747)



**Special Issue Information:**

Non-dissipative dynamics may be algebrized via Poisson brackets, in classical Hamiltonian systems, and via commutator algebra, in closed quantum systems. Dissipation breaks down dynamics algebrization, as it cannot be reduced to Poisson–commutator algebra.

Metriplectic formalism (MF) algebrizes many classical dissipative dynamics: a semi-metric bracket increasing the system entropy represents dissipation.

Recent studies have paralleled classical dissipative structures and quantum non-unitary evolutions, while the use of coherent states has traced their macroscopic limit very transparently.

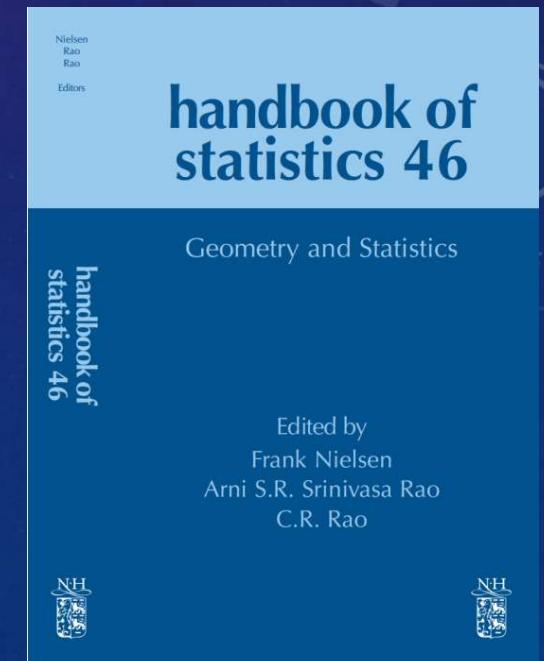
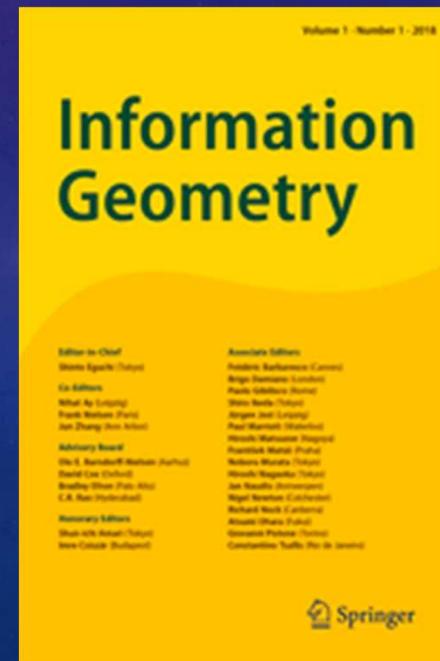
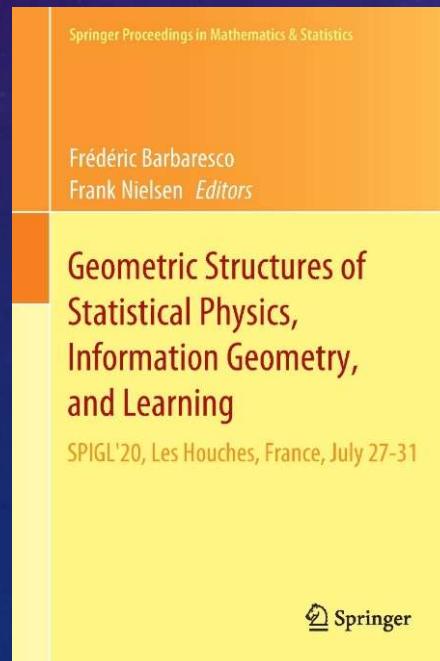
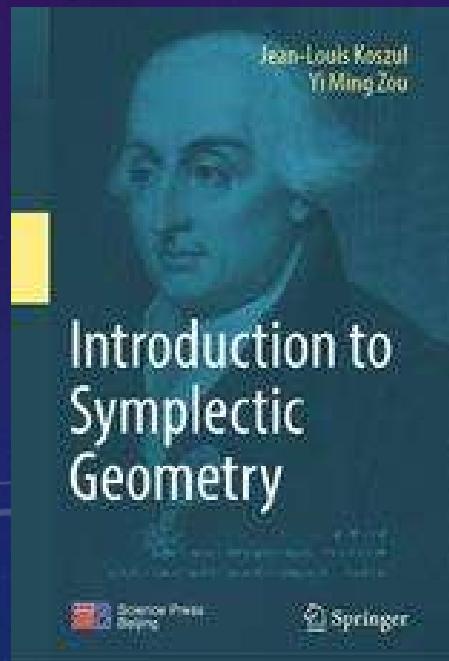
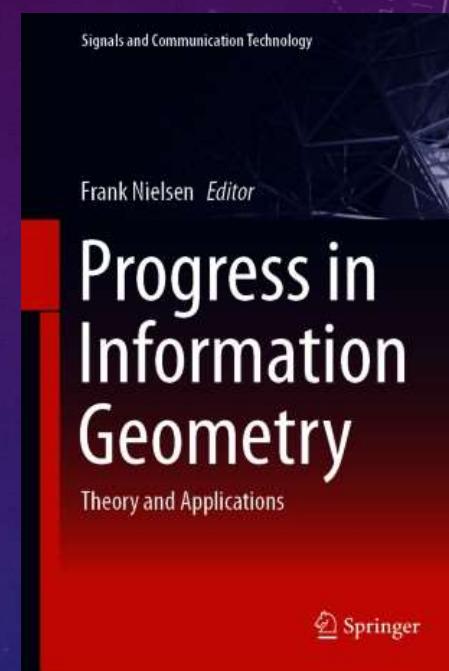
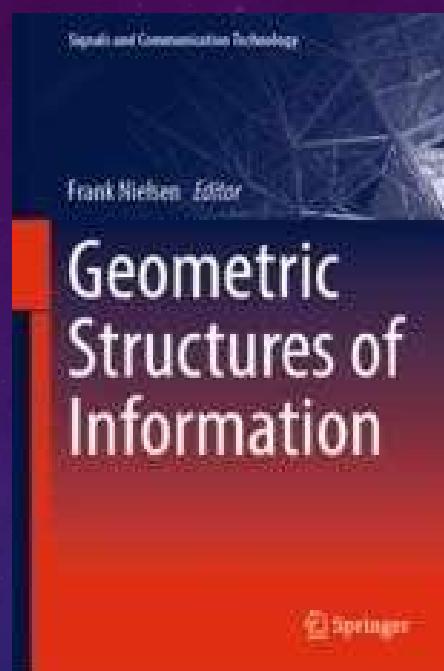
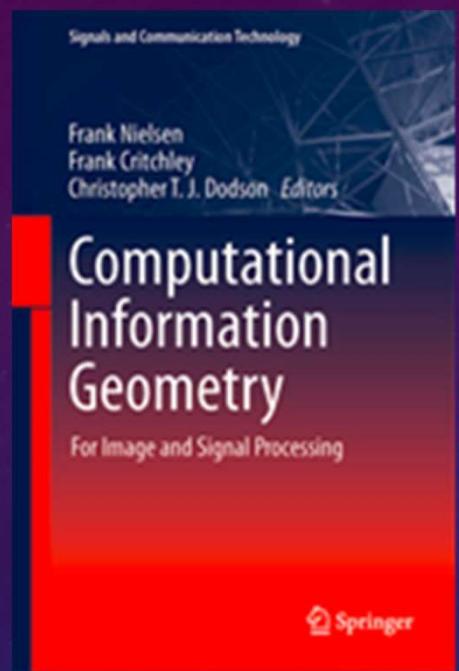
This Special Issue of Entropy intends to collect new applications and theoretical developments of beyond-Hamiltonian dynamics through differential geometric and algebraic tools, with particular reference to MF and non-unitary evolutions of quantum, and the relationship between the two. Submissions are encouraged concerning, but not limited to, the following:

- MF and non-equilibrium thermodynamics;
- Turning known theories into metriplectic systems;
- Open and dissipative quantum systems;
- Metriplectic systems in space physics, applied physics and technology and biophysics;
- Non-unitary quantum dynamics and non-Hermitian Hamiltonians.

**Journal website:** [mdpi.com/journal/entropy](https://mdpi.com/journal/entropy)

**Contact:** [entropy@mdpi.com](mailto:entropy@mdpi.com)

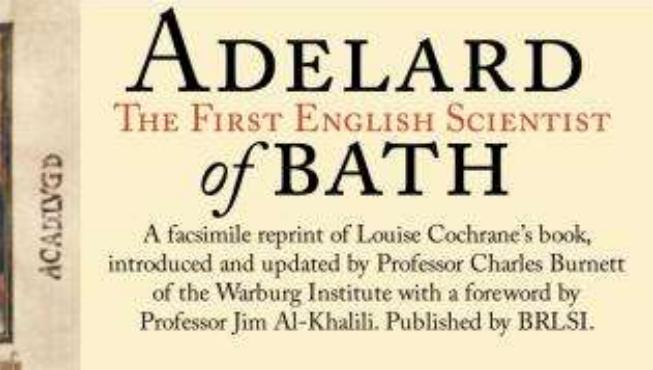
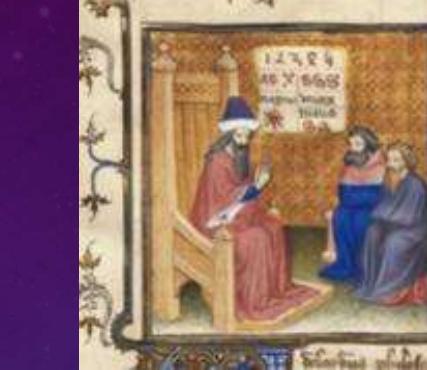
# Last Publications



# GSI Logo: Adelard of Bath



The frontispiece of an Adelard of Bath Latin translation of Euclid's Elements, c. 1309–1316; the oldest surviving Latin translation of the Elements is a 12th-century translation by Adelard from an Arabic version

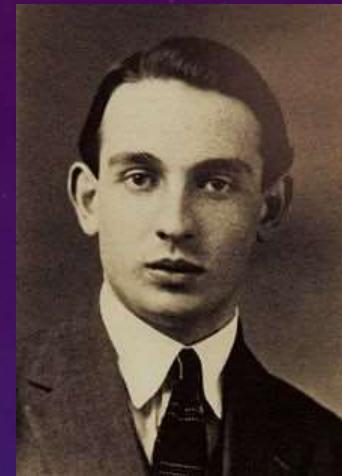


- He left England toward the end of the 11th century for Tours in France
- Adelard taught for a time at Laon, leaving Laon for travel no later than 1109.
- After Laon, he travelled to Southern Italy and Sicily no later than 1116.
- Adelard also travelled extensively throughout the "lands of the Crusades": Greece, West Asia, Sicily, Spain, and potentially Palestine.

Adelard of Bath was the first to translate **Euclid's Elements in Latin**  
Adelard of Bath has introduced the word « **Algorismus** » in Latin after his translation of Al Khuwarizmi

# GSI MUSIC SIGNAGE JEAN CARTAN

Jean Cartan  
ou le génie décapité  
(Elie Cartan's son)



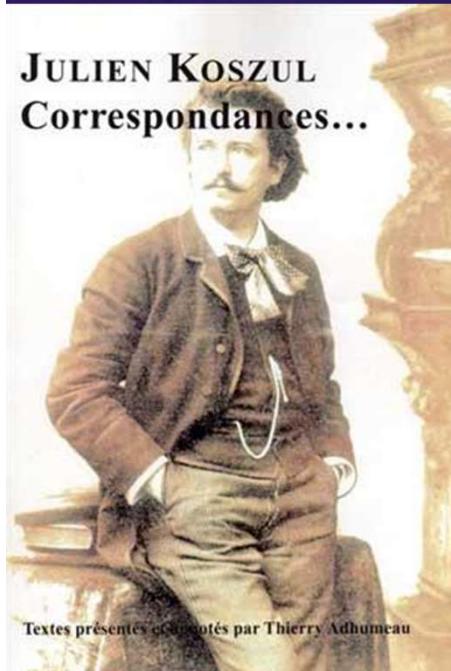
INTRODUCTION & ALLEGRO by JEAN CARTAN

<https://www.see.asso.fr/en/node/24148>



Julien Koszul => Albert Roussel => Jean Cartan

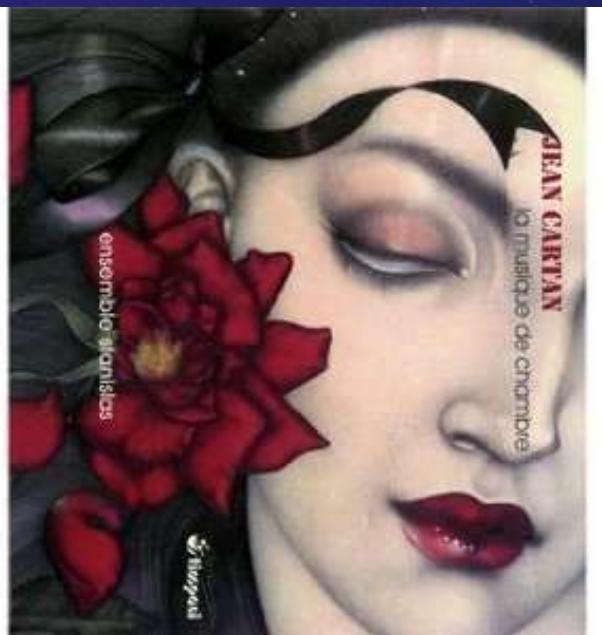
Albert Roussel studied harmony in Roubaix with **Julien Koszul**.  
Condisciple of **Olivier Messiaen** and **Maurice Duruflé**, the career of **Jean Cartan** is followed attentively by **Albert Roussel**.



Henri Dutilleux



Jean-Louis Koszul



"THE PIROUETTE: I who spin under the hand of another am safe neither in the evening nor in the morning because the one under whose hand I spin returns so suddenly that he waits neither today nor tomorrow."  
« LA PIROUETTE : moi qui tourne sous la main d'autrui je ne suis en sûreté ni le soir ni le matin car celui sous la main de qui je tourne s'en retourne si soudainement qu'il n'attend ni aujourd'hui ni demain" – Henri Baude, poète bourbonnais du 15<sup>ème</sup> siècle, dans « *Dictz moraulx pour faire tapisseries* »



Professeur de géométrie, XIV<sup>th</sup> s.  
Paris, BnF ms Français 574 f° 28 v°

### LA PIROVETE

« *le qui tourne soubz autrui main  
Nay seurete ne soir ne matin  
Car cil soubz quelle main ie tourne  
Si soudainement sen retourne  
Quil netent ne hui ne demain* »

Tapestry, Netherlands, early 16th century Wool and silk, Cluny Museum, which illustrates the sudden nature of life's hazards and dependence on fate

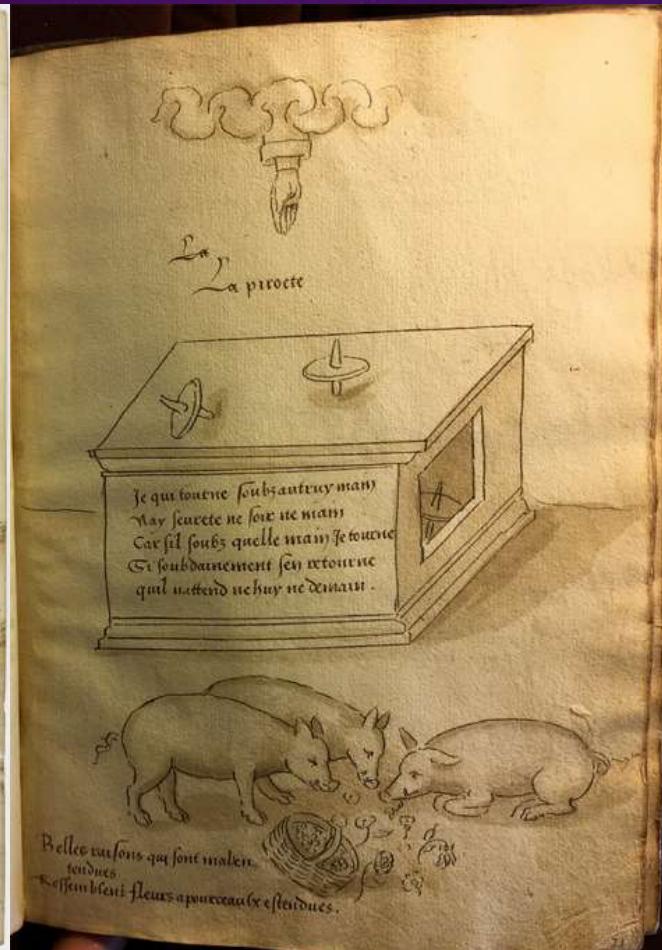
A hand emerging from the sky throws a top onto a table that resembles an altar or a tomb; on the tiles, three tops are depicted, one in motion, the other two motionless. The poem in Old French, placed against the wall of the table, evokes the uncertainty of destiny and human dependence, without any religious reference. These five verses are taken from a highly illustrated collection, *Dicx moraux pour faire tapisserie*, composed by the man of letters Henri Baude for a member of the court of the Dukes of Bourbon in the early years of the 16th century.



# ILLUSTRATIONS « DICTZ MORAULX POUR FAIRE TAPISSERIES »



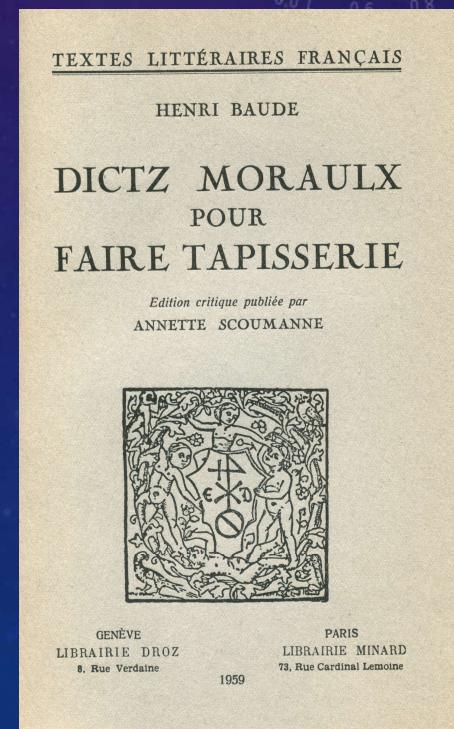
Paris, BnF, fr. 24461, f. 48r



Chantilly, Musée Condé, 509, f. 21r

Texte et image: les “Dictz moraulx” d’Henri Baude, Martina Crosio, Édition électronique, <https://journals.openedition.org/studifrancesi/41726>

Amandine Mussou, « Rotations dérisoires ?  
Toupies, sabots et pirouettes (XIIIe-XVe  
siècles) », *Bien Dire et Bien Aprandre*, 39 |  
2024, 103-126.



TEXTES LITTÉRAIRES FRANÇAIS

HENRI BAUDE

DICTZ MORAULX  
POUR  
FAIRE TAPISSERIE

*Edition critique publiée par*  
ANNETTE SCOUMANNE



GENÈVE  
LIBRAIRIE DROZ  
8, Rue Verdaine

PARIS  
LIBRAIRIE MINARD  
73, Rue Cardinal Lemoine  
1959

ENJOY GSI'25



**« There is nothing more in physical theories than symmetry groups except the mathematical construction which allows precisely to show that there is nothing more » - Jean-Marie Souriau**



# ENJOY SAINT-MALO & FRENCH BRITTANY



Saint-Malo



Dinard



Mont Saint-Michel

# Pierre Louis Moreau de Maupertuis, King's Musketeer Lieutenant of Science and Son of Saint-Malo Corsaire



Pierre Louis Moreau de  
Maupertuis



French surveyor and mathematician, working to  
measure the terrestrial meridian in Lapland

The rejection of the Newtonian approach, as well as the distrust of the Cartesian approach, lead Maupertuis to the elaboration of a cosmology different from both the finalism of some and the anti-finalism of others. It is a cosmology that cannot be attributed to any particular tradition, and that must rather be read as an independent and creative elaboration. All of Maupertuis' cosmology is based on a physical principle which he was the first to formulate, namely **the principle of least action**, the novelty of which he underlines on several occasions and generality.

7th International Conference on  
**GEOMETRIC SCIENCE OF INFORMATION**

**GSI'25**

**Saint-Malo, France**

**29th-31st of October 2025**