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Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi

Individual Projects 2020-2022

Bianca Letizia Cerchiai
**Dario Francia*
Alessio Marrani
Andrea Pallottini
Francesco Sylos Labini

Centro Fermi — December 11-12, 2019

Sugraphene

Bianca Letizia Cerchiai

(Enrico Fermi Ctr & Politecnico Torino)

Sugraphene: The Algebraic and Geometric Structure of Supergravity from black holes to condensed matter

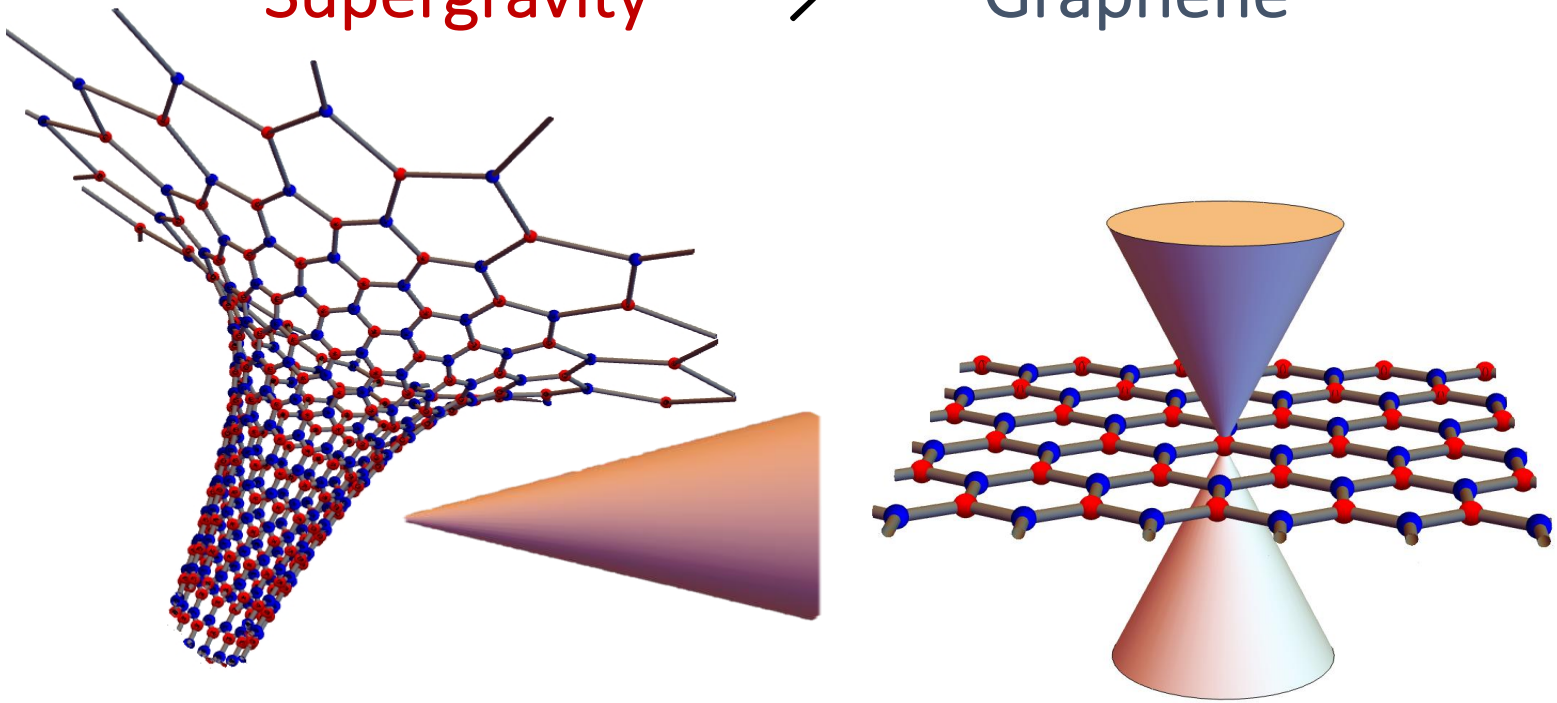
Grantee: Bianca Letizia Cerchiai

Work Institution: Politecnico di Torino, DISAT **Bando: 5(18)**

Scientific Supervisor: Mario Trigiante

Other members of the group: L. Andrianopoli, R. D'Auria, various postdocs and students

Supergravity → Graphene



Sugraphene: Objectives

Objective: Application of the dualities of supergravity to the study of graphene-like 2D materials in condensed matter.

- **The gauge/gravity correspondence relates a strongly coupled gauge theory to a weakly coupled classical gravity theory in one dimension higher.**

bulk — **boundary**

3+1-dim. Supergravity on an anti-de Sitter spacetime —**holography**→ **Electronic properties of a 2+1-dim. Layer of graphene**

- **Top-down approach: Large amout of supersymmetry makes model more predictive**

Relation of the electronic properties of graphene to deformations of the lattice geometry

- **Relevance of supersymmetry in low-energy physics** → **Interdisciplinary approach**

Sugraphene: Milestones

- **Holographic description of graphene starting from a supergravity theory with boundary on AdS_4**

2018/19: Reached 100% in [L. Andrianopoli, B.L. Cerchiai, R. D'Auria, M. Trigiante, JHEP 04 (2018) 007; L.Andrianopoli, B.L. Cerchiai, R. D'Auria, A. Gallerati, R. Noris, M. Trigiante, J. Zanelli, *N-Extended D=4 Supergravity, Unconventional SUSY and Graphene*, arXiv: 1910.03508, to appear in JHEP]

We have identified the supergravity solutions with a locally AdS_4 geometry and the correct asymptotic behaviour, so that they reproduce a model (AVZ) describing graphene-like materials [Alvarez, Valenzuela, Zanelli, JHEP 1204 (2012) 058] **in D=2+1. In collaboration with J. Zanelli, (CECs, Valdivia, Chile), we have extended the results to a system with more supersymmetries, including the K, K' valleys, and expressing the Haldane and Semenoff type masses of the graphene pseudoparticles in terms of the geometric properties of the supergravity theory in the bulk.**

- **Unconventional Gauge Fixing for Chern-Simons Supergravity**

2018/2019: Reached 90% in [L. Andrianopoli, B.L. Cerchiai, P.A. Grassi, M. Trigiante, *The Quantum Theory of Chern-Simons Supergravity,* JHEP 1906 (2019) 036, arXiv:1903.04431]

In a collaboration with UPO, we have started the embedding of our model in string theory, performing a BRST quantization, thus explaining the relation between the propagating spinor in the AVZ model and the supersymmetry parameter as a particular gauge fixing of a topological Chern-Simons theory.

2020: We want to study the inequivalence of this gauge fixing with respect to the standard gauge fixing of supersymmetry. This should provide an interpretation in terms of a topological twist.

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Sugraphene: Milestones

POLITECNICO DI TORINO

- **Holographic renormalization** [with L.Andrianopoli, R.D'Auria, R.Matrecano, O.Mišković, R.Noris, R.Olea, L.Ravera, M.Trigiante]

2020: We want to apply the holographic renormalization scheme to our AdS_4/graphene correspondence. In this framework the counterterms in the holographic renormalization should sum up to topological invariants.

- **Topological properties of the D=2+1 theory** [with L. Andrianopoli, R. D'Auria, O.Mišković, R. Olea, M. Trigiante]

2018/2019: Reached 70% : In collaboration with groups in Chile, we have identified the topological index, determining the conserved charge, related to the Nieh-Yan-Weyl symmetry.

2020: We now want to use it for the analysis of the topological properties of the 2D theory, particularly at the boundary of a 1+1 interface (boundary currents).

- **New supersymmetric self-dual M2-flux brane solutions of D=11 SUGRA with PSL(2,7) symmetry**

2018/19 Reached 100% in [B.L. Cerchiai, P. Fré, M. Trigiante, *The role of PSL(2,7) in M-theory: M2-branes, Englert equation and the septuples,* Fortsch. Phys. 67 (2019) 5, 1900020, arXiv:1812.11049]

In collaboration with UniTo we have constructed new M2-branes solutions with self-dual non-constant flux in the 8 transverse dimensions, which preserve different degrees of supersymmetry. This procedure is purely algebraic, as it is based on the symmetry of the model, described by the discrete group PSL(2,7).

Sugraphene: Publications, Conferences and Collaborations

Publications in 2019

1. **B.L. Cerchiai, P. Fré, M. Trigiante,** *The role of PSL(2,7) in M-theory: M2-branes, Englert equation and the septuples*, **Fortsch. Phys. 67 (2019) 5, 1900020, arXiv:1812.11049**
2. **L. Andrianopoli, B.L. Cerchiai, P.A. Grassi, M. Trigiante,** *The Quantum Theory of Chern-Simons Supergravity*, **JHEP 1906 (2019) 036, arXiv:1903.04431**
3. **L. Andrianopoli, B.L. Cerchiai, R. D'Auria, A. Gallerati, R. Noris, M. Trigiante, J. Zanelli,** *N-Extended D=4 Supergravity, Unconventional SUSY and Graphene*, **arXiv: 1910.03508, to appear in JHEP**

Conferences in 2019

1. **B.L. Cerchiai,** *Supergravity in a Pencil: From Supergravity to Graphene*, **Qspace 2019 Cost Meeting MP1405, Feb 2019, Comenius University Bratislava, Slovakia**
2. **B.L. Cerchiai,** *Supergraphity: From Supergravity to Graphene*, **Quantum structure of space-time Cost Workshop MP1405, Apr 2019, Bayrischzell, Germany**
3. **B.L. Cerchiai,** *N-Extended D = 4 Supergravity, Unconventional Supersymmetry and Graphene*, **SIF Congress, Sep 2019, Gran Sasso Science Institute**
4. **A. Gallerati,** *Graphene properties from curved space Dirac equation*, **European Graphene Forum, Oct 2019, Lisbon**
5. **B.L. Cerchiai,** *Supergraphity: Supergravity in a Pencil*, **ARC Italian-Russian Meeting, Dec 2019, Montecatini**

Collaborations

1. **Chile: Universidad Andrés Bello, Santiago; Universidad Católica de Valparaíso; CECs, Validivia**
2. **Italia: Università Piemonte Orientale, Alessandria; Università di Torino**

Higher spins and their symmetries

Dario Francia

(Enrico Fermi Ctr & Roma Tre U)

HIGHSPINS:
Higher spins & their symmetries

Dario Francia

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Particles are defined by symmetries

~

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Higher spins & their symmetries

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Particles are defined by symmetries

$\sim$

Elementary particles are labeled by two quantum numbers:

Mass $m \geq 0$

from translation invariance

Spin $s = 0,\ 1/2,\ 1,\ 3/2,\ 2,\ 5/2,\ 3,\ \ldots$

from rotation invariance

HIGHSPINS:
Higher spins & their symmetries

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no indications about the existence of ``preferred'' subset of values

HIGHSPINS:
Higher spins & their symmetries

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Pioneers of higher-spin theories:

Majorana 1932, Dirac 1936,
Fierz-Pauli 1939, Wigner 1939...

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Pioneers of higher-spin theories:

Majorana 1932, Dirac 1936,

Fierz-Pauli 1939, Wigner 1939...

TEORIA RELATIVISTICA DI PARTICELLE CON MOMENTO INTRINSECO ARBITRARIO

Nota di ETTORE MAJORANA

Sunto. - *L'autore stabilisce equazioni d'onda lineari nell'energia e relativisticamente invarianti per particelle aventi momento angolare intrinseco comunque prefissato.*

La teoria di DIRAC dell'elettrone fa uso, come è noto, di una funzione d'onda a quattro componenti delle quali, quando si considerino movimenti lenti, due hanno valori trascurabili mentre le altre due obbediscono in prima approssimazione all'equazione di SCHRÖDINGER.

In modo analogo una particella con momento angolare intrinseco $s\frac{h}{2\pi}\left(s = 0, \frac{1}{2}, 1, \frac{3}{2}, \ldots\right)$ è descritta nella meccanica quantistica mediante un complesso di $2s+1$ funzioni d'onda che soddisfano separatamente all'equazione di SCHRÖDINGER. Tale rappresentazione è naturalmente valida finchè si trascurano gli effetti relativistici

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Higher spins & their symmetries

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Main themes

1. Fundamental Symmetries

- Higher-spin symmetries: unifying framework for Yang-Mills and Gravitational theories, also conjectured to underlie String Theory

- Surprising connections between gluons and gravitons: Gravity = (Yang-Mills)^2 !!!

HIGHSPINS:
Higher spins & their symmetries

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II. Infrared physics

- IR physics: new inputs from old issues (asymptotic symmetries, soft theorems, and memory effects)

HIGHSPINS:
Higher spins & their symmetries

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Activity 2019

1. Fundamental Symmetries

- Asymptotic higher-spin algebras in D=4: possible link to their Anti-de Sitter counterparts
- Geometry of the Double Copy: understanding Gravity = (Yang-Mills)^2 beyond scattering amplitudes, at the Lagrangian level

HIGHSPINS:
Higher spins & their symmetries

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Activity 2019

I. Fundamental Symmetries

- Asymptotic higher-spin algebras in D=4: possible link to their Anti-de Sitter counterparts
- Geometry of the Double Copy: understanding Gravity = (Yang-Mills)^2 beyond scattering amplitudes, at the Lagrangian level

II. Infrared physics and locality

- Exploration of asymptotic symmetries and memory effects for Maxwell and Yang-Mills theories in any D

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Higher spins & their symmetries

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Milestones 2020

- Lagrangian formulation of Double-Copy systems both in the metric and in the Cartan-Weyl formulations of General Relativity

- Asymptotic symmetries for arbitrary spins in arbitrary dimensions

- Asymptotic higher-spin algebras in flat and (A)dS spacetimes and their connection to strings in the tensionless limit

The Double-Copy paradigm

Alessio Marrani

(Enrico Fermi Ctr & Padova U)

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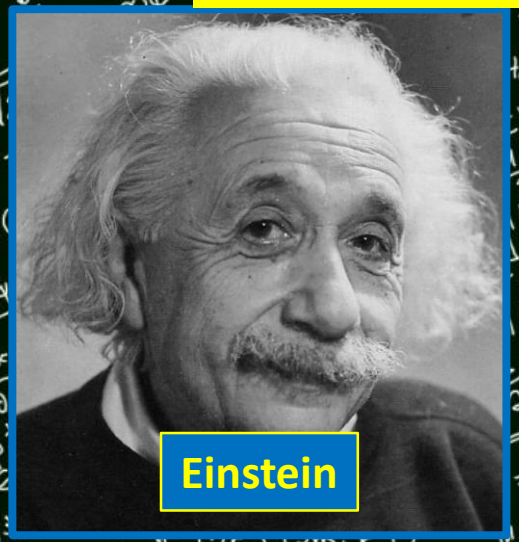
The Double Copy Paradigm

Grantee: **Alessio MARRANI**
Astronomy & Physics Dept, Padova, IT
Supervisor : **Prof. Gianguido Dall'Agata**

Strong nuclear, weak nuclear and electromagnetic forces are described by **gauge theories** gluons, W and Z bosons, and photons have **spin 1**

Gravitational force is described by **Einstein's General Relativity** gravitons have **spin 2**

But, maybe : (spin 2) = $(\text{spin } 1)^2$:



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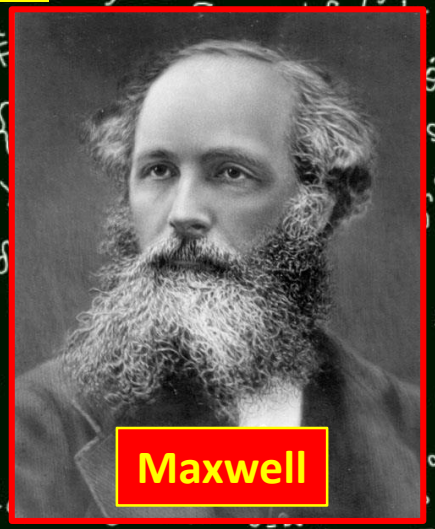

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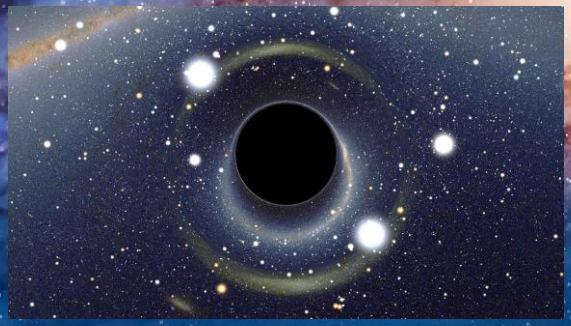
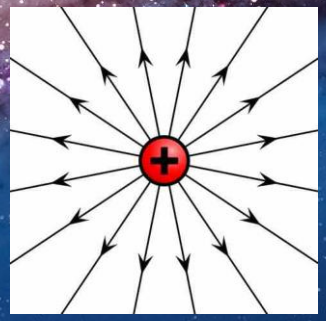
The Double Copy Paradigm

Wouldn't it be really cool if any classical solution of **General Relativity** were mapped to a **«double copy»** of a solution of a **gauge theory**?

Where to start? Obviously, from the coolest place : a **black hole**.





Can the **gravitational wave** spectrum from coalescing **black holes** be computed by a **«double copy»** ?

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The Double Copy Paradigm

Milestones obtained during the first year of Grant :

Through the double copy procedure :

1 : Construction of all supergravity models with homogeneous symmetries («sufficiently regular») from super-Yang-Mills theories (in ALL dimensions, and in particular in D=4)

Duff, AM et al., NPB934 (2018) 606

Duff, AM et al., Contemp. Math. 721 (2019) 1

2 : Construction of «twin» theories (same bosons, different fermions) for Conformal Field T

The First Time Ever! ***(this was believed to be not possible)***

Duff, AM et al., JHEP 1903 (2019) 112

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The Double Copy Paradigm

Perspectives / Tasks for the second year of Grant :

1 : Study of the Double Copy Structure within **conformal symmetry** and within **higher-spin field theories**
also in relation to the existence of supergravity in higher D's

2 : investigation of SUSY & non-SUSY vacua of maximal supergravity / M-theory through the double copy procedure :
can they be realized as the «double copy» of the vacua of gauge theories?

3 : can the «double copy» shed light on the existence of **«fermionic twins»** (same fermions, different bosons), in particular for massive theories?
[no examples known (yet!)]

CORTES

Andrea Pallottini

(Enrico Fermi Ctr & SNS)

A summary of CORTES:
Cosmological Radiative Transfer in Early Structures

Andrea Pallottini

In collaboration with:

A. Ferrara, M. Kohandel, T. K. D. Leung, S. Gallerani, L. Vallini, G. Ucci, D. Decataldo, S. Carniani, V. D'Odorico, C. Feruglio, C. Behrens, S. Bovino, K.P. Olsen, S. Salvadori

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SCUOLA NORMALE SUPERIORE

Studing galaxies in the Epoch of Reionization

which are the difference between galaxies in the Epoch of Reionization (EoR) and the ones in the local Universe, like our own Milky Way?

what is the impact of radiation in regulating the thermodynamics and chemistry of the interstellar medium of galaxies in the EoR?

how can we infer their properties with available and future observations?

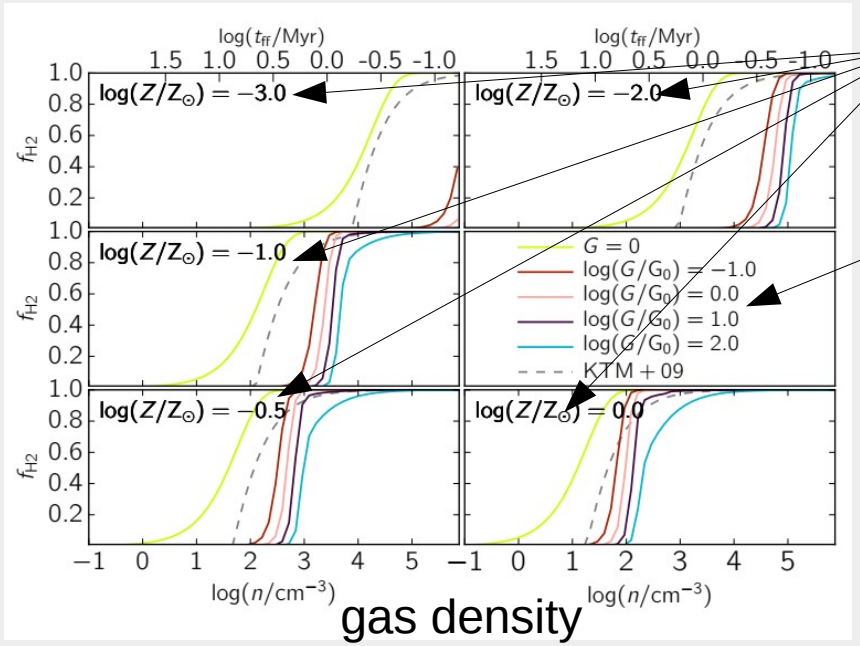
these questions can be addressed by developing and analysing cosmological zoom-in simulation with non-equilibrium chemical networks to form molecular hydrogen, turn it into stars, and tracking on the fly their radiation field to account for ionization of H and photodissociation of H_2.

carefull post-process of such simulations allow us to make line and continuum to be fairly compared with available telescopes and predictions for future facilities.

Althæa
Credit: A. Pallottini

The impact of chemistry

equilibrium vs non-equilibrium test

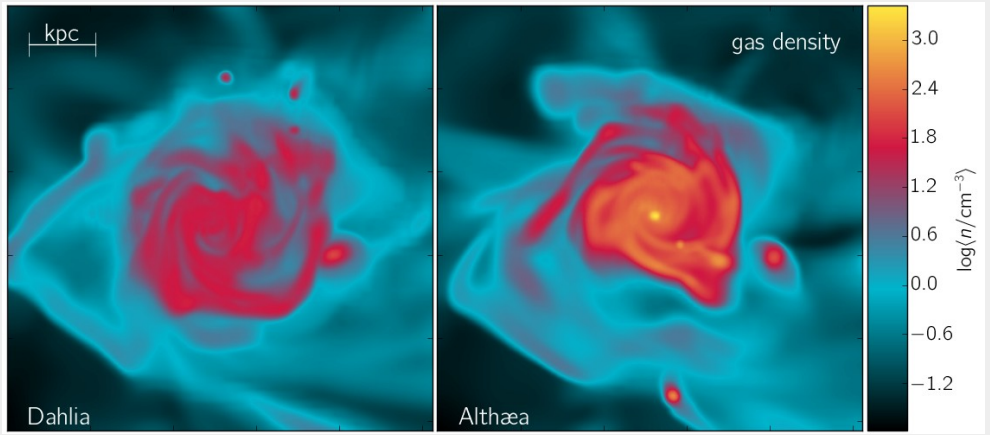


different heavy element content

intensity of the radiation field

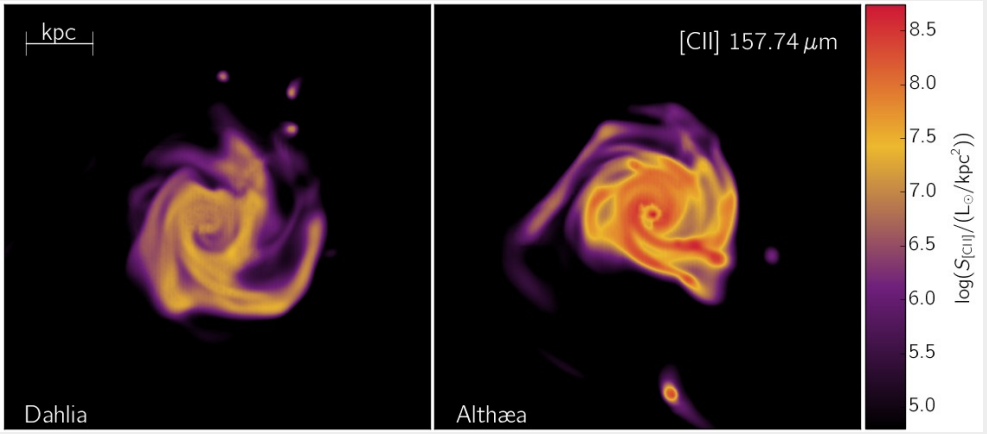
galaxy simulation with equilibrium model

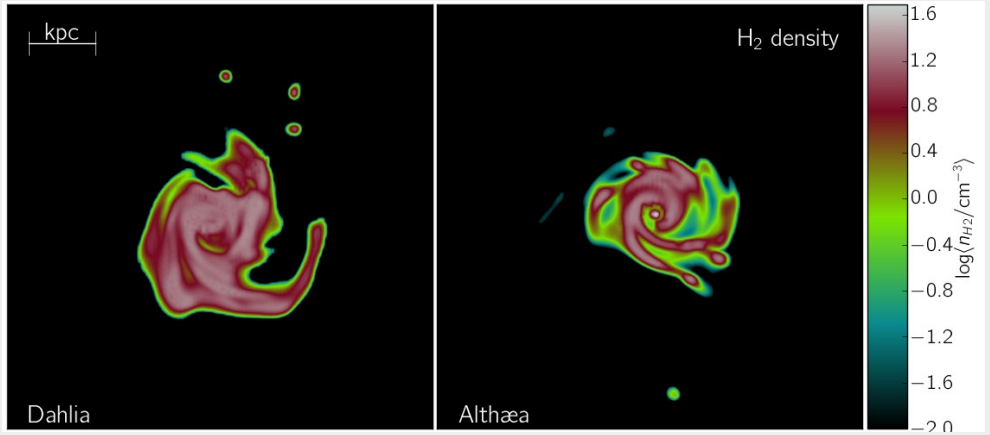
non-equilirium



proper chemical modelling does matter for emission line observations: factor 7 increase in luminosity of [CII]

Althæa is 7 times denser then Dahlia but has a lower (x4) molecular mass





mock line observations from simulated galaxies

Pallottini+17a,b, Vallini+18

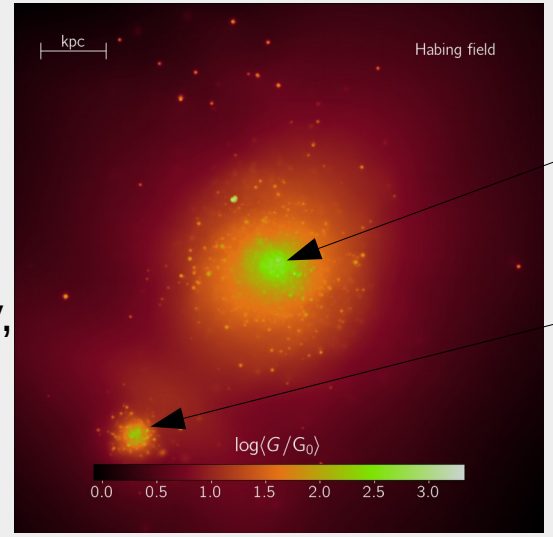
Radiative Transfer in Early Structures: Freesia

Ultra Violet radiation from stars

ionizing (hν>13.6 eV) radiation

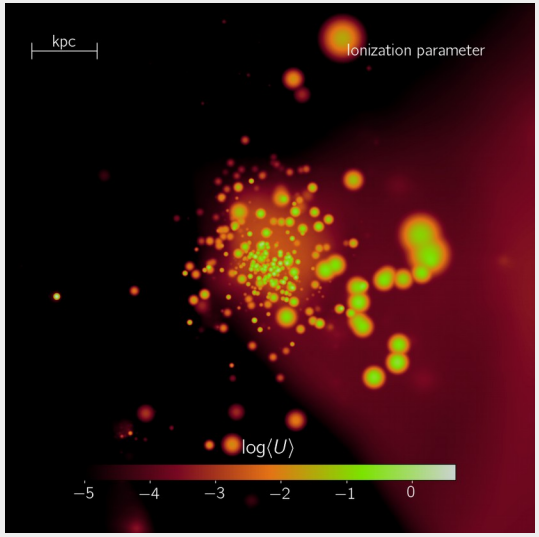
UV field rather omogeneous, with high intensity at the center stellar components

ionizing radiation very patchy, high dependence on the density field



Freesia$_a$

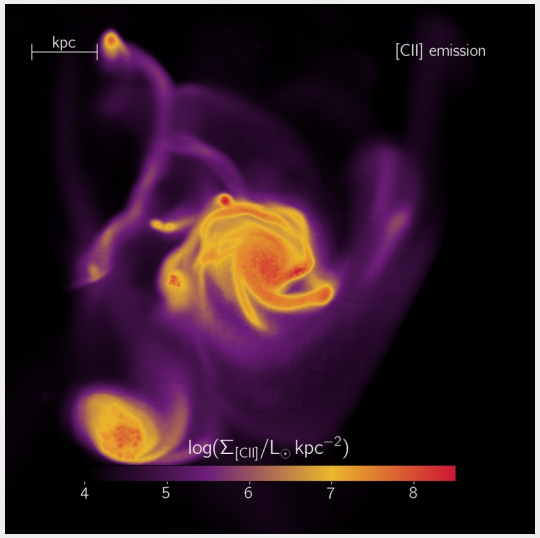
Freesia$_b$

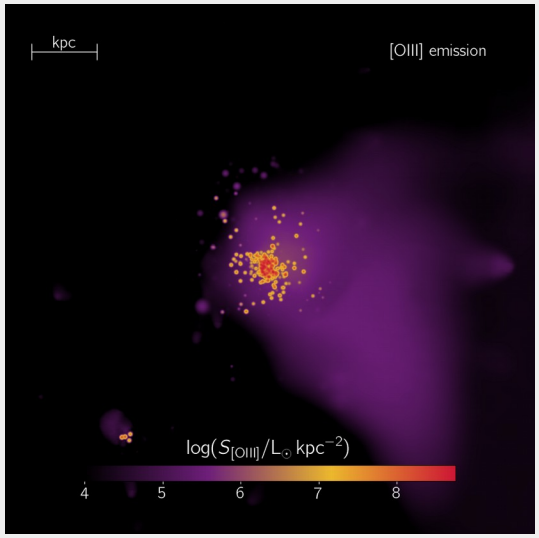


important to have observations of multiple lines from the same galaxy to better constrain models

[CII] traces dense molecular/neutral gas

[OIII] traces warm ionized gas





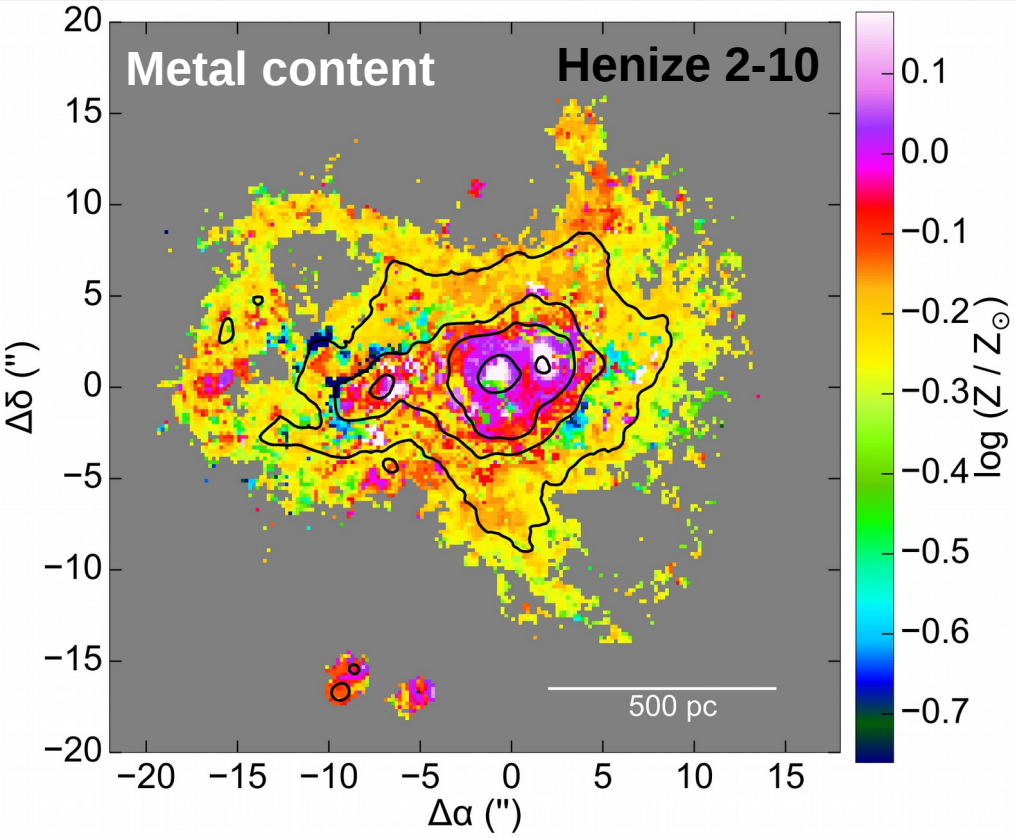
important to have multiple simulated galaxies to a have a fairer comparison

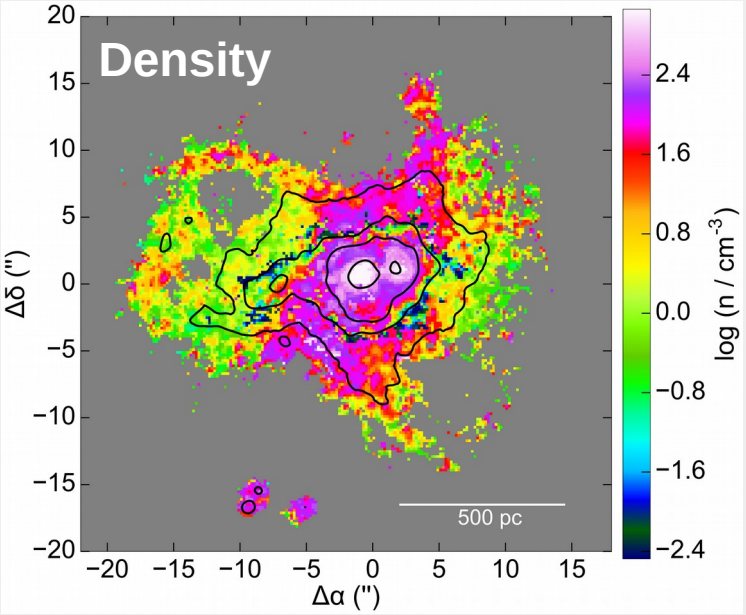
project, currently running at the CINECA

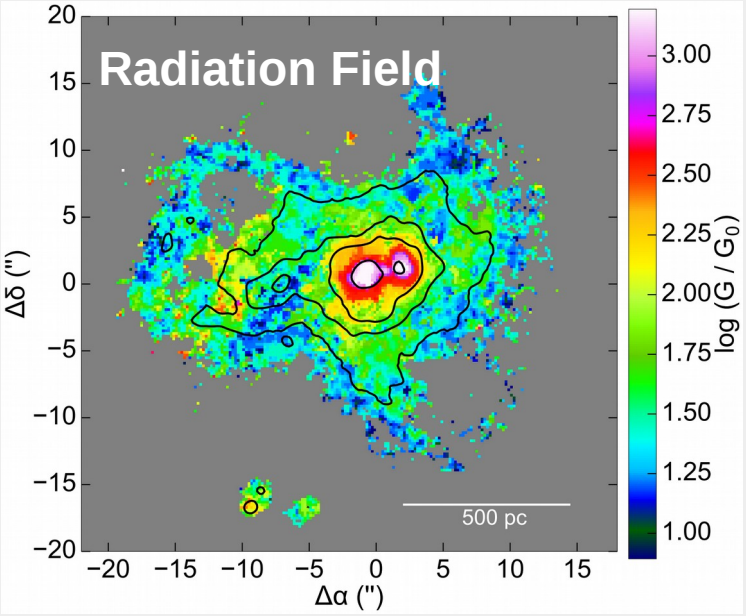
Pallottini+19, +20 in prep

Inferring galaxy properties a Machine Learning approach

Ucci+18,+19







from line observations of a local galaxy
to its physical properties via a ML approach
based on a library of emission line models

in preparation for JWST, that will allow for the same kind of analisys on early galaxies

Out-of-equilibrium gravitational dynamics

Francesco Sylos Labini

(Enrico Fermi Ctr & ISC - CNR)

Out-of-equilibrium gravitational dynamics

Francesco Sylos Labini

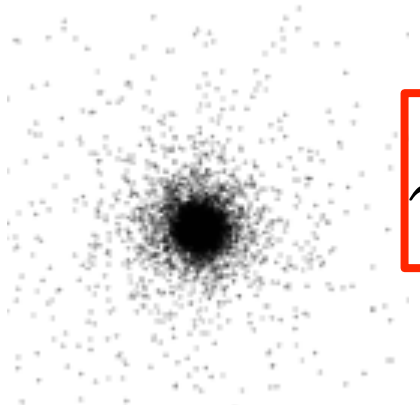
- Institute for Complex Systems, CNR (Rome, Italy)

- Enrico Fermi Center (Rome, Italy)

Self Gravitating systems

IC: out of equilibrium system

Violent relaxation: global collapse, mean-field dynamics, collisionless physics



$$\tau_D \sim \sqrt{G\rho}^{-1}$$

Quasi stationary state (virial equilibrium)

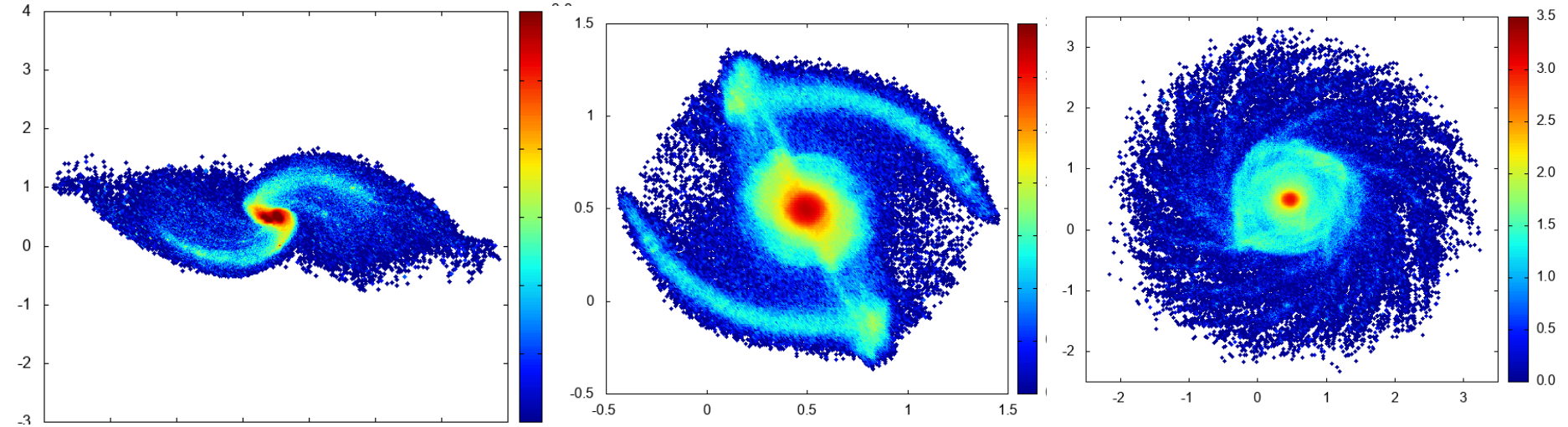
Questions

- Is collisionless relaxation really so **fast** ?
- Does the **whole** system relax at the **same** time?
- Is there **anything else** going on?

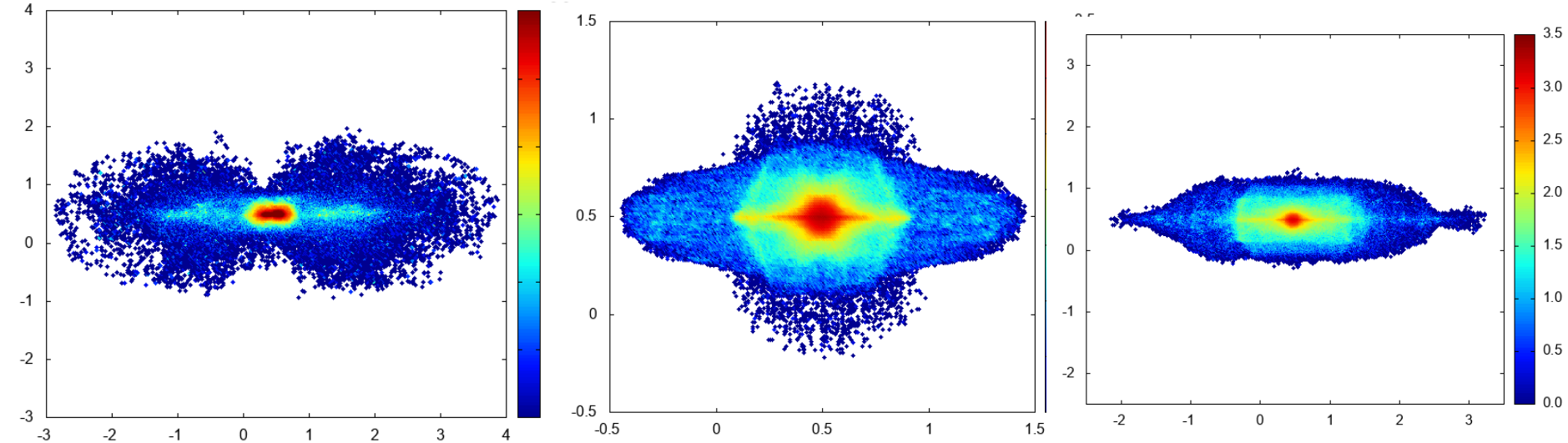
If the system is initially :

- Isolated and out of equilibrium
- Uniform enough
- With a non-zero angular momentum

Formation of a quasi stationary state (thick rotating disk) + out of equilibrium structures like spiral arms, bars rings etc.



Projection of the XY plane (rotation along Z)

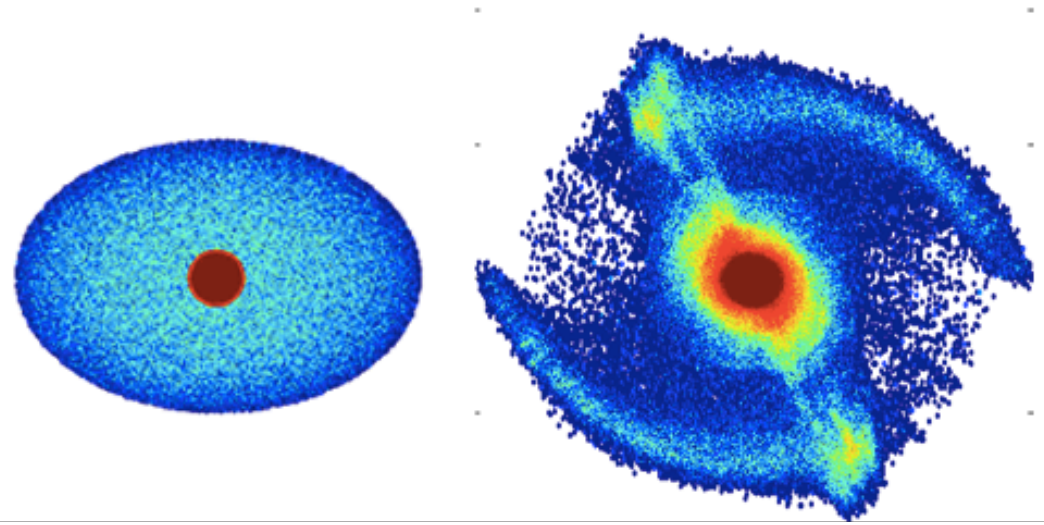


Projection of the XZ plane

Synopsis: Galactic Spirals May Form Spontaneously

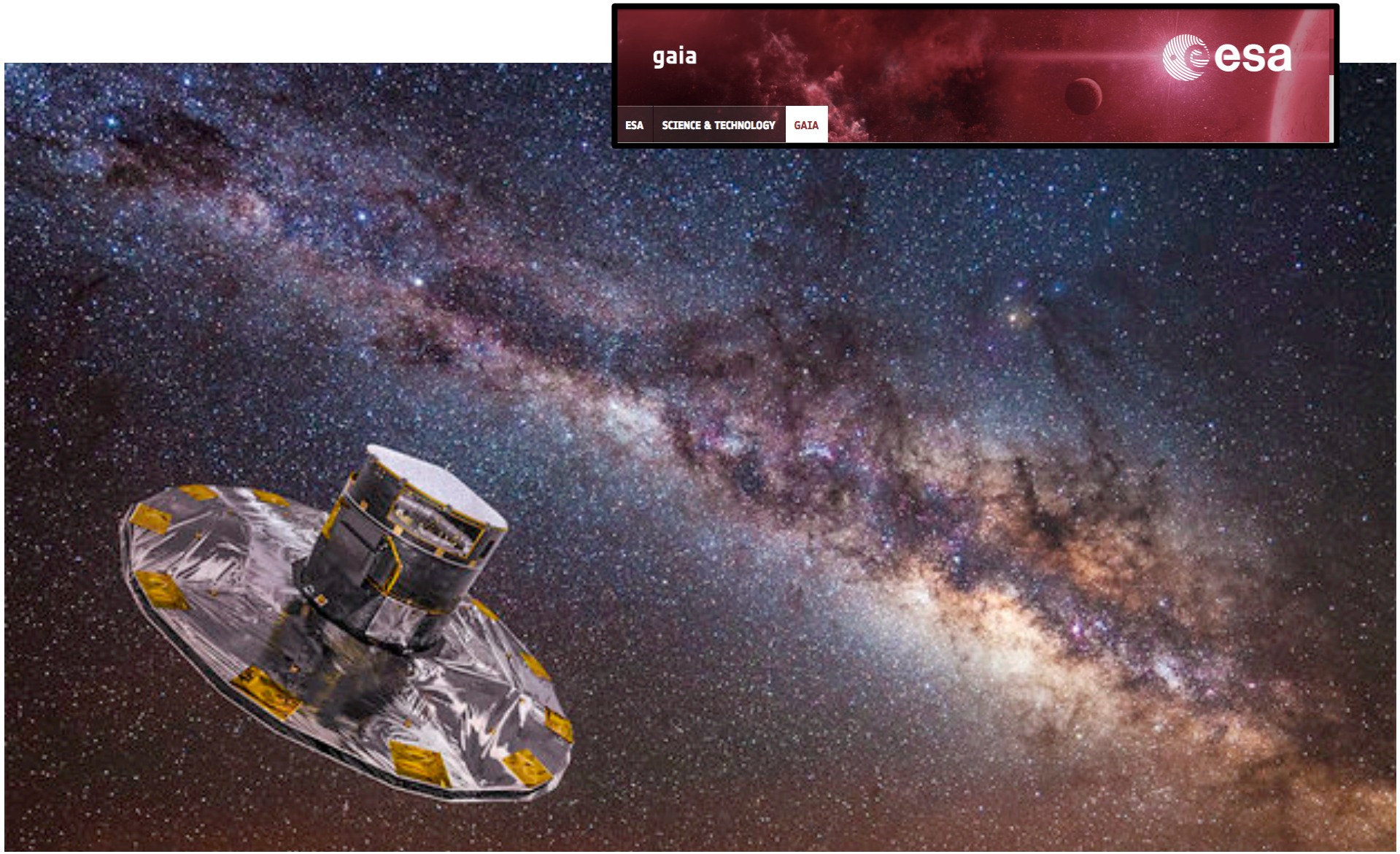
February 14, 2019

Spiral galaxies could be transient, nonequilibrium structures originating from the collapse of clouds of matter interacting solely through self-gravity.



Key feature of the non-equilibrium phase: presence of radial motions

Are there radial motions in our galaxy? The answer will be provided by



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Gaia-DR2 extended kinematical maps★

I. Method and application

M. López-Corredoira[1,2] and F. Sylos Labini[3,4,5]