

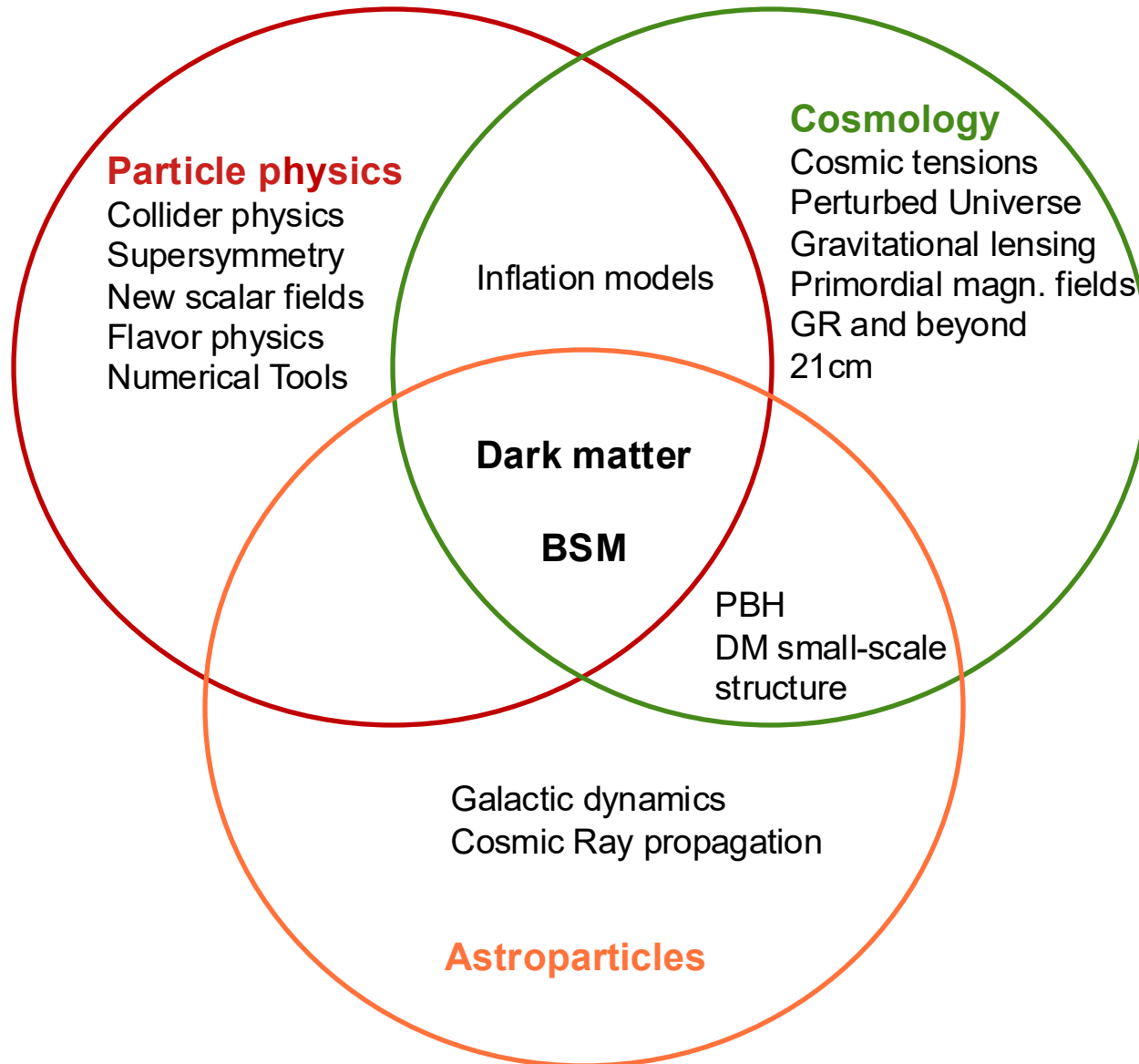
Laboratoire Univers et Particules de Montpellier

# **Team Particles, Astroparticles et Cosmology : Theory**

**(PACT)**



# Scientific themes





# Methodology

The PACT team members are [theorists](#) and [phenomenologists](#), their main tools are

- Pen-and-paper and symbolic (Mathematica,...) computations
- Numerical codes (Fortran, C++, Python)
- Bayesian analyses: Numerical parameter scans, MCMC
- $N$ -body simulations

# Permanent members today



Felix Brümmer (MCF)  
Cyril Hugonie (MCF)  
Julien Larena (MCF)  
Denis Puy (PR)



Pierre Fleury (CR)  
Karsten Jedamzik (CR)  
Gilbert Moulaka (CR)  
Julien Lavallo (DR)  
Vivian Poulin (CR)  
Théo Simon (CR)

Main activity: particle physics, astroparticles, cosmology

# Non-permanent members today

## Emeriti (3)

Michel Capdequi-Peyranère, MCF emeritus

Pierre Grangé, DR emeritus

Stephan Narison, DR emeritus

## Postdocs (3)

Thomas Montandon, ERC NewRecords 2023-26

Giacomo Queirolo, ANR ELROND 2024-26

Elsa Teixeira, ERC NewRecords, 2024-26

## PhD students (6)

Théodore Fischer, UM, Felix Brümmer w/ Michele Frigerio@LPTHE, 2024-27

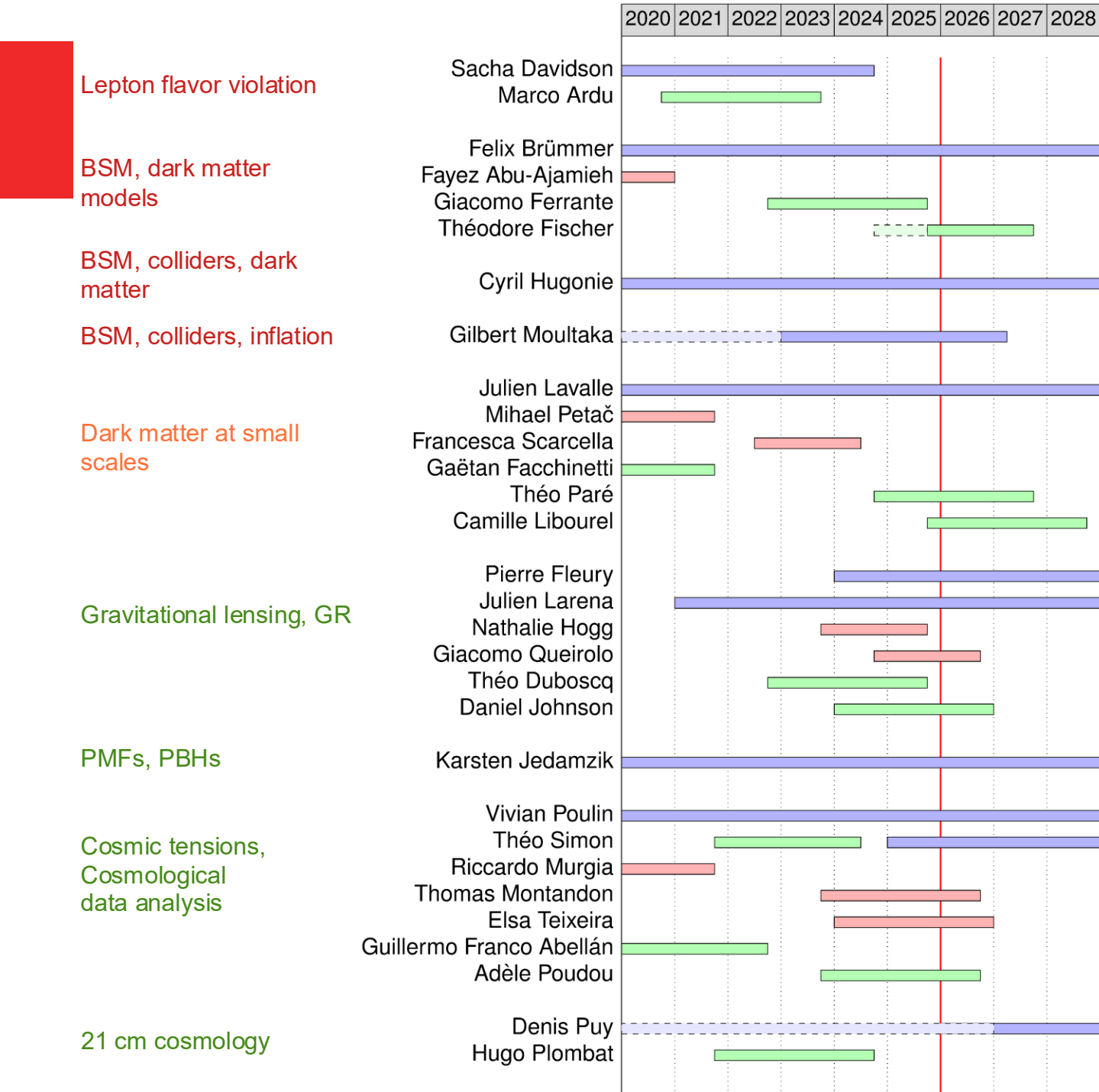
Daniel Johnson, FirstRand (ZA), Pierre Fleury & Julien Larena, 2024-27

Camille Libourel, UM, Julien Larena & Julien Laval, 2025-28

Théo Paré, UM, Julien Laval, 2024-27

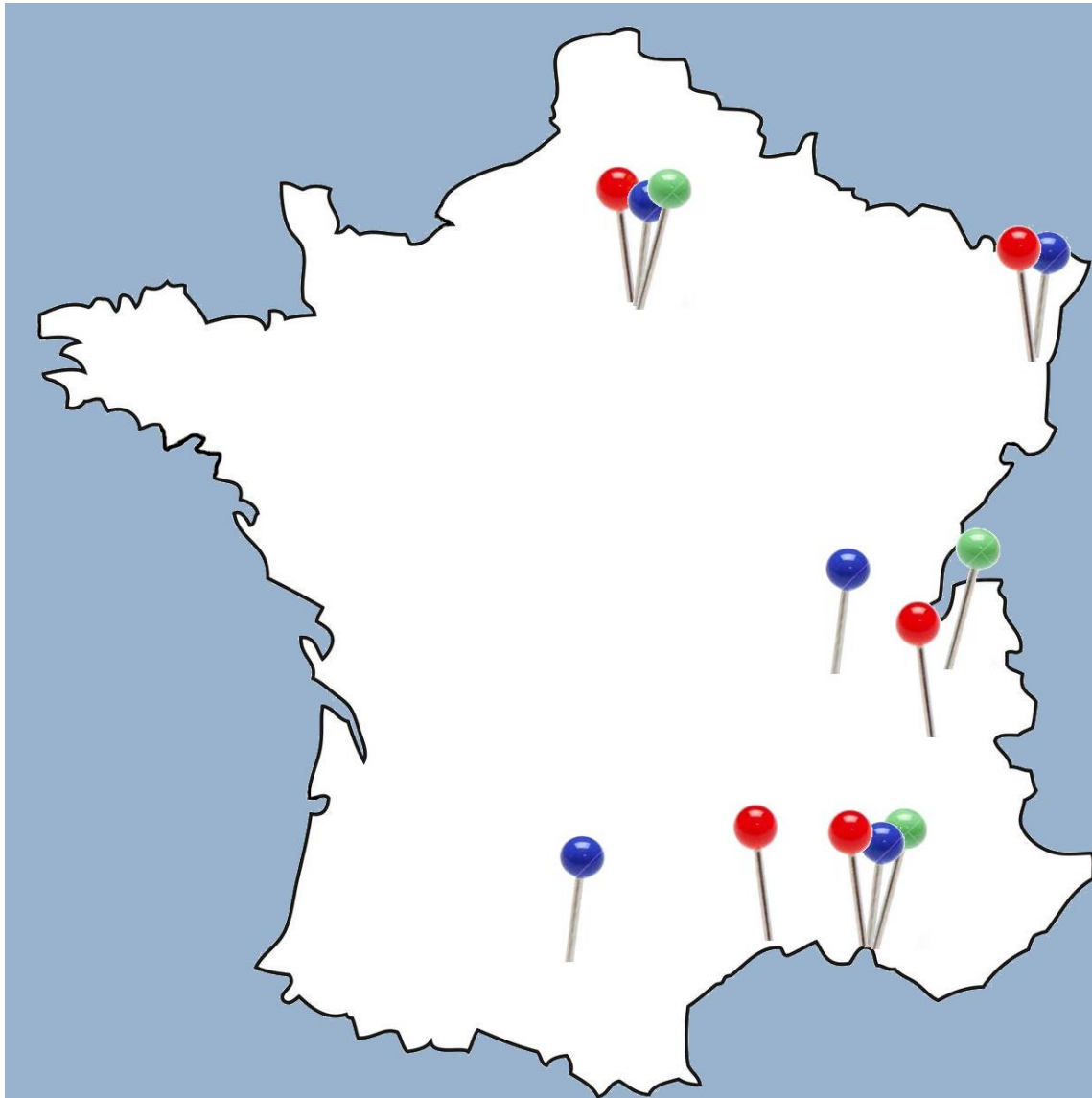
Adèle Poudou, ERC, Vivian Poulin, 2023-26

Yannick Tanguy, Denis Puy



permanents,  
 postdocs,  
 students

# Collaborations in France



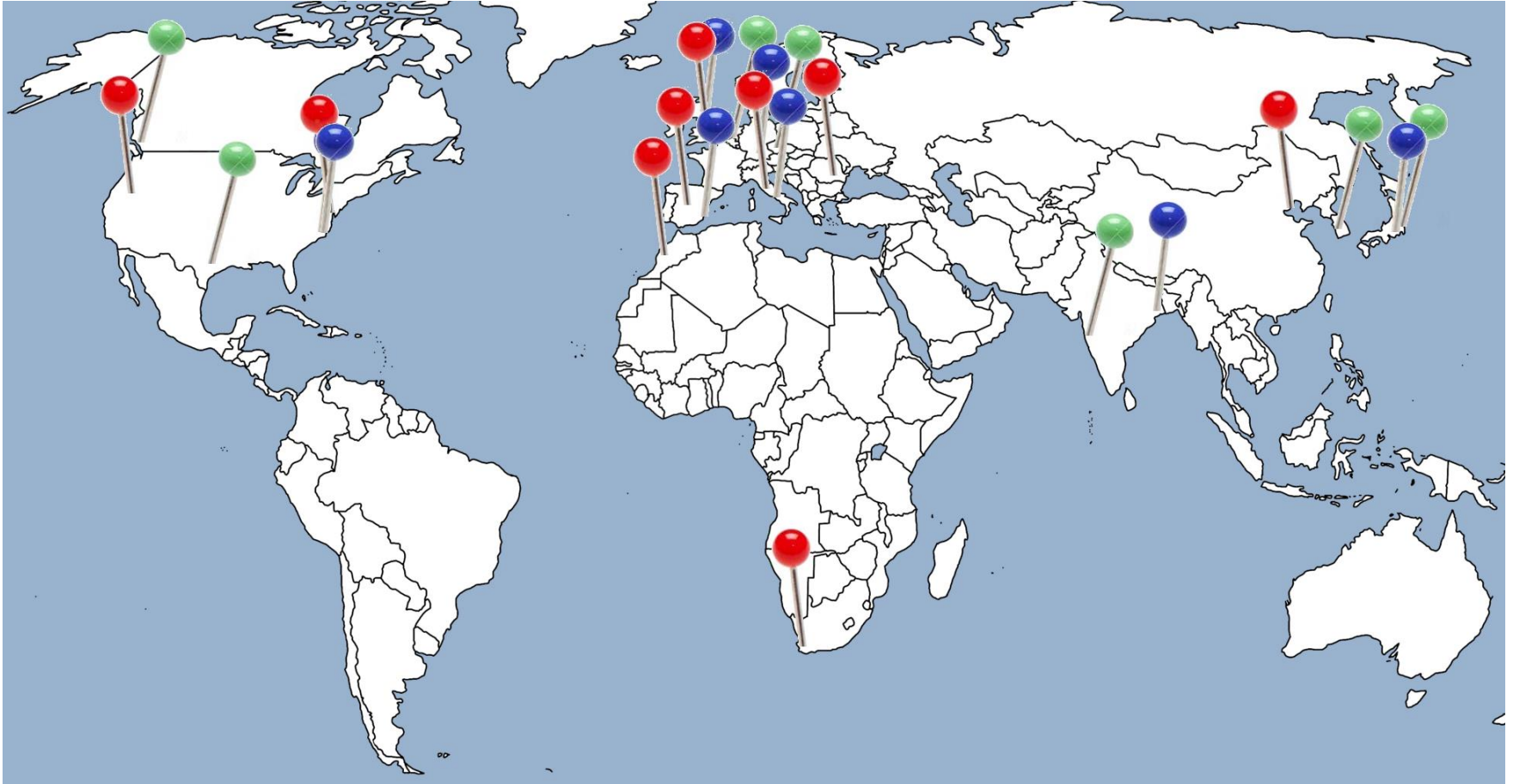
APC Paris  
IAP Paris  
LPTHE Paris  
IJCLab Orsay  
IPhT Saclay

ObAS Strasbourg  
IPHC Strasbourg

LAPTh Annecy  
IP2I Lyon  
LPSC Grenoble

IRAP Toulouse  
L2C Montpellier  
CPT Marseille  
CPPM Marseille  
LAM Marseille

# Collaborations worldwide



- Active visitor's program with several high-profile researchers
- More than 20 seminars / year



# Projects overview



European Research Council  
Established by the European Commission

## Major projects with third-party funding (details below):

- [ERC starting grant "NewRecords"](#), 2023-2027, PI Vivian Poulin  
(New crisis and old mysteries: Resolving cosmic tensions to reveal the dark sector)
- [ANR "GaDaMa"](#), 2018-2022, PI Julien Laval  
(Galactic Dark Matter)
- [ANR "ELROND"](#), 2023-2027, PI Pierre Fleury  
(Einstein Lensing Rings to Observe the Non-baryonic matter Distribution)
- [ANR "Cosmag"](#), 2025-2029, co-PI Karsten Jedamzik  
(Search for Cosmological Magnetic Fields)

# Teaching

**PACT members are involved in [academic teaching](#) at several levels:**

- In the [physics bachelor](#) (licence de physique) at Montpellier University: Felix Brümmer, Cyril Hugonie, Julien Larena
- In the [physics master](#), in particular in the master "[Cosmos, Champs et Particules](#)": the above + Sacha Davidson, Julien Laval, Vivian Poulin
- Undergraduate [internship projects](#) (stages L3, M1 et M2) are regularly supervised by PACT members
- At the graduate level, several PACT members have taught at [Collège Doctoral](#) and [summer schools](#): Les Houches, VSOP, NBI Neutrino school
- [Academic administration](#): Cyril Hugonie is co-coordinator of the physics master studies at Montpellier University. Julien Larena is vice-director of the Physics Department and coordinator of the CCP master.

# PhD students

**10 PhD students** supervised 2019-2024

- Thesis ongoing: **3** (+ 2 who joined in 2025)
  - Graduated before 2025: **5**
  - Graduated by now: **2** more
- postdocs: **5**, permanent staff: **1**, left physics: **1**

## Funding

UM doctoral school I2S: **4** scholarships

CNRS/IN2P3: **3** scholarships

ERC/ENS/other: **1** scholarship each



# Collective duties

## Workshop and conferences

- Lensing workshop in Montpellier (bi-annual)
- News from the Dark (annual)
- PONT conference (tri-annual)
- GDR CoPhy "task force" meetings
- Théorie, Univers et Gravitation (annual)

## Management duties

- GDR CoPhy steering committee
- IRN Terascale scientific management committee
- CosmoVerse COST action (French representative & WG leader)
- Festival d'Astronomie de Fleurance steering committee
- École de Gif

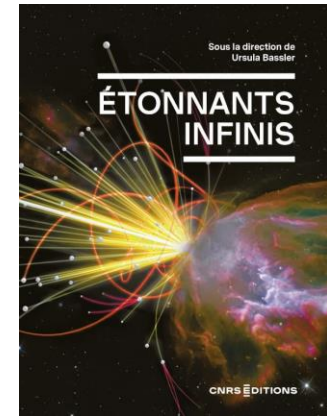
## Other duties

- Examiners at Polytechnique and ENS
- Editor an GRG and then Open Journal of Astrophysics
- Jury member of Prix Thibaud de l'Académie des Sciences, Belles-Lettres et Arts de Lyon

# Publication statistics, prizes, honours

- **CNRS Bronze Medal** (V. Poulin)
- **Jacques Herbrand Prize of the SFP** (V. Poulin) for his "Original results proposing a model to explain previously unexplained measurements of the Universe's expansion rate."
- **Buchalter Cosmology Prize** (K. Jedamzik) for their paper "Relieving the Hubble tension with primordial magnetic fields"
- Overall **> 100** articles published in peer-reviewed journals during the reference period

# Outreach



- Contribution to the CNRS book *Étonnants infinis*
- Translation of *Cosmology's Century* by J. Peebles
- Radio appearances (France Culture, France Bleu)
- Popular science articles (*CERN Courier*, *Pour la Science*)
- Interviews (*Le Monde*, *Midi Libre*, *Ciel & Espace*, *Epsilon*, *Sky&Telescope...*)
- Participation in the Festival d'Astronomie de Fleurance
- Outreach talks in high schools, planetaria, Université du Tiers Temps, MJC, elementary schools etc.
- Courses at Université du Tiers Temps
- Invited course at Collège de France

COSMOLOGIE  
MODERNE  
Origine, nature et évolution de l'Univers:  
époque de l'enfance et de l'âge adulte



# Cosmology in PACT

## Fundamental questions

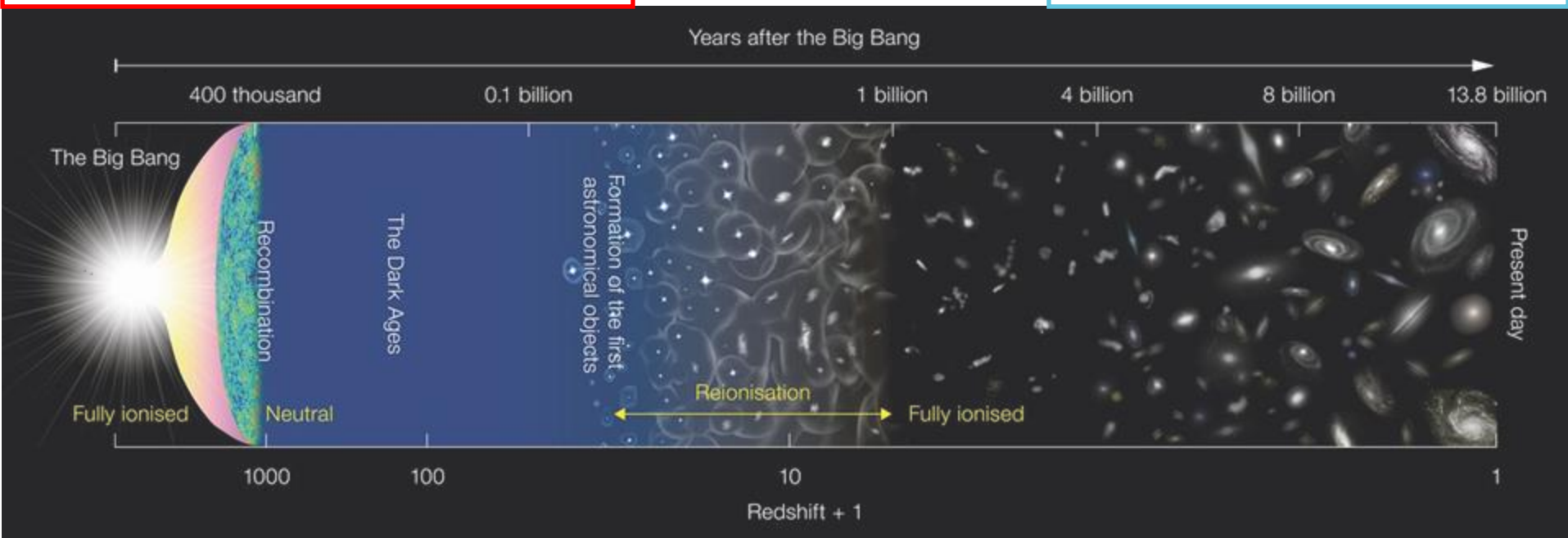
- Dark matter and dark energy
- General relativity and modified gravity
- Cosmological principle
- Cosmic Tensions
- Primordial black holes & magnetic fields

our identity



## Observational probes

- Cosmic Microwave Background
- Baryon Acoustic Oscillations
- Type Ia supernovae
- Large-scale structure
- Gravitational lensing



## Theoretical and data-analysis tools

- Cosmological perturbation theory
- Effective field theory of large-scale structure
- N-point correlation functions
- Weak gravitational lensing

## Collaborations and data

- *Euclid*
- DESI
- SKA
- TDCOSMO

# Cosmic Tensions

The  $\Lambda$ CDM model calibrated on CMB data faces several observational challenges:

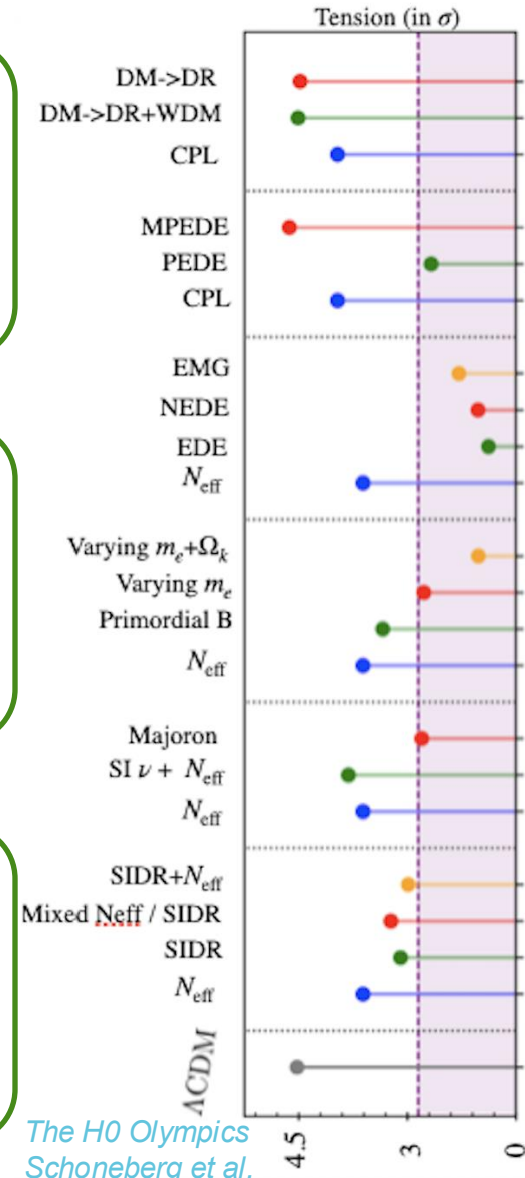
- The inferred value of the Hubble parameter  $H_0$  is too low
- The amplitude of matter fluctuations on 8 Mpc scales,  $\sigma_8$ , is too high
- DESI and Type Ia supernova data favor a dynamical dark energy component

The team is highly active on cosmological tensions and enjoys strong international visibility:

- Early dark energy (>1000 citations)
- Primordial magnetic fields (>300 citations)
- Unstable dark matter (>150 citations)
- Review on cosmological tensions (>500 citations)

The team is supported by ANR and ERC funding on this topic:

- **ERC Starting Grant “NewRecords”:**  
Vivian Poulin (PI), Thomas Montandon and Elsa Teixeira (postdocs), Adèle Poudou (PhD student)
- **ANR “Cosmag” project:**  
Karsten Jedamzik (PI) + 1 postdoc (starting autumn 2026)



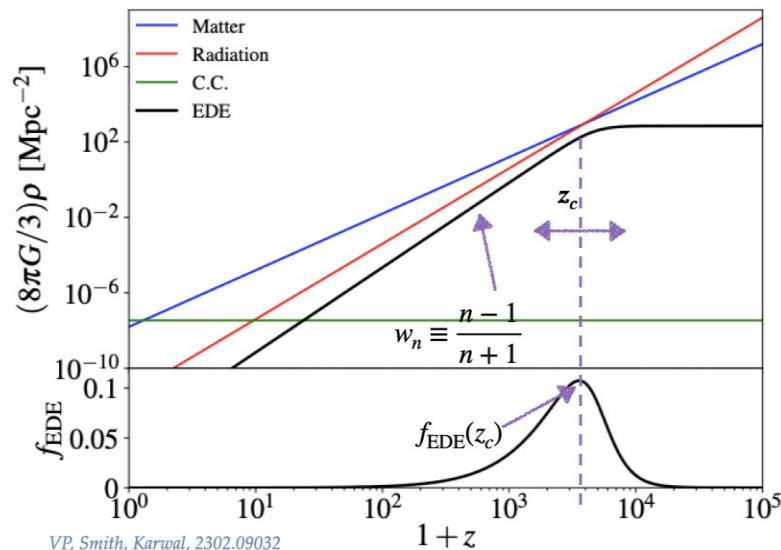


# Early Dark Energy

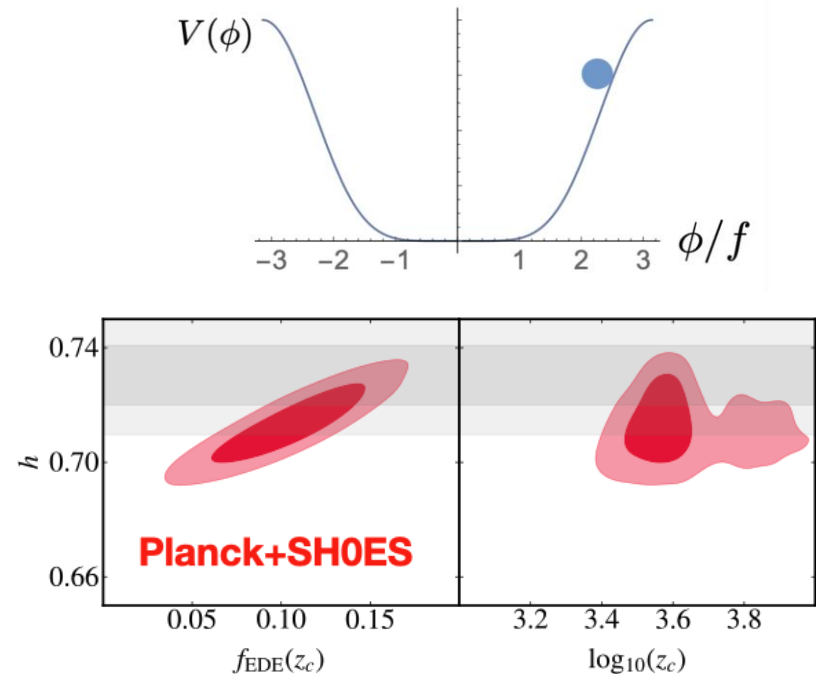
- A small **boost** in the pre-recombination **expansion history** triggered **by a scalar-field**

$$\ddot{\phi} + 3H\dot{\phi} + \frac{dV_n(\phi)}{d\phi} = 0$$

$$V_n(\phi) = m^2 f^2 [1 - \cos(\phi/f)]^n$$



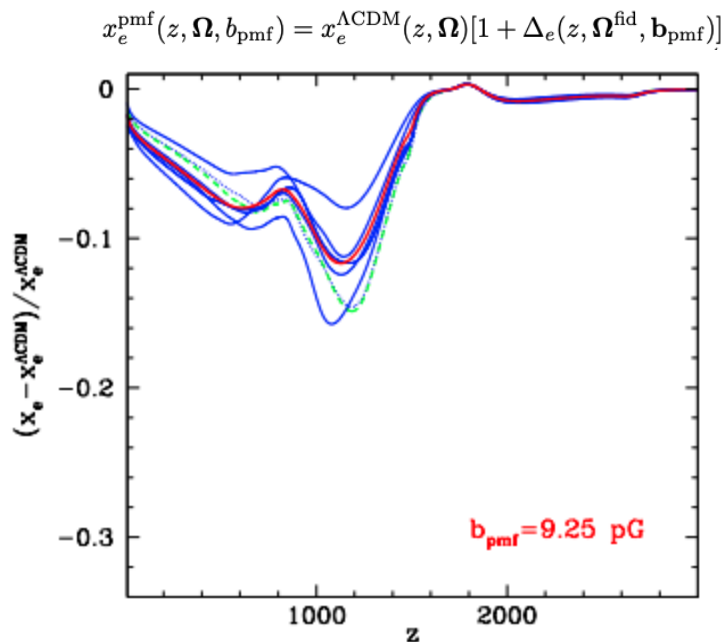
VP, Smith, Karwal, 2302.09032



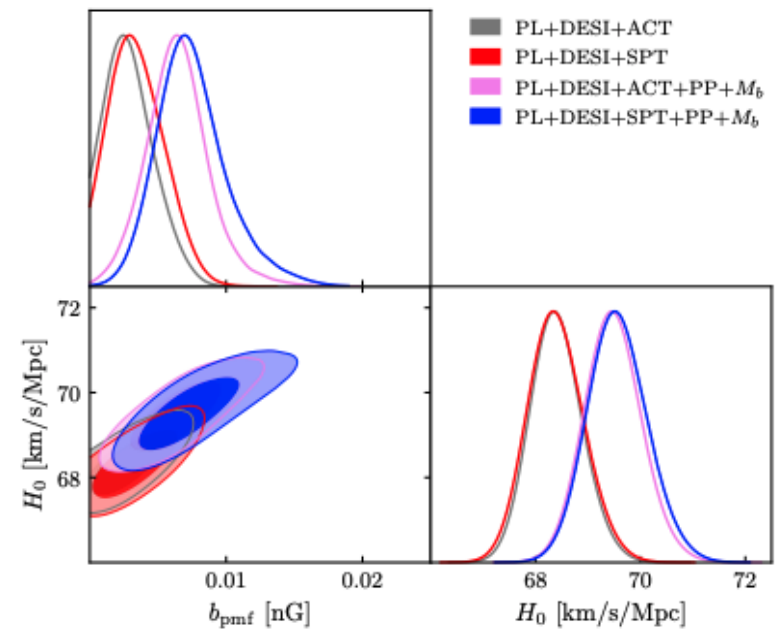
- 10% of EDE around  $z = 3500$**  can reduce the sound horizon and increase  $H_0$
- Test of EDE **against many datasets**: Planck, ACT, SPT ; DESI ; EFTofBOSS

# Primordial Magnetic Fields

- **Primordial Magnetic Fields** (PMFs) in the pre-recombination plasma would alter the free-electron fraction  $x_e(z)$ : this can reduce the sound horizon and **increase  $H_0$**
- Realistic **MHD simulations confirm** (and even improve) earlier results with toy models



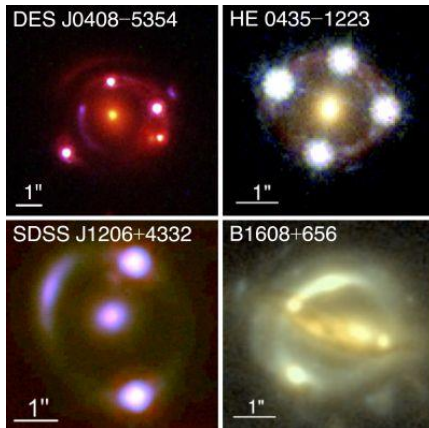
Results of different MHD simulations showing the deviation to  $x_e(z)$



# Gravitational lensing

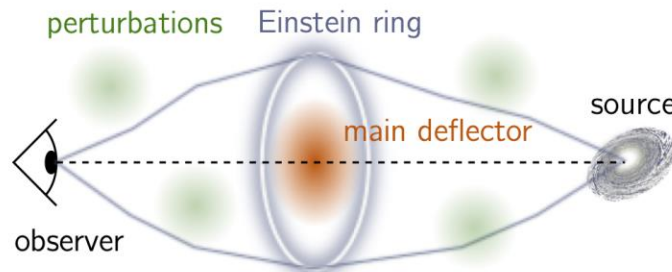
## Strong lensing

galactic dark matter,  $H_0$



## PACT lensing group

Weak lensing of strong lensing



*Fleury, Larena, Uzan (2021)*

- **Full theory** of line-of-sight (LOS) effects
- Discovery of the **LOS shear**

## Weak lensing

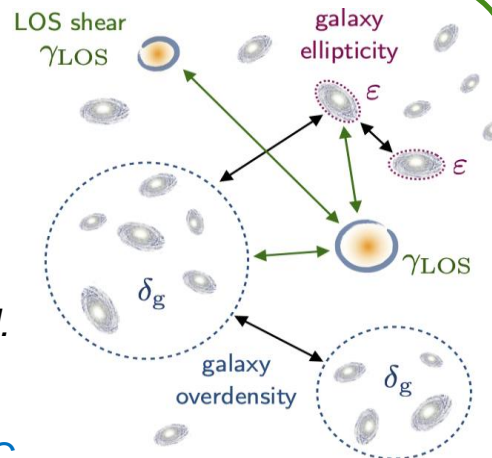
large-scale dark matter,  $\Omega_m$ ,  $\sigma_8$



## The ELROND project

Cosmology with LOS shear

- Proof of concept for measurability of LOS shear (Hogg et al. 2022)
- Cosmology forecasts for *Euclid*. (Duboscq et al. 2026, in prep.)
- Project supported by [ANR JCJC](#)



## But also...

- LOS effects for **TDCOSMO collaboration**
- Cosmology and dark matter with **double lenses**
- Bi-annual lensing workshop in Montpellier

# Theoretical and analysis tools

The PACT team develops new **theoretical tools and observables** to exploit cosmic probes:

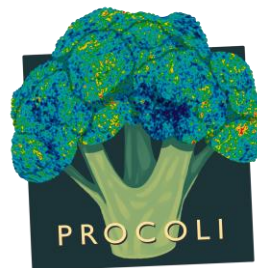
- Perturbation theory applied to beyond LambdaCDM / modified gravity models
- Effective-field theory of large-scale structures
- Galaxy power spectrum and bi-spectrum
- Line-of-sight shear from gravitational lensing

The PACT team **develops codes** to make **model predictions** and perform **statistical analyses**:

- Contribution to the CLASS and MontePython code for Bayesian analyses
- Development of the ProCoLi code: Profiling Cosmological Likelihoods
- Usage of N-body codes: gadget, gevolution
- Contribution to Lenstronomy



## LENSTRONOMY



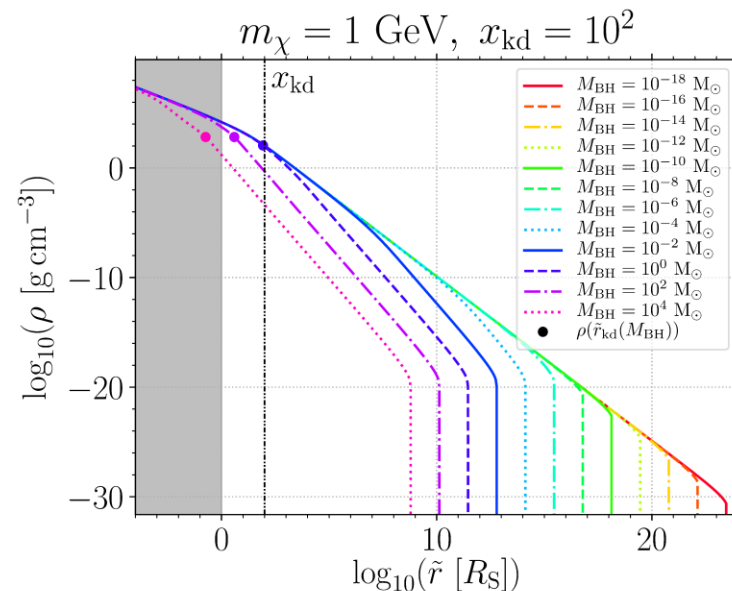
# Dark Matter & Primordial Black Holes

The nature and phenomenology of **dark matter** are central to many PACT research projects.

The structure of DM on subgalactic scales deeply correlates with its fundamental properties, which has triggered long-term interest and several studies.

For example, it is interesting to study scenarios where **particle dark matter** exists alongside **primordial black holes (PBHs)**.

**DM accumulates around PBHs** in radiation domination (<50kyrs after Big Bang) to form very **dense spikes**, whose shapes can be predicted (Boudaud+'21, incl. J. Laval + LAPTh+IFT).



Recent: If **particle DM** can self-annihilate, it is **mutually exclusive with PBHs** more massive than  $\sim 10^{-10}$  solar masses (Laval&Salati'25). Internal collab. ongoing (incl. V. Poulin). Other work on PBH microlensing in Petac, Laval, Jedamzik '22

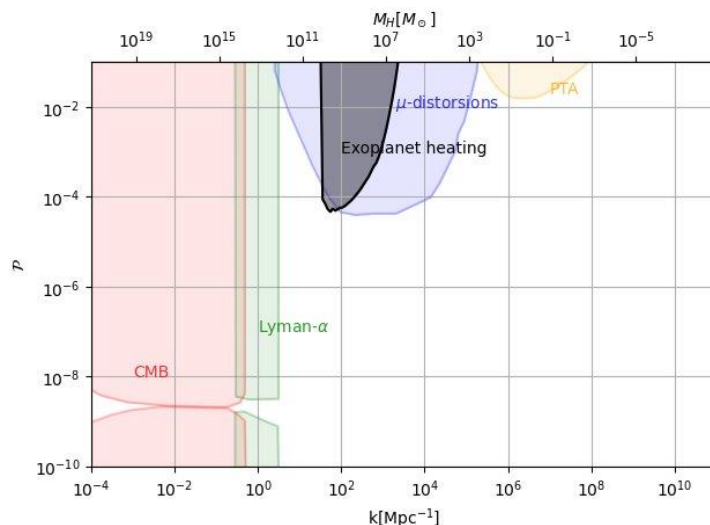
# DM on small scales and non-standard primordial power spectrum

The structure of DM on subgalactic scales also influences the [statistical properties of primordial density fluctuations](#), encoded in the primordial power spectrum

→ research program on [DM subhalo searches](#) to probe CDM signatures (e.g. Facchinetti, Lavalley+'22)

[Heating of baryonic systems](#) can also be used to gravitationally probe the DM substructure. Efficient for [ultra-compact-minihalos](#) (= failed PBHs), formed by distortions in the primordial power spectrum: use heating of MW galactic disk, or heating of exoplanetary systems

Constraints on the amplitude of the primordial power spectrum as function of wavenumber inferred from forbidden heating of exoplanetary systems by a population of UCMHs (Paré & Lavalley, in prep.)



Ongoing: PhD T. Paré (Lavalley) + PhD C. Libourel on PTA probes of DM substructure (Larena & Lavalley) + foreseen collab. with Jedamzik on PMFs.

# Particle physics in PACT: Overview

## Research themes:

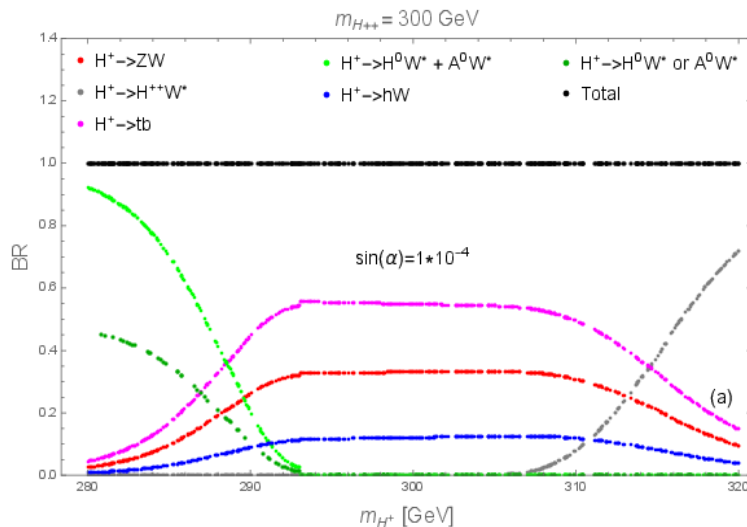
- Models beyond the Standard Model with extended scalar sectors
- Particle physics models for inflation
- Tools for supersymmetry (SuSpect and NMSSMTools)
- New physics at the LHC
- Lepton flavor violation
- QCD and formal QFT

# Particle physics in PACT: Extended scalar sectors

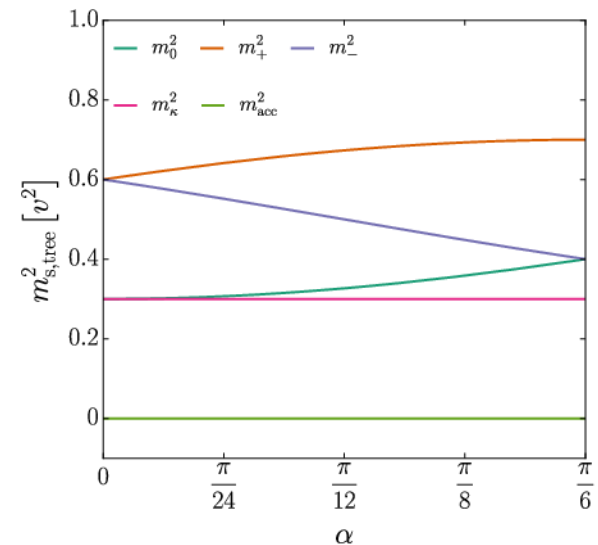
The SM Higgs boson is an example of an elementary scalar

Some extensions of the SM feature additional scalar fields: e.g. scalar superpartners in SUSY, extra Higgs doublets, Higgs triplets, SUSY singlets, accidentally light scalars

We have built models with extra scalars which could play a role in electroweak symmetry breaking and cosmology and studied their phenomenology



Decays of a triplet Higgs (Moultaka et al. '24)



Spectrum of a model with accidentally light scalars (Brümmer, Ferrante et al. '23)

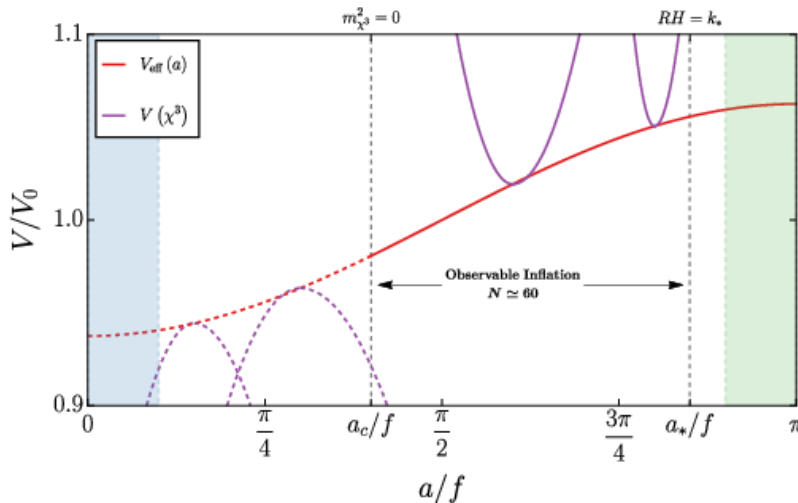


# Particle physics in PACT: Models for inflation

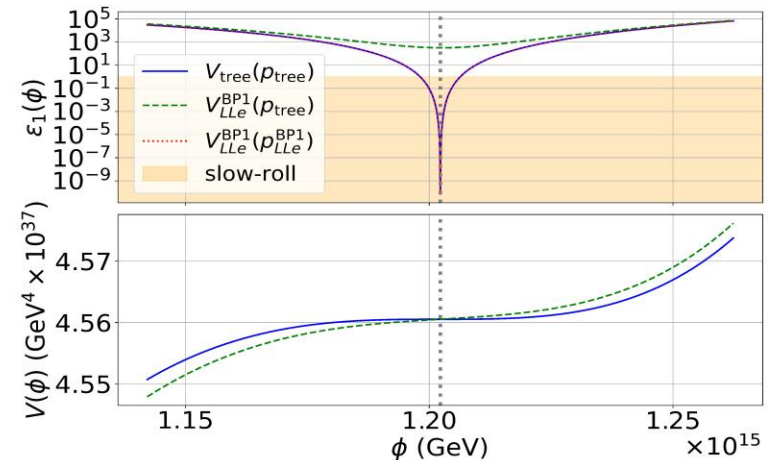
A field-theoretic model for (low-scale) **cosmic inflation** needs a **scalar field** with an almost-**flat potential**

Inflaton candidates:

- Supersymmetric scalars (e.g. **MSSM inflation**)
- Pseudo-Goldstone bosons ("natural inflation")
- New **accidentally light scalars**



Inflaton potential in a natural hybrid inflation model (Brümmer, Ferrante et al. '24)



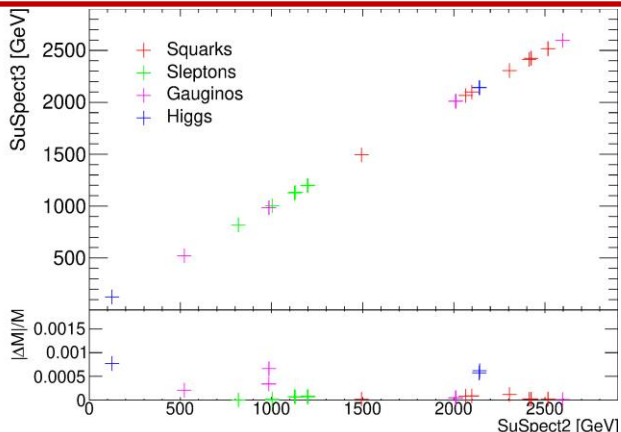
Inflaton potential in inflection-point MSSM inflation. Tree versus RGE (Weymann, Moulta et al. '23)

# Particle physics in PACT: Tools for supersymmetry

## SusySpectrum calculator

**SuSpect2,3** compute the Higgs and sparticle masses and couplings in the general and constrained MSSM, including radiative corrections and radiative EWSB. It relates physics at different scales: the (Grand Unified, SUSY breaking, Inflation) scale and the electroweak scale, **fixing the phenomenology and guiding experimental searches**.

(SuSpect2 > 1100 citations)



Mass spectrum: SuSpect2 versus SuSpect3  
(J.L. Kneur, G. Moultaka, D. Zerwas et al. '23)

## NMSSMTools

Package to study **NMSSM phenomenology**

- Takes input parameters at the SUSY, GUT or GMSB scale (2-loop RGEs), one point or (MCMC) scans
- Computes **masses**, **couplings** and **decay widths** of **Higgs bosons** and **sparticles** with 2-loop corrections
- Checks all **experimental constraints** on the Higgs sector from LEP and LHC, B/K physics and sparticle searches (interface with **SModels**)
- Computes **DM relic density** + **(in)direct detection cross sections**, checks all constraints (**micrOMEGAs**)

(C. Hugonie et al. : 4 papers > 1260 citations)

# Particle physics in PACT: New physics at the LHC

## Higgs Triplets at the LHC?

Standard Model extensions, motivated by massive Majorana Neutrinos, predict:

- Exotic doubly-charged scalars  $H^{\pm\pm}$
- Charged & neutral scalars  $H^{\pm}, A^0, H^0, h^0$

Minimal version: [production in pairs](#)

Decays to gauge bosons, [busy pheno](#)

Hard to exclude → [new search strategies](#)

(Collaboration with ATLAS experimentalists;

Ducu, Moulaka et al. '24)

With >600 PB of data, excesses are bound to occur: [fluctuations or BSM telltales?](#)

[CMS & ATLAS excesses](#) in searches

for neutral scalar resonances:

$h_{95\text{GeV}} \rightarrow \tau\tau, \gamma\gamma$

$H_{650\text{GeV}} \rightarrow WW, h_{95} + h_{125} (4\sigma !)$

$(H_{320\text{GeV}} \rightarrow h_{125} + h_{125}), \dots$

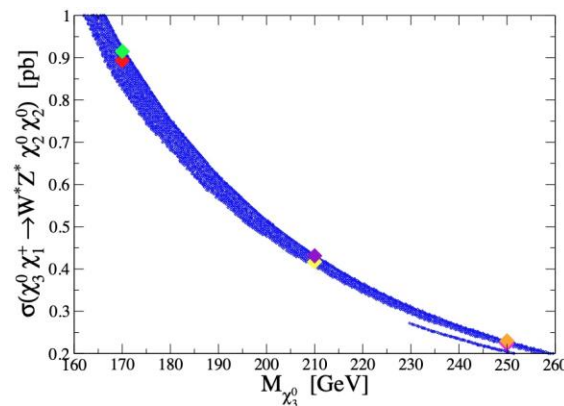
[650GeV](#) + [unitarity](#) imply [H<sup>±±</sup> should exist](#)

Needs [extended triplet model](#) to fit it all

(Kundu, Moulaka, Mondal, '24)

## Sparticles at the LHC?

ATLAS and CMS excesses in searches for neutralinos + charginos can be fitted in the NMSSM assuming singlino LSP + higgsino NLSP with compressed spectrum



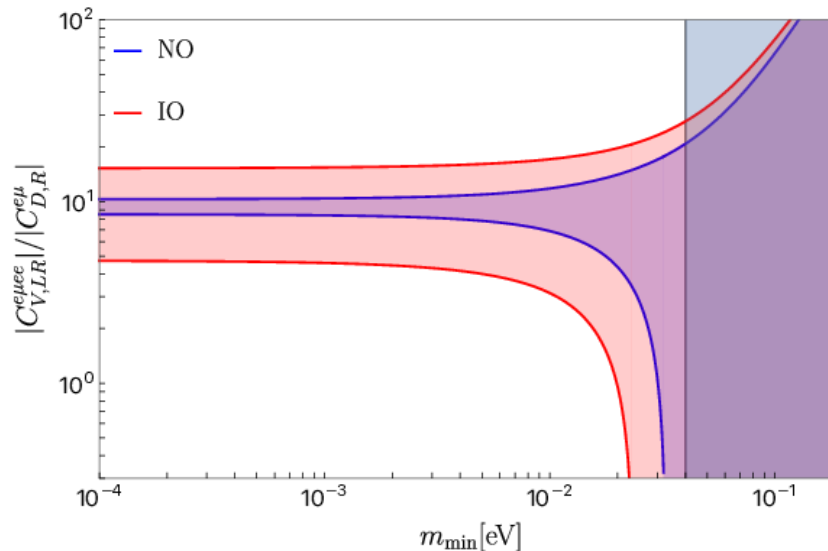
Coannihilation in the higgsino-sector gives correct relic density; the singlino LSP has direct detection cross sections below present and future sensitivities

Extra Higgs at 95 GeV as suggested by LEP data ( $b\bar{b}$ ) and more recently LHC ( $\gamma\gamma$ ) (C. Hugonie et al. '24)

# Particle physics in PACT: Lepton flavor violation

Charged LFV must occur (neutrino oscillations) but is a **small** effect in the SM → a **sensitive probe** of leptonic **BSM physics**, the **neutrino mass mechanism** and possibly the **Baryon Asymmetry of the Universe**

Present experiments are going to **greatly improve their sensitivities**:  
theoretical work is needed



Wilson coefficients for  $\mu \rightarrow e$  transitions in a neutrino mass model, computed in effective field theory, as a function of the smallest neutrino mass, for normal and inverted ordering (Ardu, Davidson et al. '24)

# Particle physics in PACT: QCD, QFT, H triplets

The [PACT emeriti](#) are continuing to actively contribute to research and to publish their results.

- Michel Capdequi-Peyranère is working on vacuum stability and unitarity conditions in Higgs triplet models, with Gilbert Moulaka (PRD '21)
- Pierre Grangé has worked on the axial anomaly in the formalism of Taylor-Lagrange renormalization
- Stephan Narison has published several papers QCD sum rules and their applications to  $e^+e^- \rightarrow$  hadron scattering and to hadron spectroscopy

# Strengths, weaknesses, opportunities, threats

## S

- Wide range of competences
- Expertise in both primordial cosmology and elementary particle physics
- High international visibility
- Active/lively research environment: seminars, JCs, (international) visitors
- Even distribution of seniority levels among permanent members

## W

- Not enough exchange between cosmologists and particle theorists – the dual expertise is not being optimally exploited

## O

- There is potential for, and interest in, more cross-topic collaboration
- A future CNRS recruit could help encourage this

## T

- Particle theory at Montpellier is at risk of becoming marginalized: Gilbert Moultaika will retire in 2027; departure of Sacha Davidson and others in the particle theory team of L2C; retired colleagues have not been replaced
- Office space has diminished w.r.t. before the renovation of the building. Nearly no space for further growth.
- Fundamental physics is not a Montpellier University's priorities: difficult to benefit from e.g. local postdoc funding, similar calls for proposals

# Perspectives

## Research priorities for the next 5 years

- Maintain our **international visibility and involvement in community structuring** on a wide range of topics in particules, astroparticules, cosmology
  - **Reinforce** interactions within the team on **early universe topics**
  - Forthcoming data releases of *Euclid*, LSST, Simons Observatory, 21cm  
→ strengthen **PACT's leading role** in **analysis** and **interpretation** to constrain new physics (**+ ERC / ANR grant ongoing + proposals**)
  - Develop and support **numerical tools for BSM searches** in the context of the coming High Luminosity LHC run
  - Further develop the search for **small scales gravitational signatures** of the nature of dark matter and the primordial power spectrum (ANR + networking calls)
- ++ Exploit possible collaboration with other LUPM teams, e.g. on the subject of **astrophysical signals of New Physics**



# Perspectives

## Short-term HR priorities

Ensure that [particle physics](#) research can continue within PACT and strengthen its [connections](#) with the Astro/Cosmo themes

→ LUPM recruitment priority: [CNRS researcher position "Theoretical Particle Physics / Cosmology"](#)

[MCF position](#) in synergy with these topics

(numerous retirements in the Physics Department in the next few years)

Maintain a strong [national and international visitor program](#)



# Long term

