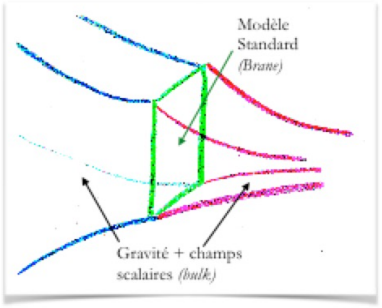
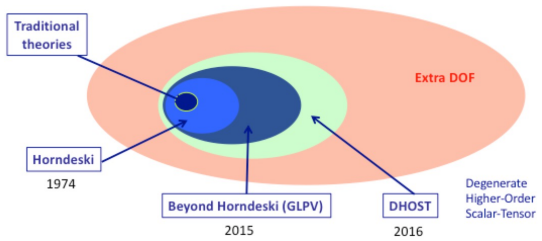
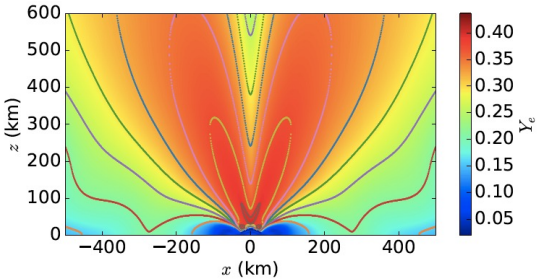
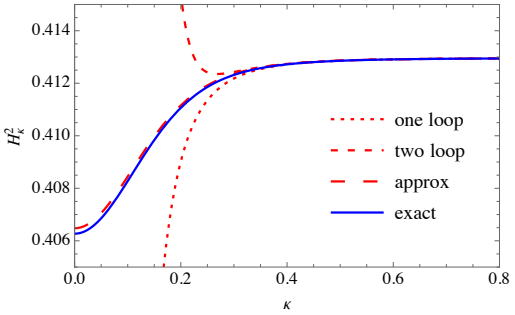
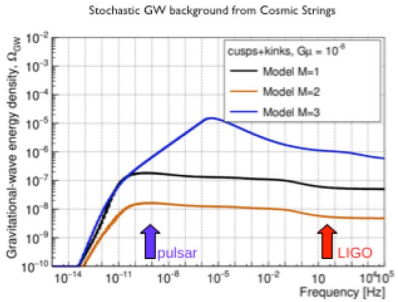


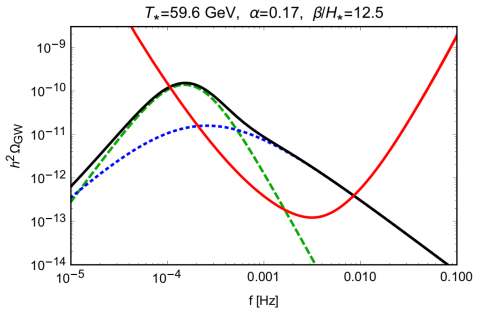




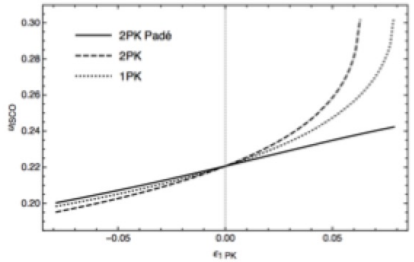
APC Theory Group

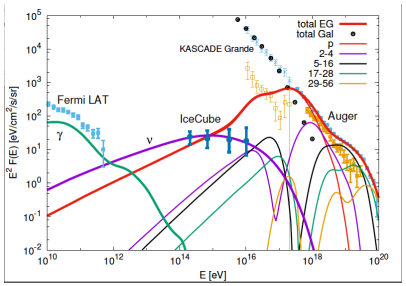


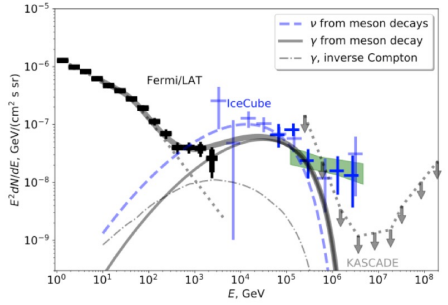




Dmitri Semikoz







Theory in APC

Major Open Questions

Dynamics of the Universe: Early stage and Evolution

- The early Universe:
  - Quantum Gravity
- Origin of cosmic structure:
  - Inflation
- Evolution of Large Scale Structure
  - Cosmological Constant

Matter/Energy content of the Universe

- Matter-antimatter asymmetry
- Neutrino physics
- Higgs Physics
- Beyond the standard model:
  - Dark Matter
  - Dark Energy

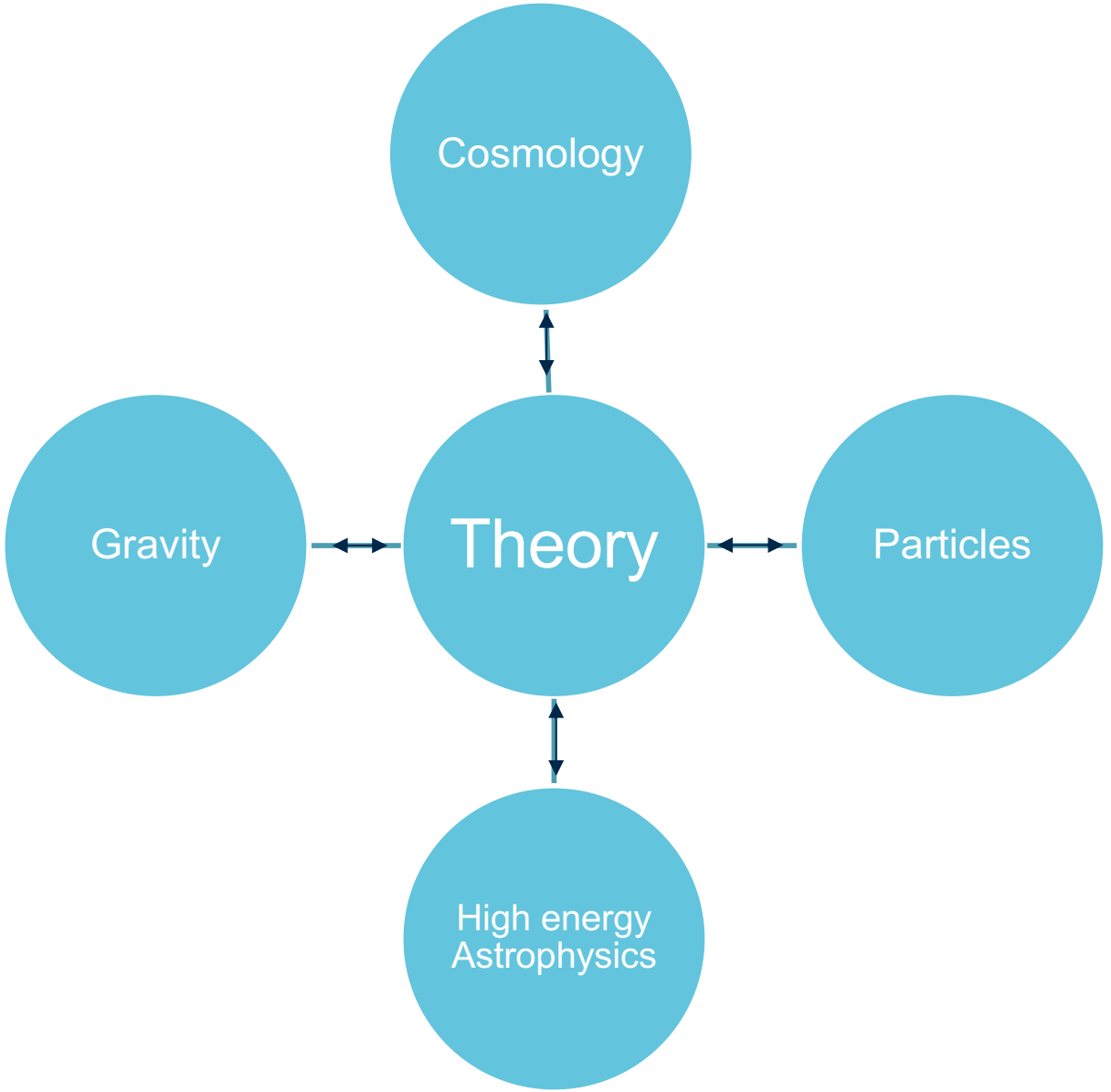
Nature of Spacetime & Gravity

- Gravity beyond GR
- Gravity in the strong regime
- Gravity at the quantum scale

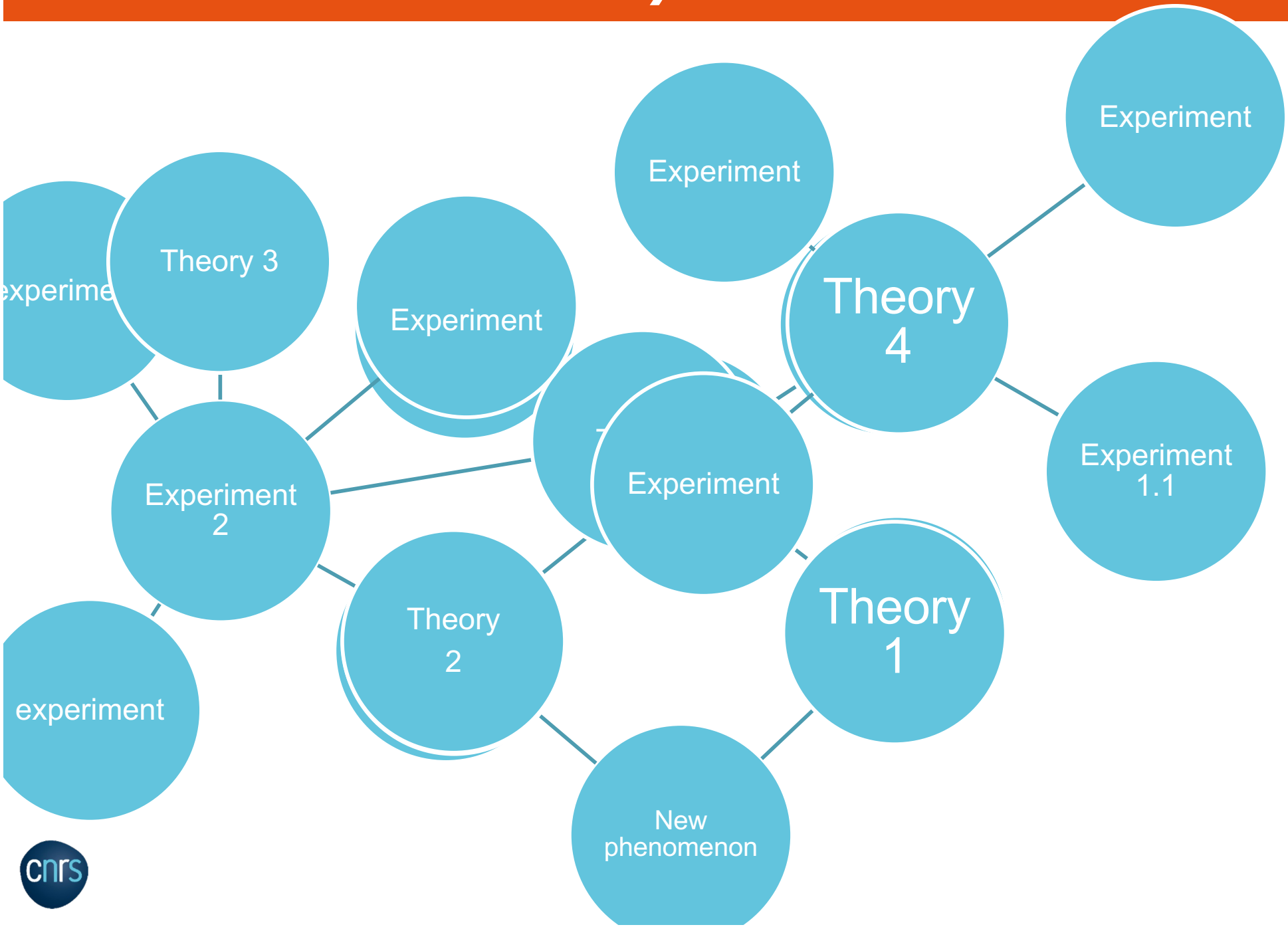
The Violent Universe

- Multimessenger Universe
  - Gamma, X, GW, Neutrinos
  - Compact objects
  - Cosmic Accelerators

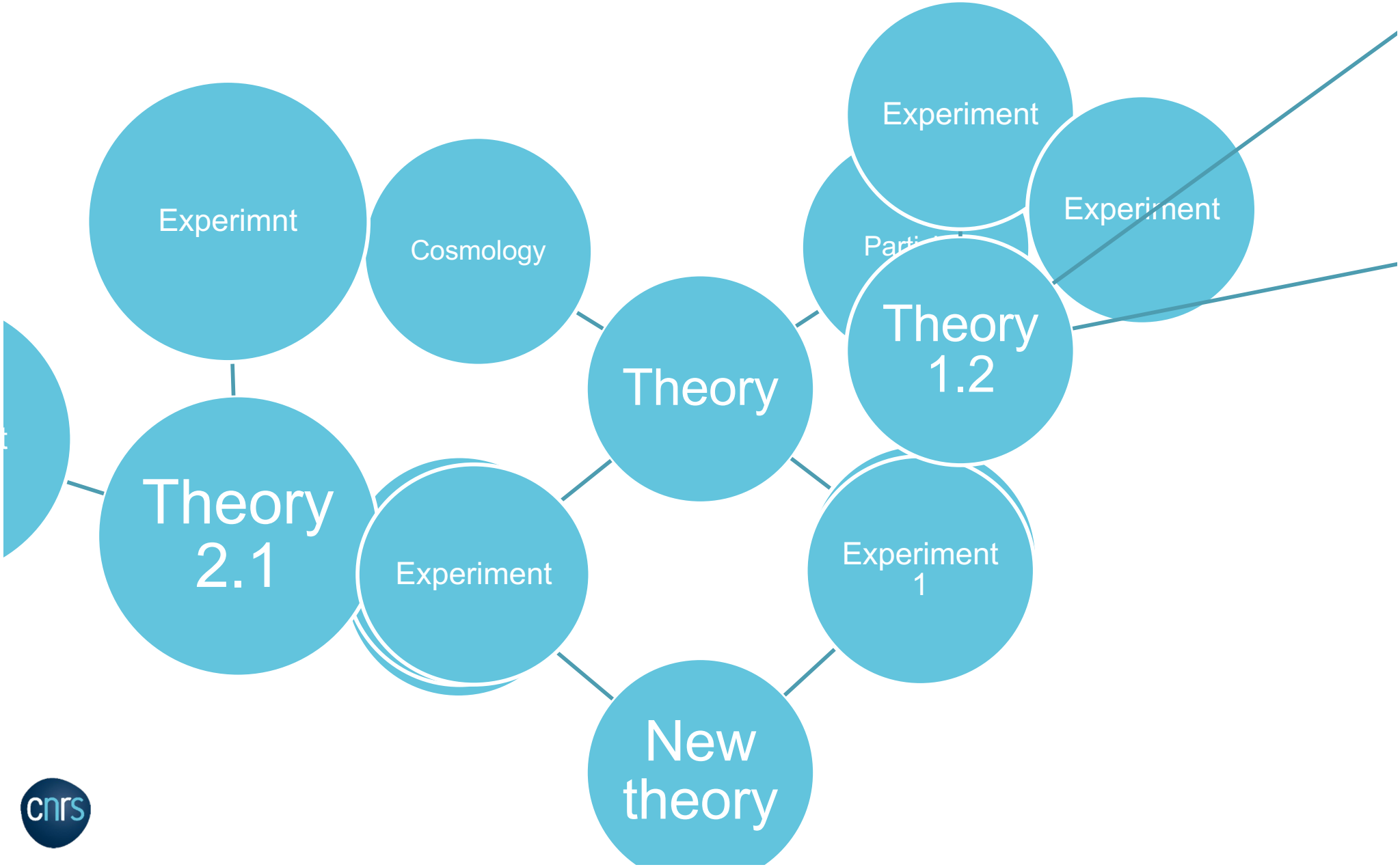
Theory in APC



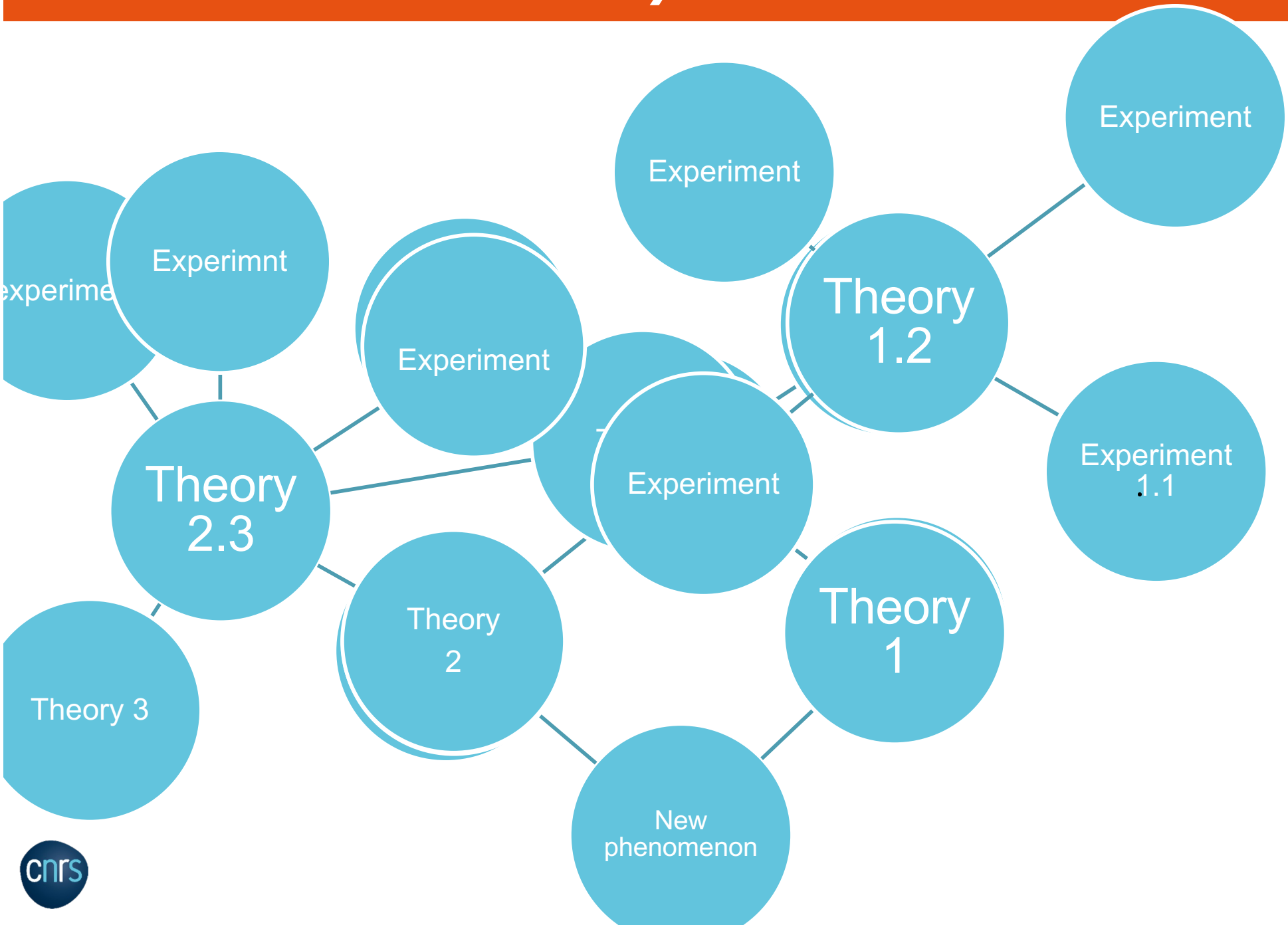
Theory in APC



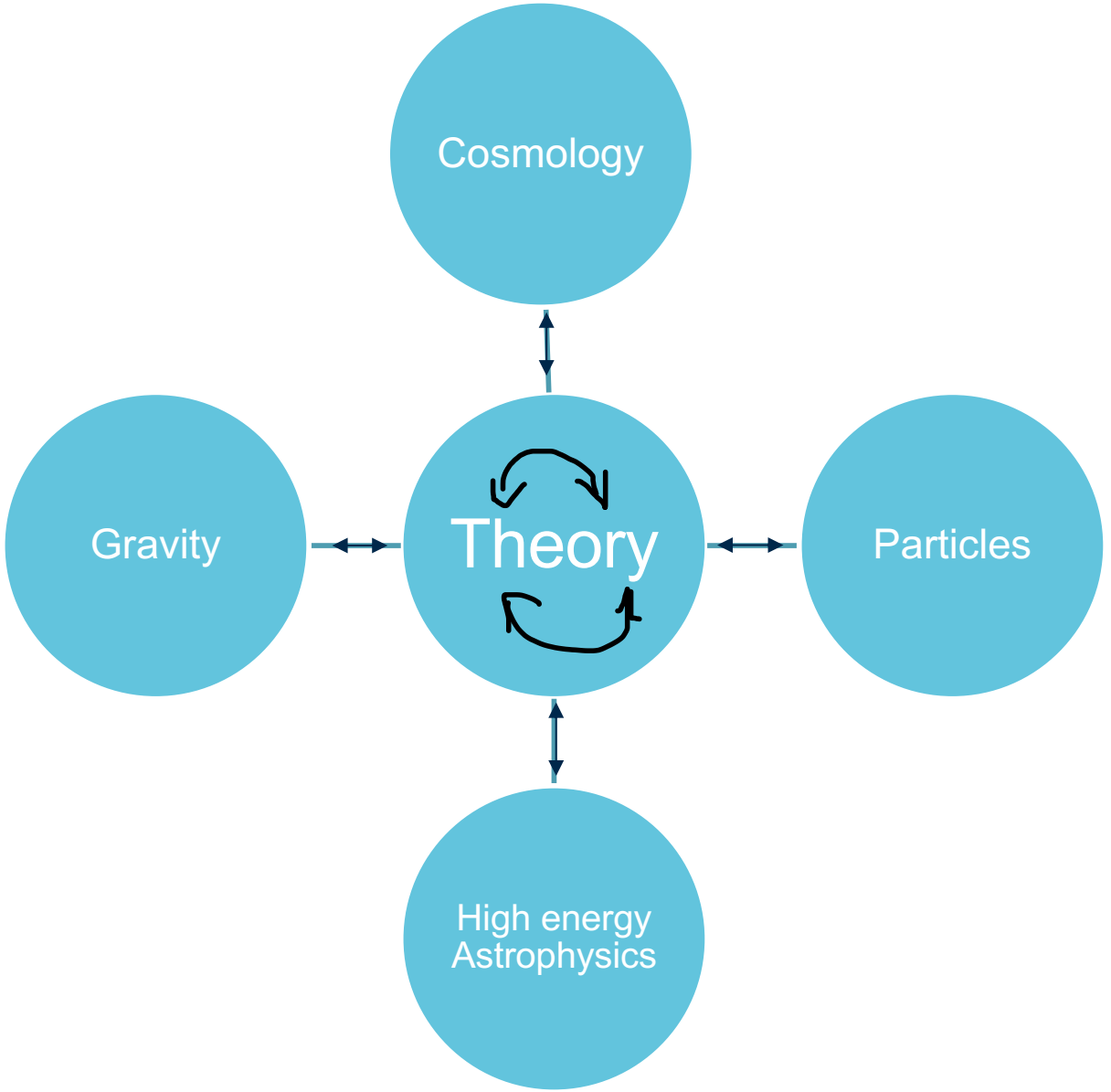
Theory in APC



Theory in APC



Theory in APC



Theory group: 28 members

- Responsable scientifique de l'équipe :
- Head of group Dmitri Semikoz, vice-head Eric Huguet

Liste des chercheurs de l'équipe : 12+3 permanents

• CNRS.		University Paris Cite		Emeritus/bénévole	
• Gwenael Giacinti	DR	Huguet Eric	MCF/ ***HDR***	Gazeau Jean-Piere	PR
• Kiritsis Elias	DR	Mourad Jihad	PR	Lachièze-Rey Marc.	DR
• Langlois David	DR	Neronov Andrii	PR	Renaud Jacque	PR
• Lemoine Martin	DR	Nitti Francesco	PR		
• Luca Santoni	CR/HDR	Serreau Julien	MCF/ ***HDR***		
• Semikoz Dmitri	DR				
• Volpe Cristina	DR				

Postdocs: 4+2

Sophie Aerdker (M.Lemoine) Alessandro Longo (L.Santoni)
Andrea Olzi (F.Nitti) Alexander Korochkin (D.Semikoz)
Wenlian Lee (A.Neronov) Thomas Colas (D.Langlois)

PhD Students: 9+1

Apostolides Thomas (E.Kiritsis)
Betrand Theodore (F.Nitti)
Blunier Jeffrey (A.Neronov)
Combaluzier-Szteinsznaider Oscar (L.Santoni)
Fourquet Philippe (Eric Huguet)
Maksim Kleimenov (G.Giacinti)
Le Bihan Sébastien (M.Lemoine)
Ligout Etienne (D.Langlois)
Raymond Jean-Loup (F.Nitti)
Zhu Zanfeng (D.Semikoz)

Theory in APC

Major theory problems studied in APC theory:

- Unification of particle physics and Gravity:
  - String theory
  - Holography -> dark energy
- New developments in quantum field theory
- Gravity theory – cosmology/ modified gravity
- (pre)-inflation theory
- Neutrinos from SN /decays
- Dark current / cosmic ray physics: acceleration/propagation theory/ source models / GMF models
- Multi-messenger astrophysics /theoretical models
- Cosmological magnetic fields /theory and observational signatures

Highlight #1 String theory and Holography

Ahmad Ghodsi, Elias Kiritsis (APC), Parisa Mashayekhi, Francesco Nitti (APC)

In https://arxiv.org/abs/2505.23366 we analyzed linear fluctuations of five-dimensional Einstein-Dilaton theories dual to holographic QFTs defined on four-dimensional de Sitter and Anti-de Sitter space-times. We identify the physical degrees of freedom and determine the general feature of the spectra of eigenstates. These correspond to towers of spin-0 and spin-2 particles propagating in 4d (A)dS . In the case of dS, the spectra are continuos and gapped by the dS curvature scale; for AdS, the spectra are discrete (see figure)

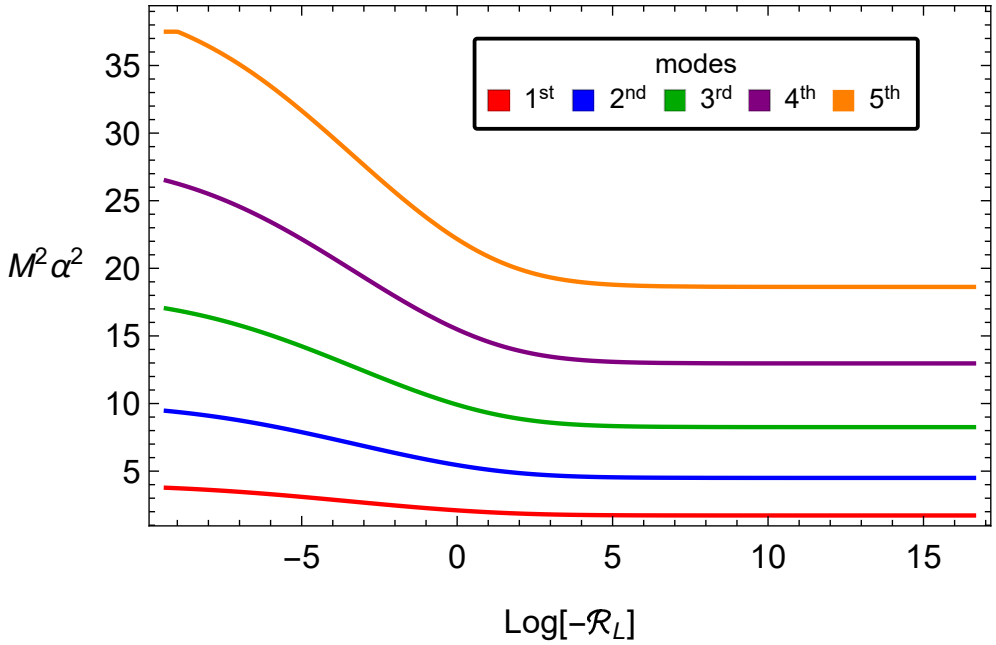
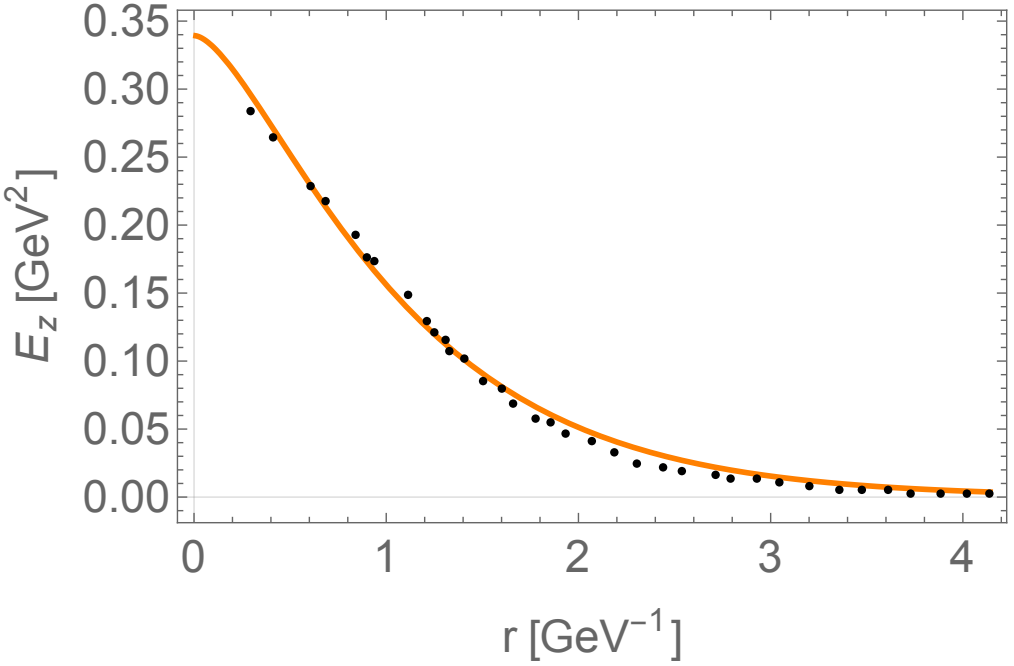


Figure 1: an example of the first few modes of a holographic RG flow dual to a QFT on AdS_4 . The plots show the behavior of the mass (in units of AdS curvature) as a function of the boundary curvature.

Highlight #2 Infrared regime of QCD

Scenario for quark confinement from infrared safe Yang-Mills dynamics, M. Pelaez, U . Reinosa, J. Serreau (APC), M. Tissier, N.Wschebor, *Phys.Rev.D* 112 (2025) 9, 094017

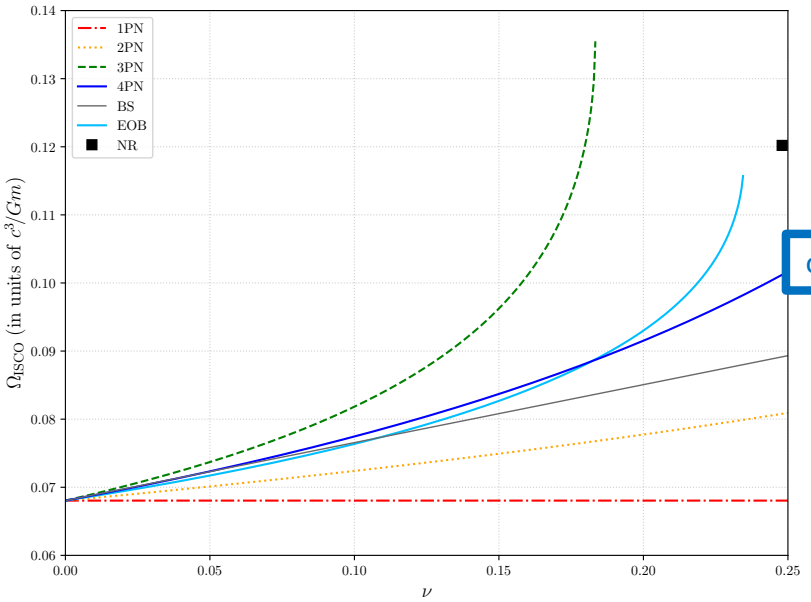
- We revisit the non-Abelian dipole problem in the context of a simple semiclassical approach to Yang-Mills dynamics that incorporates some essential features of the gluon propagator and we obtain a nontrivial flux tube solution for the chromoelectric field, yielding a simple appealing scenario for quark confinement, one of the most fundamental aspect of strong interactions.



The flux tube profile of the chromoelectric field in the plane transverse to the axis joining the quark-antiquark pair: Lattice data (points) vs. our analytical result (curve).

Highlight #3 Binaries

Innermost stable circular orbit (ISCO) of arbitrary-mass compact binaries at 4th post-Newtonian order



our result

ISCO frequency in terms of the mass ratio v, from 1PN to 4PN orders. The Barack-Sago (BS) first-order GSF result is presented as a solid grey line. The ISCO estimate from numerical relativity for equal masses is shown as a black square

Luc Blanchet, David Langlois & Etienne Ligout (APC),
Phys.Rev.D 112 (2025) 6, 064025 [arXiv: 2505.01278 [gr-qc]]

Computation, at **4PN order**, of the ISCO of arbitrary-mass compact binaries, using 2 methods: perturbation of the **equations of motion in harmonic coordinates;** perturbation of the **Hamiltonian in ADM coordinates**, including the **tail contribution** in both cases.

$$\nu = \frac{m_1 m_2}{(m_1 + m_2)^2}$$

Highlight #4 Gravity theory

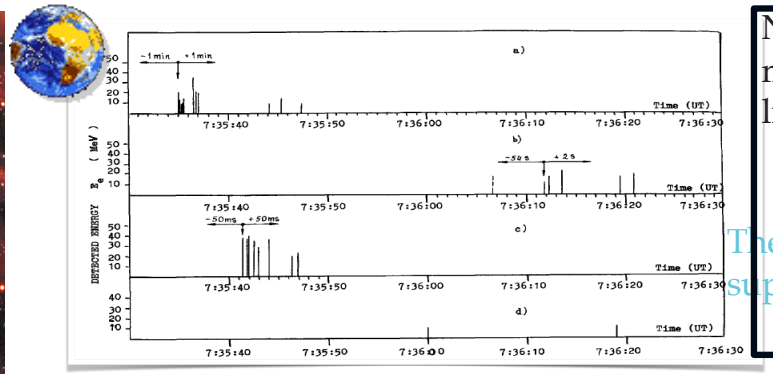
Dynamical Tidal Response of Schwarzschild Black Holes

Oscar Combaluzier-Szteinsznaider, Daniel Glazer,
Austin Joyce, Maria J. Rodriguez, and Luca Santoni

We extended the calculation of tidal effects beyond leading order, incorporating both dynamical (time-dependent) and nonlinear contributions. Although formally subleading, these effects can be significantly enhanced in neutron stars. In particular, we showed that third-generation gravitational-wave detectors such as the Einstein Telescope could measure them across a range of neutron-star masses and equations of state. Conversely, neglecting these effects can lead to significant biases in parameter estimation and inferences of the nuclear equation of state (JHEP 05 (2026) 074 + work in progress). For black holes, we demonstrated that these subleading tidal effects are governed by a nontrivial underlying symmetry structure that constrains the tidal response (JHEP 03 (2025) 124; 2511.02372).

Highlight #5 neutrino decay to Majoron

SN1987A and neutrino non-radiative decay



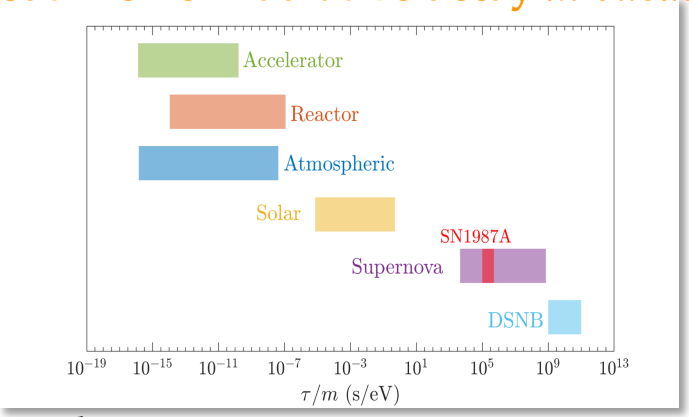
Neutrino being massive, they can decay into a massless (or almost) massless (pseudo)scalar like the Majoron – candidate for light dark matter.

$$\nu_i \to \nu_j + \phi \quad \text{or} \quad \nu_i \to \bar{\nu}_j + \phi$$

The neutrino fluxes suppressed by $\exp\left(-\frac{L}{\tau}\times\frac{m}{E}\right)$ (mass / energy)

lifetime

Neutrino non-radiative decay *in vacuum*

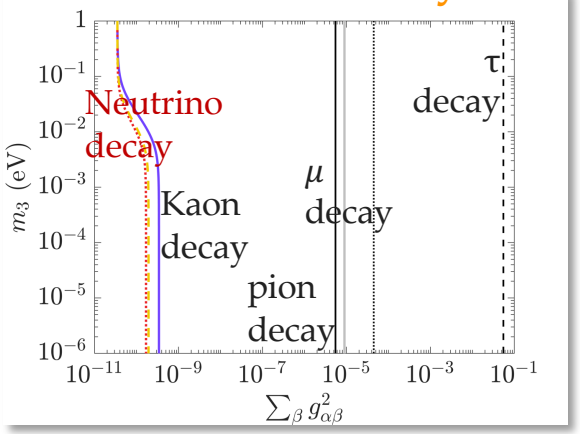


First likelihood analysis of 24 SN1987A in Kamiokande, IMB and Baksan including neutrino decay

$\frac{\tau}{m} > 1.2\times10^{5}$(90% CL). for ν_1,, ν_2 (IO) – **PDG 2024**

Ivanez-Ballesteros and Volpe, PLB 2023, 2307.03549

Neutrino non-radiative decay *in matter*



First likelihood analysis including neutrino decay in matter into Majorons: very competitive limits on neutrino-Majoron couplings. - –**PDG 2026**

Ivanez-Ballesteros, Volpe, PRD Lettter 2026, 2410.11517

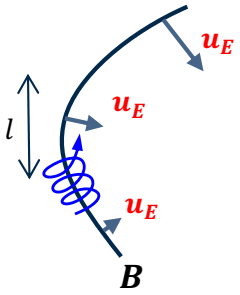
Highlight #6 Acceleration theory and NGC 1068

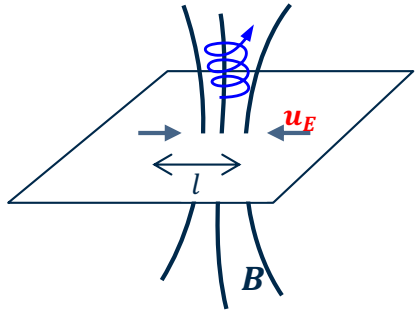
M. Lemoine

<u>Theory of particle acceleration in extreme environments:</u>

→ an effective theory of stochastic acceleration (“generalized Fermi”) combining GR tools and turbulence physics

M. Lemoine [Phys. Rev. **E**, in press (2025), arXiv:2501.19136]

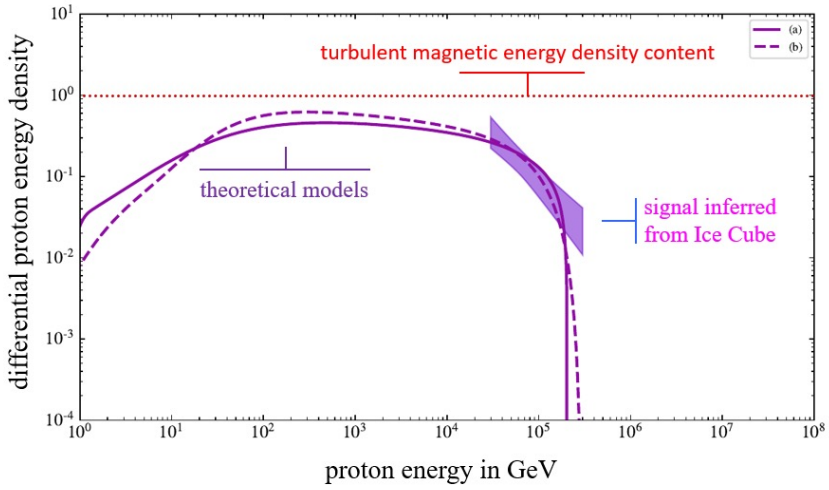




<u>Multimessenger astrophysics:</u>

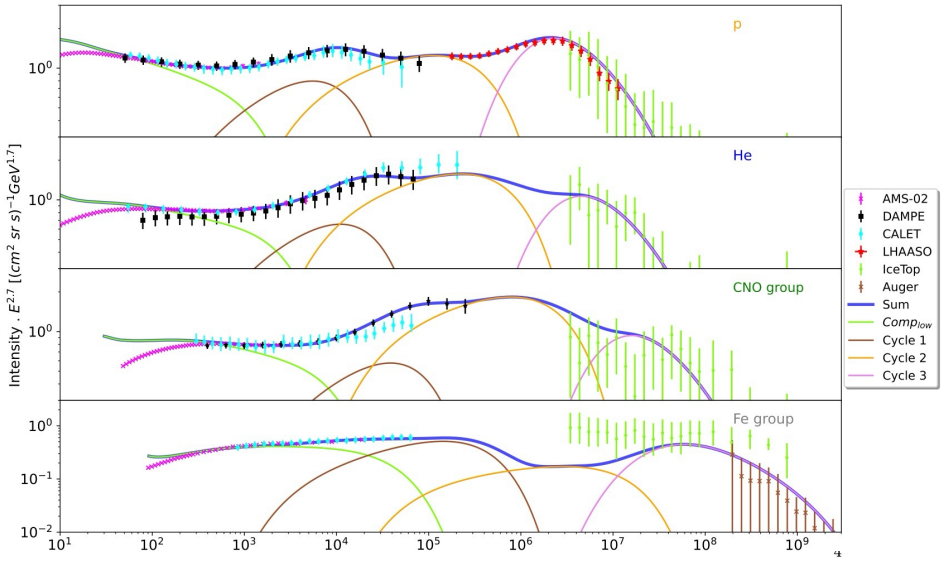
→ a theoretical model of proton acceleration to VHE in the turbulent corona of AGN black holes, connection to neutrinos from NGC1068

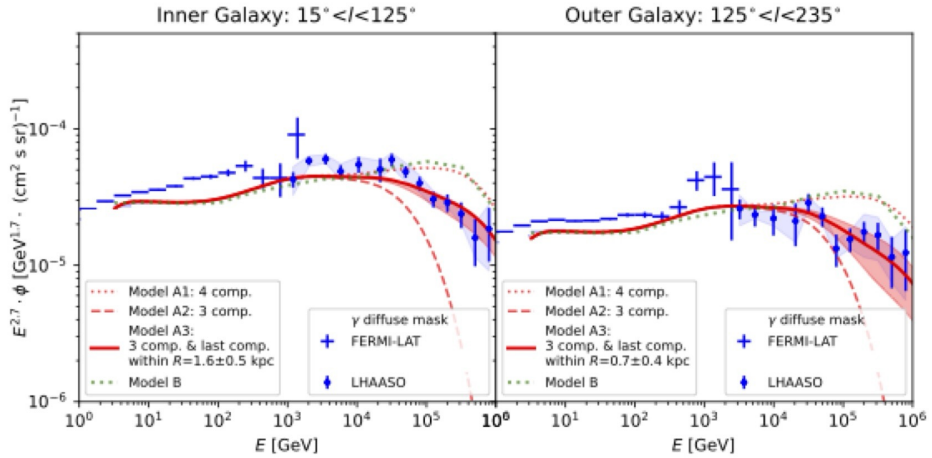
M. Lemoine, F. Rieger [A&A **697**, A124 (2025)]

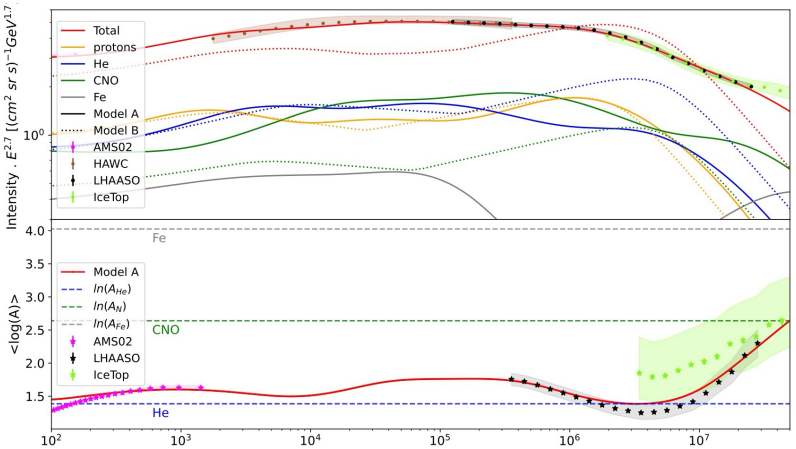


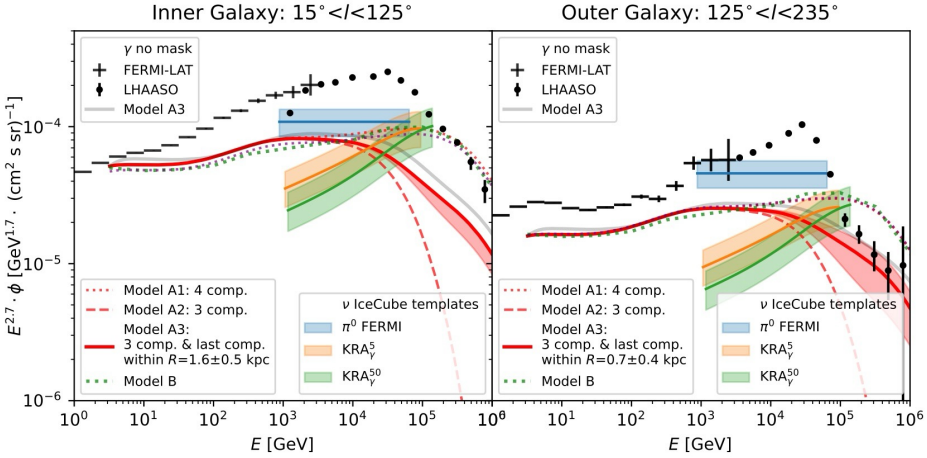
Highlight #7 Multi-messenger study of Milky Way

C. Prevotat, Zh. Zhu , S. Koldobskiy, A. Neronov, D.Semikoz and M. Ahlers,
Phys.Rev.D 112 (2025) 12, 123033



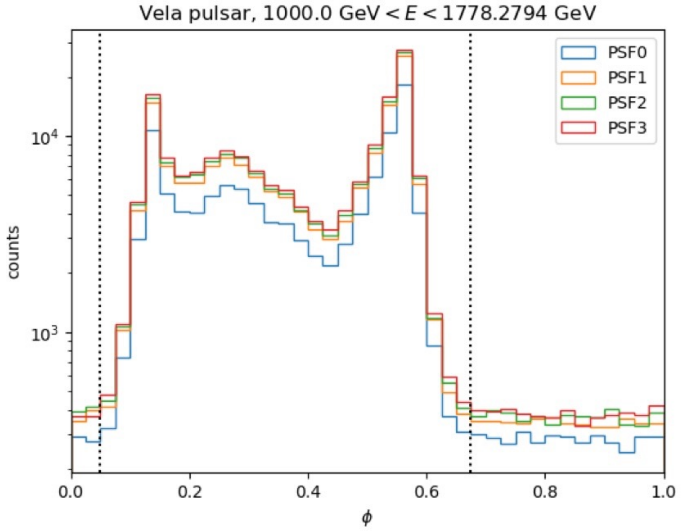


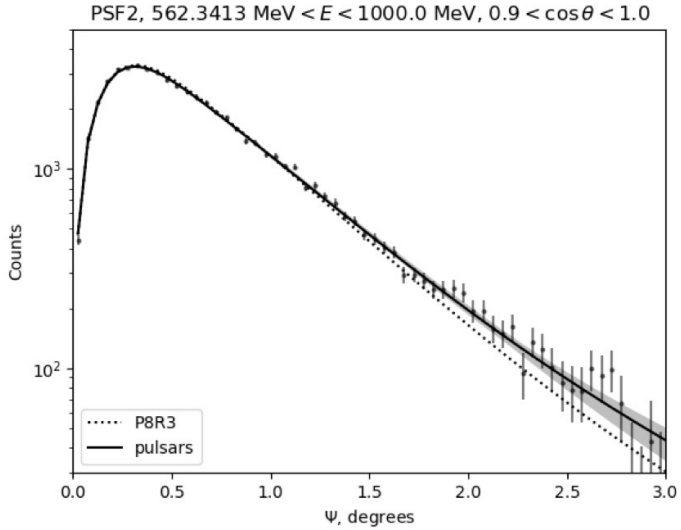


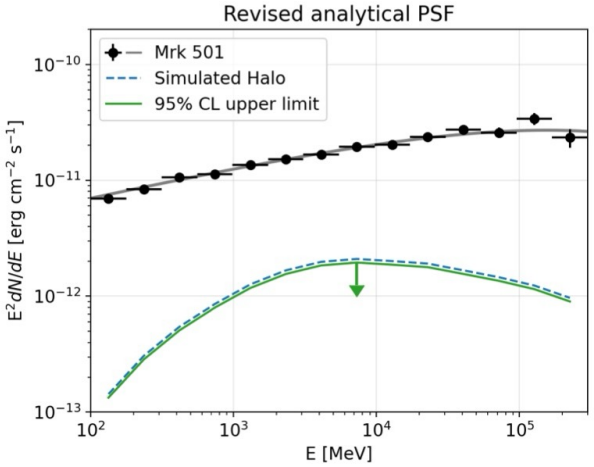


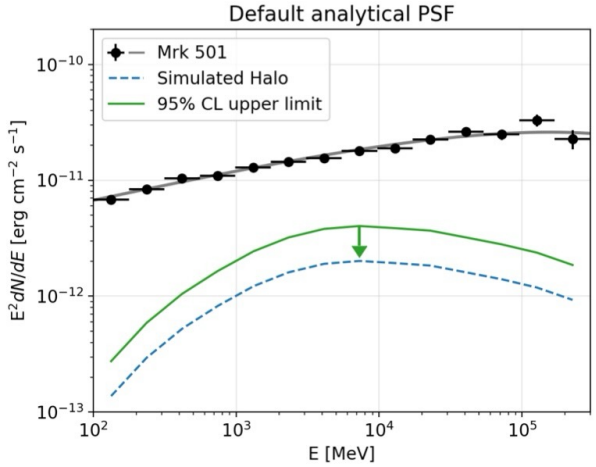
Highlight #8 Pulsar-based modeling of Fermi PSF

- J. Blunier, A. Neronov and D. Semikoz, 2602.14764









No evidence of signal around Mkn 501

Interaction within APC #1 ANR from 3 APC groups PI Martin Lemoine

ANR HENBoS (High Energy Neutrinos from massive Black hOle Systems)

PRME: single team at APC (groups: Théorie, AHE and Particules) – D. Allard, J. Aublin, B. Baret, F. Casse, M. Cerutti, S. Gabici, M. Lemoine (PI), A. Neronov, E. Parizot, D. Semikoz, R. Terrier, P. Varnière

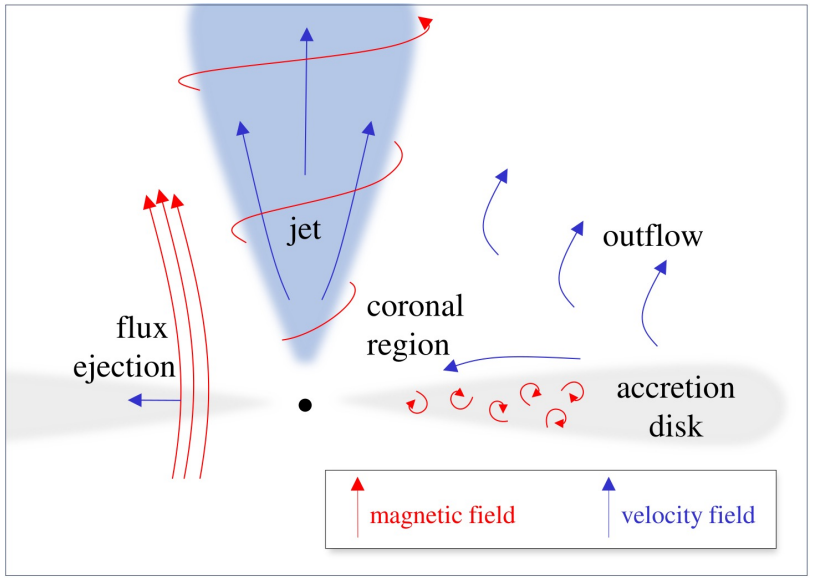
Funded personnel: 1 post-doc (3yrs) + 1 PhD

Rationale: develop a self-consistent, first-principles view of massive black hole environments as sources of VHE particles (cosmic rays, photons and neutrinos), by combining:

1. theoretical expertise in particle acceleration

2. numerical simulations (GRMHD, GRMHD-PIC, PIC)

3. expertise in phenomenology and detection of VHE multi-messengers.



Interaction within APC #2 LHAASO between Theory and AHE

Scientist responsible for project : D.Semikoz

List of researchers in the project: S.Gabici, G.Giacinti , A.Neronov

- **IT: D.Savchenko (LHAASO data + data analysis with gamampy)**
- **PhD A.Inventar, J.Blunier, Zh.Zhu**

- **APC contribution to LHAASO**
- Microquasar V4641 in high zenith angle analysis
- Theoretical models for several LHAASO papers
- APC team is one of 3 working groups on Second LHAASO Catalog of sources
- APC team one of two working groups on diffuse gamma-rays
- New directions in LHAASO including cosmological magnetic fields

Future example: Cosmological magnetic field

Scientist responsible for project : A.Neronov (APC)

ERC synergy 10 Meuro: APC is leading organisation

What is the origin of cosmic magnetism?

What mechanisims in the primordial Universe could magnetise the cosmic web we observe today?

Are magnetic fields the source of the stochastic gravitational wave background?

Can we do early Universe cosmology combining gravitational waves and magnetic fields?

Conclusion

- APC Theory team is strong in many theoretical directions and has expertise in all essential directions of APC research including cosmology, gravity, field theory, neutrinos and astroparticle physics
- APC theory team actively interacts with other teams in APC
- In next 3-5 years APC theory team will develop theoretical research within directions financed by ANR and ERC including Holography, Gravity theory, high energy neutrino from BH, multi-messenger signatures of Cosmic Rays and Cosmological Magnetic Fields