LAPTh Astroparticle and Cosmology Group

*Main activities we're **currently** interested into*

- Indirect Dark Matter Searches, signals & backgrounds (**IDM**)
- HE astrophysics, notably "diffuse" fluxes (cosmic rays (**CR**) & **gammas, ν**)
- Particle cosmology (**Cosmo**)
- GRB as a new mode of stellar collapse (**GRB**)

06/12/2017

MEMBERS & TOPICS

3 Enseignant-Chercheurs

+ 1.5 PhD students (Nina Smirnova, Céline Armand)
+ 1 long-term visitor (Ilia Kalashnikov)
+ 0.5 postdoc (Bryan Zaldivar)

(unusually low: we're the LAPTh group with the largest number of stages/PhD/ trainings)

2+1 CNRS staff researchers

Pascal Chardonnet

Pierre Salati

Richard Taillet

Pasquale D. Serpico

Francesca Calore

Céline Boehm

since 2011 at IPPP, Durham

WHOM TO TALK WITH (FIRST)

- For CR-related applications: P. Salati, R. Taillet.
- For GRB-related: P. Chardonnet.
- For gamma-rays, population studies, multimessengers: mostly F. Calore (to minor extent P. Serpico, possibly P. Salati)
- Indirect dark matter detection: F. Calore, P. Salati, P. Serpico, R. Taillet (probably in this order…)
- Particle cosmology: P. Serpico (minor involvement / expression of interest by F. Calore, P. Salati)

GRBs & PAIR INSTABILITY SNAE

- Study of **pair instability supernovae as GRB engines**, both analytics and simulations used

- Current & near future focus on phenomenology (X ray and gamma spectra & bolometric emission, Amati relation, nucleosynthesis, etc.) as well as cosmological aspects (e.g. significant increase in GRB vs. z expected). Implications for future surveys, like THESEUS

Mostly developed in collaboration with Russian colleagues & within the International Erasmus Mundus program coordinated by *P. Chardonnet*

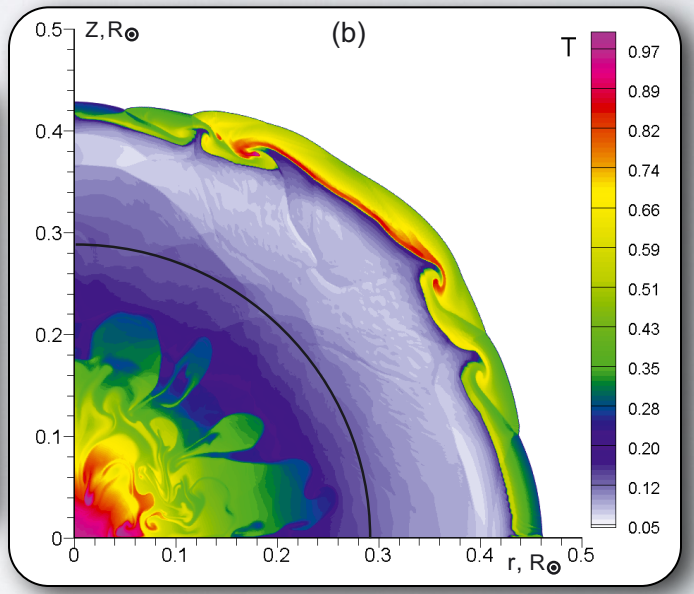
A&A 558, A10 (2013)
DOI: 10.1051/0004-6361/201321312

Astronomy & Astrophysics

Multidimensional simulations of pair-instability supernovae

A. A. Baranov[1], P. Chardonnet[1], V. M. Chechetkin[2,3], A. A. Filina[1], and M. V. Popov[1,2]

[1] LAPTh, Univ. de Savoie, CNRS, BP 110, 74941 Annecy-le-Vieux, France
e-mail: chardonnet@lapp.in2p3.fr
[2] Keldysh Institute of Applied Mathematics, Russian Academy of Science, Miusskaya sq. 4, 125047 Moscow, Russia
[3] National Research Nuclear University "MEPhI", Kashirskoe sh. 31, 115409 Moscow, Russia



IMPLICATION IN THESEUS

Astrophysics > Instrumentation and Methods for Astrophysics

The Transient High Energy Sky and Early Universe Surveyor (THESEUS)

L. Amati, P. O'Brien, D. Goetz, E. Bozzo, C. Tenzer, F. Frontera, G. Ghirlanda, C. Labanti, J. P. Osborne, G. Stratta, N. Tanvir, R. Willingale, P. Attina, R. Campana, A.J. Castro-Tirado, C. Contini, F. Fuschino, A. Gomboc, R. Hudec, P. Orleanski, E. Renotte, T. Rodic, Z. Bagoly, A. Blain, P. Callanan, S. Covino, A. Ferrara, E. Le Floch, M. Marisaldi, S. Mereghetti, P. Rosati, A. Vacchi, P. D'Avanzo, P. Giommi, A. Gomboc, S. Piranomonte, L. Piro, V. Reglero, A. Rossi, A. Santangelo, R. Salvaterra, G. Tagliaferri, S. Vergani, S. Vinciguerra, M. Briggs, E. Campolongo, R. Ciolfi, V. Connaughton, B. Cordier, B. Morelli, M. Orlandini, C. Adami, A. Argan, J.-L. Atteia, N. Auricchio, L. Balazs, G. Baldazzi, S. Basa, R. Basak, P. Bellutti, M. G. Bernardini, G. Bertuccio, J. Braga, M. Branchesi, et al. (148 additional authors not shown)

(Submitted on 12 Oct 2017 (v1), last revised 13 Oct 2017 (this version, v2))

THESEUS is a space mission concept aimed at exploiting Gamma-Ray Bursts for investigating the early Universe and at providing a substantial advancement of multi-messenger and time-domain astrophysics. These goals will be achieved through a unique combination of instruments allowing GRBs and X-ray transients detection over a broad FOV (more than 1sr) with 0.5-1 arcmin localization, an energy band extending from several MeVs down to 0.3 keV and high sensitivity to transient sources in the soft X-ray domain, as well as on-board prompt (few minutes) follow-up with a 0.7 m class IR telescope with both imaging and spectroscopic capabilities. THESEUS will be perfectly suited for addressing the main open issues in cosmology such as, e.g., star formation rate and metallicity evolution of the inter-stellar and intra-galactic medium up to redshift ~10, signatures of Pop III stars, sources and physics of re-ionization, and the faint end of the galaxy luminosity function. In addition, it will provide unprecedented capability to monitor the X-ray variable sky, thus detecting, localizing, and identifying the electromagnetic counterparts to sources of gravitational radiation, which may be routinely detected in the late '20s / early '30s by next generation facilities like aLIGO/ aVirgo, eLISA, KAGRA, and Einstein Telescope. THESEUS will also provide powerful synergies with the next generation of multi-wavelength observatories (e.g., LSST, ELT, SKA, CTA, ATHENA).

THESEUS payload

- **Soft X-ray Imager (SXI):** a set of « Lobster-Eye » X-ray (0.3 - 6 keV) telescopes covering a total FOV of 1 sr field with 0.5 – 1 arcmin source location accuracy, provided by a **UK** led consortium

- **InfraRed Telescope (IRT):** a 70 cm class near-infrared (up to 2 microns) telescope (IRT) with imaging and moderate spectral capabilities provided by a **Spain (M4) / France (M5)** led consortium

- **X/Gamma-ray Spectrometer (XGS)**: non-imaging spectrometer (XGS) based on SDD+CsI, covering the same FOV than the Lobster telescope extending its energy band up to 20 MeV. This instrument will be provided by an **Italian** led consortium

THESEUS
Transient High Energy Sources and Early Universe Surveyor

Lead Proposer: Lorenzo Amati (INAF – IASF Bologna, Italy)

M4 proposal coordinators: Lorenzo Amati, Paul O'Brien (Univ. Leicester, UK), Diego Gotz (CEA-Paris, France), Alberto Castro-Tirado (IAA, Spain)

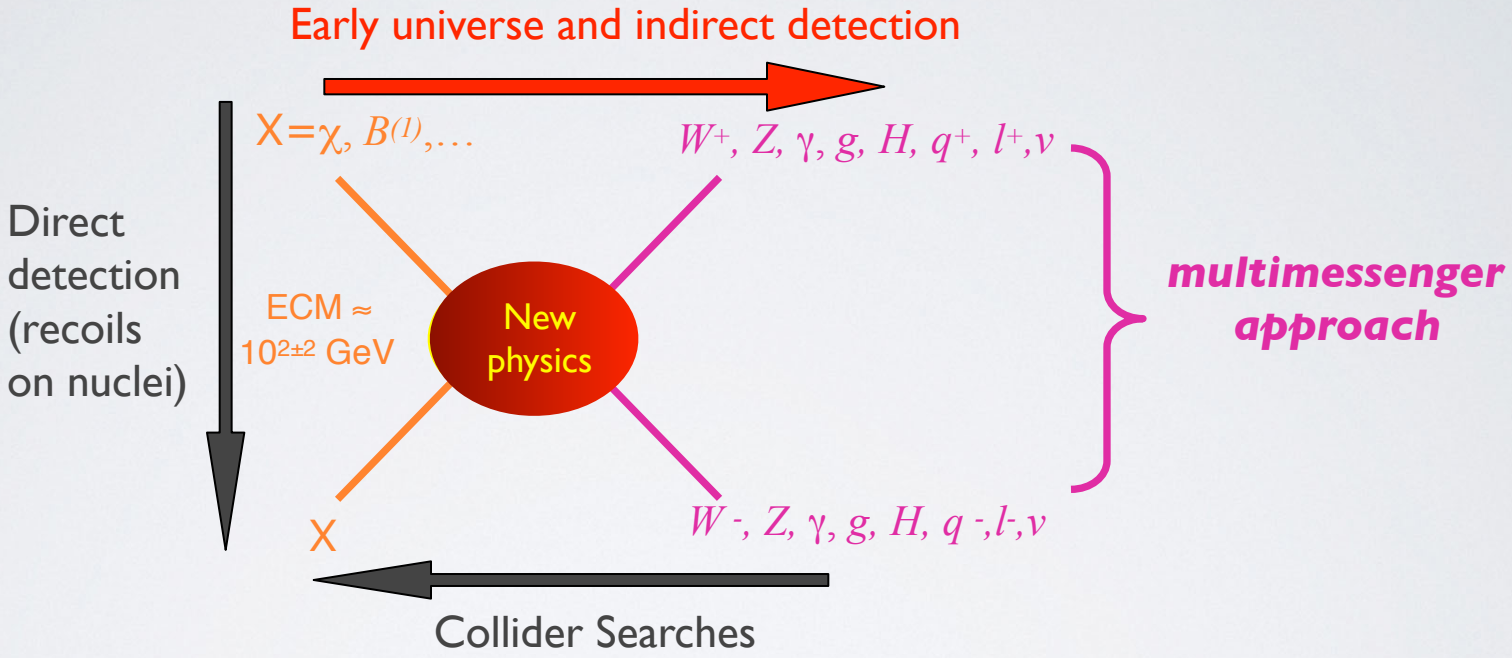
Payload consortium: Italy, UK, Spain, France, Denmark, Poland, Czech Republic, ESA (+ Hungary, Slovenia, Ireland)

International partners: USA (+ interest from Brasil, Japan, Israel, Turkey)

INTERFACE ACTIVITY: "WIMP HUNTING"

GOAL: testing the *hypothesis* that dark matter is constituted of weakly interacting massive particles (at GeV-TeV scale)

(some efforts on non-WIMP candidates, too)



In short, what we do:

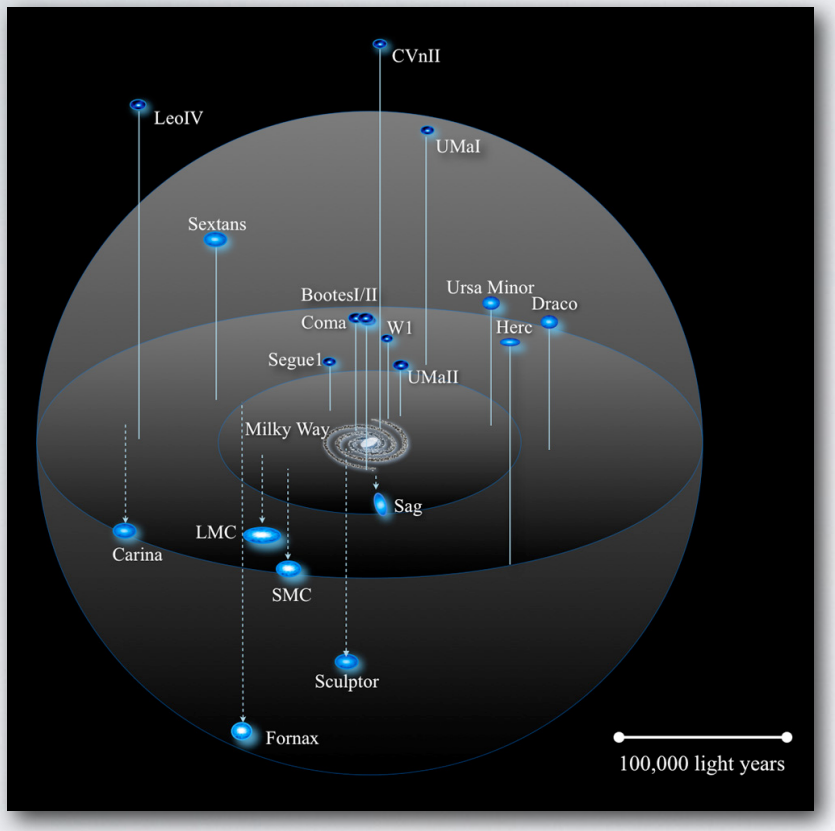
- compute signals due to different (classes of) candidates
- assess/uncover relevant astrophysical backgrounds
- cross-checks claimed hints (>1/year...)

Where to look and what?

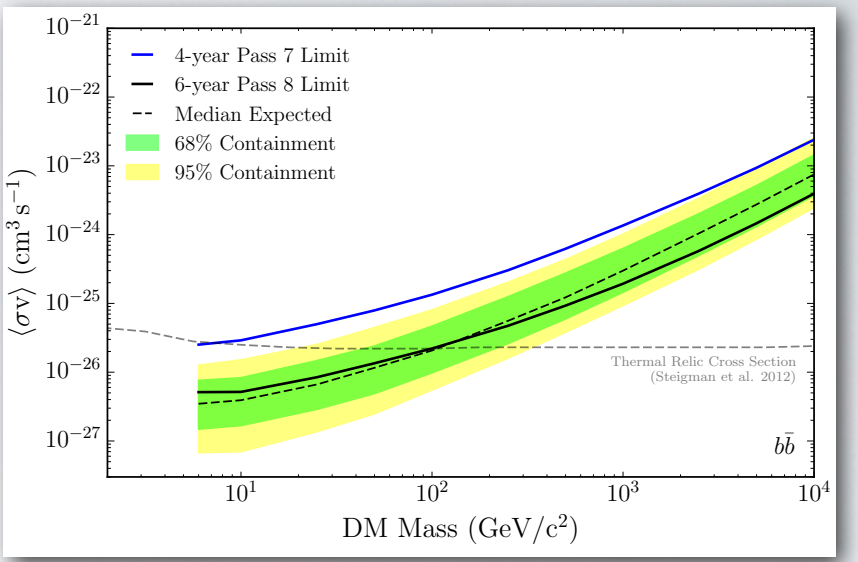
EX: DWARF GALAXIES IN GAMMAS

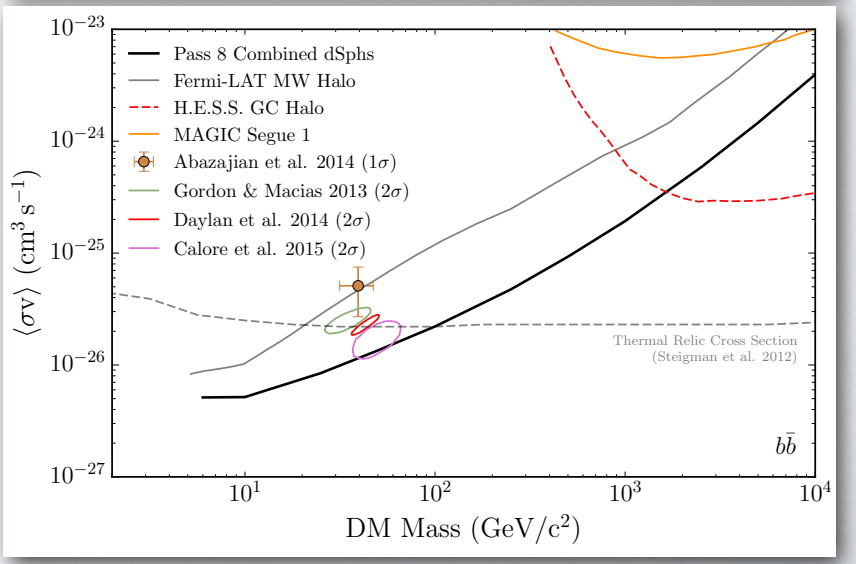
Best DM bounds from Fermi-LAT come from stacking these objects

M.Ackermann et al. PRL115, 231301 (2015)



satellites of Milky Way with high DM/baryon content
(1 to 3 orders of magnitude higher than the MW)
Almost ideal S/N





PAST, PRESENT AND FUTURE

It has already been a topic for LAPP (HESS)-LAPTh collaboration in the past

A. Abramowski et al. [H.E.S.S. Collaboration+ A. Goudelis, P. D. Serpico],
"Search for dark matter annihilation signatures in H.E.S.S. observations of Dwarf Spheroidal Galaxies,"
Phys. Rev. D 90, 112012 (2014)

for the first time within HESS, comparisons with models beyond the simplest MSSM SUSY scenarios (extra singlet, some leptophilic models…)

Currently using data-driven method (rather than "Galprop prediction") & some basic machine-learning techniques to assess the astrophysical background for these searches and its uncertainty.

F. Calore, P. D. Serpico, B. Zaldivar, in preparation

Master and PhD thesis of Céline Armand (with V. Poireau & F. Calore) mostly related to this topic, within HESS and looking ahead to CTA

IN GENERAL, NEED TO WORRY ABOUT FOREGROUNDS…

…*(outside the community of theoretical particle physicists)* also known as "**interesting astrophysical signals**", carrying a lot of information!

"Diffuse-like" emission from unresolved pulsars
F. Calore, M. Di Mauro, F. Donato, "Diffuse gamma-ray emission from galactic pulsars," ApJ 796, (2014)

leptonic interactions with interstellar light *T. Delahaye, C. Boehm…*

Diffuse emission from hadronic interaction in the Galactic disk ISM
T. Delahaye, A. Fiasson, M. Pohl and P. Salati, "The GeV-TeV Galactic gamma-ray diffuse emission I. Uncertainties in the predictions of the hadronic component," Astron. Astrophys. 531, A37 (2011)

"Diffuse-like" emission from unresolved AGN
M. Di Mauro, F. Calore, F. Donato, M. Ajello and L. Latronico, "Diffuse gamma-ray emission from misaligned active galactic nuclei," ApJ 780, 161 (2014)

M. Di Mauro, F. Donato, G. Lamanna, D. A. Sanchez and P. D. Serpico, "Diffuse gamma-ray emission from unresolved BL Lac objects," ApJ 786, 129 (2014)

A HOT TOPIC CASE STUDY: GAMMA-RAY EXCESS FROM GAL. CENTER!

several groups claimed a statistically significant gamma-ray excess over diffuse emission *model* + *known* astrophysical sources in Fermi-LAT data, eventually confirmed by Fermi

*L. Goodenough and D. Hooper, "**Possible Evidence** For Dark Matter Annihilation In The Inner Milky Way From The Fermi Gamma Ray Space Telescope," **0910**.2998*
D. Hooper and L. Goodenough, PLB 697, 412 (2011) [1010.2752]
K. N. Abazajian and M. Kaplinghat, PRD 86, 083511 (2012) [1207.6047]
D. Hooper, I. Cholis, T. Linden, J. Siegal-Gaskins and T. Slatyer, PRD 88, 083009 (2013) [1305.0830]
C. Gordon and O. Macias, PRD 88, 083521 (2013) [1306.5725]
K. N. Abazajian, N. Canac, S. Horiuchi and M. Kaplinghat, 1402.4090
*T. Daylan et al. "The Characterization of the Gamma-Ray Signal from the Central Milky Way: A **Compelling Case** for Annihilating Dark Matter", **1402**.6703*
...
F. Calore, I. Cholis and C. Weniger, "Background model systematics for the Fermi GeV excess," arXiv:1409.0042
…
M. Ajello et al. [Fermi-LAT Collaboration], "Fermi-LAT Observations of High-Energy γ-Ray Emission Toward the Galactic Center," ApJ 819, 44 (2016) [1511.02938]
M. Ackermann et al. [Fermi-LAT Collaboration] "The Fermi Galactic Center GeV Excess and Implications for Dark Matter," Astrophys J. 840, 1, 43 (2017)

compatible with a 20-80 GeV with "thermal cross section"~few 10^{-26} cm^3/s into quarks, preferentially, with slightly steeper than NFW halo profile

INTERPRETING THE GALACTIC CENTER EXCESS

- ➡ Do we understand diffuse background well enough
(Not for spectral details, yes for establishing the existence)
- ➡ What about time dependence?
- ➡ What about an unresolved source population?

J. Petrovic, P. D. Serpico and G. Zaharijas, "Galactic Center gamma-ray "excess" from an active past of the Galactic Centre?," JCAP 1410 (2014) 052 [1405.7928]

F. Calore, I. Cholis and C. Weniger, "Background model systematics for the Fermi GeV excess," JCAP 1503, 038 (2015) [1409.0042]

J. Petrovic, P. D. Serpico and G. Zaharijas, "Millisecond pulsars and the Galactic Center gamma-ray excess: the importance of luminosity function and secondary emission," JCAP 1502, 023 (2015) [1411.2980]

F. Calore, I. Cholis, C. McCabe and C. Weniger, "A Tale of Tails: Dark Matter Interpretations of the Fermi GeV Excess in Light of Background Model Systematics," Phys. Rev. D 91, 063003 (2015) [1411.4647]

I. Cholis, C. Evoli, F. Calore, T. Linden, C. Weniger and D. Hooper, "The Galactic Center GeV Excess from a Series of Leptonic Cosmic-Ray Outbursts," JCAP 1512, 005 (2015) [1506.05119]

…

LATE NEWS:

SEEMS TO BE DUE TO UNRESOLVED SOURCES

S. K. Lee, M. Lisanti, B. R. Safdi, T. R. Slatyer and W. Xue, "Evidence for Unresolved Gamma-Ray Point Sources in the Inner Galaxy," Phys.Rev.Lett. 116 (2016), 051103

based on 'pixel-statistics'

R. Bartels, S. Krishnamurthy and C. Weniger, "Strong support for the millisecond pulsar origin of the Galactic center GeV excess," Phys.Rev.Lett. 116 (2016), 051102

based on wavelet transform

Crucial test for this hypothesis: Find them!

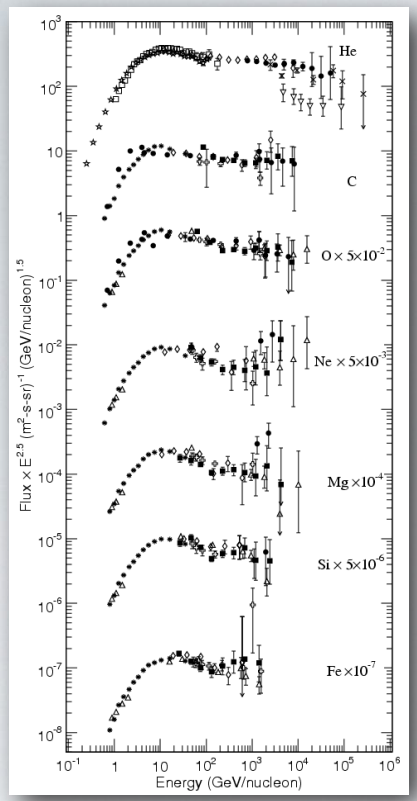
F. Calore et al., "Radio detection prospects for a bulge population of millisecond pulsars as suggested by Fermi LAT observations of the inner Galaxy," ApJ. 827, 143 (2016)

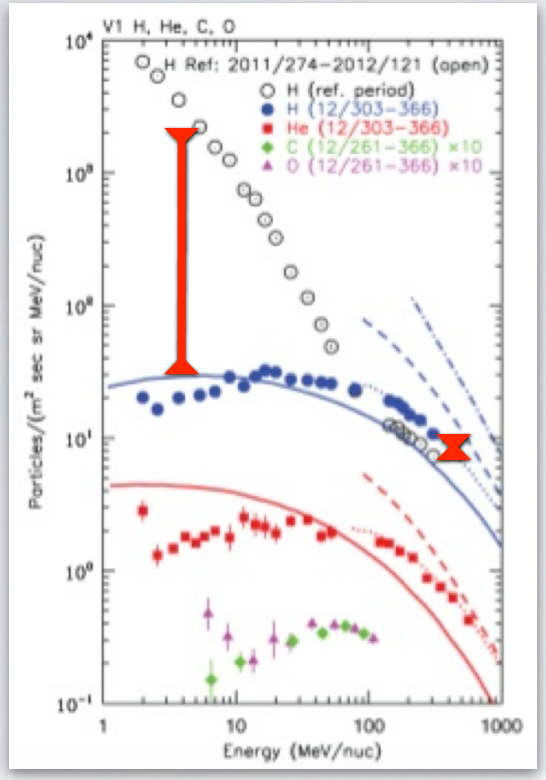
Implication in survey: MEERKAT - TRAPUM in 2018

Extra indirect evidence: morphology traces stellar profiles, correlations with other stellar environments…

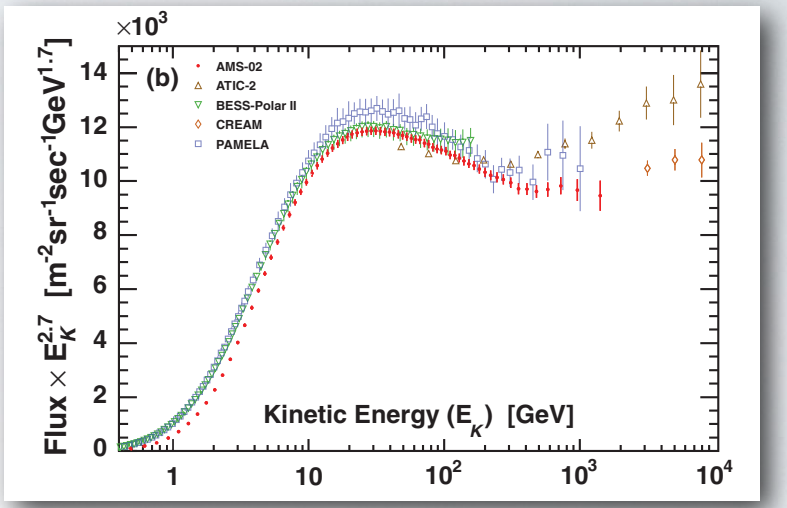
R. Bartels, E. Storm, C. Weniger and F. Calore, "The Fermi-LAT GeV Excess Traces Stellar Mass in the Galactic Bulge," arXiv:1711.04778
C. Eckner, X. Hou, P. D. Serpico et al., "Millisecond pulsar origin of the Galactic center excess and extended gamma-ray emission from Andromeda - a closer look," arXiv:1711.05127

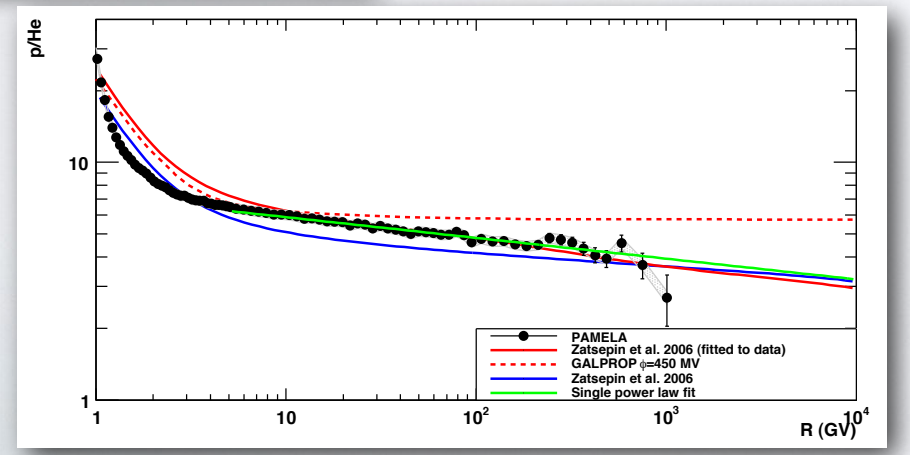
CHARGED CR BREAKTHROUGH YEARS

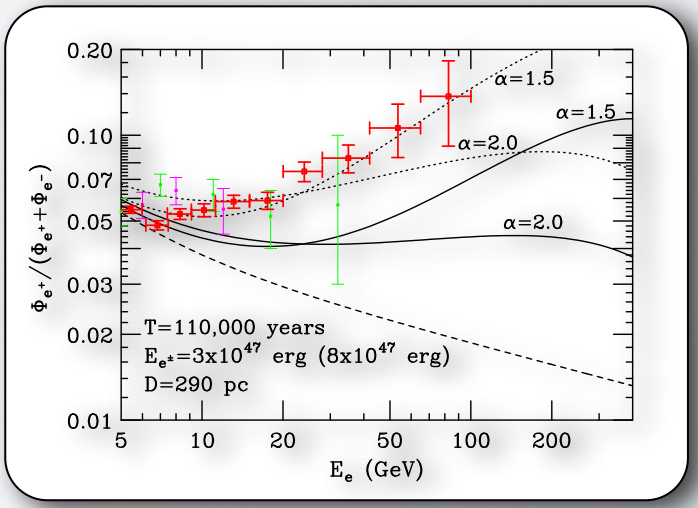




Thanks to CREAM, PAMELA, Voyager, AMS-02…
still continuing with CALET, DAMPE…







INFERENCES FROM PRECISION DATA

Examples of a long-standing collaboration LAPTh-LAPP-LPSC (& beyond) - CRAC (© P. Salati)
Lately joining forces notably for positrons

M. Boudaud et al., ``A new look at the cosmic ray positron fraction," Astron. Astrophys. 575, A67 (2015)
M.~Boudaud et al., "The pinching method for Galactic cosmic ray positrons: implications in the light of precision measurements," Astron. Astrophys. 605, A17 (2017)

antiprotons (officially only theorists…)

and B/C interpretation

Y. Génolini, A. Putze, P. Salati and P. D. Serpico, "Theoretical uncertainties in extracting cosmic-ray diffusion parameters: the boron-to-carbon ratio," Astron. Astrophys. 580, A9 (2015)

Y. Génolini, et al. ``Indications for a high-rigidity break in the cosmic-ray diffusion coefficient," Phys. Rev. Letters, in press [1706.09812]

suggesting a propagation origin for the spectral breaks in hadronic CR spectra observed by AMS

ASSESSMENT OF THEORY ERRORS: LOCAL SOURCE EFFECTS

Overall flux coming from N discrete sources $\Psi = \sum_{i=1}^{N} \psi_i$ does not necessarily match "continuum" average $\langle \Psi \rangle = \frac{q\,\nu}{2\,h\,\pi R^2}\,\frac{h\,L}{K}$

Actual flux obeys a prob. distribution obtained as convolution of single pdfs $P_N(\Psi) = \int_{\psi_1}\int_{\psi_2}..\int_{\psi_N} p(\psi_1)\,p(\psi_2)..p(\psi_N)\,\delta\left(\sum_i^N \psi_i - \Psi\right)\,\mathrm{d}\psi_1\mathrm{d}\psi_2..\mathrm{d}\psi_N$

It turns out that the diffusive solution $\psi = \frac{q}{(4\pi K\tau)^{3/2}}\exp\left(-\frac{d^2}{4K\tau}\right)$

implies *power-law pdf p(ψ)* with *infinite variance*

(Central Limit Theorem does not apply, fat-tail distributions!)

"Stable Laws" replace Gaussians for some range of N,Ψ

with current exp. precision, *sizable probability to see deviations from average theory predictions*, even if the model is correct!

Y. Génolini, P. Salati, P. D. Serpico, R. Taillet, Astron. Astrophys. 600, A68 (2017)

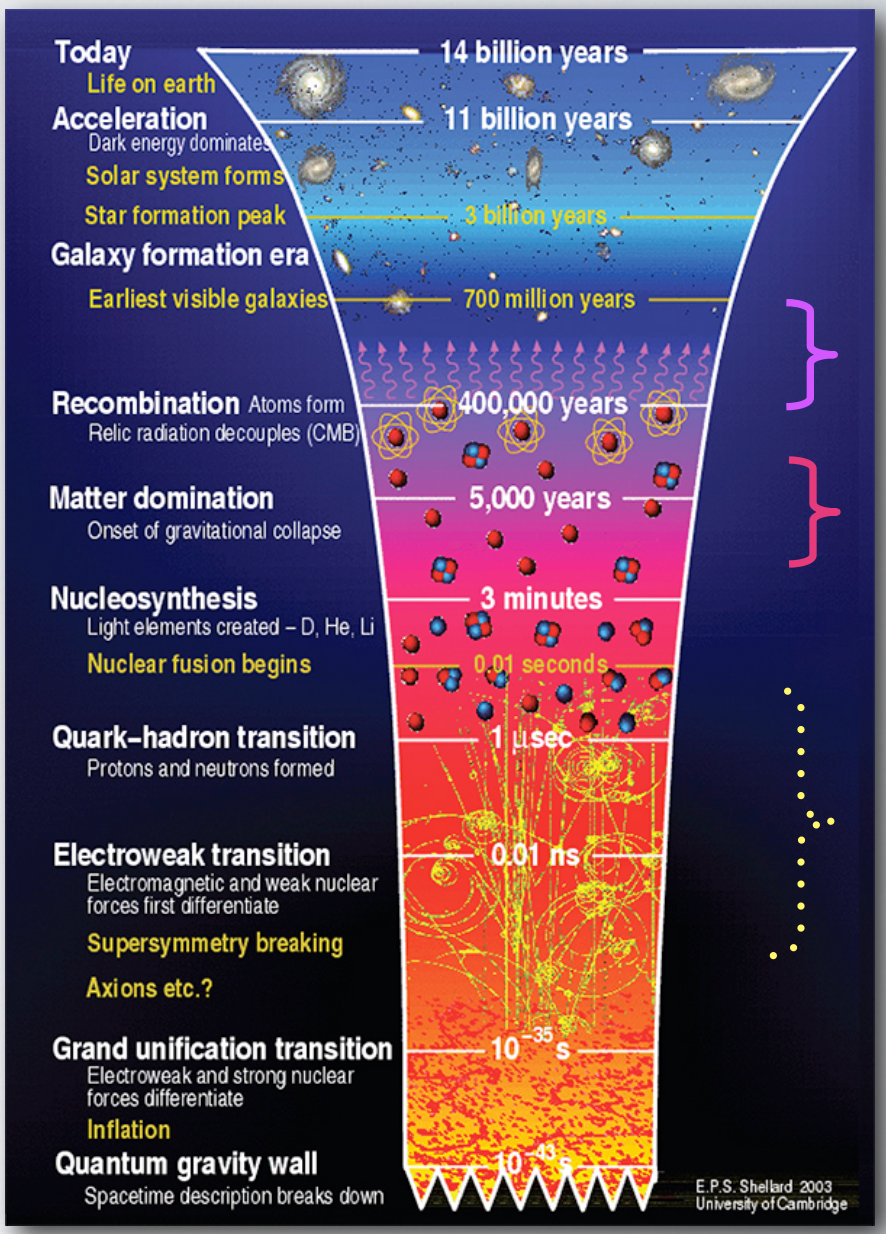
PARTICLE COSMOLOGY

Explore the particle physics diagnostics potential of new cosmological windows, like:

- pre-recombination, from BBN to CMB (e.g. non-thermal BBN, CMB distortion)
- or post-recombination till the formation of the first virialized structures (e.g. reionization, intergalactic medium heating, 21 cm radiation…)
- relics from radiation-domination, e.g. phase transitions, Primordial Black Holes (PBH)

Links with colliders / BSM physics / future searches (e.g. LISA)

1 PhD and 1 postdoc just left, currently mostly done in external collaborations



SOME EXAMPLES

- **CMB bounds on relics from the Early universe**

  - Change of potential wells / anomalous ISW due to decay into relativistic species, or PBH evaporations, or mergers (if making sizable DM fraction)
  - Injection of e.m. energy, altered reionization/optical depth: bounds on annihilating and decaying WIMPs, sterile ν's, evaporating PBH, PBH accretion… sensitive down to 10^{-11} of the DM!

V. Poulin, P. D. Serpico, J. Lesgourgues, "A fresh look at linear cosmological constraints on a decaying dark matter component," JCAP 1608 036 (2016).
"Cosmological constraints on exotic injection of electromagnetic energy," JCAP 1703, 043 (2017)
V. Poulin, P. D. Serpico, F. Calore, S. Clesse and K. Kohri, "CMB bounds on disk-accreting massive primordial black holes," Phys. Rev. D 96, 083524 (2017)

- **non-thermal effects on BBN & CMB**

  - precision calculations of energetic particles spectra in the primordial plasma. Effects on photodissociation of primordial elements, CMB energy spectrum distortions… links with sterile ν sector?
  - BBN & long-lived searches at colliders (and/or exotic DM candidates.)

V. Poulin, P. D. Serpico, "Loophole to the Universal Photon Spectrum in Electromagnetic Cascades and Application to the Cosmological Lithium Problem," Phys. Rev. Lett.114 , 091101 (2015) "Nonuniversal BBN bounds on electromagnetically decaying particles," Phys. Rev. D 91,103007 (2015)
S. Banerjee, G. Bélanger, B. Mukhopadhyaya, P. D. Serpico, "Signatures of sneutrino dark matter in an extension of the CMSSM," JHEP 1607, 095 (2016)

- **Pre-BBN: Exotic Electroweak Phase Transition, Inflation…**

If EW sector described by classically conformal dynamics, 1st-order, six massless quark QCD phase transition occurs first, which then triggers the electroweak symmetry breaking. Light weakly coupled particles are predicted, implications for collider searches. Renewed possibilities for electroweak baryogenesis, altered dark matter production, sizable gravitational wave production (LISA?), possibly PBH…

S. Iso, P. D. Serpico, K. Shimada, "QCD-Electroweak First-Order Phase Transition in a Supercooled Universe," Phys. Rev. Lett. 119, 141301 (2017)