Highlights of the IFAC group DRAFT VERSION as of Jan. 18th 2014

IFAC

(Fundamental Interactions, Astroparticle physics and Cosmology)

Scientific Highlights

Cyril Hugonie
(IFAC coordinator)
BSM

Michel Capdequi-Peyranère
BSM (retired 09/13)

Stephan Narison
QCD

Particle Physics:
Standard Model (QCD) +
Beyond the Standard Model

IFAC

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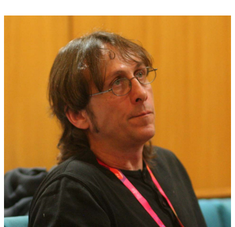
Dark matter:
Candidate particles
Indirect/direct searches

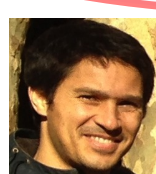
Cosmic-ray physics

Early Universe
and
Cosmology

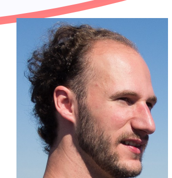
IFAC



Karsten Jedamzik
EU&C, DM, BSM



Julien Lavalle
DM, CR, BSM



Stephano Magni (PhD)
DM, CR

+ Emiriti:
Pierre Grangé (QFT)
Fernand Renard (BSM)

Selected Highlights

** Very basic introduction on Supersymmetry and by-products (for non-experts)

* **H1:** Phenomenology in the **Next-to-Minimal Supersymmetric Standard Model** (NMSSM) – Cyril Hugonie++.

* **H2:** Cosmic-ray **antiproton constraints** on annihilating **Dark Matter** particles – Julien Lavalle++.

* **H3:** Cosmic Microwave Background (**CMB**) **constraints on primordial magnetic fields** – Karsten Jedamzik ++.

NB: many other interesting results by other IFAC members.
Dict.: ++ = et alii (abbrev. et al.)

Supersymmetry

Context:

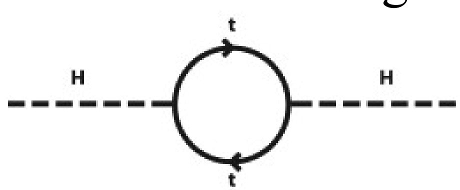
Standard model (SM) of elementary particles:

=> successful predictions (e.g. W, Z + …. **Higgs boson!**), **BUT** does not account for:

- matter/antimatter asymmetry
- neutrino masses, mass hierarchy
- etc. (dark matter + inflation + quantum gravity + grand unification + ...)

=> New physics is required => new energy scale(s) in the theory.

If a new high-energy scale Λ is introduced, the SM Higgs sector gets unstable, as the Higgs boson mass receives large quantum corrections $\propto \Lambda^2 >> m_H^2$ ($m_H \sim 100$ GeV):

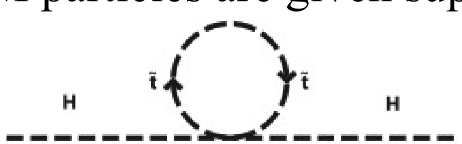


$$\delta m_H^2 \propto -\lambda_f^2 \Lambda^2$$

The so-called **hierarchy (fine-tuning) problem**

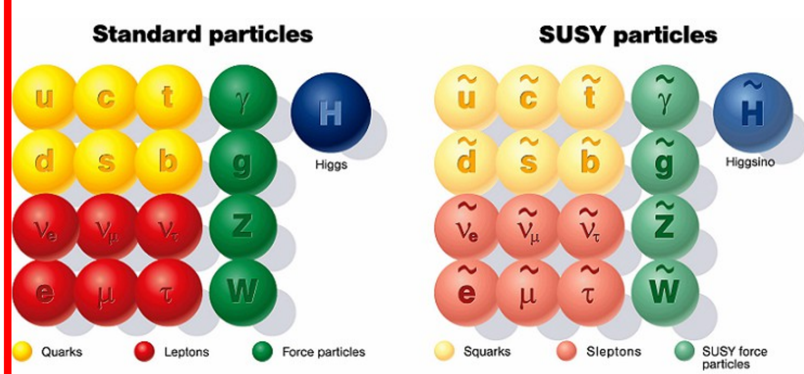
Supersymmetry/Supergravity (SUSY/SUGRA)
→ a (non-unique) potential paradigmatic solution

=> SM particles are given superpartners (bosons ↔ fermions)



$$\delta m_H^2 \propto \lambda_{\tilde{f}} \Lambda^2$$

** long thought to solve hierarchy pb (very mildly LHC says)
** Higgs mechanism more natural (dynamical in cMSSM)
** proton stability => R-parity => lightest SUSY particle stable
=> Dark matter candidates! (e.g. neutralino, sneutrino, gravitino)



+ richer Higgs sector
(more states than in SM)

Highlight 1

A SUSY scenario: The NMSSM

Supersymmetric phenomenology:

MSSM: Minimal Supersymmetric Standard Model $\mathcal{W}_{\text{MSSM}} \supset \mu\, \widehat{H}_u\, \widehat{H}_d$

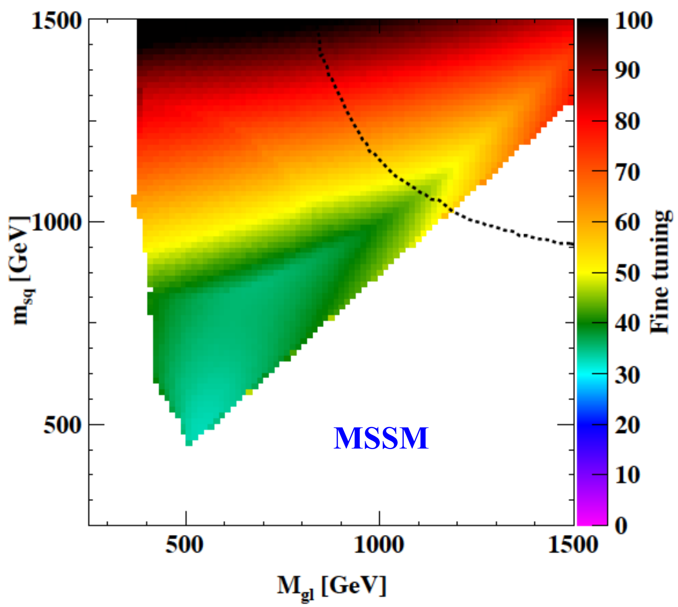
MSSM includes a (SUSY) mixing term mu, constrained to be ~ 1 TeV for the SM Higgs mechanism to work => no theoretical reason for that (not natural: should be SUSY scale instead).

Next-to-MSSM: promotes mu as a new singlet chiral superfield $\mathcal{W}_{\text{NMSSM}} \supset \lambda\, \widehat{S}\, \widehat{H}_u\, \widehat{H}_d + \frac{\kappa}{3}\, \widehat{S}^3$

=> 2 extra singlet-like Higgs states (scalar+pseudo-scalar) + 1 extra singlet-like neutralino (singlino dark matter)

Virtues: less fine-tuning (pre-LHC), richer Higgs sector, possibly very light particles (singlino + Higgs states).

At LUPM: Dev. of calculation tools (NMSSMtools) → particle mass spectrum and couplings + pheno Higgs/DM.

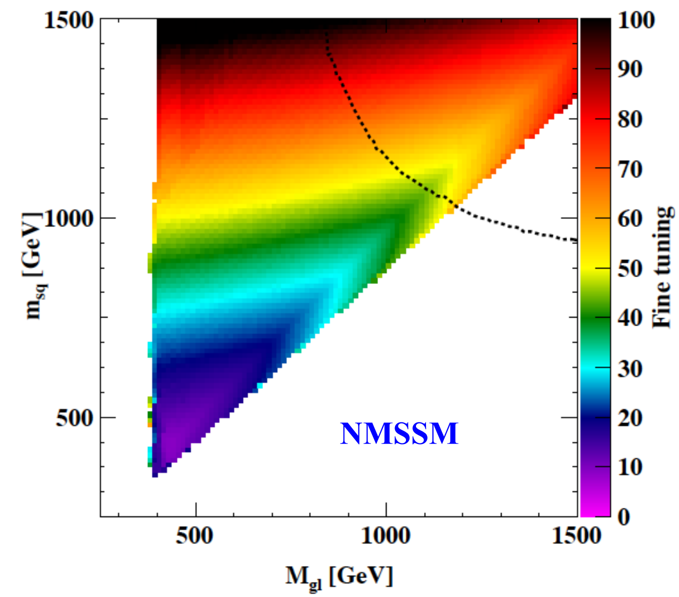


A fine-tuning measurement

$$\Delta_i^{\text{Susy}} = \left| \frac{\partial \ln(M_Z)}{\partial \ln(p_i^{\text{Susy}})} \right|$$

Ellwanger, Espitalier-Noël & **Hugonie**
JHEP (2011)

Based on **NMSSMtools**
(Ellwanger, Gunion & **Hugonie**)

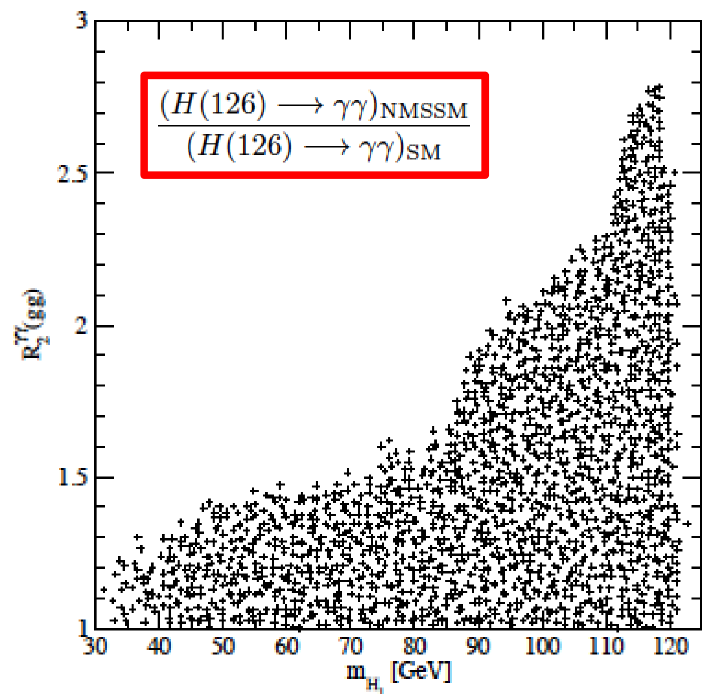


NMSSM: light Higgs and dark matter

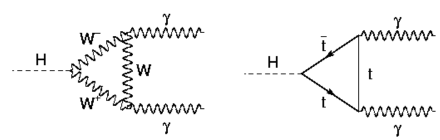
Higgs phenomenology:

Higgs boson discovery in 2012

** A second CP-even Higgs could be lighter than the one discovered at LHC at 126 GeV!
=> interesting non-standard search/discovery prospects! (within reach of LHC-run2).



Branching ratio of H (126 GeV) decay vs. h mass (wrt SM values)



Ellwanger & **Hugonie**
AHEP (2012)

At LUPM: (from NMSSMtools)

*** Second lighter Higgs natural in NMSSM => modification of 126 GeV Higgs decay**
=> not possible in MSSM => NMSSM signature
=> may modify branching ratio into gamma-gamma.

Important result after first LHC data (small excess in gamma-gamma, though not statistically relevant).

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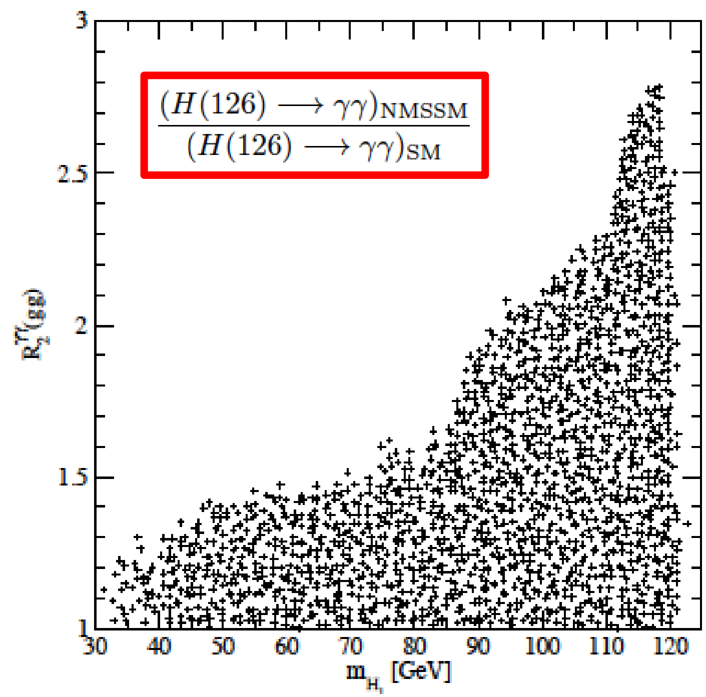

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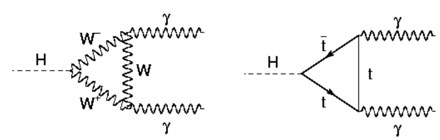

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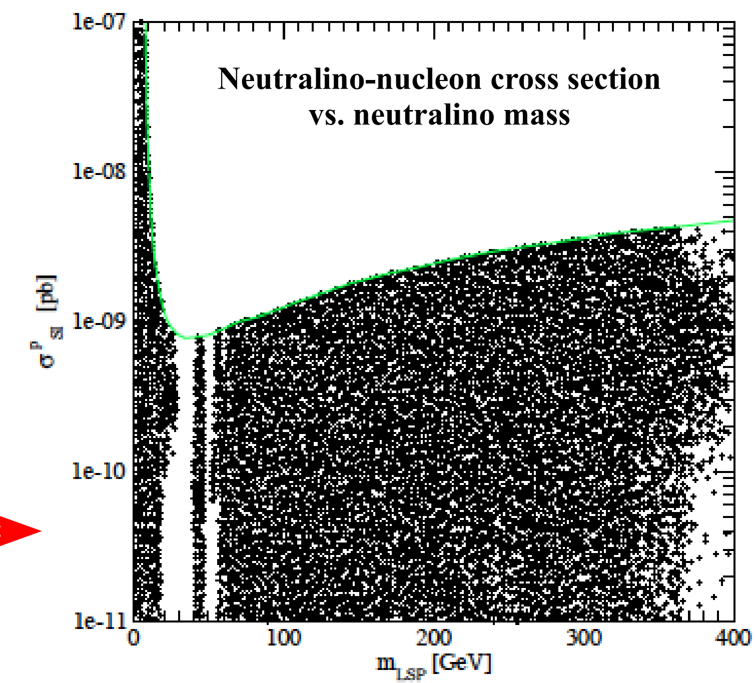
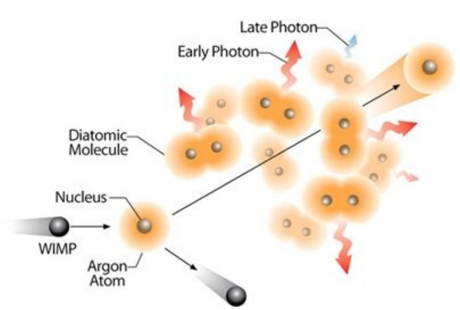
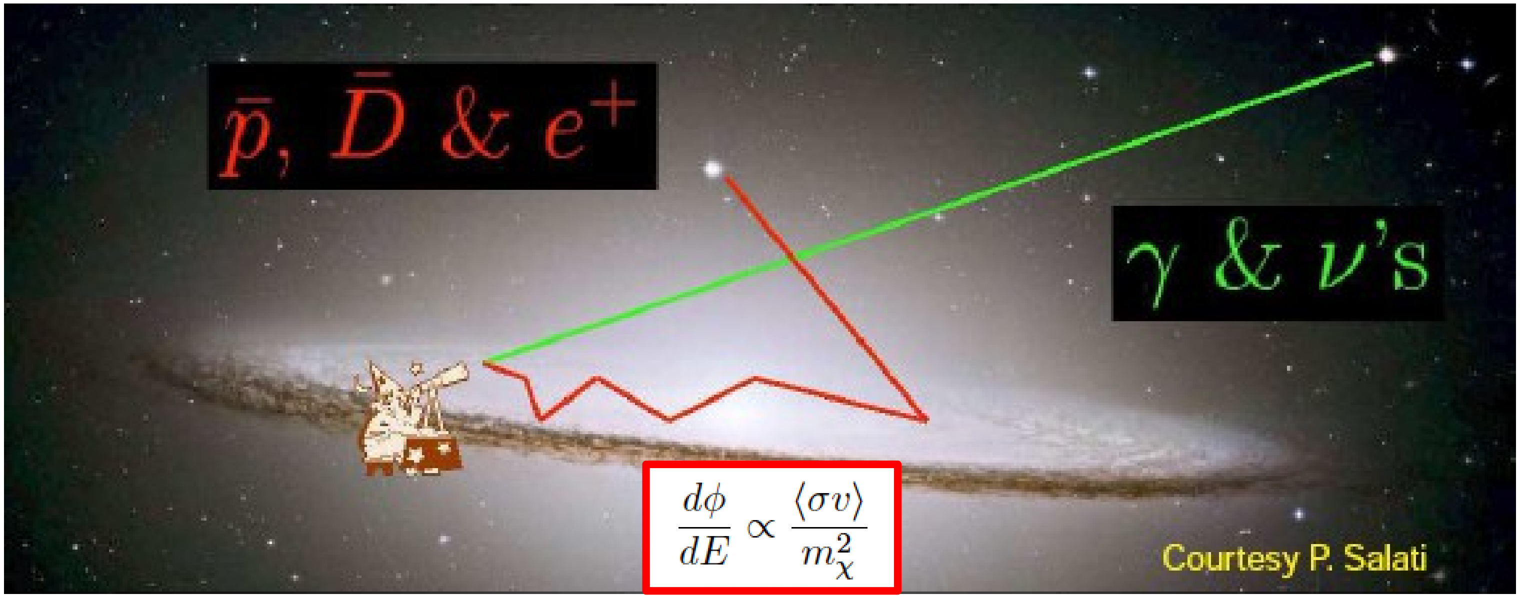


Direct DM detection example

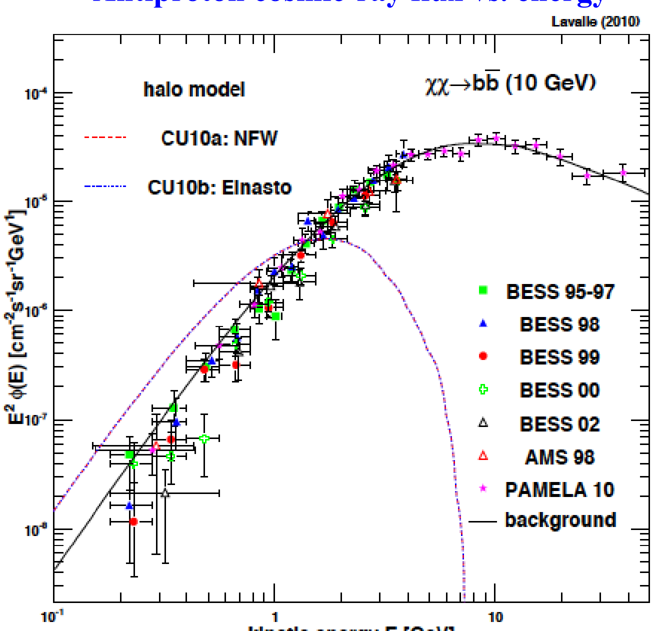


Consequences on neutralino DM:
=> neutralino can be very light (singlino)
=> interesting region for direct detection
=> constrained by indirect searches

Indirect dark matter searches: Light WIMPs and antiprotons



Antiproton cosmic-ray flux vs. energy



$$\chi\,\bar{\chi} \longrightarrow q\,\bar{q} \longrightarrow p\,\bar{p},\, e^+\,e^-,\gamma,\,...$$

If light WIMPs annihilate into quarks, cosmic-ray antiproton data induce severe constraints => 10 GeV WIMPs excluded (if S-wave annihilation into quarks) → relevant to interpretation of direct detection hints.

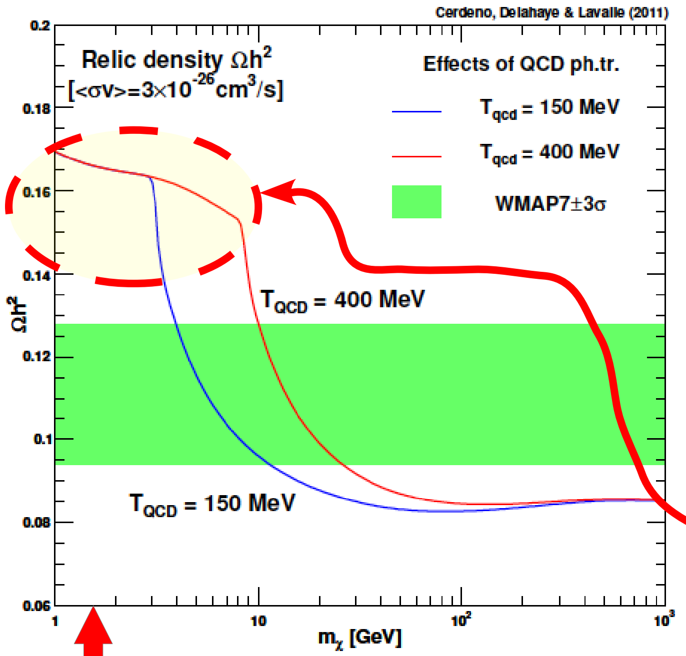
=> Constraints stronger than with gamma-rays!

AMS-02 data will allow improvements.

Lavalle, PRD (2011)

Indirect dark matter searches: Singlino-like candidates (e.g. NMSSM)

Relic density vs. mass

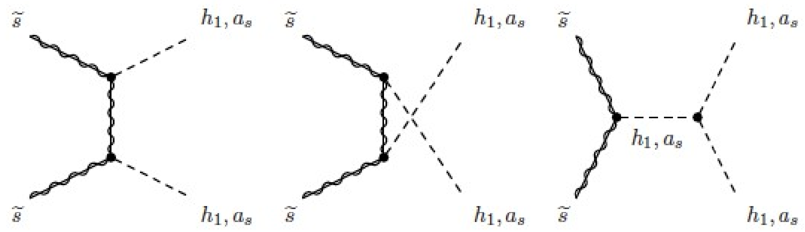


Cerdeno, Delahaye & **Lavalle**
NPB (2012)

$$\Omega_\chi \tilde{\propto} \frac{1}{g_\star^{1/2}(x_{\rm dec})\,\langle\sigma v\rangle}$$

Singlino-like DM (e.g. NMSSM) may instead annihilate into light Higgs bosons
=> light DM candidate (1-20 GeV)
=> interesting cases for direct detection

Annihilation diagrams



=> Annihilation cross-section can be larger than canonical value (degrees of freedom in the early universe).

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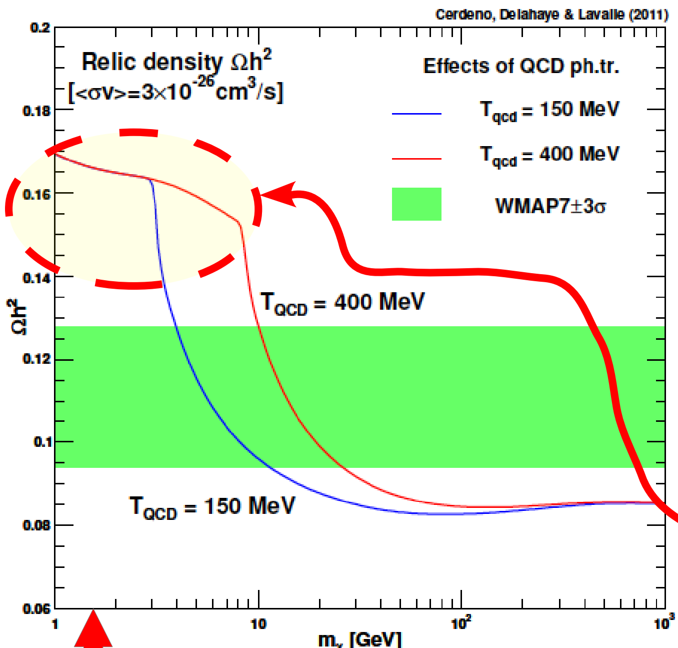

Cerdeno, Delahaye & **Lavalle**
NPB (2012)

$$\Omega_\chi \,\tilde{\propto}\, \frac{1}{g_\star^{1/2}(x_{\rm dec})\,\langle\sigma v\rangle}$$

$$\langle\sigma v\rangle \approx \underbrace{\overbrace{a}^{\text{in galaxies}} + b/x + \mathcal{O}(x^{-2})}_{\text{relic density}}$$

$$x \equiv m_\chi/T \propto m_\chi/v^2$$

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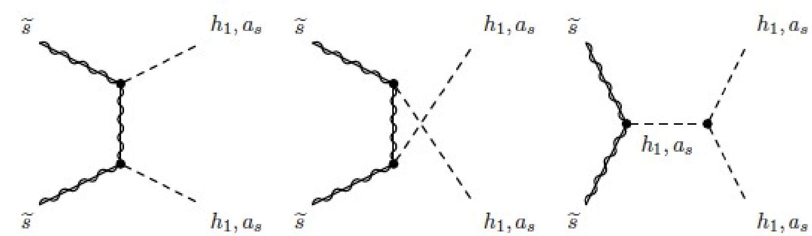


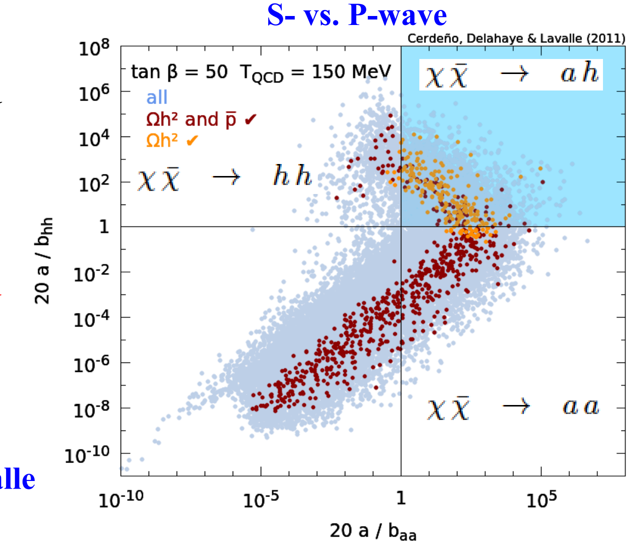
=> Annihilation cross-section can be larger than canonical value (degrees of freedom in the early universe).

=> Use that light Higgs → quarks
=> antiproton constraints!

=> but not necessarily S-wave dominated (S-wave only if annihilation in scalar+pseudo-scalar dominates).

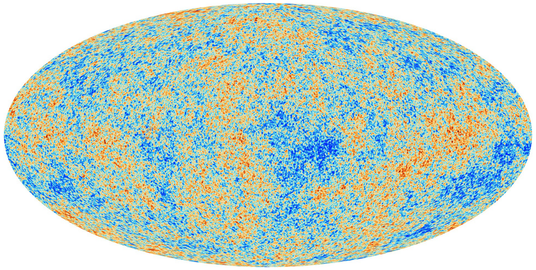
Strong antiproton constraints when a/b>>1
(annihilation in the Galaxy efficient)
=> very useful for model selection.

S- vs. P-wave



Cerdeno, Delahaye & **Lavalle**
NPB (2012)

Highlight 3



Credit: Planck/ESA

CMB Constraints on primordial magnetic fields

* **Primordial Magnetogenesis**: how were the primordial magnetic fields (B) generated? During/after inflation?
=> achieved amplitudes depend on models (B generated during inflation disfavored)
=> set the intergalactic, intercluster, B-field.

Contrary to common belief, small-scale primordial B-fields may induce density perturbation at recombination on scales observable by CMB experiments (Abel & **Jedamzik**, JCAP 2013).

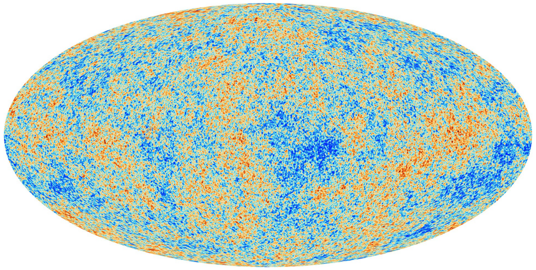
From Euler (Navier-Stockes) equations:

$$\frac{\partial \vec{v}}{\partial t} + (\vec{v}\cdot\vec{\nabla})\vec{v} + c_s^2 \frac{\vec{\nabla}\rho}{\rho} = -\alpha\,\vec{v} - \frac{\vec{B}\times(\vec{\nabla}\times\vec{B})}{4\,\pi\,\rho}$$

$$\frac{\partial \rho}{\partial t} - \vec{\nabla}(\rho\,\vec{v}) = 0$$

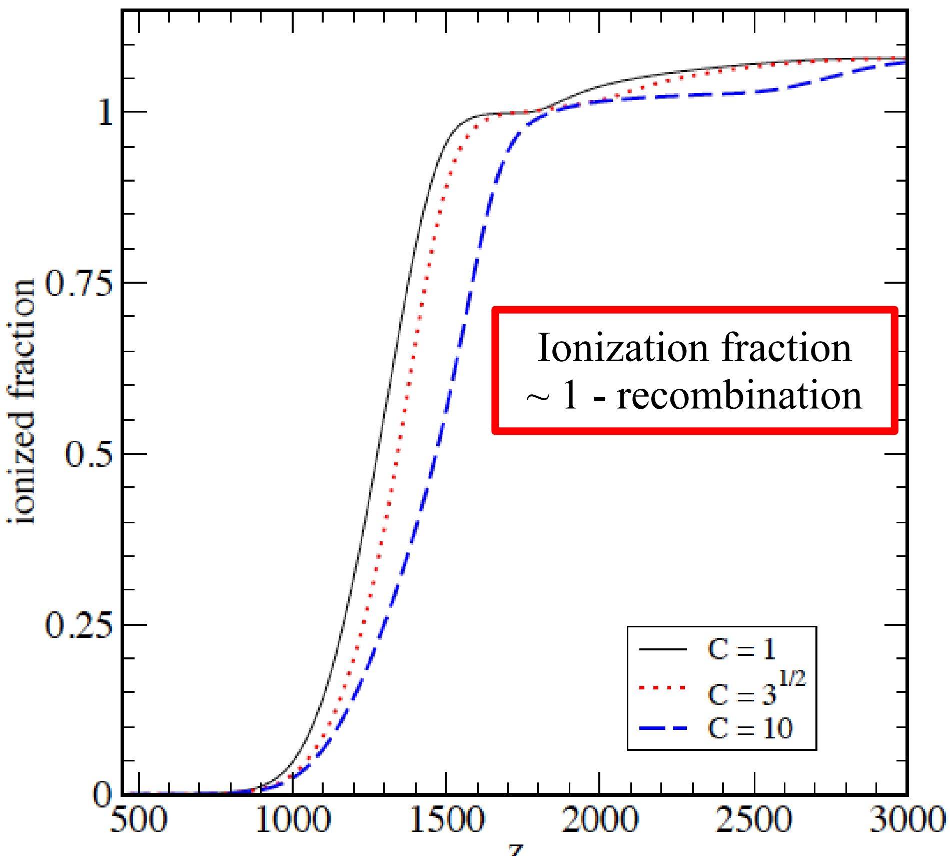
$$\frac{\delta\rho}{\rho} \approx \min\left[1, \left(\frac{v_A}{c_s}\right)^2 \propto B^2\right]$$

Density perturbations induced by B-field!

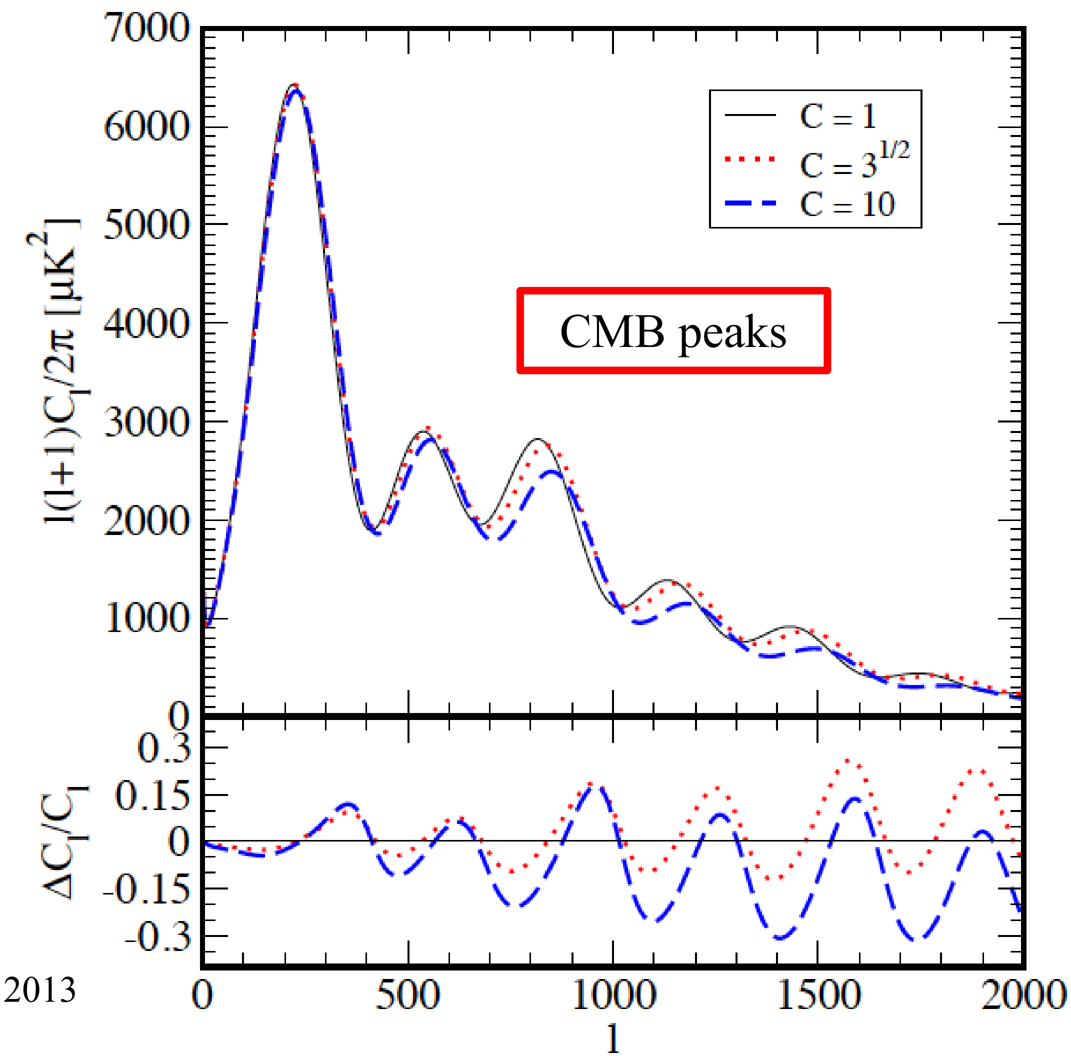

Credit: Planck/ESA

CMB Constraints on primordial magnetic fields

=> Recombination may occur earlier
=> CMB peaks moved, Silk damping amplified.



Abel & **Jedamzik**, JCAP 2013



Planck experiment may detect/exclude.
Warning: Challenging because need % accuracy in dark matter / dark energy measurements.