DESY Theory Workshop

Parallel Session 2: Cosmology & Astroparticle Physics

The 130GeV gamma-ray line and DM model-building constraints from continuum gamma rays, radio and antiproton data

Universität Hamburg

DER FORSCHUNG | DER LEHRE | DER BILDUNG

Masaki Asano, Torsten Bringmann,
Günter Sigl & Martin Vollmann

II. Institut für Theoretische Physik

Universität Hamburg

Outline

- The “Weniger's” 130GeV gamma-ray line
- Consequences on further observable phenomena
- Optical Theorem
- Continuum Gamma Ray, Antiproton & Radio Constraints
- Derived constraints on Im($M_{i\to j}$)
- Applications
- Conclusions

The "Weniger's" 130GeV *Line*

(Quasi-)monochromatic γ-ray line at the GC ⇒ Smoking-gun signature for indirect DM searches

- Weniger's analysis (1204.2797):
  - 43 months of *Fermi-LAT* data
  - Optimized target regions
  - → **3.2$\boldsymbol{\sigma}$ Gamma-ray line with $\boldsymbol{E_\gamma}$=130GeV**
- If interpreted as $\chi\chi \rightarrow \gamma\gamma$, γZ or γH ⇨ m_χ = {130GeV, 145GeV, 155GeV} & $\sigma v \sim 10^{-27}\mathrm{cm}^3/\mathrm{s}$
- DM interpretation on debate

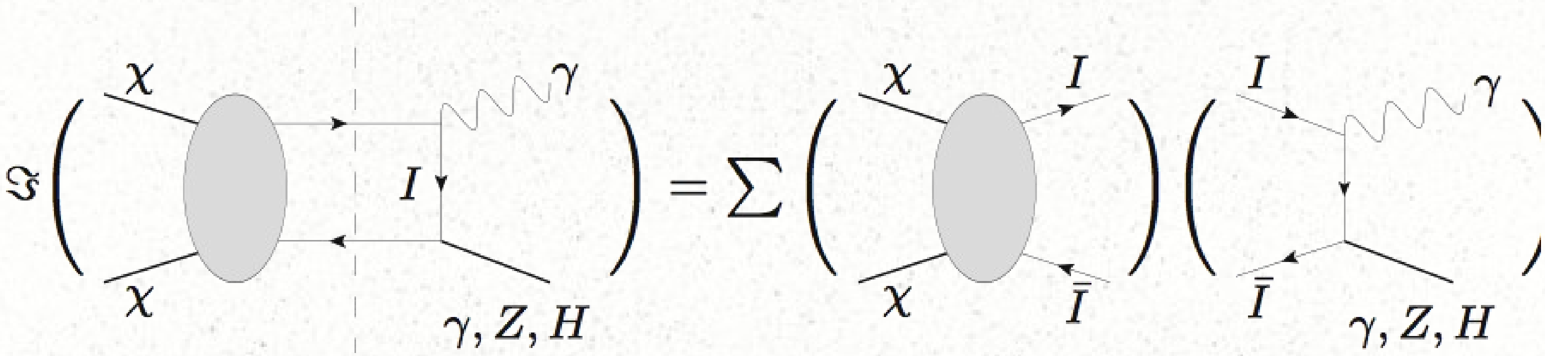
Consequences on further observable phenomena

- $\chi\chi \rightarrow \gamma\gamma$, γZ & γH ⇨ 1-loop processes (χ's are electrically neutral)
- Some questions you might be asking yourselves:
  - ✍ What kind of particles run on the loops?
  - ✍ If these were SM pairs, how are the associated *tree-level* annihilation cross sections related to the line's?
  - ✍ Can we derive such relations in a model-independent way?

💡 *"Generalized" Optical Theorem* (see Abazajian et al. Hep-ph/1111.2835)

Optical Theorem

- We make use of the “generalized” optical theorem



- With two conditions, though:
  - Interaction must respect CP and Lorentz invariance
  - Initial $|i\rangle$ and final $|f\rangle$ states must be eigenstates of the *CM* total angular momentum *J,M*.

Remark: The case where the initial and final states are identical yields to the familiar optical theorem

Optical Theorem (Cont.)

- The master formula

$$r_{i\to f} \equiv \frac{\left(\Im\left[\mathcal{M}_{i\to f}\right]\right)^2}{|\mathcal{M}_{i\to f}|^2} \propto \frac{\sum_I \sigma_{i\to I} \sum_I \sigma_{f\to I}}{\sigma_{i\to f}}$$

constraints Im($M_{i\to j}$)/$M_{i\to j}$, since as input we have

$\sum_I \sigma_{f\to I}$ from the Standard Model

$\sum_I \sigma_{i\to I}$ from the continuum γ-ray, antiproton and radio constraints

$\sigma_{i\to f}$ from Weniger's ansatz

Computation of tree-level amplitudes

- Initial state $\Longrightarrow$ s-wave (L=0)

  ↪ Squared amplitudes of e.g. p-waves are proportional to β^2 (typically ~ 10^{-6})

- J & CP conservation $\Longrightarrow$ $|f\rangle$ (=$|\gamma\gamma\rangle$,$|\gamma Z\rangle$ or $|\gamma H\rangle$) share the associated (J & CP) quantum numbers with $|i\rangle$(= $|\chi\chi\rangle$) and also with $|I\rangle$

Computation of tree-level Amplitudes (Cont.)

$M_{f \to l}$ computation

- Obtain the 4-momentum space amplitudes by means of Feynman rules
- Integrate these times appropriate spherical harmonics to get definite L states
- Use the appropriate Clebsch-Gordan coeficients to get definite S states

Continuum γ-ray, Antiproton & Radio Constraints

SM products of DM annihilations may fragment into stable particles (including γ, $e^{\pm}$,$p^{\pm}$,...) which can (among many other processes)

- Undergo diffusion
- Interact with the low-energy radiation background (e.g. ICS)
- Get bent in the Galactic Magnetic Field and emit synchrotron radiation

$$\Downarrow$$

Relatively well understood continuum γ spectrum, Antiproton fluxes and Synchrotron radiation

Dark Matter Profile

$$\rho_\chi(r) = \rho_\odot \exp\left(\frac{2}{\alpha}\frac{R_\odot^\alpha}{r_s^\alpha}\right) \exp\left(-\frac{2}{\alpha}\frac{r^\alpha}{r_s^\alpha}\right)$$

where $\alpha = 0.17,\ r_s = 20\,\mathrm{kpc},\ R_\odot = 8.5\,\mathrm{kpc}$ &
$\rho_\odot = 0.4\,\mathrm{GeV\,cm}^{-3}$

Continuum Gamma Rays

We use the most recent sets of constraints

- Dwarf spheroidal galaxies ([Fermi-LAT collab.] 1108.3546)
  - They adopt NFW profiles respect to the centers of the dwarfs
- Galactic Center (Cholis et al. 1207.1468)
  - Slightly different DM profile
    - Constraints scale with $J \equiv \int_{\Delta\Omega} d\Omega \int_{l.o.s.} \mathrm{d}s\rho^2(r)$
    - ⇒ Multiply by a factor

Antiprotons

We adopt two different CR propagation models (see Evoli et al. [astro-ph.HE 1108.0664])

- 'KRA' (L=4kpc,)
- 'CON' (L=10kpc)

- With help of DarkSUSY obtain the primary antiproton flux coming from DM annihilations
- Prescription to constrain DM annihilation rates:

Minimally expected Astrophysical background + Signal < PAMELA data + 3σ

Synchrotron Radiation

- $e^{\pm}$ bent in the Galactic Magnetic Field emit synchrotron radiation at radio frequencies
- Galactic Magnetic Field

$$B(r) = 7.2\,\mathrm{mG} \times \begin{cases} (R_{\mathrm{acc}}/r)^{5/4} & r < R_{\mathrm{acc}} \\ (R_{\mathrm{acc}}/r)^{2} & R_{\mathrm{acc}} < r \lesssim 100 R_{\mathrm{acc}} \\ 10^{-4} & r \gtrsim 100 R_{\mathrm{acc}} \end{cases}$$

where $R_{\mathrm{acc}} \approx 0.04\,\mathrm{pc}$ is the accretion radius of the central SMBH

- Synchrotron radiation spectrum for energy-loss dominated distribution of $e^{\pm}$

$$\nu \frac{\mathrm{d}W_{\mathrm{syn.}}}{\mathrm{d}\nu} \approx \frac{(\sigma v)_{\chi\chi\to\mathrm{SM}}}{2M_\chi^2} \int_{\mathrm{cone}|r\lesssim 1.4\,\mathrm{pc}} E_c \rho_\chi^2(r) N_e(E_c)\,\mathrm{dV}$$

- Prescription: $\nu \frac{\mathrm{d}W_{\mathrm{syn.}}}{\mathrm{d}\nu}\Big|_{\nu=408\,\mathrm{MHz}} < 50\,\mathrm{mJy}$

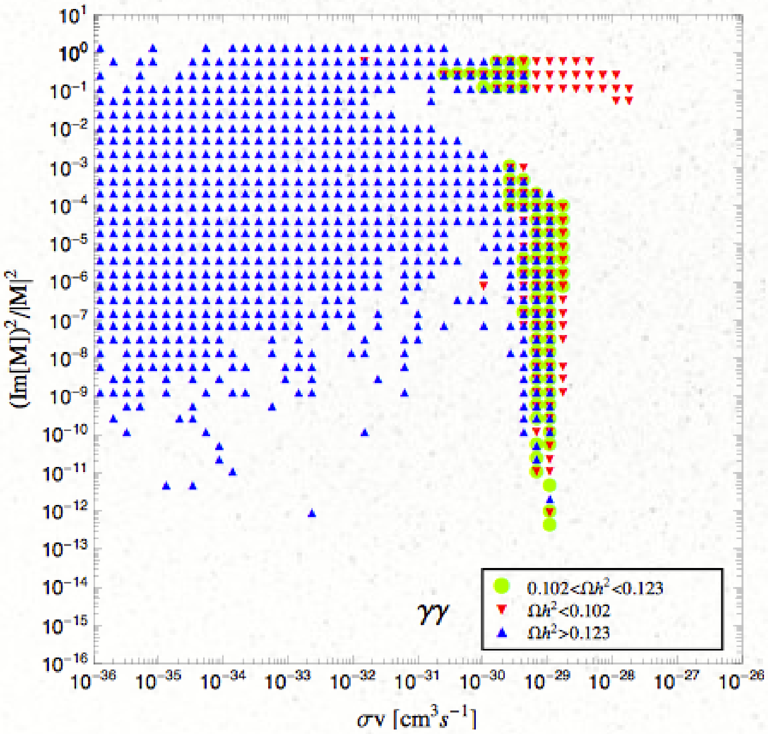
Preliminary Constraints on $\mathrm{Im}(M_{i\to j})$

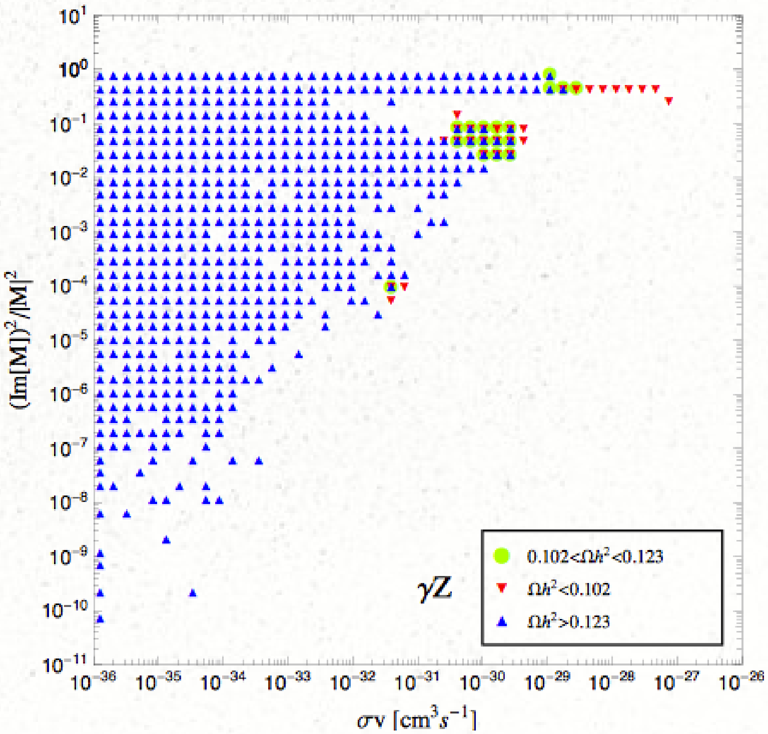
Majorana WIMP	cont. gamma (GC)	antiprotons ('KRA', $L = 4\,\mathrm{kpc}$)	synchrotron
$b\bar{b}$	1.0×10^{-5} (3.1×10^{-6})	5.1×10^{-6} (1.6×10^{-6})	1.37×10^{-5} (4.14×10^{-6})
$\tau^+\tau^-$	4.9×10^{-5} (2.0×10^{-7})	—	9.03×10^{-5} (3.95×10^{-7})
$\mu^+\mu^-$	8.7×10^{-7} (3.3×10^{-9})	—	5.66×10^{-7} (2.57×10^{-9})
e^+e^-	2.9×10^{-11} (8.7×10^{-14})	—	3.34×10^{-11} (1.54×10^{-13})
W^+W^-	0.037 (0.21)	0.014 (0.083)	0.046 (0.026)

Bounds on $r_{i\to j}$ for $m_\chi = 130\,\mathrm{GeV}$ $(145\,\mathrm{GeV})$. Loops dominated by the mentioned particle/antiparticle pairs

Applications to model-building

- Using DarkSUSY scan over several supersymmetric models and obtain





Conclusions

- Interesting debate on the 130GeV gamma-ray line at the GC
- If proven right, theoretical implications rule out a number of models with DM candidates
- Optical Theorem proves useful for this task.
  - Nonetheless, if Weniger's theory is proven wrong, it is still a very powerful tool to assess new physics
- Even though several SUSY theories seem not to explain all the observations + the gamma-ray line, there is still room for models consistent with both of them
  - However, DM would not be thermally produced