Constraining SUSY parameters through collisions of AGN jets with Neutralino dark matter

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With A. Rajaraman, T. Tait, JCAP 1205 (2012) 027
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Who is responsible to questions?
AGN: Probe TeV New Physics

• Active Galactic Nuclei (AGN) is a natural accelerator
• Complementary approach to probe new physics at TeV scale:
  • can study dark matter properties
  • test some models, e.g. SUSY, Extra Dimension
  • might be sensitive to parameter region (not sensitive at LHC)
• In this talk:
  • dark matter particle scatters with AGN jet and radiate photons
  • observe the photon energy flux through Fermi-LAT
  • potentially constrain parameter space of SUSY models
AGN: a Natural Accelerator

http://www.isdc.unige.ch/gallery.cgi?INTEGRAL
Detect High Energy Gamma Ray from DM Scattering with AGN Jet


Our estimate of the signal for electron-bino scattering into photons from a single AGN source is too low to be discerned by currently proposed experiments, but future detectors of much higher sensitivity might be able to see a signal.
Fermi-LAT is a multi-purpose telescope:

- To understand the mechanisms of particle acceleration in active galactic nuclei (AGN), pulsars, and supernova remnants (SNR).

- Probe dark matter (e.g. by looking for an excess of gamma rays from the center of the Milky Way) and early Universe.
Centaurus A: closest Active Galaxy

N. Neumayer, arXiv:1002.0965

Basic parameters:
\[ d_{AGN} \approx 3.7 \text{ Mpc} \]
\[ M_{BH} \approx (5.5 \pm 3.0) \times 10^7 \text{ M}_{\odot} \]
\[ t_{BH} \approx 10^8 - 10^{10} \text{ yrs} \]
\[ <\sigma v> \approx 10^{-30} - 10^{-26} \text{ cm}^3 \text{ s}^{-1} \]
\[ \theta \approx 68^\circ \]
\[ L_e \approx 10^{43} - 10^{46} \text{ erg s}^{-1} \]
Photon Energy Flux of Centaurus A from Fermi-LAT

Black bowtie: best fit 0.1 – 30 GeV LAT flux and $\Gamma$ with statistical errors only.

Green bowtie: + systematic errors.

Dashed Lines: extrapolation from the LAT spectrum into the HESS energy range.
Some Questions from Fermi-LAT Results...

- Is it possible to explain drop-off feature through dark matter scattering with AGN jet?
- Is it possible to constrain parameter space for certain SUSY models?
Photon Energy Flux\( \nu F_{\nu} \)

M. Gorchtein, S. Profumo, L. Ubaldi, Phys. Rev. D 82, 083514 (2010);

Photon Energy Flux: \( \nu F_{\nu} \sim E_{\gamma}^2 \frac{d\Phi_{\gamma}}{dE_{\gamma}} \)

\[
\frac{d\Phi_{\gamma}}{dE_{\gamma}} = \int \left[ (\delta_{DM}) \times \left( \frac{1}{d_{AGN}^2} \frac{d\Phi_{AGN}^{AGN}}{dE_{j}} \right) \times \left( \frac{1}{m_{\tilde{\chi}}} \frac{d^2\sigma}{dE_{\gamma}d\Omega_{\gamma}} \right) \right] dE_{j}
\]

Factor I: Dark Matter Density Profile

Factor II: energy distribution of AGN jet

Factor III: scattering cross section
Dark Matter Profile $\delta_{DM}$


**Cusp density profile:**

$$\delta_{DM} \equiv \langle \rho_{DM} R_{DM} \rangle = \int_{r_{\text{min}}}^{r_{\text{max}}} \rho_{DM}(r) dr$$

$$\rho_{DM}(r) = \frac{\rho'(r) \rho_{\text{core}}}{\rho'(r) + \rho_{\text{core}}}$$

$$\rho_{\text{core}} \approx \frac{m_{\chi}}{\langle \sigma v \rangle_0 t_{BH}}$$

$$\rho'(r) \propto r^{-\alpha}$$

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M. Gorchtein, S. Profumo, L. Ubaldi, 
Dark Matter Profile $\delta_{DM}$ (Cont.)

Integrating along the radius to obtain $\delta_{DM}$:

- It is SENSITIVE to $\rho_{\text{core}} \{m_\chi, \langle \sigma v \rangle, t_{BH}\}$;
- It is LESS sensitive to $r_{\text{min}}, r_{\text{max}}$;
- It is LESS sensitive to various parameters in $\rho'(r)$, such as power index $\alpha$.

We get:

$$\delta_{DM} = 10^8 - 10^{11} M_{\text{sun}} pc^{-2}$$
Electron Energy Distribution $d\Phi_{\text{AGN} e}^{\text{AGN}}/d\gamma$

- We assume electron AGN jet
- To obtain $d\Phi_{\text{AGN} e}^{\text{AGN}}/d\gamma$ in the Lab frame (Black Hole frame):
  - **We assume it follows Broken Power Law** in the Blob frame

In the Blob frame, electron energy distribution is isotropic

$$
\frac{d\Phi_{\text{AGN} e}^{\text{AGN}}}{d\gamma'}(\gamma') = \frac{1}{2} k_e \gamma'^{-s_1} [1 + (\frac{\gamma'}{\gamma'_{br}})^{s_2-s_1}]^{-1} \quad \gamma' = \frac{E'_e}{m_e} \\
(\gamma'_{\text{min}} < \gamma' < \gamma'_{\text{max}})
$$

$s_1 = 1.8, \quad s_2 = 3.5, \quad \gamma'_{br} = 4 \times 10^5, \quad \gamma'_{\text{min}} = 8 \times 10^2, \quad \gamma'_{\text{max}} = 10^8$

- **Transform** $d\Phi_{\text{AGN} e}^{\text{AGN}}/d\gamma'$ **from Blob frame to Lab frame** ($\Gamma_B \cong 3$)
- **Factor** $k_e$ can be obtained through Jet power in electron in the Lab frame

$$
L_e = \int_{-1}^{1} \frac{d\mu}{\Gamma_B (1 - \beta_B \mu)} \int_{\gamma_{\text{min}}}^{\gamma_{\text{max}}} d\gamma (m_e \gamma) \frac{d\Phi_{\text{AGN} e}^{\text{AGN}}}{d\gamma} (\gamma (\Gamma_B (1 - \beta_B \mu))) \\
(\mu = \cos \theta)
$$
Differential Cross Section $d^2\sigma/dE_\gamma \, d\Omega_\gamma$

- It is Model Dependent!
- I will present one SUSY model:
  - Neutralino ($\tilde{\chi}$) is the DM candidate
  - DM and electron AGN jet scatter and radiate photon

$$e + \tilde{\chi}(\rightarrow \tilde{e}) \rightarrow e + \tilde{\chi} + \gamma$$
**Theoretical Model**

**s Channel:**

\[ s = (p_1 + p_2)^2 \]

**u Channel:**

\[ u = (p_1 - p'_2)^2 \]

\[ u' = (p_2 - p'_1)^2 \]

**Gauge Invariant!**
Kinematics:
In Black Hole frame:
Initial $\tilde{\chi}$ at rest, initial AGN electron jet inject and scatter;
AGN jet is very collimated.

Parameters:

$m_\tilde{e} = 100\,\text{GeV}; \quad m_\tilde{\chi} = 60\,\text{GeV}; \quad \theta = 68^\circ$

Interaction couplings see J. Edsjo, arXiv:hep-ph/9704384v1
calculate all of the s-channel and u-channel as well as their interference terms;

make sure gauge invariance;

three enhancement effects:
- Resonance effect: $M_1 - M_3$
- Collinear effect: $M_2, M_5$
- Soft radiation effect: $M_2, M_5$

the electron energy has to be high enough to create high energy photon;

s resonance can be missing when the photon energy is too high;

and further explain the drop-off feature.
Differential Cross Section (Cont.)

\[ m_\tilde{e} = 100\text{GeV}; \quad m_\tilde{\chi} = 60\text{GeV} \]

\[ E_\gamma = 10\text{GeV} \]

\[ E_\gamma = 30\text{GeV} \]

\[ E_\gamma = 50\text{GeV} \]
Photon Energy Flux

Theory
Constraints

Counting Approach:

\[ \frac{S}{\sigma} \geq 2 \quad S = \int vS_v dE_\gamma \quad \sigma \sim 2.5 \times 10^{-12} \text{erg s}^{-1} \text{cm}^{-2} \]

Excluded Region:
inside contours

Different colors:
different photon energy range

Black dotted line:
LEP II null searches (PDG)

\[ \Delta m = m_{\tilde{e}} - m_{\tilde{\chi}} \]
Conclusion

• AGN can be an interesting object to probe TeV new physics
  – Understand some dark matter features
  – Test various theoretical models
• There are still large uncertainties about AGN
  – need better understanding of AGN
  – worth much more further investigations.