Stefano Profumo
UC Santa Cruz

Non-thermal X-rays from Dark Matter annihilation

The 16th International Conference on Supersymmetry and the Unification of Fundamental Interactions

June 16 - 21, 2008
Seoul, Korea - The COEX Center
Clusters are the largest bound Dark Matter structures in the Universe.

Natural targets to search for observational signatures of particle DM.

The annihilation of weakly interacting DM particles produces a multi-wavelength spectrum, from gamma rays to radio frequencies.
Particle Dark Matter and Galaxy Clusters

Generic Feature of DM multi-wavelength spectrum: significant hard X Ray component from non-thermal electrons/positrons produced in DM pair annihilation

Could Hard X Rays from Galaxy Clusters have to do with Dark Matter?

Particle Dark Matter and Galaxy Clusters

Generic **Feature** of DM multi-wavelength spectrum: significant **hard X Ray** component from non-thermal **electrons/positrons** produced in DM pair annihilation

Could Hard X Rays from Galaxy **Clusters** have to do with **Dark Matter**?

- Are hard X Ray emissions from clusters compatible with a **DM production** scenario?
- Is the required DM model a viable **particle** setup?
- How can we **test** this scenario?

The Ophiuchus Galaxy Cluster

**Nearby** (z~0.028), rich galaxy cluster

Second **brightest** cluster in the 2-10 keV band

Located in the direction of the **Galactic Center** (l=0.5°, b=9.4°)

Very high temperature **plasma** (~ 10 keV [ASCA, ROSAT])
The Ophiuchus Galaxy Cluster

*Nearby* (z~0.028), rich galaxy cluster
Second *brightest* cluster in the 2-10 keV band
Located in the direction of the *Galactic Center* (l=0.5°, b=9.4°)
Very high temperature *plasma* (~ 10 keV [ASCA, ROSAT])

*Non-thermal* activity, observations:
- Associated to the steep-spectrum *radio* source MSH-17-203
- Excess (~2σ) detected by *BeppoSAX*
- Recent high significance detection (~6.4σ) above 20 keV with *IBIS/ISGRI hard X-ray* imager onboard *INTEGRAL*
The Ophiuchus Galaxy Cluster

*Nearby* (z~0.028), rich galaxy cluster
Second *brightest* cluster in the 2-10 keV band
Located in the direction of the **Galactic Center** (l=0.5°, b=9.4°)
Very high temperature **plasma** (~ 10 keV [ASCA, ROSAT])

**Non-thermal** activity, observations:
- Associated to the steep-spectrum **radio** source MSH-17-203
- Excess (~2 σ) detected by **BeppoSAX**
- Recent high significance detection (~6.4 σ) above 20 keV with **IBIS/ISGRI hard X-ray** imager onboard **INTEGRAL**

**Specific case** - motivated by (1) firm hard X-ray obs (2) gamma-ray limits
**Systematic** study of other clusters under way

*(Profumo; Jeltema, Kehayias and Profumo)*
Ophiuchus
(the serpent holder)
In the field of view of **INTEGRAL** while observing the **Galactic Center** region

**Long** total observing time (~ 3 Ms)

High energy tail detected with high **significance** (~ 6.4 $\sigma$) in excess of the thermal emission

**Non-thermal** spectrum

Eckert et al, arXiv:0712.2326
Non-thermal activity in clusters: “Astrophysics”

Relativistic populations and radiative processes in clusters:

Energy sources:
- kinetic energy from structure formation
- supernovae & active galactic nuclei

Plasma processes:
- turbulent cascade & plasma waves
- shock waves

Relativistic particle pop.:
- re-acceleration CR electrons
- primary CR electrons
- secondary CR electrons

Observational diagnostics:
- radio synchrotron emission
- IC: hard X-ray & gamma-ray emission
- gamma-ray emission

Pfrommer et al, 0707.1707
Non-thermal activity in clusters: Dark Matter

$\chi \chi \pi \gamma$ decays from the hadronization of quark-antiquark, $W^+W^-$ final states

Prompt lepton pair production

DM annihilations produce Gamma Rays as well as energetic electrons/positrons, with peculiar injection spectra
Non-thermal activity in clusters: Dark Matter

Electrons and Positrons diffuse and loose energy

**Inverse Compton** off CMB and starlight photons, **Bremsstrahlung** and **Synchrotron** emission produce radiation from radio to gamma-ray frequencies

1. **Source Term**
   \[ Q(E, \tilde{x}) \propto \frac{\rho_{DM}^2(\tilde{x})}{m_{DM}^2} \left\langle \sigma \chi \gamma \right\rangle v_{rel} \frac{dN_e(E)}{dE} \]

2. **Transport Equation**
   \[ \frac{\partial}{\partial t} \frac{dn_e}{dE} = \nabla \left[ D(E, \tilde{x}) \nabla \frac{dn_e}{dE} \right] + \frac{\partial}{\partial E} \left[ b(E, \tilde{x}) \frac{dn_e}{dE} \right] + Q(E, \tilde{x}) \]
Non-thermal activity in clusters: Dark Matter

Electrons and Positrons diffuse and loose energy

**Inverse Compton** off CMB and starlight photons, **Bremsstrahlung** and **Synchrotron** emission produce radiation from radio to gamma-ray frequencies

1. **Source Term**

\[
Q(E, \vec{x}) \propto \frac{\rho_{\text{DM}}^2(\vec{x})}{m_{\text{DM}}^2} \left\langle \sigma_{\chi \gamma} v_{\text{rel}} \right\rangle \frac{dN_e(E)}{dE}
\]

2. **Transport Equation**

\[
\frac{\partial}{\partial t} \frac{dn_e}{dE} = \nabla \left[ D(E, \vec{x}) \nabla \frac{dn_e}{dE} \right] + \frac{\partial}{\partial E} \left[ b(E, \vec{x}) \frac{dn_e}{dE} \right] + Q(E, \vec{x})
\]

\[
b = b_{\text{IC}} + b_{\text{Coul}} + b_{\text{Syn}} + b_{\text{Brem}}
\]
Non-thermal activity in clusters: Dark Matter

Electrons and Positrons diffuse and loose energy

**Inverse Compton** off CMB and starlight photons, **Bremsstrahlung** and **Synchrotron** emission produce radiation from radio to gamma-ray frequencies

1. **Source Term**

\[ Q(E, \vec{x}) \propto \frac{\rho_{DM}^2(\vec{x})}{m_{DM}^2} \left< \sigma_{\chi\chi} \right> \frac{dN_e(E)}{dE} \]

2. **Transport Equation**

\[ \frac{\partial}{\partial t} \frac{dn_e}{dE} = \nabla \left[ D(E, \vec{x}) \nabla \frac{dn_e}{dE} \right] + \frac{\partial}{\partial E} \left[ b(E, \vec{x}) \frac{dn_e}{dE} \right] + Q(E, \vec{x}) \]

3. **Compute the Signals**

(\text{IC off CMB/starlight, Synchrotron emission,} \ldots)

\[ n_e^{EQ}(E, \vec{x}) \]
Non-thermal activity in clusters: Dark Matter

Electron / Positron **Injection Spectra** from DM annihilation sensitively depend upon the dominant annihilation **final state**
Non-thermal activity in clusters: Dark Matter

Electron / Positron Injection Spectra from DM annihilation sensitively depend upon the dominant annihilation final state

\[ m_{\text{DM}} = 82 \text{ GeV} \]
\[ m_{\text{DM}} = 46 \text{ GeV} \]
\[ m_{\text{DM}} = 10 \text{ GeV} \]

\[ W \rightarrow e \nu_e \]
Non-thermal activity in clusters: Dark Matter

Can we **fit** the hard X-ray emission with a Dark Matter induced component?

- Pick three representative DM pair annihilation **final states** (here, $\tau^+\tau^-$, $W^+W^-$ and $b\bar{b}$)
- Extract best-fit **normalization**
- Find best fit **masses**, for a given final state (resp, 10, 82, 46 GeV)

Fitting hard X-ray data

Hard X-ray emission: generic feature of DM multi-wavelength spectra

Significant differences at lower/higher energies

Compatible with EGRET limit on gamma ray emission
(no detection from Oph.)

The Dark Matter particle model

Uncertainties in the **normalization** (DM profile, substructures etc.)

Educated **assumptions** lead to (conservative) **Cross Section** estimates

Cross Sections **compatible** with other Indirect Searches (**antimatter, galactic center gamma rays etc.**)

The Full Glory Multi-Wavelength SED

At last, GLAST!

Successfully launched at 9.13AM PDT on Wednesday, June 11 2008 on a Delta-II rocket from KSC

Science data in July!
At last, GLAST!

Successfully launched at 9.13AM PDT on Wednesday, June 11 2008 on a Delta-II rocket from KSC

Science data in July!

“...GLAST, a gamma-ray telescope searching for unseen physics in the stars of the galaxies”

[NASA TV commentator, 2 sec after launch]
Robert Johnson
[designed the electronics for LAT
group leader for DM/New Physics]

Bill Atwood
[conceived and designed GLAST]

Both have devoted the last ~ 15 years to the experiment…
Cheers! The **GLAST** spacecraft successfully separated from the second stage of the Delta II rocket.
Prospects for GLAST

“Guaranteed” gamma-ray detection with GLAST, if hard X-ray originate from DM annihilations

Can we differentiate from conventional gamma-ray emissions?


Prospects for GLAST

“Guaranteed” gamma-ray detection with GLAST, if hard X-ray originate from DM annihilations

Can we differentiate from conventional gamma-ray emissions?


Smoking gun: monochromatic annihilation, \( E_\gamma = m_{\text{DM}} \) (line)

Reasonably small BR, similar e.g. to SUSY expectations (\(~10^{-3} – 10^{-4}\)"

Similarly to “conventional” non-thermal electron models, (e.g. IC from mono-energetic ~GeV electrons, Eckert et al, 2007) the average magnetic field in the DM scenario must be ~ 0.1 µG, smaller than Faraday rotation estimates.

Summary

- **Hard X Ray** of non-thermal origin detected from the Ophiuchus G.C.

- **Dark Matter annihilation** is a possible source of non-thermal $e^+e^-$

- The Dark Matter hypothesis will be conclusively **probed by GLAST**

- Monochromatic **gamma-ray line** detection also very promising

- **Radio** data compatible with average magnetic field $\sim 0.1 \, \mu G$