Black Holes as DM annihilation “boosters”

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True surface density of DM, Moore et al. 2005
But annihilation fluxes depend on the density SQUARED
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But this is a very naïve picture!

- Potential wells near galactic centers are dominated by baryons
- Black Holes are ubiquitous and dominate the innermost regions
- Take advantage of new developments in Astrophysics and Cosmology
Given all these uncertainties (plus the particle physics uncertainties):

How can you convince particle physicists that you have actually *discovered* DM?

i.e. can Astrophysics provide a *smoking-gun* signature for DM?
(Somewhat arbitrary)

**Black Holes: Definitions**

- **Stellar Mass BHs**
  - Endpoint of stellar evolution
  - Indirectly observed
  - Robust evidence
  - Lower limits on mass from obs.

- **Intermediate Mass BHs**
  - Maybe form in Glob. clusters
  - Maybe observed as ULXs
  - Seed for SMBHs?
  - Speculative but probable!

- **Supermassive BHs**
  - Unknown origin
  - Ubiquitous!
  - Robust evidence
  - Mass correlated with host halo

\[ M \leq 10^2 M_\odot \]
\[ 10^2 M_\odot \leq M \leq 10^6 M_\odot \]
\[ 10^6 M_\odot \leq M \leq 10^9 M_\odot \]
Convincing evidence for BHs, right in our (cosmic) backyard.
Where do the observed BHs come from?

- We don’t know! But they are ubiquitous.

- High-redshift quasars suggest that $10^9$ Msun BHs were already in place when the Universe was only 1Gyr old.

- Circumstance that can be understood in terms of rapid growth starting from massive seeds.

CREDIT: Sloan Digital Sky Survey, Apache Point Observatory
Scenario I: Seeds of $10^2$ Msun

- At $z \approx 18$, first stars form (image: formation of a protostar, from http://www.tomabel.com)

- Zero metallicity Pop III stars with masses in the range $M \approx 60 - 140$ Msun and $M > 260$ Msun collapse directly to black holes

- Stars with $140 < M/\text{M}_\odot < 260$ disrupted by pulsation pair production instability, leaving behind no remnant

Scenario II: Seeds of $10^5$ Msun

- In halos with efficient molecular hydrogen cooling and which do not experience any major mergers, a protogalactic disk forms and can evolve uninterrupted.

- Effective viscosity transfers mass inward

- A baryonic mass of order $10^5$ Msun loses its angular momentum and is transferred to the center of the halo.

- Central object may be briefly pressure-supported, but it eventually collapses to form a black hole

Koushiappas, Bullock & Dekel 2004
*Adiabatic* growth of a Black Hole: BHs as “Annihilation Boosters”!

\[ \rho \propto r^{-\gamma} \]

\[ \rho \propto r^{-\gamma_{sp}} \]

Conserve Mass & Angular Momentum:

\[ \gamma_{sp} = \frac{9-2\gamma}{4-\gamma} \]
Collisional growth of Spikes (in presence of Stellar Cusps)
An intuitive description of Dark Matter “Spikes”

GB & Merritt 2005
Populating the MW halo with mini-spikes

- **Populate halos at high z** with prescription from given IMBHs model
- Evolve mini-halos with **semi-analytic codes** (Zentner, Bullock 2003, Zentner et al. 2004)
- Obtain **statistical realization** of MW halo at z=0 (RED dots)
- Iterate (BLUE dots)
- **Average** results over realizations (GB, Zentner & Silk 2005)
Gamma-Rays from DM Mini-spikes around IMBHs

Inserting typical values for the DM candidate and the spike, we find in scenario II

\[
\Phi(E, D) = \Phi_0 \frac{dN}{dE} \left( \frac{\sigma v}{10^{-26} \text{cm}^3/\text{s}} \right) \left( \frac{m_x}{100 \text{GeV}} \right)^{-2} \left( \frac{D}{\text{kpc}} \right)^{-2} \left( \frac{\rho(r_{sp})}{10^2 \text{GeVcm}^{-3}} \right)^2 \left( \frac{r_{sp}}{\text{pc}} \right)^{\frac{14}{3}} \left( \frac{r_{cut}}{10^{-3} \text{pc}} \right)^{-\frac{5}{3}}
\]

\[
\Phi_0 = 9 \times 10^{-10} \text{cm}^{-2}\text{s}^{-1}
\]

• One would naively expect that the flux scales with \(\sigma v/m^2\)

• BUT The maximum density is higher for the pessimistic case, and \(r_{cut} = r_{cut}(m, \sigma v)\). This partially compensates for the decrease in flux due to the prefactor \(\sigma v/m^2\)

• The final luminosity of the objects is thus proportional to \(~ (\sigma v)^{2/7} m^{-9/7}~\)

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Gamma-Rays from DM Mini-spikes

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\[ \Phi_0 = 9 \times 10^{-10} \text{cm}^{-2} \text{s}^{-1} \]

Note the normalization of the flux:
Each Black Hole would be as luminous (in terms of annihilation radiation) as the whole Galaxy!!

KEY POINT!
**Results:**

- Very high fluxes!
- Sources off the disk (need large field of view to search for them)
- Tens of sources with IDENTICAL spectrum: smoking-gun for DM
- Scatter among different realizations relatively small
- Can use ACTs to study sources $\geq 300$ GeV
Alternative strategy:
Use MAGIC or other ACTs to re-observe selected unidentified EGRET (and GLAST…) sources.

Criteria for EGRET:
• Off the disk
• Appropriate spectrum
• Extrapolate spectra at high energies for a reasonable guess on the detectability

Ongoing collaboration with MAGIC group
Observational Strategies

Full-sky search with GLAST

Probe high $m_\chi$ with ACTs

Full-sky search, simulation of sources and spectra
G. Busetto, R. Rando

Re-observation of EGRET sources, selection of candidates
M. Doro, M. Gaug, M. Mariotti, V. Scalzotto

HESS
MAGIC
VERITAS
Interesting alternative: Neutrino Telescopes

Antares

IceCube

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Prospects for detection with Neutrino Telescopes

\[ N_{BH}(>R) \]

\[ R \text{ [yr}^{-1} \text{]} ]

\[ m_x = 1 \text{ TeV} \]
\[ \sigma v = 10^{-28} \text{cm}^3 \text{ s}^{-1} \]
\[ E_{\mu}^{th} = 100 \text{ GeV} \]
Ann. channel b\bar{b}

GB 2006
CONCLUSIONS

- BHs can effectively “boost” the DM annihilation signal

- *Intermediate Mass Black Holes* may represent a unique opportunity to discover Dark Matter particles

- GLAST can rule out this scenario or prove it right. Importance of ACTs (MAGIC, HESS, VERITAS, CANGAROO) in extending the search at higher energies

- Neutrino telescopes IceCube and ANTARES might be able to detect neutrinos from mini-spikes

- Further applications: see talks of S. Ando (gamma-ray background) and P. Brun (anti-matter) in the DM session!
Why “annihilations”? 

\[ \frac{dn_X}{dt} - 3Hn_X = -\langle \sigma v \rangle [n_X^2 - (n_X^{eq})^2] \]

\[ \dot{n}_X(r, t) = -\sigma v n_X^2 \]

Rough estimate of the relic density:

\[ \Omega_X h^2 \approx \frac{3 \times 10^{-27} \text{cm}^3 \text{s}^{-1}}{\langle \sigma v \rangle} \]

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Electroweak-scale cross sections can reproduce correct relic density. LSP in SUSY scenarios, KK DM in UED scenarios are OK!!
Spectrum per annihilation

GB, Zentner & Silk 2005  \( E/m_\chi \)
Annihilation Radiation

Initial State \( (X = \chi \text{ or } B^{(1)}) \)

Direct production
Hadronization and decay

Neutrinos
- Direct production
- Decay of heavy quarks
- Hadronization followed by decay of charged pions

Photons
- Direct production
- Hadronization then decay of neutral pions

\( e^+ e^- \) pairs
- Direct production
- Hadronization then decay of charged pions

Relevant final states
Interesting applications: Work in progress...

Gamma-ray Background

Ahn, Bertone, Merritt & Zhang 2006

Anti-matter searches

Bertone, Brun & Salati 2006

clump fraction $f = 0.2$
clump boost $B_e = 100$
NFW DM Halo $\rho \propto 1/r$
$a_{scale} = 25$ kpc

PRELIMINARY