Gamma-rays from Dark Matter Mini-Spikes in Andromeda Galaxy M31

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based on astro-ph/0703757 by M. Fornasa, M. Taoso and G.Bertone

Adiabatic growth of a black hole: spike formation

From a power-law density profile, a“spike” can form with a new slope:

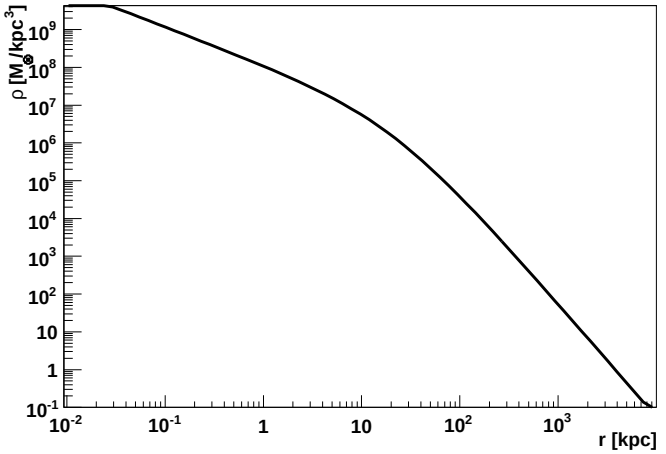
$$\rho(r) \propto \left(\frac{r}{r_s}\right)^{-\gamma} \longrightarrow \rho_{sp}(r) \propto \left(\frac{r}{r_{sp}}\right)^{-\gamma_{sp}} \qquad \gamma_{sp} = \frac{9-2\gamma}{4-\gamma}$$

$$0 \leq \gamma \leq 1.5 \qquad 2.25 \leq \gamma_{sp} \leq 2.4$$

Navarro-Frank-White DM profile:

$$\rho(r) = \rho_0 \left(\frac{r_s}{r}\right)\left(1+\frac{r}{r_s}\right)^{-2}$$

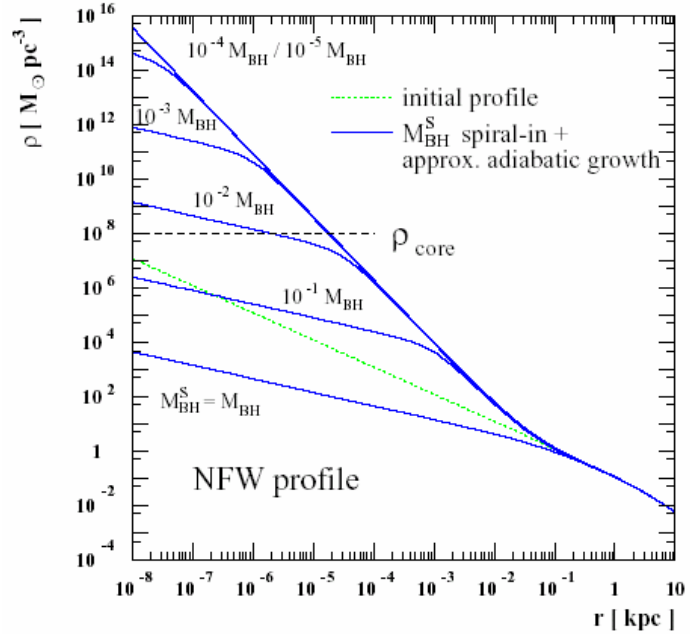
NFW (γ_{INNEP}= 1) $\longrightarrow$ γ_{sp}= 7/3



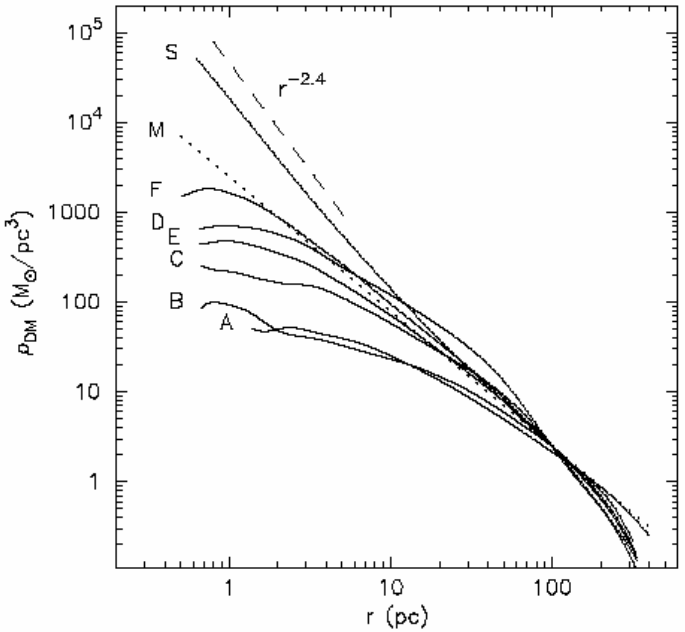
Spike formation at the Galactic center

Arguments against spikes formation:

- off-center black hole formation
- gravitational interaction with stars
- merger and BH binary effects



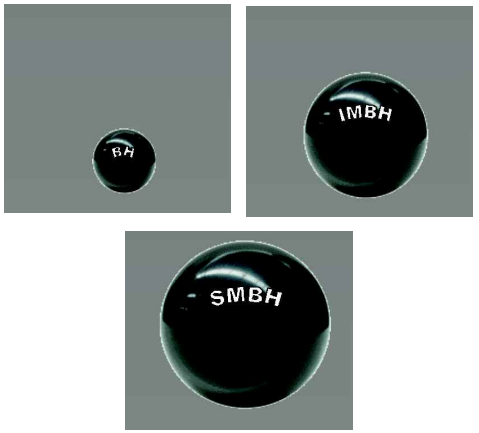
Ullio, Zhao, Kamionkowski,
astro-ph/0101481



Merritt, Milosavljevic, Verde, Jimenez
astro-ph/0201376

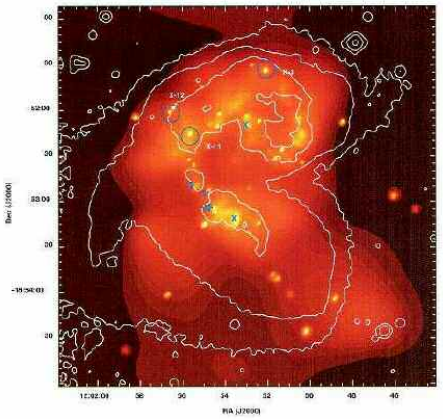
Intermediate Mass Black Holes (IMBHs)

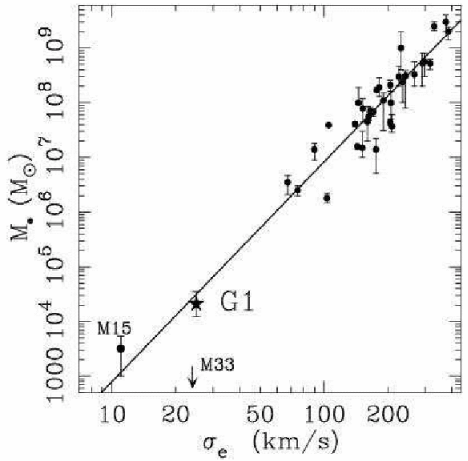
- mass from 20 $M_\odot$ to 10^6 $M_\odot$
- no one actually ever "detected" an Intermediate Mass Black Hole



Evidences for IMBHs:

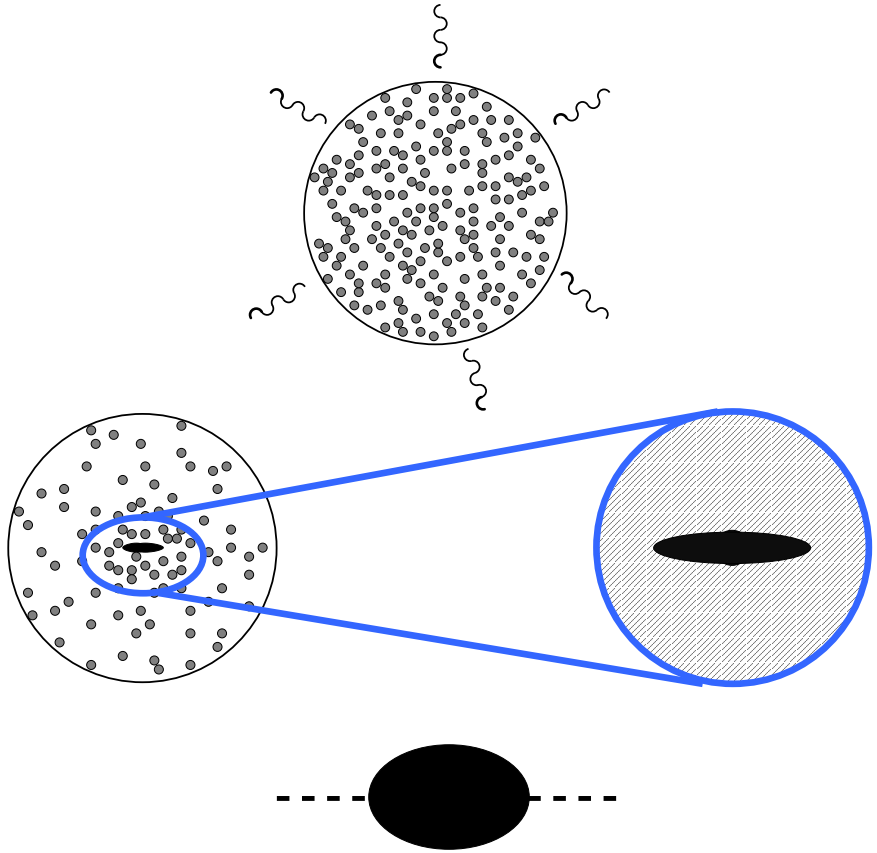
- Ultra Luminous X-ray sources (ULXs)
- extrapolation of M-σ relation of SMBHs to globular clusters
- IMBHs would provide massive seeds for the growth of SMBHs





Miller, Colbert, astro-ph/0308402

Intermediate Mass Black Holes (IMBHs)



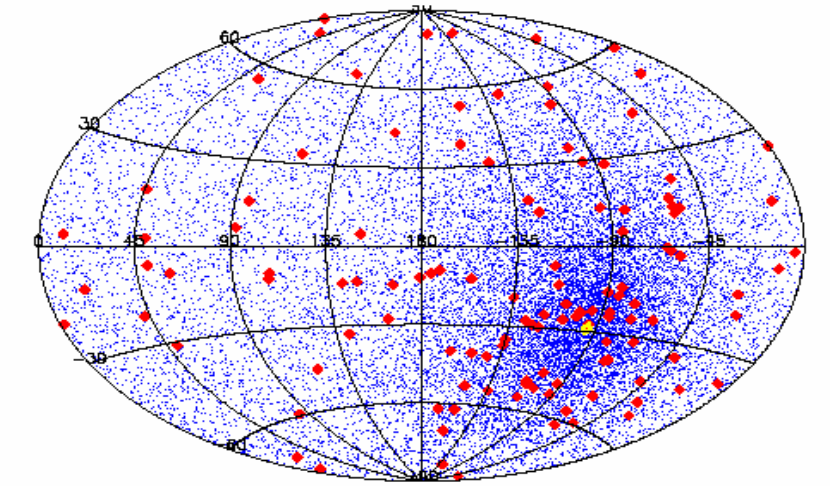
$$M_\bullet = 3.8 \cdot 10^4 M_\odot \left(\frac{\kappa}{0.5}\right) \left(\frac{f}{0.03}\right)^{3/2} \left(\frac{M_{vir}}{10^7 M_\odot}\right) \cdot \left(\frac{1+z}{18}\right)^{3/2} \left(\frac{t}{10\ \mathrm{Myr}}\right)$$

Koushiappas, Bullock, Dekel, astro-ph/0311487

IMBHs in the Wilky Way

- initial catalogue of IMBHs in mini-halos
- merging tree
- selection of unmerged mini-halos
- no baryonic content and the BH lays in the center

Bertone, Zentner, Silk, astro-ph/0509565



IMBHs catalogue for Andromeda

How IMBHs are characterized:

- realization ID
- Black Hole Mass [$M_\odot$]
- IMBH distance from the center of the Galaxy [kpc]
- r_{sp} [kpc]
- $\rho(r_{sp})$ [$M_\odot$/kpc^3]

	Milky Way	**Andromeda**
Distance to the center	8.5 kpc	784.0 kpc
Virial Mass	$1.0 \cdot 10^{12}\ M_\odot$	$6.8 \cdot 10^{11}\ M_\odot$
Virial Radius	205 kpc	180 kpc

M31 IMBHs average values: Number = 65.2±14.5

Mass = $1.5 \cdot 10^5\ M_\odot$

Distance to the center R = 32.3 kpc.

Annihilation Fluxes

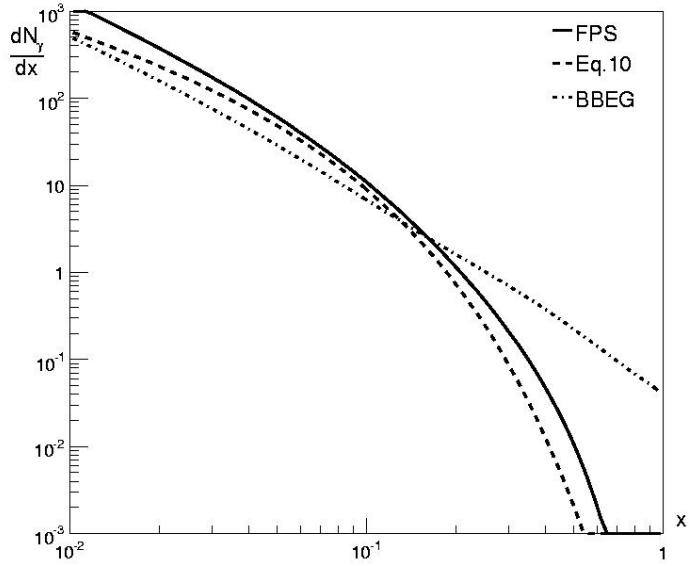
$$\Phi(E) = \frac{\sigma v}{2m_\chi^2}\frac{1}{d^2}\int_{r_{cut}}^{r_{sp}} \rho^2(r) r^2 dr \; \frac{dN_\gamma(E)}{dE}$$

- DM candidate: lightest neutralino in MSSM
- focused on hadronization of *b* quarks
- fit from simulated data, using standard package as PYTHIA ($x = E/m_\chi$)

$$\frac{dN_\gamma^b(x)}{dx} = x^a e^{b+cx+dx^2+ex^3}$$

a=-1.5
b=0.37
c=-16.05
d=18.01
e=-19.50
for m_χ=1 TeV

Fornengo, Pieri, Scopel,
hep-ph/0407342



Detection of IMBHs with ACTs

$$n = \frac{n_\gamma}{\sqrt{n_{bkg}}} = \sqrt{T}\frac{\int A_{eff}(E,\theta)\frac{d\Phi}{dE}dEd\theta}{\sqrt{\int A_{eff}(E,\theta)\frac{d\Phi_{bkg}}{dE}dEd\theta}}$$

Origin of background:

- EGRET:

$$\frac{d\Phi_{extra/gal}}{d\Omega} = 2.29\cdot 10^{-6}E^{-2.1}\frac{\gamma}{\mathrm{cm^2 s\ GeV\ sr}}$$

- Hadronic and electronic:

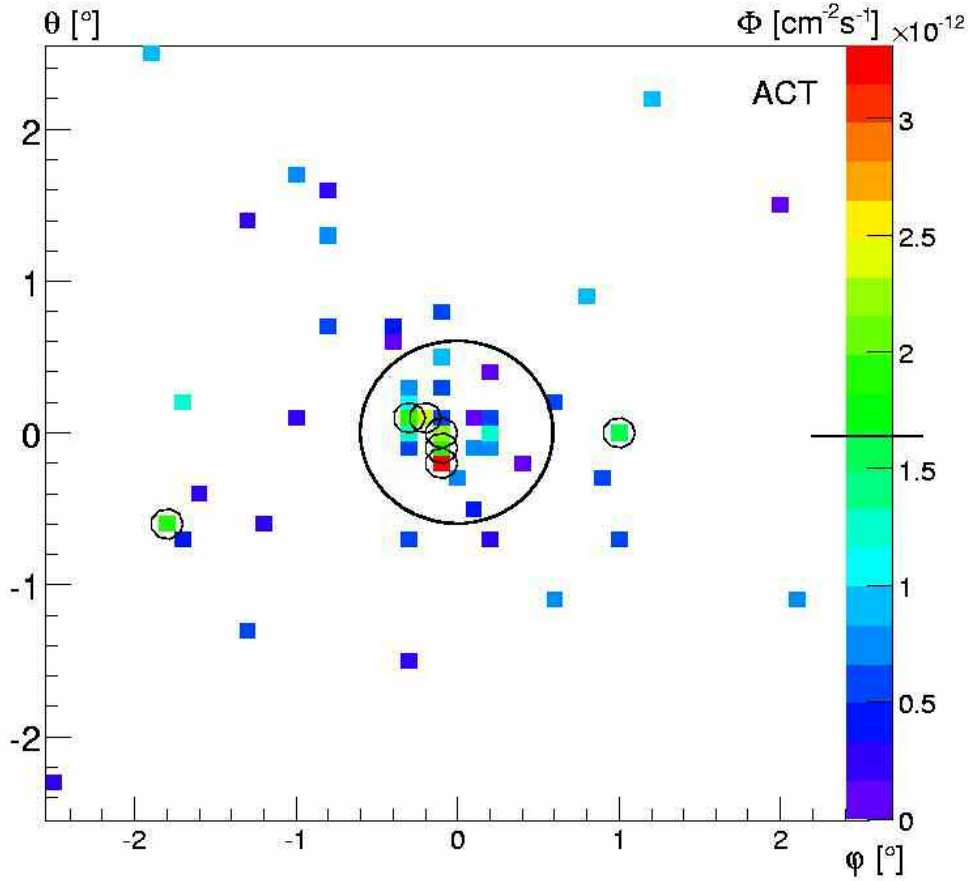
$$\frac{d\Phi_h}{d\Omega} = \epsilon_h \cdot 1.49\cdot E^{-2.74}\frac{\mathrm{p}}{\mathrm{cm^2 s\ GeV\ sr}}$$

$$\frac{d\Phi_e}{d\Omega} = 6.9\cdot 10^{-2}E^{-3.3}\frac{\mathrm{e}}{\mathrm{cm^2 s\ GeV\ sr}}$$

- m_χ=1 TeV and σv=3·10^{-26} cm^{3}s^{-1}
- E_{th}=100 GeV
- ACT angular resolution:0.1°
- ACT effective area is 3·10^4 m^2
- exposure time: 100 hours

ACT sensitivity for a 5σ detection: 1.6·10^{-12} cm^{-2}s^{-1}

Detection of IMBHs with ACTs



Number of IMBHs over ACT sensitivity is
5.2 ± 3.1 for m_{χ}=1 TeV

Detection of IMBHs with GLAST

- m_χ=150 GeV and $\sigma v=3\cdot10^{-26}$ cm^{3}s^{-1}
- E_{th}=10 MeV
- Effective area X the exposure time (2 months) = $8\cdot10^9$ cm^{2}s
- ACT angular resolution:

3° (10 MeV - 500 MeV), 0.5° (500 MeV - 4 GeV), 0.15° (E> 4 GeV)

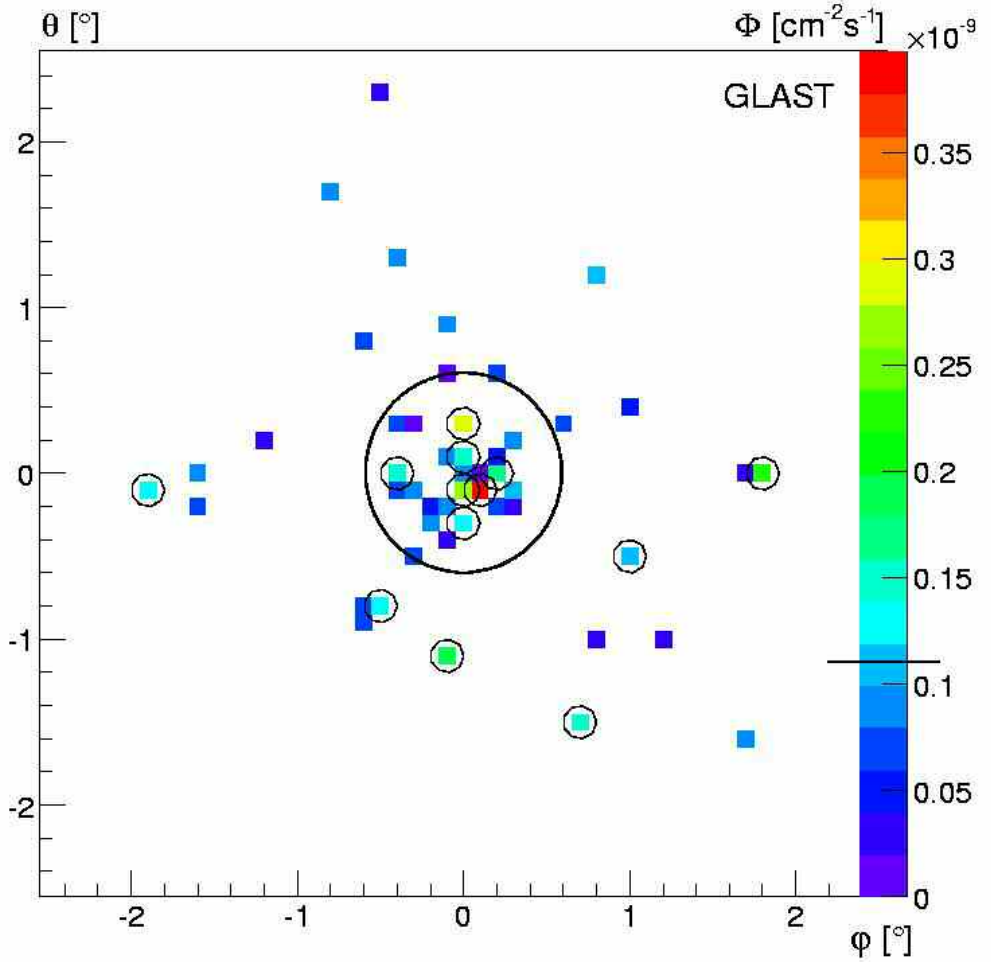
↓

A selection is made: only high-energy photons (above 4 GeV) are considered

- extragalactic background
- hadronic and electronic backgrounds are absent

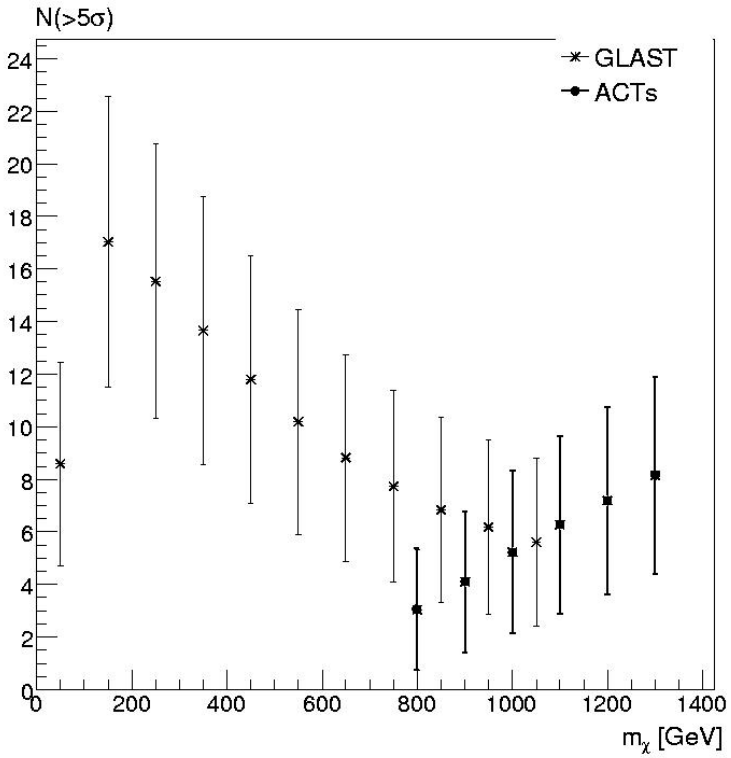
Sensitivity for a 5 σ detection in 2 months: $1.1\cdot10^{-10}$cm^{-2}s^{-1}

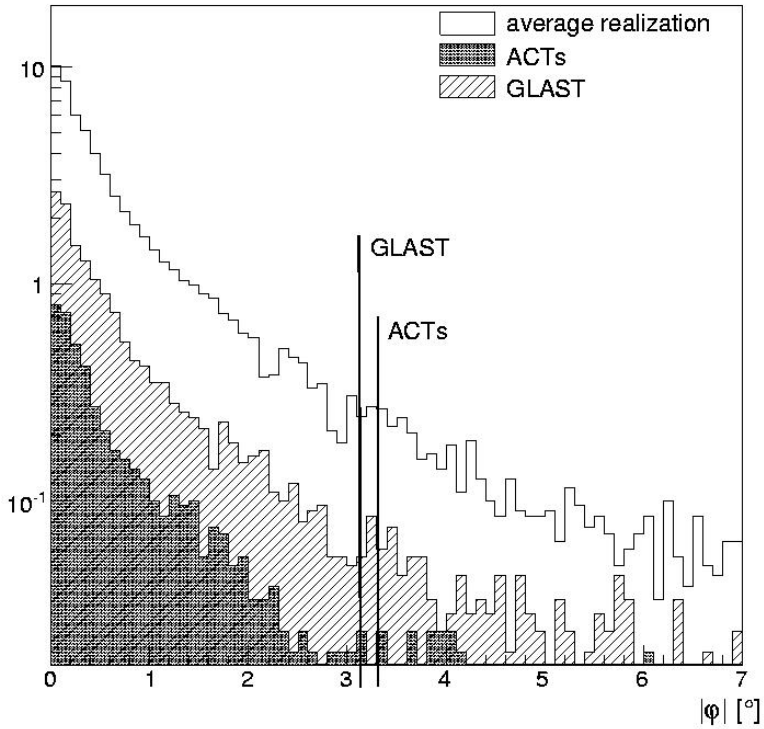
Detection of IMBHs with GLAST



Number of IMBHs over GLAST sensitivity is
17.1 ± 5.8 for m_{χ}=150 GeV

Prospects for detection





Conclusions

- fluxes from DM annihilations in mini-halos around IMBHs that populate the Andromeda Galaxy have been computed

- detection with an ACT is very challenging, due to the hadron background

- the scenario with GLAST is more promising, even if the best angular resolution is achieved only after a strict selection (very high-energy photons)

- the picture is that of isolated, point-like, bright sources in a region 3° wide around the Andromeda center

Differential energy spectrum

FPS (Fornengo-Pieri-Scopel)

- MSSM is assumed and the DM candidate is a neutralino
- focused only on the main channel (hadronization of *b* quarks)
- fit from simulated data, using standard package as PYTHIA ($x=E/m_\chi$)
- differential spectrum for τ leptons hadronization is presented too (see later)

$$\frac{dN_\gamma^b(x)}{dx} = x^a e^{b+cx+dx^2+ex^3}$$

(*a*, *b*, *c*, *d*, *e*)=(-1.5, 0.37, -16.05, 18.01, -19.50)

$$\frac{dN_\gamma^\tau(x)}{dx} = x^a(bx+cx^2+dx^3)e^{ex} \qquad (17)$$

(*a*, *b*, *c*, *d*, *e*)=(-1.31, 6.94, -4.93, -0.51, -4.53)

Kretzer Fragmentation Functions

- DM candidate is again a neutralino
- FF is the probability to have an hadron *h* with xQ^2 from a parton *p* with Q^2

Differential energy spectrum

• focused on the photon production from a π^0 resulting from quarks *b* (i.e. *p*=*b*, *h*=π^0)

$$f(x) = \frac{7.53}{x^{0.87} e^{14.62x}} \tag{18}$$

• a flat spectrum for photons from pions is assumed

$$\frac{dN_\gamma(x)}{dx} = \int_x^1 f(x') \frac{2}{x'} dx' \tag{19}$$

BBEG (Bergstrom-Bringmann-Eriksson-Gustafsson)

• differential spectrum is calculated for a DM candidate from Universal Extra-Dimension, what is called $B^{(1)}$

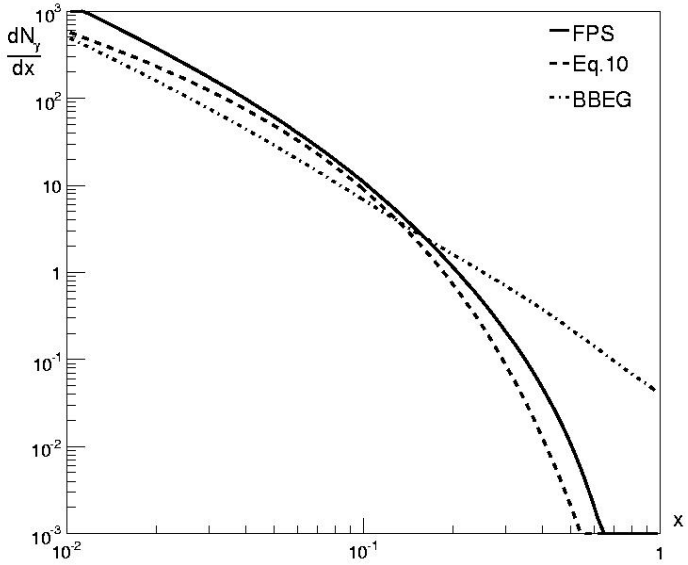
• contribution of primary photons from charged leptons is no longer neglected ($B^{(1)}B^{(1)} \rightarrow \gamma l^+ l^-$)

$$\frac{dN_\gamma^l(x)}{dx} = \sum_{l=e,\mu} \frac{\alpha}{\pi} \frac{x^2 - 2x + 2}{x} \ln \left[\frac{m^2_{B^{(1)}}}{m_l^2} (1 - x) \right] \tag{20}$$

Differential energy spectrum

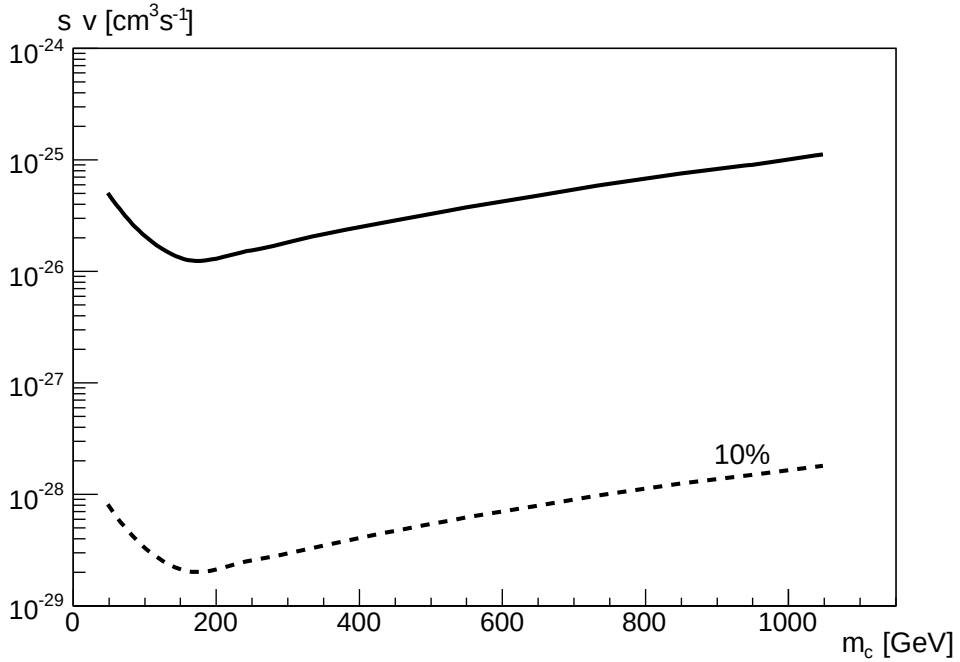
	Flux from Andromeda
FPS	$1.33 \cdot 10^{-14}\ cm^{-2}s^{-1}$
Kretzer FFs	$9.79 \cdot 10^{-13}\ cm^{-2}s^{-1}$
BBEG	$1.60 \cdot 10^{-14}\ cm^{-2}s^{-1}$

From now on, only the FPS parametrization will be used

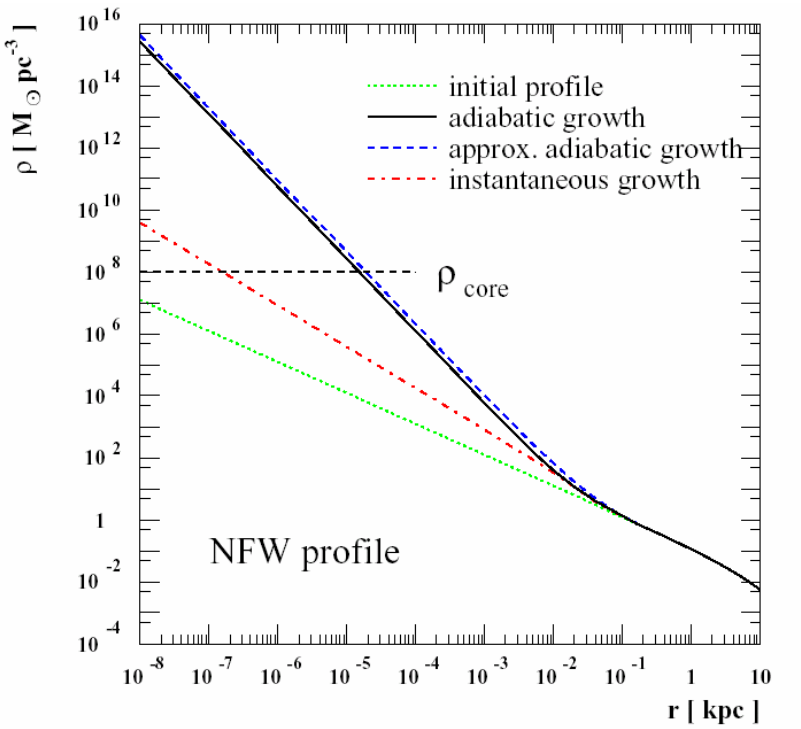


Exclusion Plot

- Solid line: all realizations with at least one detectable IMBH
- Dashed line: 20 realizations over 200 with at least one detectable IMBH



Spike formation at the Galactic center



Ullio, Zhao, Kamionkowski, astro-ph/0101481

$$\rho_{lim} = \rho_{sp}(r_{lim}) = \frac{m_\chi}{\sigma v (t - t_f)}$$

$$r_{cut} = \mathrm{Max}[4R_{Schw}, r_{lim}]$$

IMBHs in the Wilky Way

astro-ph/0509565, Bertone, Zentner and Silk:

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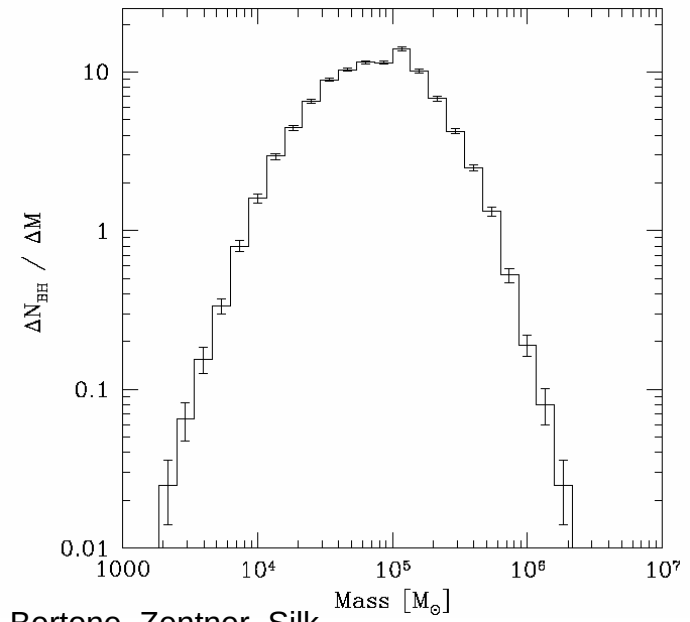
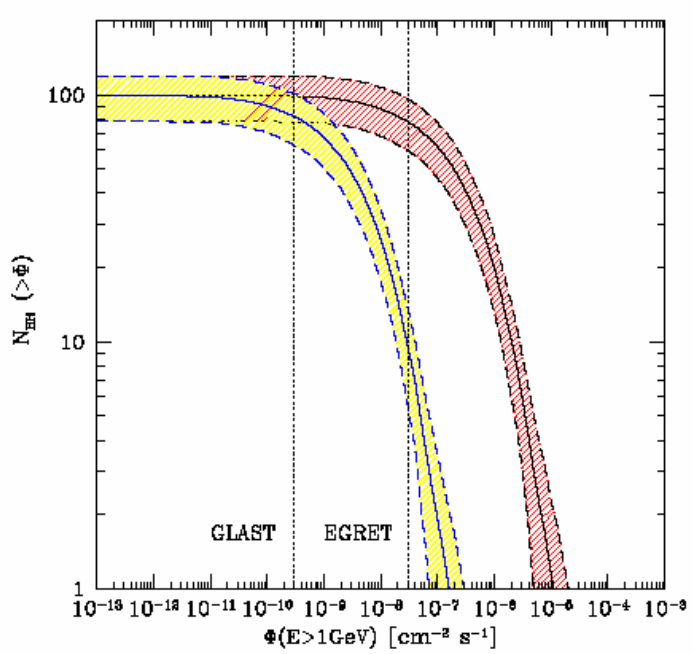


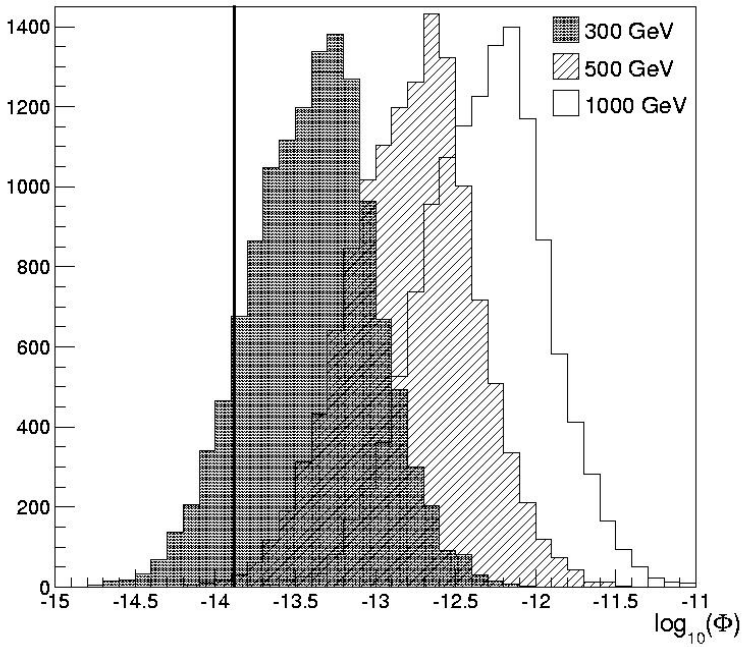


Bertone, Zentner, Silk,
Astro-ph/0509565

Thresold effect

$$\Phi(E) \sim (\sigma v)^{2/7} m_\chi^{-9/7} \qquad (11)$$

$$\Phi = \int_{E_{thr}}^{m_\chi} \Phi(E) dE \qquad (12)$$

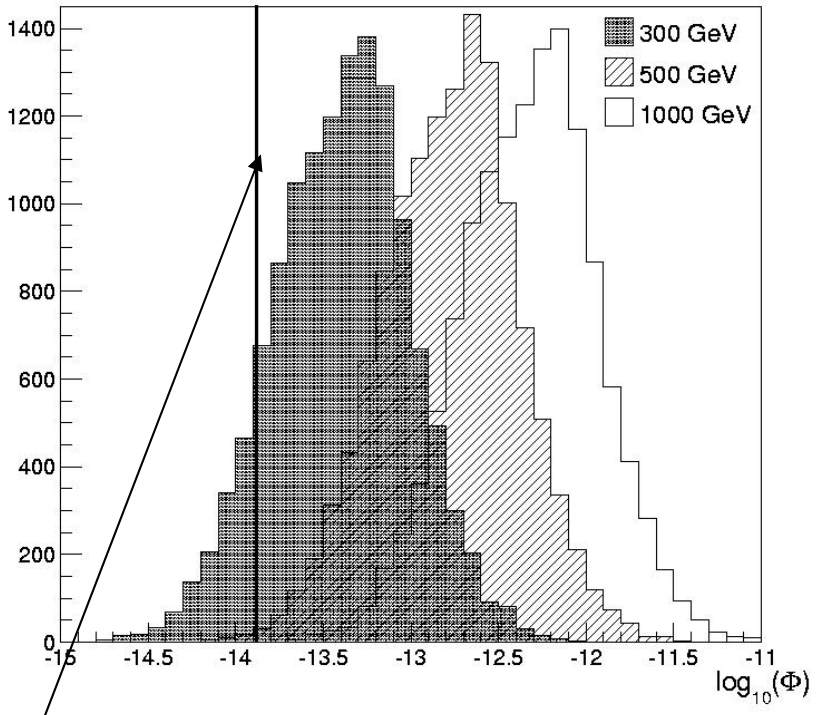


	Φ (E_{thr}=4 GeV)
m_χ = 50 GeV	$5.26 \cdot 10^{-11}$ cm^{-2}s^{-1}
m_χ = 150 GeV	$7.65 \cdot 10^{-11}$ cm^{-2}s^{-1}
m_χ = 300 GeV	$6.92 \cdot 10^{-11}$ cm^{-2}s^{-1}
m_χ = 500 GeV	$5.81 \cdot 10^{-11}$ cm^{-2}s^{-1}

	E_{thr}	m_χ
ACTs	100 GeV	1 TeV
GLAST	4 GeV (see later)	150 GeV

Annihilation Fluxes

Luminosity function of IMBHs
(Integral fluxes over 100 GeV, $\sigma v = 3 \cdot 10^{-26}$ cm^{3}s^{-1})



Flux from the Andromeda NFW profile
(m_χ = 1 TeV)