Search for dark matter annihilations around Intermediate Mass Black Holes with the H.E.S.S. experiment

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Definition of black holes

- **Stellar mass black holes: $M_{\bullet} < 10^2$ M**
  - endpoint of stellar evolution
  - indirectly observed
- **Supermassive black holes: $M_{\bullet} \in [10^6 , 10^9]$ M**
  - ubiquitous
  - unknown origin
  - mass correlated with host halo

Robust evidence

- **Intermediate mass black holes: $M_{\bullet} \in [10^2 , 10^6]$ M**
  - maybe form in globular clusters
  - maybe observed as ULXs
  - seed for SMBHs?

More Speculative!

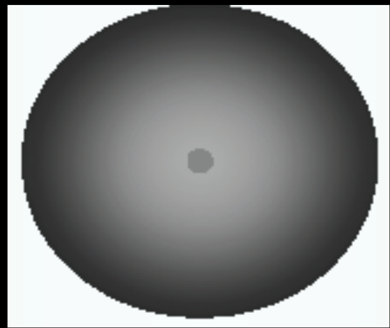
IMBH formation scenarios

Scenario 1:
- seeds of ~ 10^2 M_{sun}
- relics from first stars (pop. III)

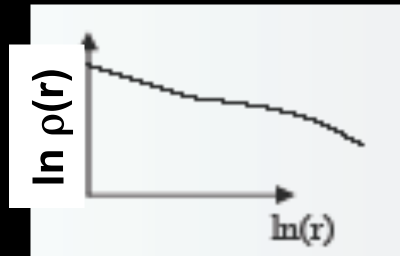
Scenario 2:
- seeds of ~ 10^5 M_{sun}
- collapse of molecular hydrogen clouds

Increase of the density in both cases

$\gamma = 0$

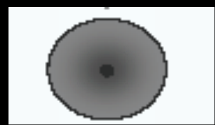


$\gamma = 1$

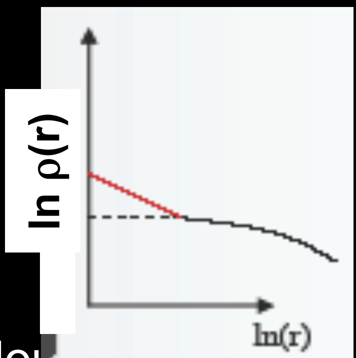


Adiabatic Growth
(Gondolo, Silk 1999)

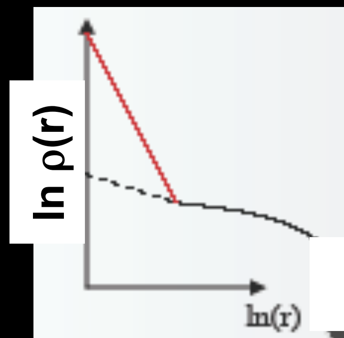
$$\gamma_{SP} = \frac{9 - 2\gamma}{4 - \gamma}$$



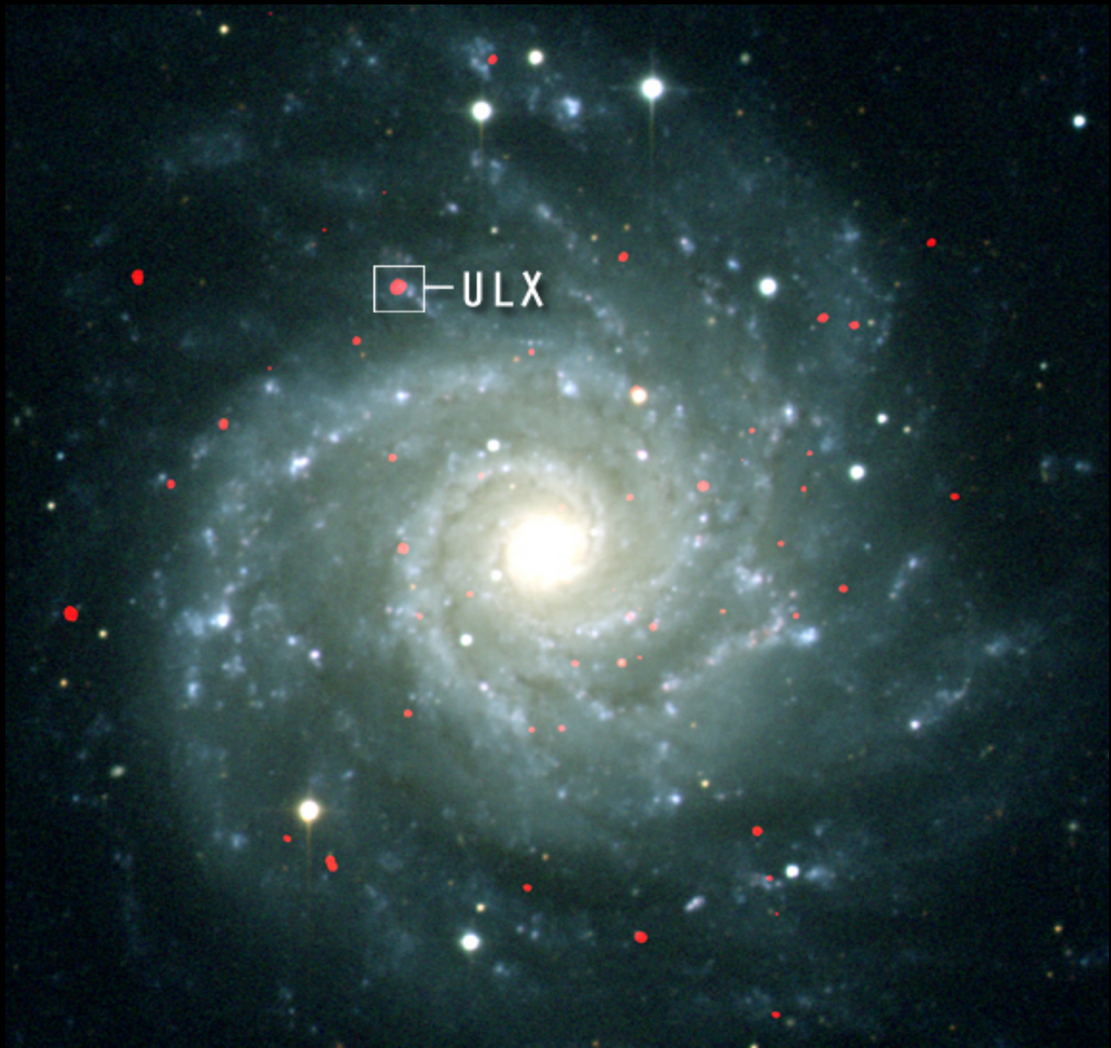
$\gamma_{SP} = 3/2$



$\gamma_{SP} = 7/3$

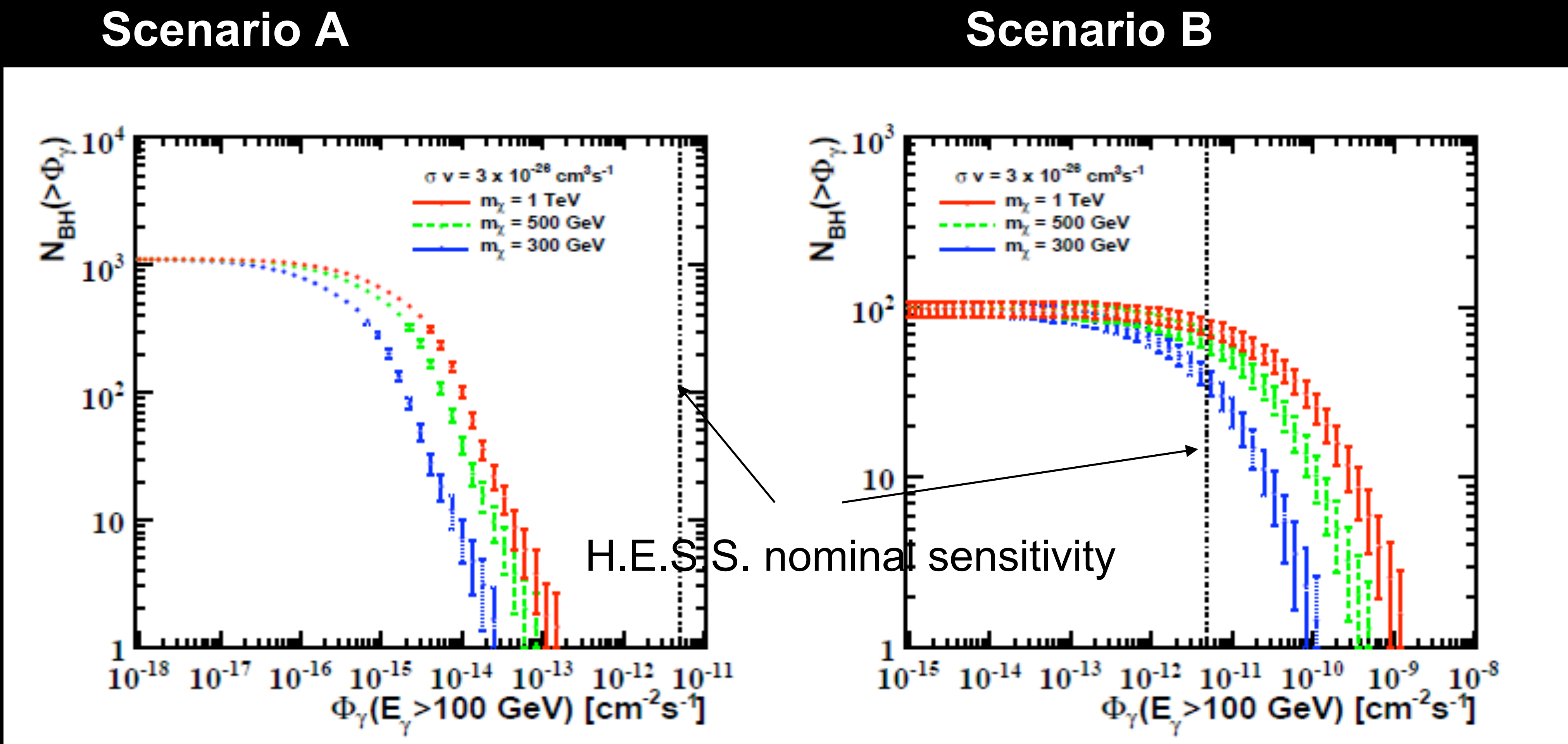


DM mini-spikes
around Intermediate Mass Black Holes



- ~100 IMBHs de ~10^5 $M_\odot$ in the Galactic halo (Koushiappas, 2004)
- Accumulation of DM around these objetcs (Bertone, 2005)
- Plausibly present in Galactic globular clusters : NGC6388, NGC6266, Ω Centauri,…
- Objects of the IMBH size predicted by N-body simulations

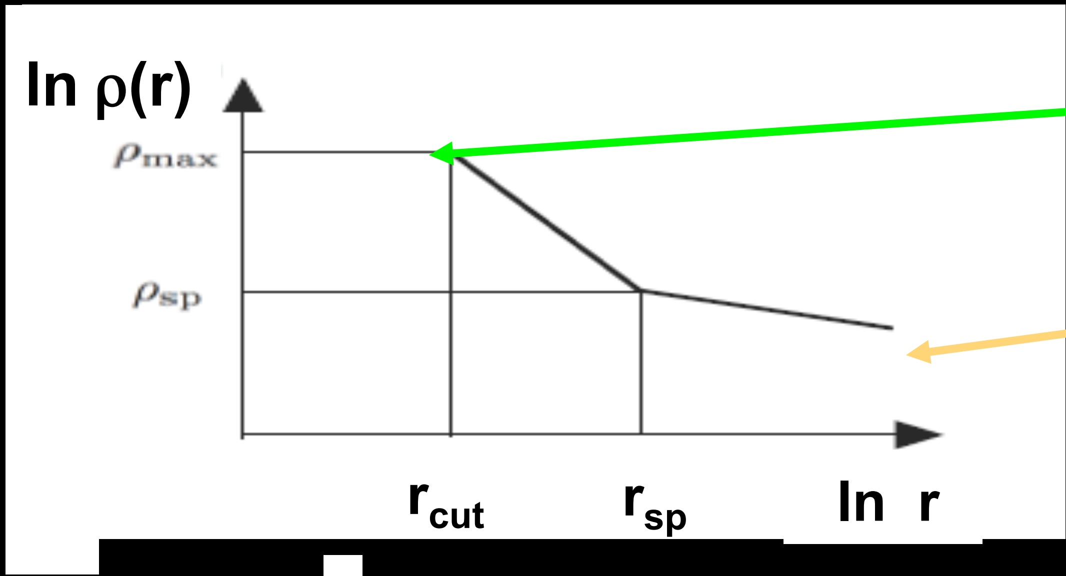
Gamma-ray luminosity from IMBH scenarios



- Scenario A is out of reach for H.E.S.S.
- H.E.S.S. sensitivity can put strong constraints on particle physics models in scenario B

IMBHs in scenario B (1)

Dark matter distribution around a IMBH :



plateau

$\rho_{max} \propto m_\chi / \sigma v$

External profile
(e.g. NFW)

$r_{cut} \propto (\sigma v / m_\chi)^{-3/7}$

$R_{SP} \sim 1$ pc

Naively, with the dependence on r_{cut}

$$\Gamma \propto \frac{(\sigma v)^{2/7}}{m_X^{9/7}}$$

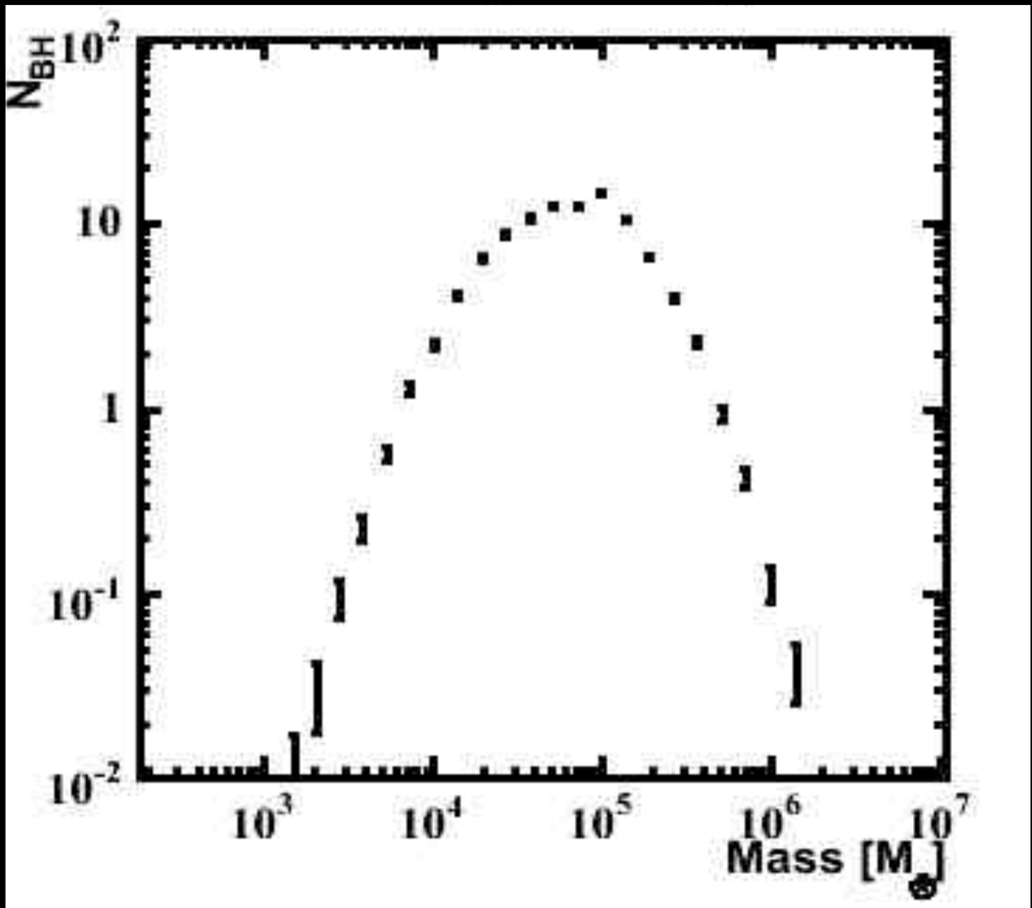
Gamma-ray flux from a spike around IMBH:

$$\Phi(E,D) = \Phi_0 \underbrace{\frac{\mathrm{d}N}{\mathrm{d}E}\left(\frac{\sigma v}{10^{-26}\mathrm{cm}^3/\mathrm{s}}\right)\left(\frac{m_\chi}{100\mathrm{GeV}}\right)^{-2}}_{\text{Annihilation spectrum and cross section, mass}} \times \underbrace{\left(\frac{D}{\mathrm{kpc}}\right)^{-2}\left(\frac{\rho(r_{sp})}{10^2\mathrm{GeV cm}^{-3}}\right)^{2}}_{\text{Radial profile}} \times \left(\frac{r_{sp}}{\mathrm{pc}}\right)^{\frac{14}{3}}\underbrace{\left(\frac{r_{cut}}{10^{-3}\mathrm{pc}}\right)^{-\frac{5}{3}}}_{\text{Core}}$$

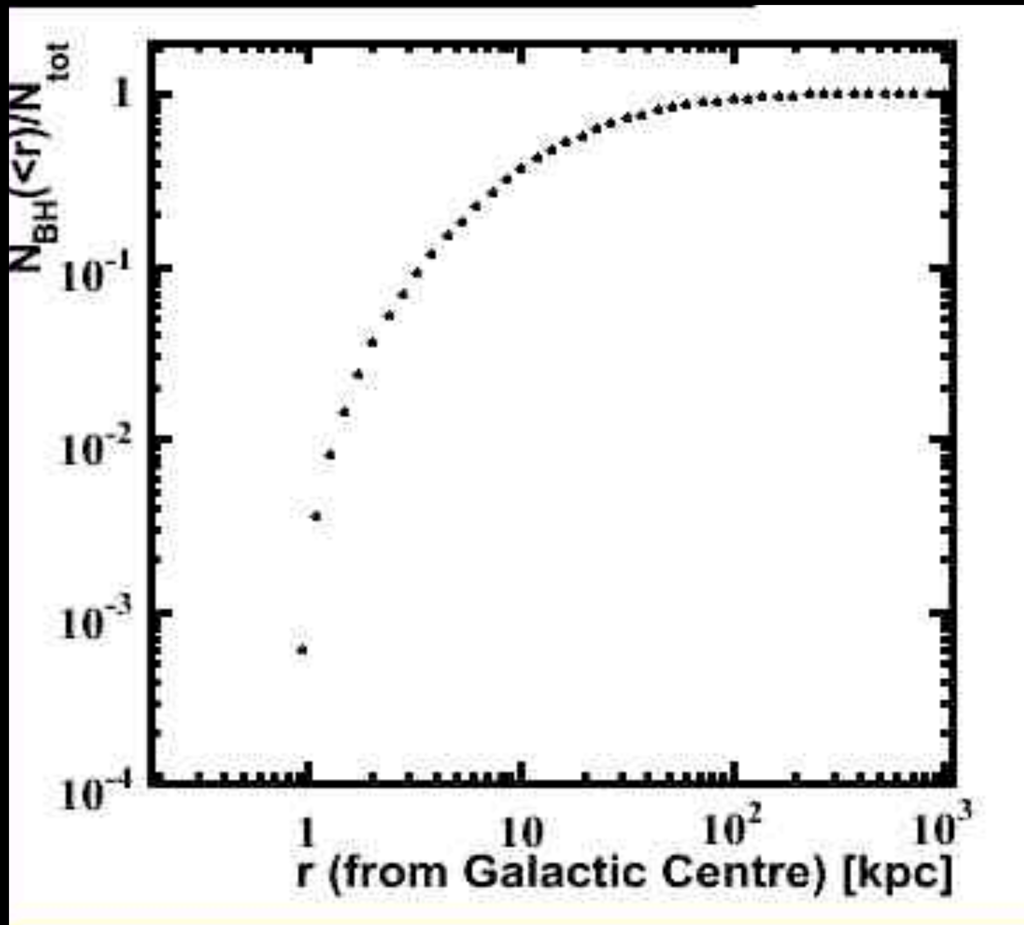
Bertone et al.
Phys. Rev. D
72,103517(2005)

IMBHs in scenario B (2)

Mass distribution

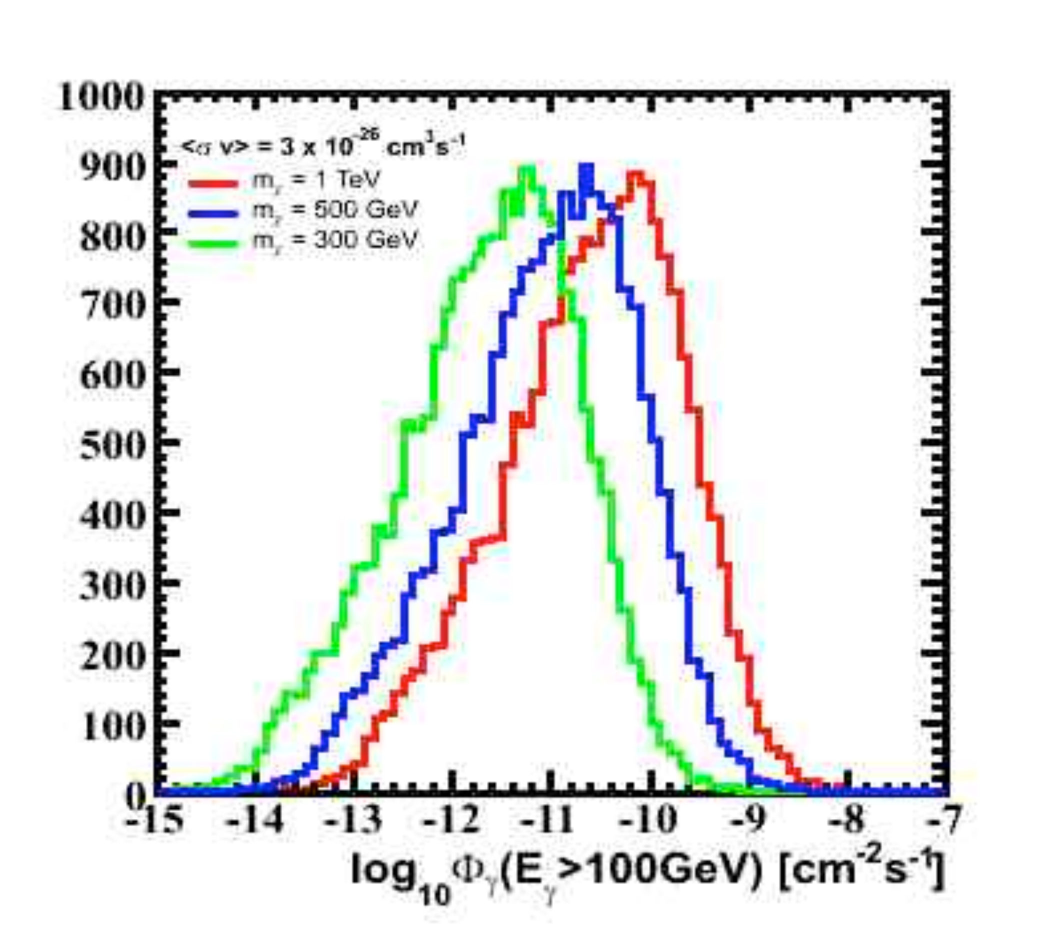


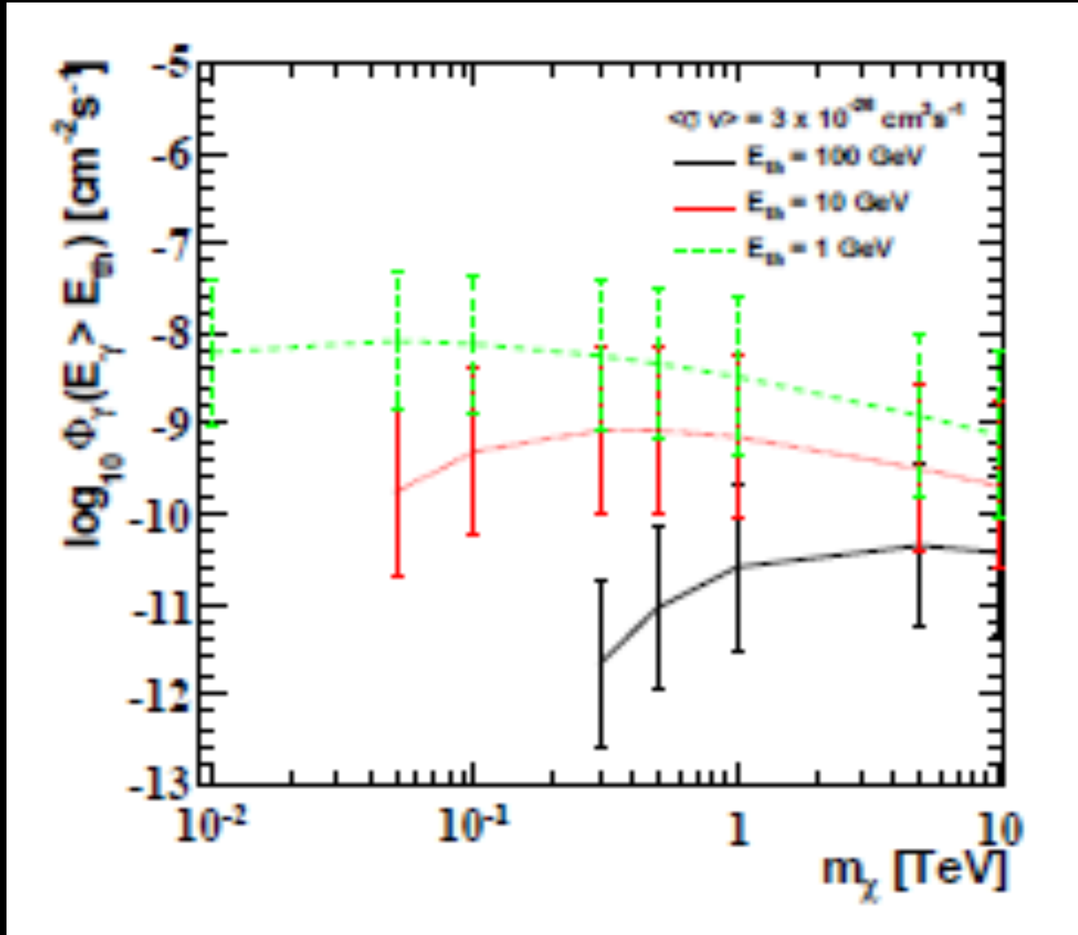
Cumulative radial distribution



- Masses ~ 10^5 M_{sun}
- Increase of IMBH density towards the Galactic Center
- Point-like sources for H.E.S.S. (~10^{-3}pc at ~10 kpc from Galatic Centre)

Gamma-ray luminosity from IMBHs in scenario B





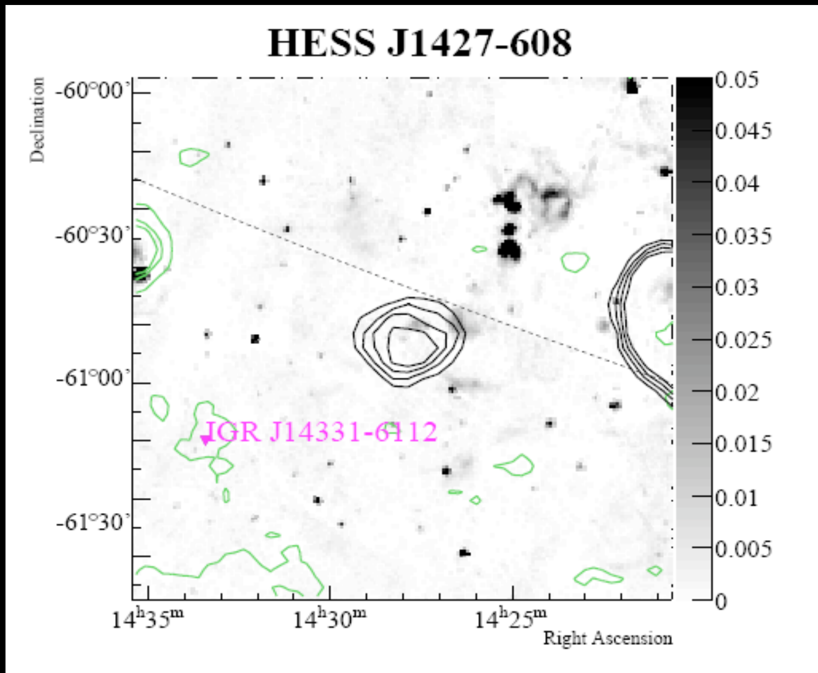
- Dependence on the neutralino mass
- The maximum integrated flux is obtained well above the energy threshold

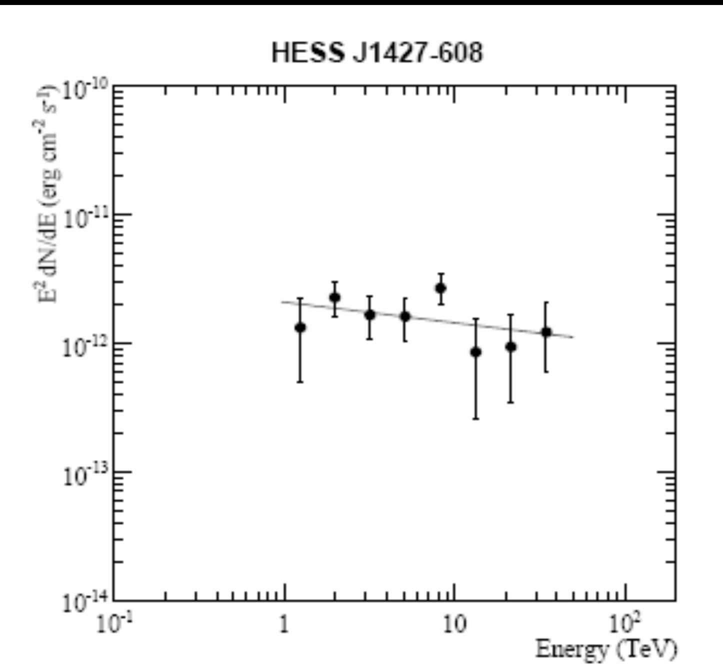
Candidates within H.E.S.S. sources ?

No plausible IMBH candidate within the H.E.S.S. data
e.g. unidentified sources do not show the expected features :
- intrinsic spatial extension
- pure power-law spectrum up to ~10 TeV

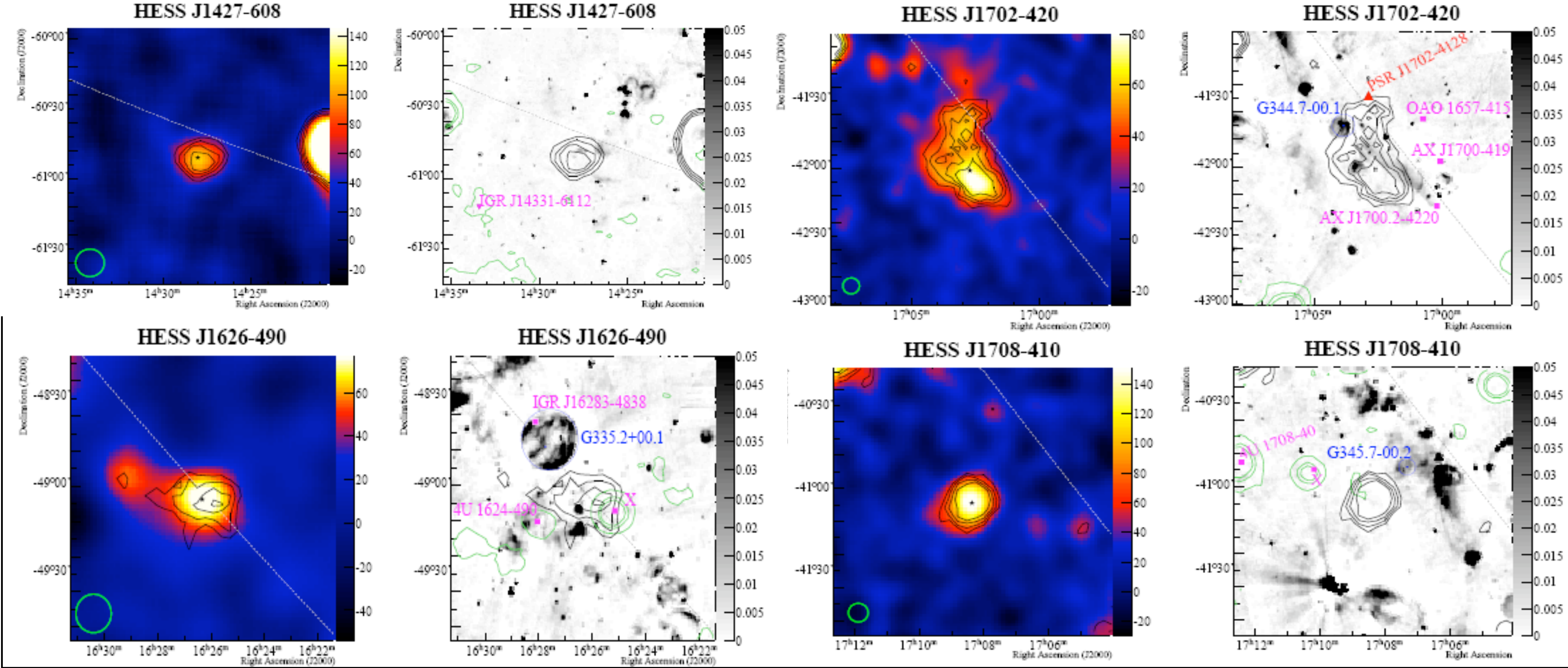
<u>Ex:</u> HESS J1427-608

- **Detection > 7σ**
- **Extension : 5'**
- **Power-law spectrum**
  $\Gamma = 2.2 \pm 0.1_{stat} \pm 0.2_{syst}$
- **No plausible counterpart**



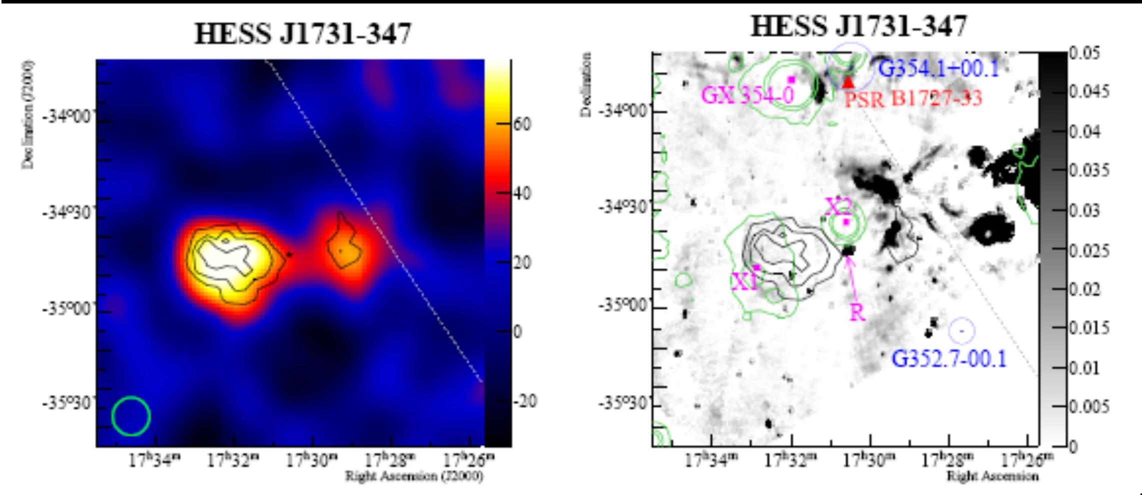


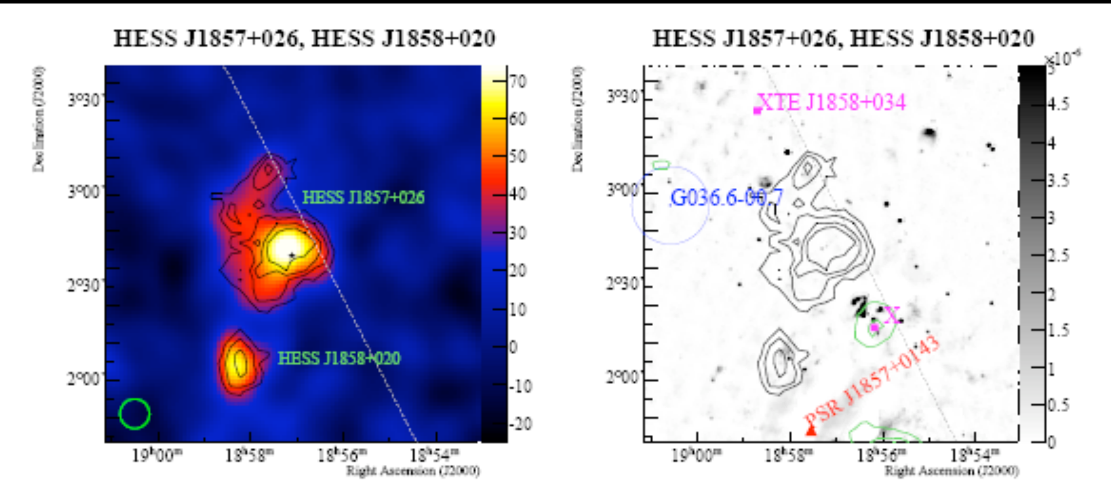
H.E.S.S. unidentified sources: morphology and search for counterparts (1)

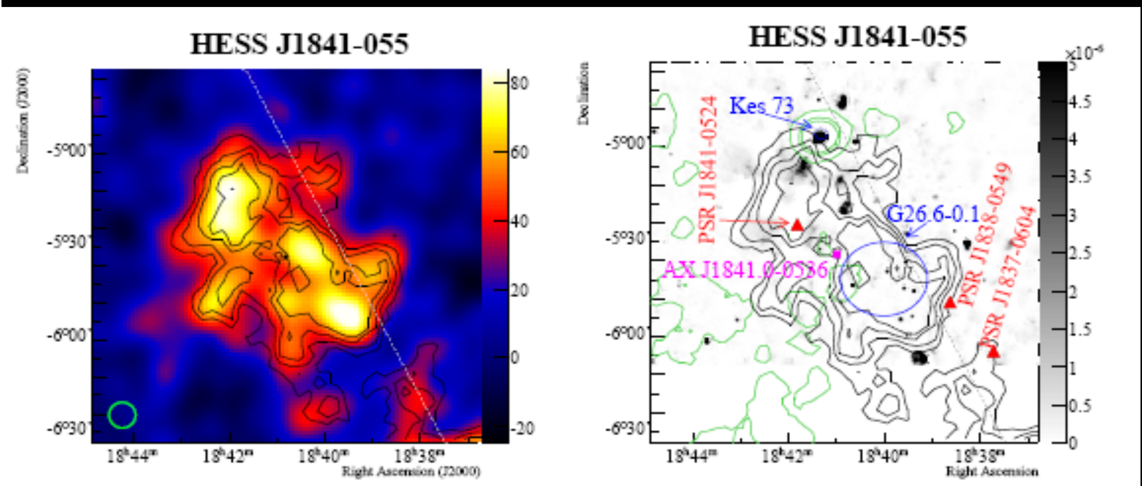


H.E.S.S. Collaboration: F. Aharonian et al. A&A 477 1 (2008) 353-363

H.E.S.S. unidentified sources: morphology and search for counterparts (2)







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H.E.S.S. unidentified sources

Source	Right Ascension	Declination	$l(°)$	$b(°)$	Time (hrs)	S (σ)	Excess (cts)
HESS J1427−608	$14^h27^m52^s$	−60°51′00”	314.409	-0.145	21	7.3	197
HESS J1626−490	$16^h26^m04^s$	−49°05′13”	334.772	0.045	12	7.5	153
HESS J1702−420†	$17^h02^m44^s$	−42°00′57”	344.304	-0.184	9	12.8	412
HESS J1708−410†	$17^h08^m24^s$	−41°05′24”	345.683	-0.469	39	10.7	513
HESS J1731−347	$17^h31^m55^s$	−34°42′36”	353.565	-0.622	14	8.1	218
HESS J1841−055	$18^h40^m55^s$	−05°33′00”	26.795	-0.197	26	10.6	346
HESS J1857+026	$18^h57^m11^s$	02°40′00”	35.972	-0.056	21	8.7	223
HESS J1858+020	$18^h58^m20^s$	02°05′24”	35.578	-0.581	25	7.0	168

- Discovered in the Galactic plane survey
- No counterpart from radio to X wavelengths
- All are extended sources!
- Spectrum compatible with pure power-law spectrum

Source	σ_1 (°)	σ_2 (°)	Angle (°)
HESS J1427−608	0.04 ± 0.02	0.08 ± 0.03	80 ± 17
HESS J1626−490	0.07 ± 0.02	0.10 ± 0.05	3 ± 40
HESS J1702−420	0.30 ± 0.02	0.15 ± 0.01	68 ± 7
HESS J1708−410	0.06 ± 0.01	0.08 ± 0.01	-20 ± 23
HESS J1731−347	0.18 ± 0.07	0.11 ± 0.03	-89 ± 21
HESS J1841−055	0.41 ± 0.04	0.25 ± 0.02	39 ± 6
HESS J1857+026	0.11 ± 0.08	0.08 ± 0.03	-3 ± 49
HESS J1858+020	0.08 ± 0.02	0.02 ± 0.04	4 ± 17

H.E.S.S. flux sensitivity map in the Galactic plane survey

- Data analysis on a large field of view

⇒ H.E.S.S. data in the Galactic plane survey : ~400 h
pointing on identified sources excluded (ex: runs son the Galactic Center)

- Computation of H.E.S.S. sky maps within the field of view

⇒ H.E.S.S. flux sensitivity map in [-3,3]x[-30,60] deg^2

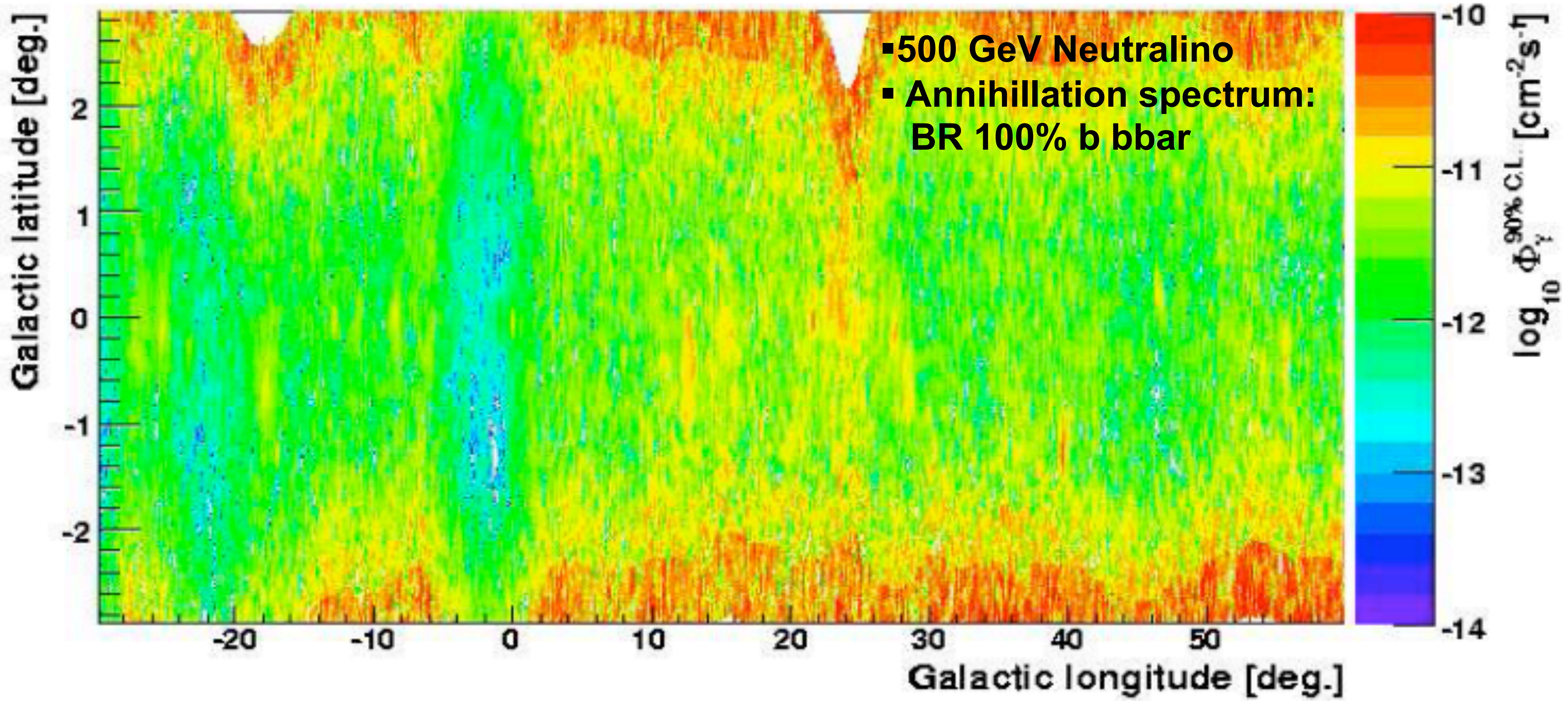
- Constraints within a specific clump scenario : the IMBH scenario

⇒ Exclusion limits within the IMBH scenario

Computation of sky maps in the survey range:

- **gamma map**
- **normalized background map**
- **acceptance map**
- **exposure map**

H.E.S.S. flux sensitivity map to Dark Matter annihilations

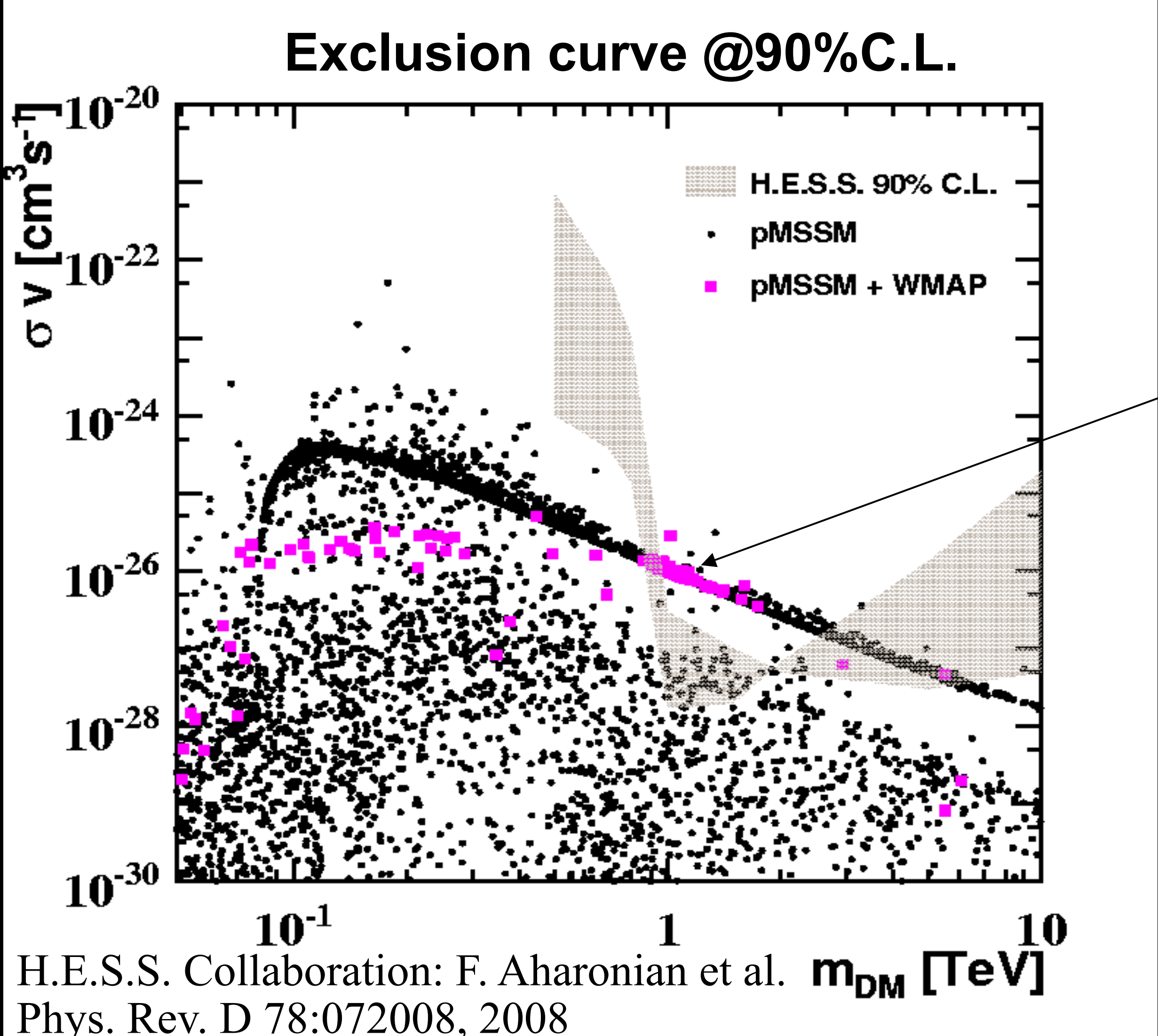


H.E.S.S. Collaboration: F. Aharonian et al. Phys. Rev. D 78:072008, 2008

- H.E.S.S. flux sensitivity map in a large field of view: [-30,60] x[-3,3] deg.^{2}

$\Rightarrow$ at the level of 10^{-12} cm^{-2}s^{-1}

Exclusion limits for SUSY models



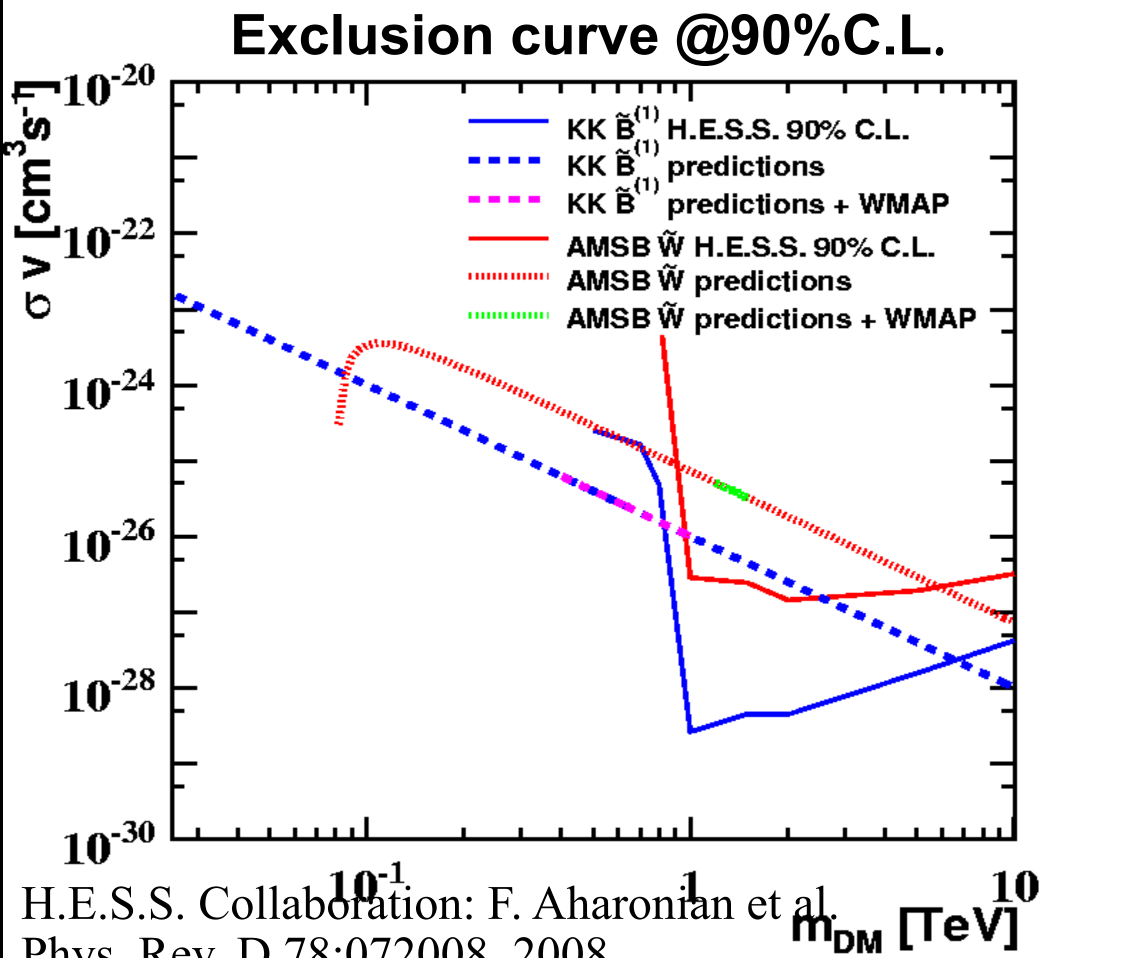
- Models generated with DarkSUSY

Models satisfying WMAP contraints on CDM relic density

- Annihilation spectrum from PYTHIA simulations

Strong constraints on the particle physics models in the TeV range within the scenario B

Exclusion limits for Kaluza-Klein and AMSB models



H.E.S.S. Collaboration: F. Aharonian et al.
Phys. Rev. D 78:072008, 2008

- Kaluza-Klein: branching ratios from Servant & Tait 2003
- AMSB models: neutralinos assumed to be pure winos

- Strong constraints on the particle physics models in the TeV range within the scenario B

Summary

- **H.E.S.S. flux sensitivity map to a dark Matter annihilation flux in the Galactic plane survey :[-3,3] deg. x [-30,60] deg.**
  $\Rightarrow$ ~10^{-12} $cm^{-2}s^{-1}$ in a large field of view

- **No plausible candidate for IMBHs within H.E.S.S. data so far**

- **First experimental constraints from IACTs in a Dark Matter clump scenario (albeit optimistic)**

- **Strong constraints on particle physics models in the scenario B for IMBH masses of ~ 10^5 M_{sun}**