INDIRECT DARK MATTER SEARCH WITH HESS

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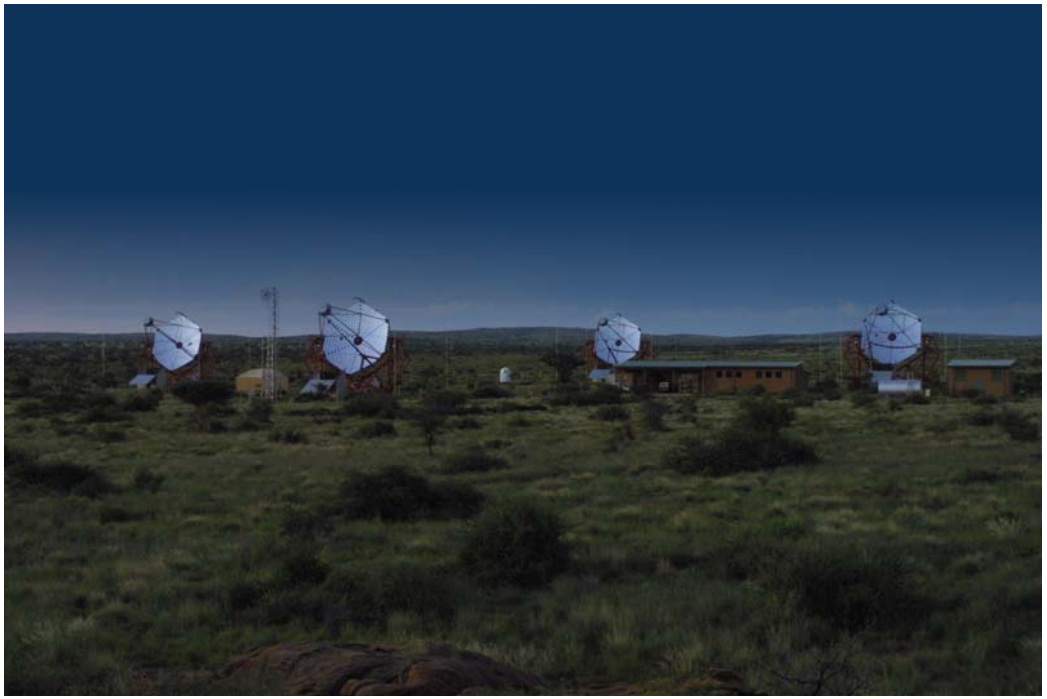
on behalf of the HESS collaboration

Outline

- HESS
  - The HESS telescope array
  - Overview of HESS DM searches
- HESS DM search towards dwarf galaxies
  - Sgr dwarf and Canis Major overdensity
  - new results on Sculptor and Carina dwarfs
- HESS DM search towards globular clusters
- Summary

The HESS Cherenkov telescope array

High Energy Stereoscopic System
located in Namibia, latitude=-23°, altitude=1800 m
~180 physicists, 35 institutes



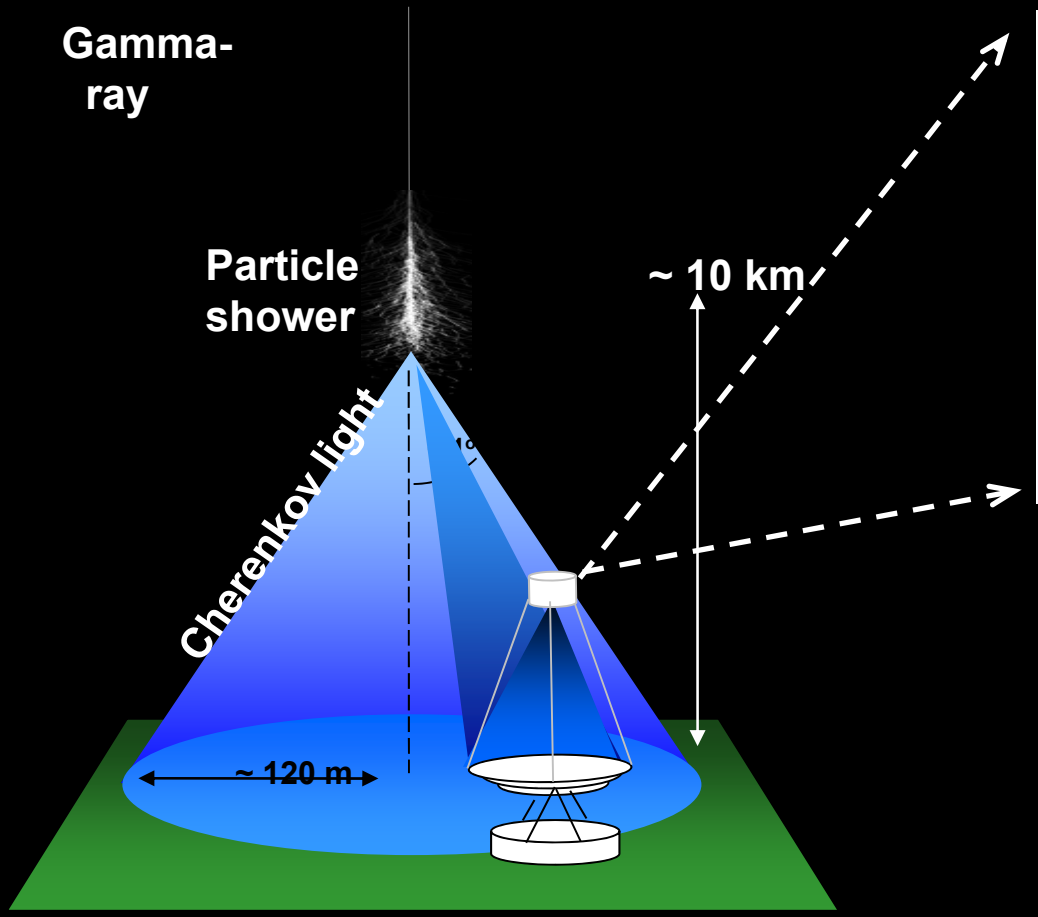
4 telescopes,
mirrors: 107 m^2 each
cameras 960 PMT
FOV= 5°
energy threshold ~100GeV

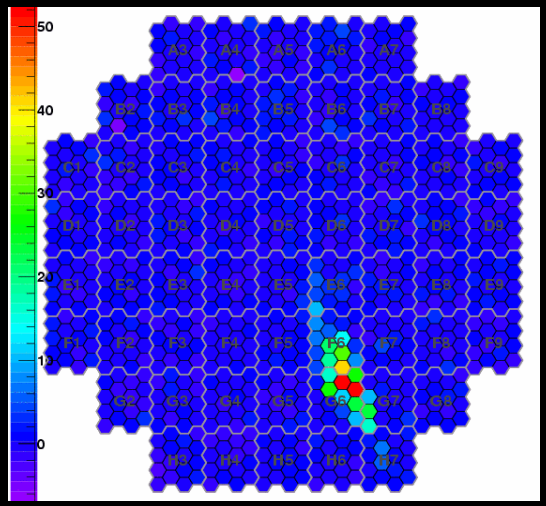
full array running > january 2004

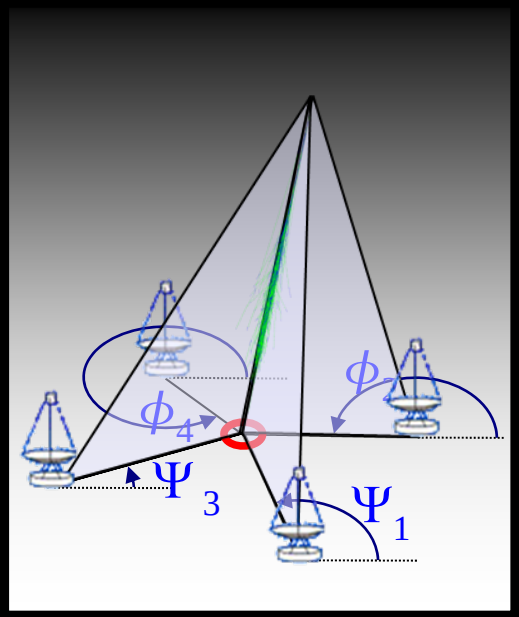
5^{th} telescope to be installed in 2010-2011
mirror: 600m^2, 2048 PMT, FOV=3.5°, trigger threshold=20 GeV

Ground-based VHE gamma-ray instruments

Imaging atmospheric Cherenkov telescopes







- brief flash ~3 ns
- **steroscopy**:

cosmic ray background rejection
improved gamma ray reconstruction

Indirect dark matter search strategy

WIMP annihilation flux into γ rays observed in solid angle $\Delta\Omega$:

$$\frac{d\phi_\gamma}{dE} \propto \left[\frac{dN_\gamma}{dE}\left(\frac{<\sigma v>}{3\ 10^{-26} cm^3/s}\right)\left(\frac{1\,\mathrm{TeV}}{M_\chi}\right)^2\right]\left[\bar{J}(\Delta\Omega)\,\Delta\Omega\right] \qquad \Delta\Omega_{\mathrm{HESS}} = 10^{-5}\ \mathrm{sr}$$

particle model

f^{AP}: dark halo model

- dN_γ/dE given by selected particle models:
  - neutralinos (MSSM)
  - U Extra Dimensions (*Servant, Tait 2003*) boson B

- Astrophysical factor:

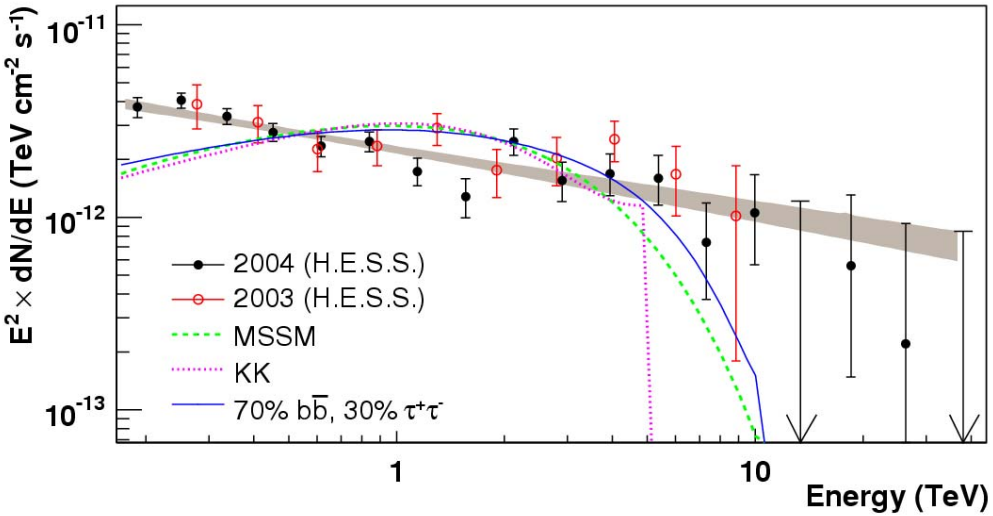
$$f^{AP} = \bar{J}\Delta\Omega \propto \int_{l.o.s} \rho_{DM}{}^2 dl$$

$\Rightarrow$ dense targets

Observed by HESS: Galactic Center
nearby dwarf galaxies, globular clusters
center of galaxy clusters (M87..)
searches for clumps, IMBH

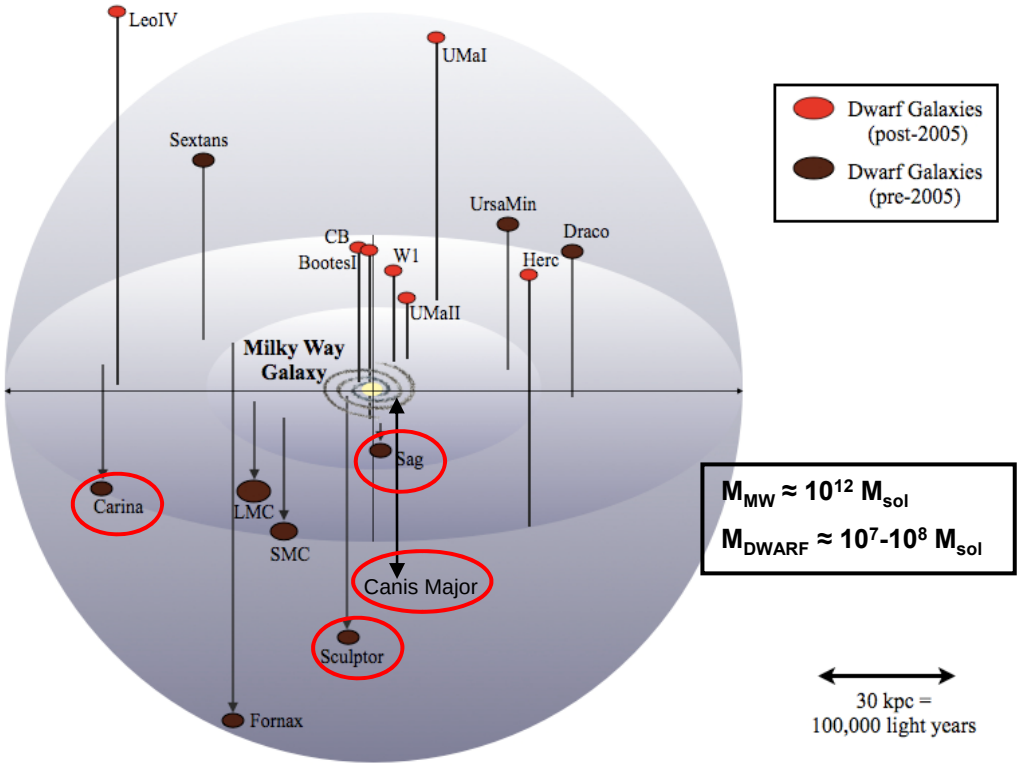
Overview of HESS DM searches

- Galactic Center
  - limits on $\langle\sigma v\rangle$ at the level of 10^{-24} cm^3 s^{-1}
  - *F.Aharonian et al., Phys.Rev. Letters, 97, 221102 (2006)*



- IMBH
  - strong constraints provided these objects exist
  - *F.Aharonian et al, Phys.Rev D 78, 072008 (2008)*
- High energy electrons (ATIC/PAMELA signal)
  - *F.Aharonian et al, A & A, 508, 561 (2009)*
- Dwarf galaxies

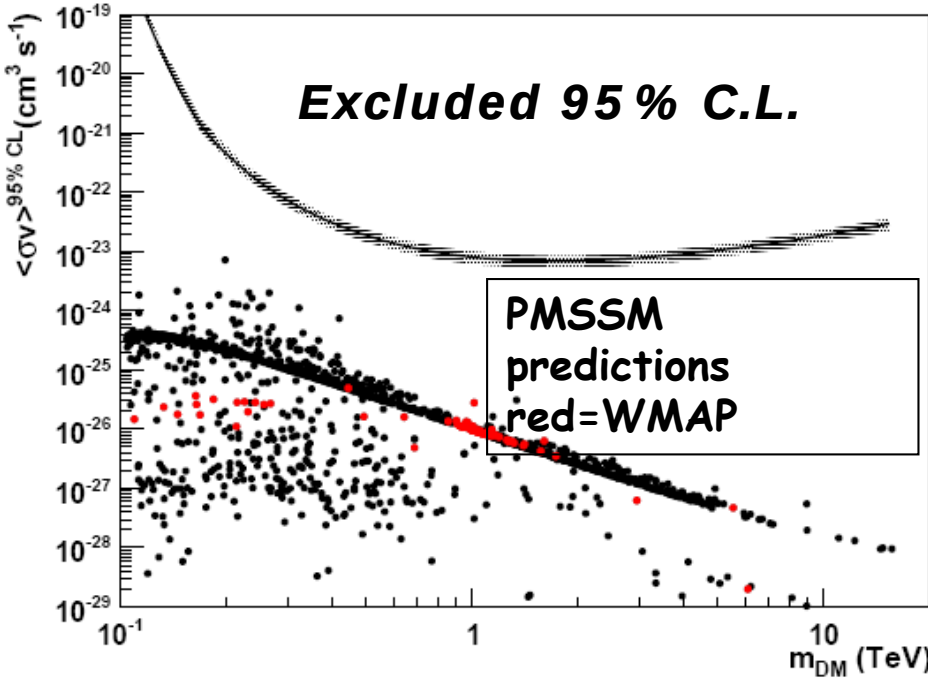
Dwarf spheroidal galaxies



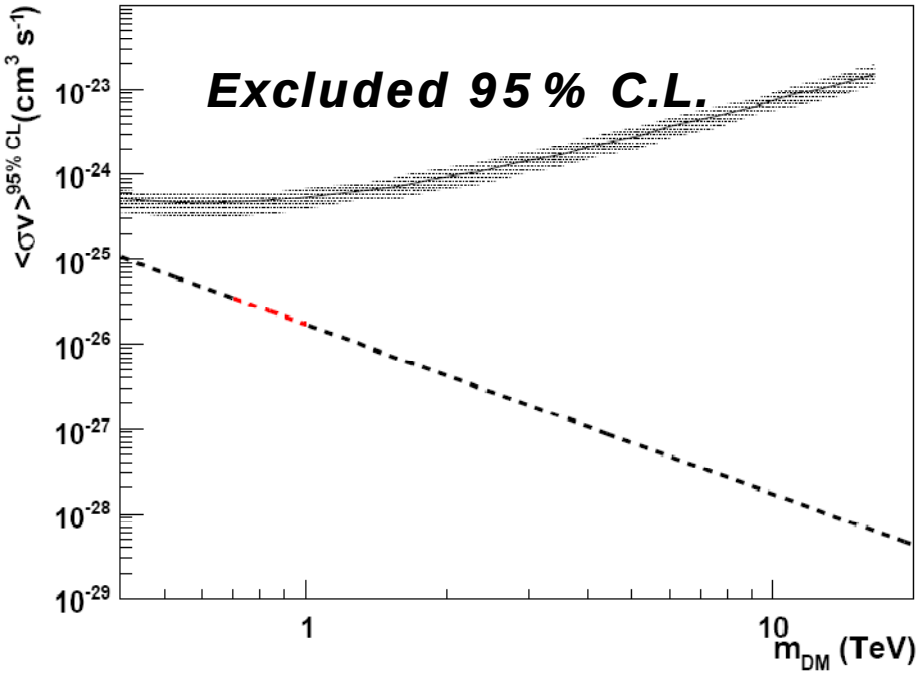
- dark matter dominated
- data on surface brightness, velocity dispersion, globular clusters for most of them ⇒ **galactic structure well modelled**
- mass range 10^7 - 10^9 $M_\odot$
- observed by HESS: Sagittarius, Canis Major, **Carina**, **Sculptor**

Canis major: exclusion plots

MSSM limits



Kaluza-Klein UED

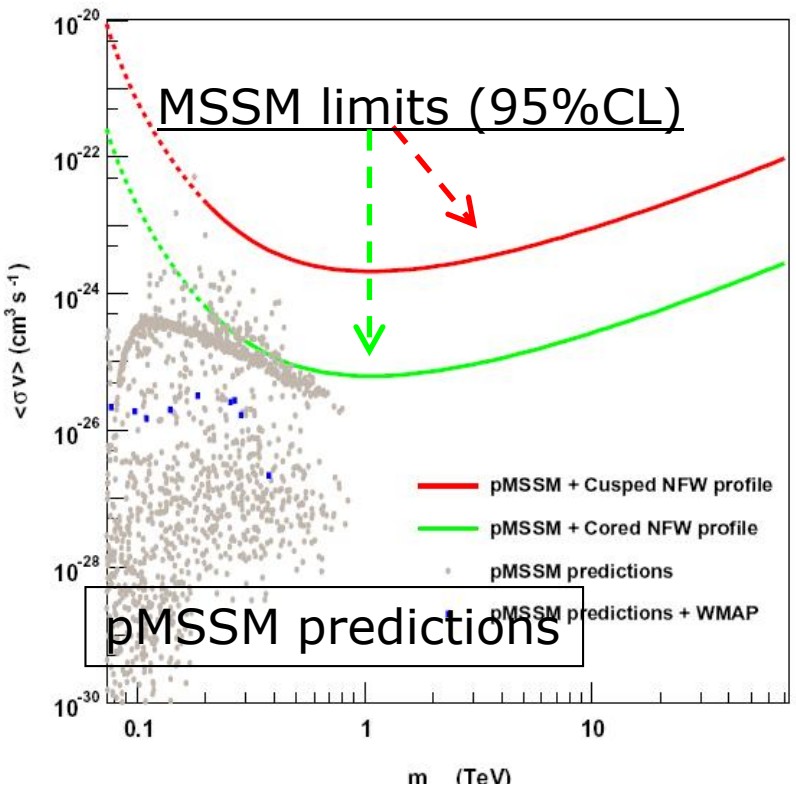


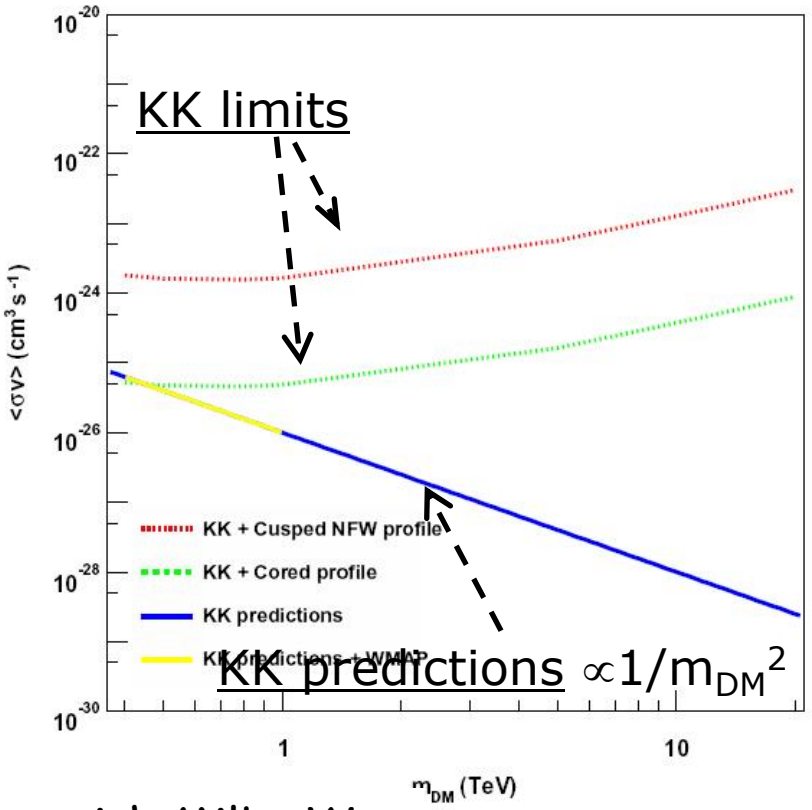
- overdensity discovered 2004, nearby (7 kpc)
- status as a dwarf galaxy disputed
- halo modeling based on galaxy formation theory
- $<\sigma v>_{min} \approx 5\ 10^{-24}\ cm^3\ s^{-1}$ (MSSM)
- *F. Aharonian et al, ApJ 691, 175 (2009)*

$$\frac{\bar{J}_{CMa}}{\bar{J}^{GC}_{NFW}} \approx 0.2$$

with the assumption
$M_{CMa} = 3\ 10^8\ M_{sol}$

Sgr Dwarf: exclusion plots





- nearby galaxy (24 kpc), in interaction with Milky Way
- galactic modeling difficult (tidal stripping)

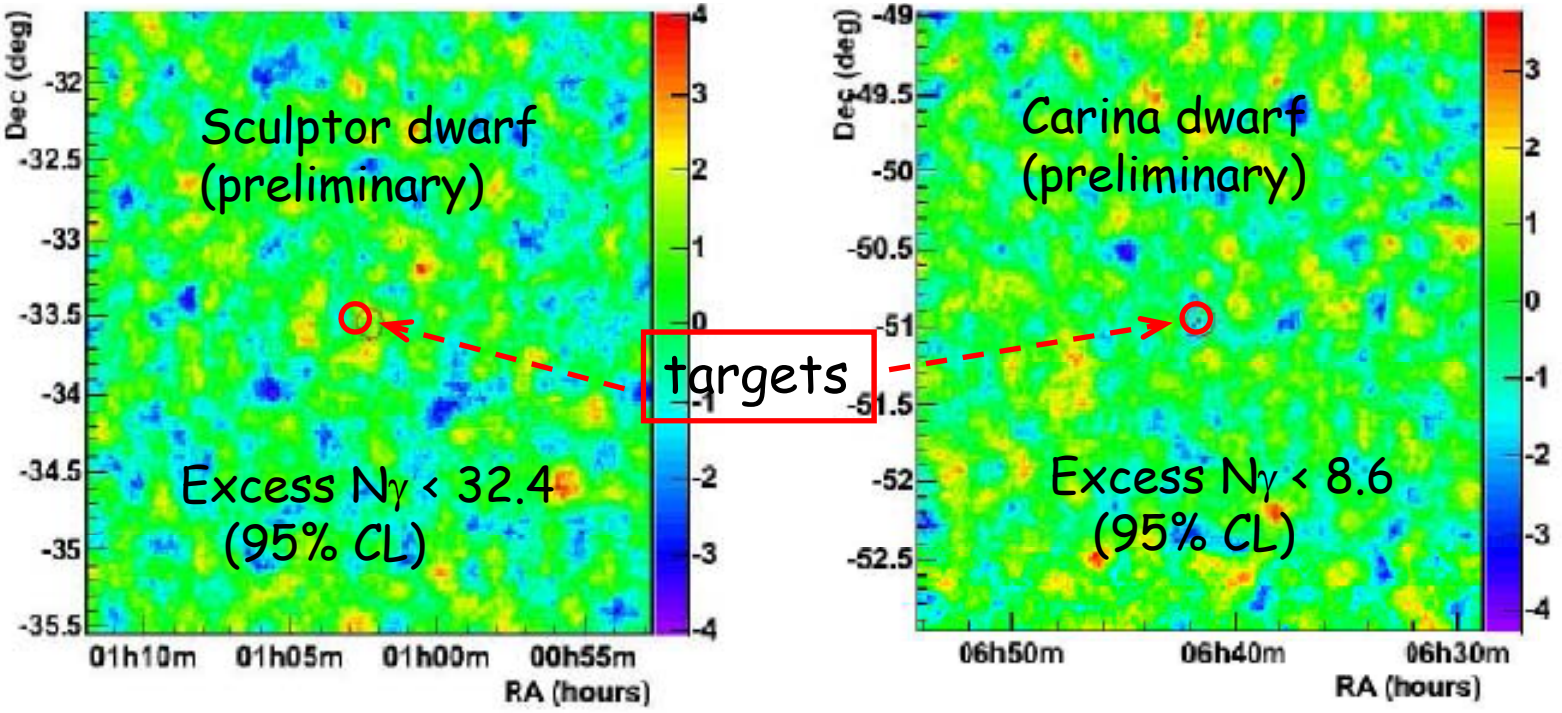
$$\frac{\bar{J}_{\mathrm{Sgr}}}{\bar{J}^{\mathrm{GC}}_{\mathrm{NFW}}} = 0.07 - 2.6$$

- $\langle\sigma v\rangle_{min} \approx 5\ 10^{-24}\ cm^3\ s^{-1}$ (MSSM, NFW profile)
- *F.Aharonian et al, Astropart.Physics 29,55(2008)*
  F. Aharonian et al, Astropart. Physics 33,274 (2010)

HESS observations towards Carina/Sculptor

— data taken in 2008 (Sculptor) and 2008-2009 (Carina)

	distance (kpc)	t observation	<zenith angle>	Eff threshold (GeV)
Carina dwarf	101	14.8 h	34 °	320
Sculptor dwarf	79	11.8 h	14°	220



DM modeling of Sculptor and Carina

- 2 halo profiles:

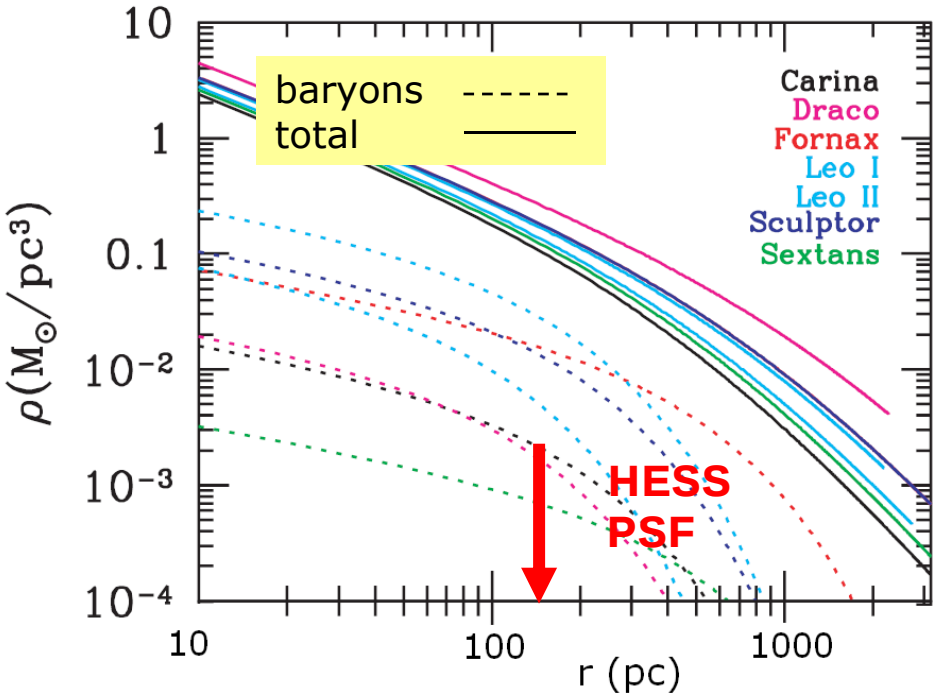
$$\rho_{\mathrm{NFW}} = \frac{\rho_o r_S}{r} \frac{1}{(1+r/r_S)^2} \quad \text{NFW}$$

$$\rho_{\mathrm{core}} = \frac{\rho_c r_c^2}{r^2 + r_c^2} \quad \text{core}$$

- models parameters fitted to velocity dispersion and luminosity profile data.
- models taken from publications:
  - Sculptor: G. Battaglia thesis (2007)
    Battaglia et al , (2008)
  - Carina: Gilmore et al (2007)
    Walker et al (2007)
- Astrophysical factors $\bar{J}$

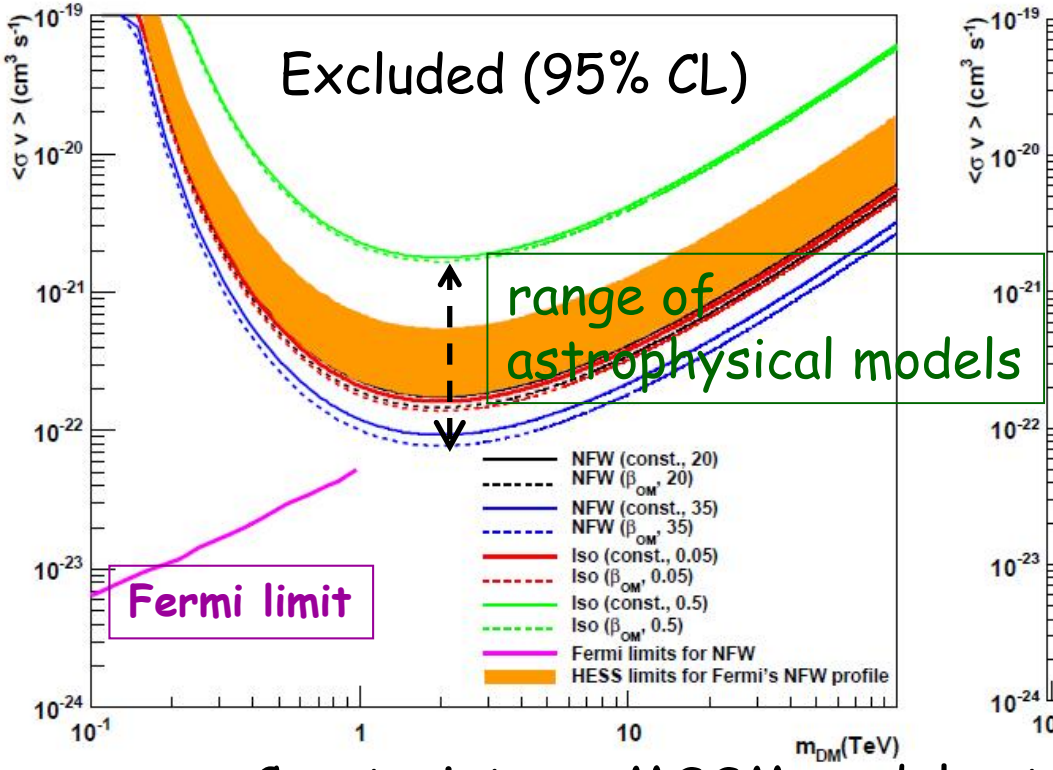
$$\frac{\bar{J}_{\mathrm{Sculptor}}}{\bar{J}^{\mathrm{GC}}_{\mathrm{NFW}}} = (0.2 - 2.3)\cdot 10^{-2}$$

$$\frac{\bar{J}_{\mathrm{Carina}}}{\bar{J}^{\mathrm{GC}}_{\mathrm{NFW}}} = (0.7 - 1.5)\cdot 10^{-3}$$

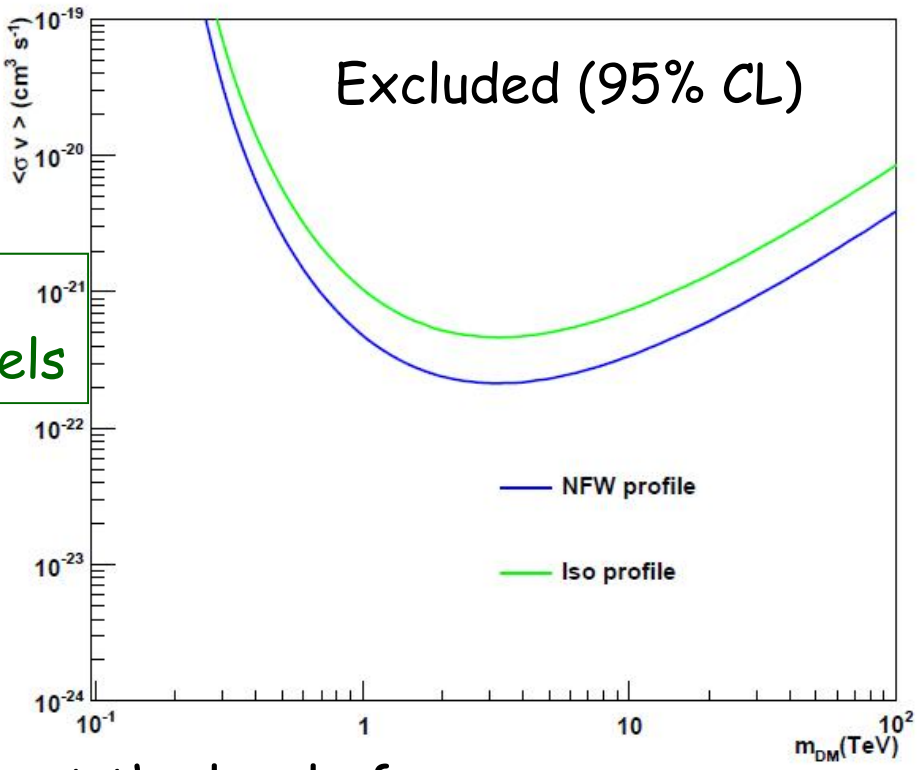


Sculptor and Carina: exclusion limits (MSSM)

Sculptor dwarf (PRELIMINARY)



Carina dwarf (PRELIMINARY)



- Constraints on MSSM models at the level of
  $\langle\sigma v\rangle_{min} = 5\ 10^{-22}\ cm^3\ s^{-1}$
- Astrophysical uncertainties ~ 1 order of magnitude

Signal boosts

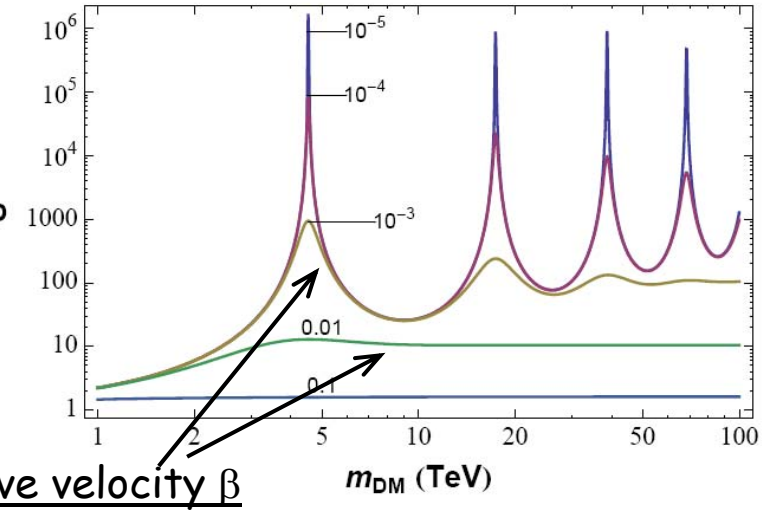
- astrophysics:
  - « clumps »: few % enhancement for Carina/Sculptor

- particle physics:
  - Sommerfeld effect:
    - effective low velocity dispersions

$$\beta = \frac{v}{c} << \alpha_2 \approx 0.03$$

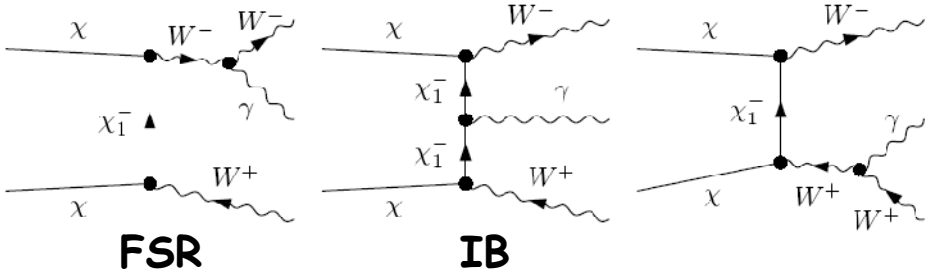
    - resonances at:

$$M_\chi = \frac{M_Z}{\alpha_2} n^2 = 4.45 n^2 \text{ TeV}$$

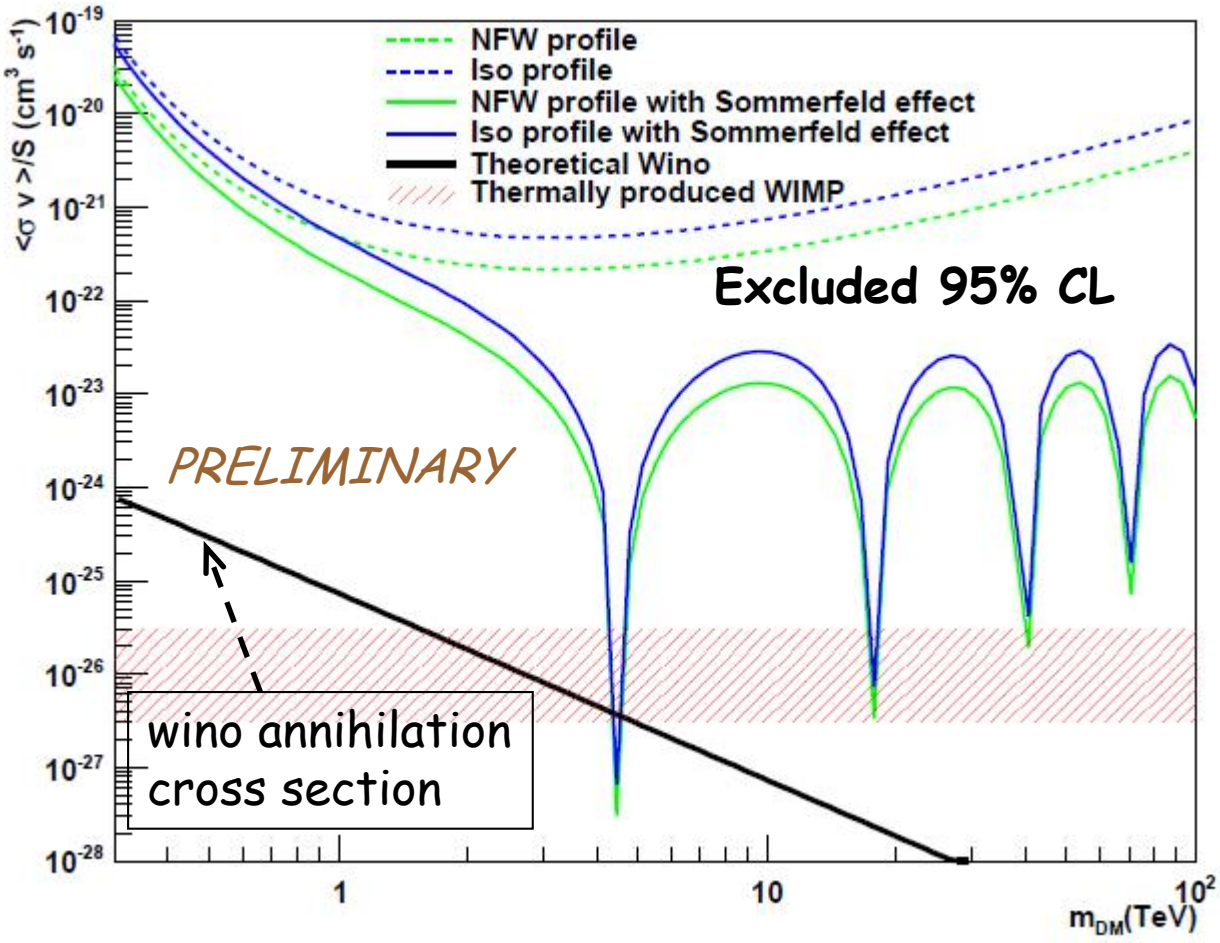


  - Internal Brehmstrahlung
    - annihilation to W^+W^-, $f\bar{f}$

(χ heavy higgsino-like)



Carina dwarf : Sommerfeld effect



— dispersion velocity σ = 7.5 km/s

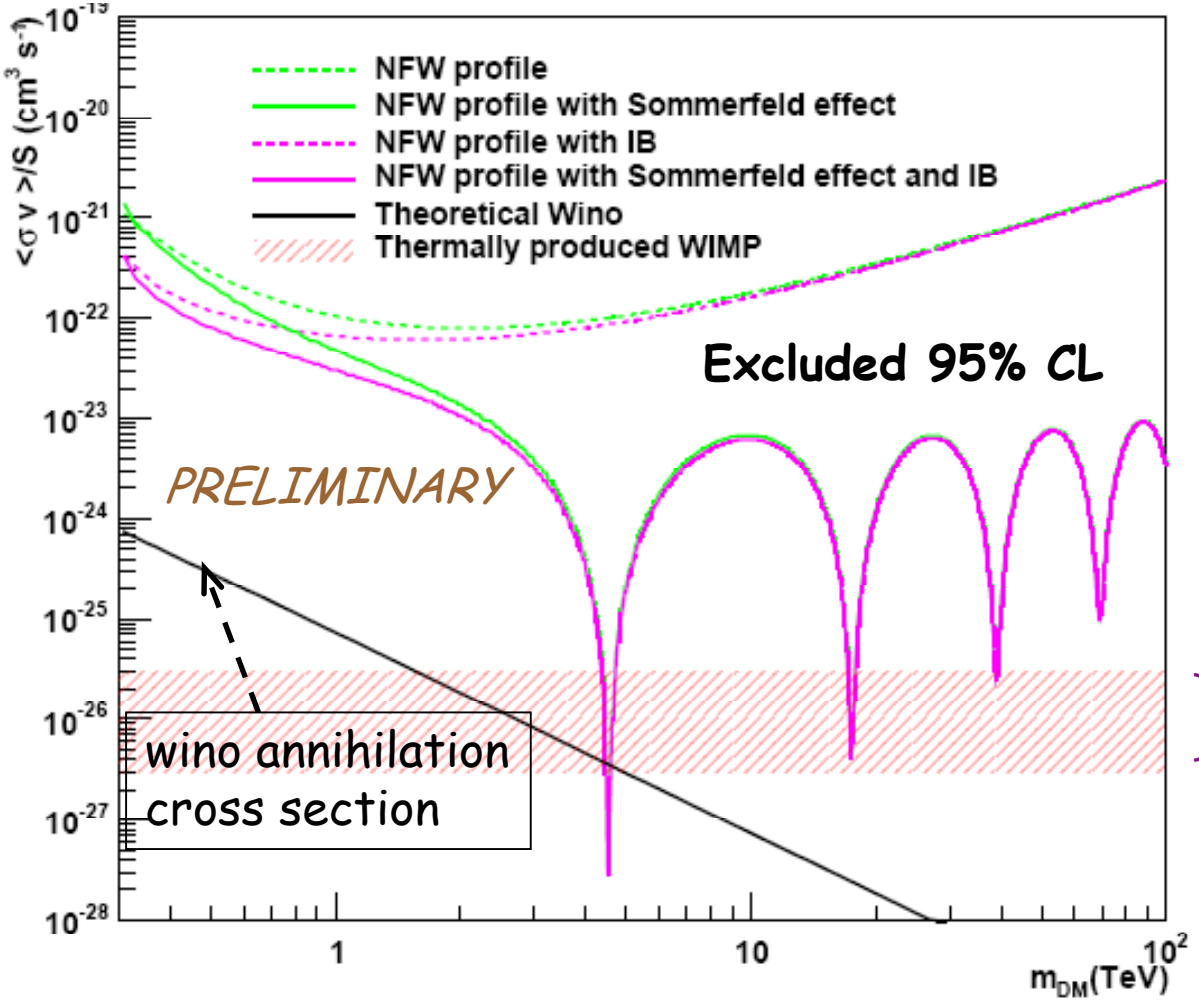
— $\beta \sim 2\ 10^{-5} \ll \alpha_2 = 1/30$

$\Rightarrow$ Sommerfeld boost expected to be important for models with pure wino χ

} thermal wimp annihilation cross section

— some models excluded near $M\chi \approx 4.5$ TeV

Scuptor dwarf: enhancements from IB and Sommerfeld effect

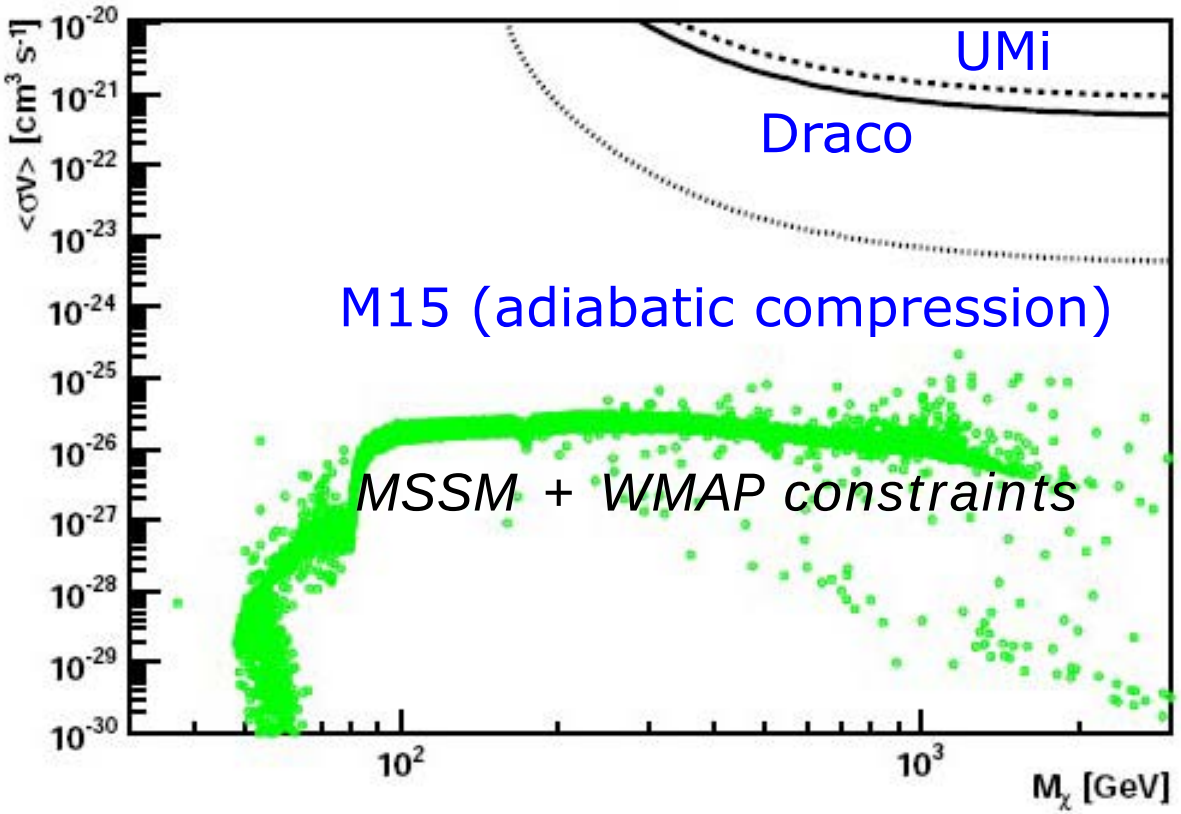


- dispersion velocity σ = 10 km/s
- Sommerfeld boost also expected to be important for models with pure wino χ
- effect of IB important for M_χ < 1 TeV

} thermal wimp annihilation cross section

Are globular clusters better than dwarf galaxies?

- Whipple telescope (single, ø= 10 m)
- Globular cluster M15: 1.2 hours (2002)
- analysis threshold: 400 GeV
- no excess events: Flux(M15) < .38 C.U (95% C.L)

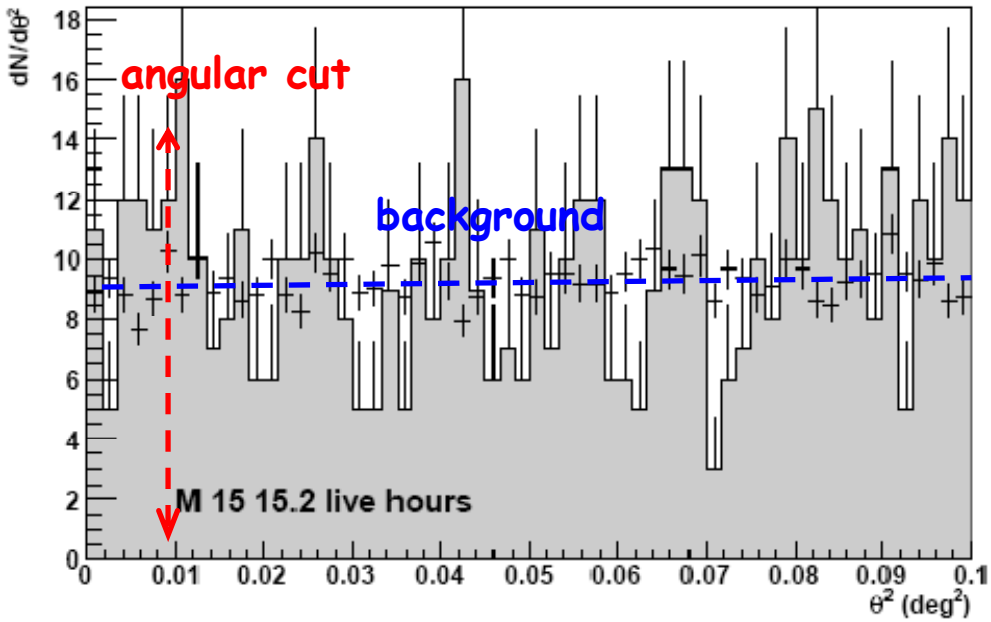


- Limits as constraining as Canis Major with just 1 hour observation !

*M.Wood et al (**Whipple**) ApJ 678, 594 (2008)*

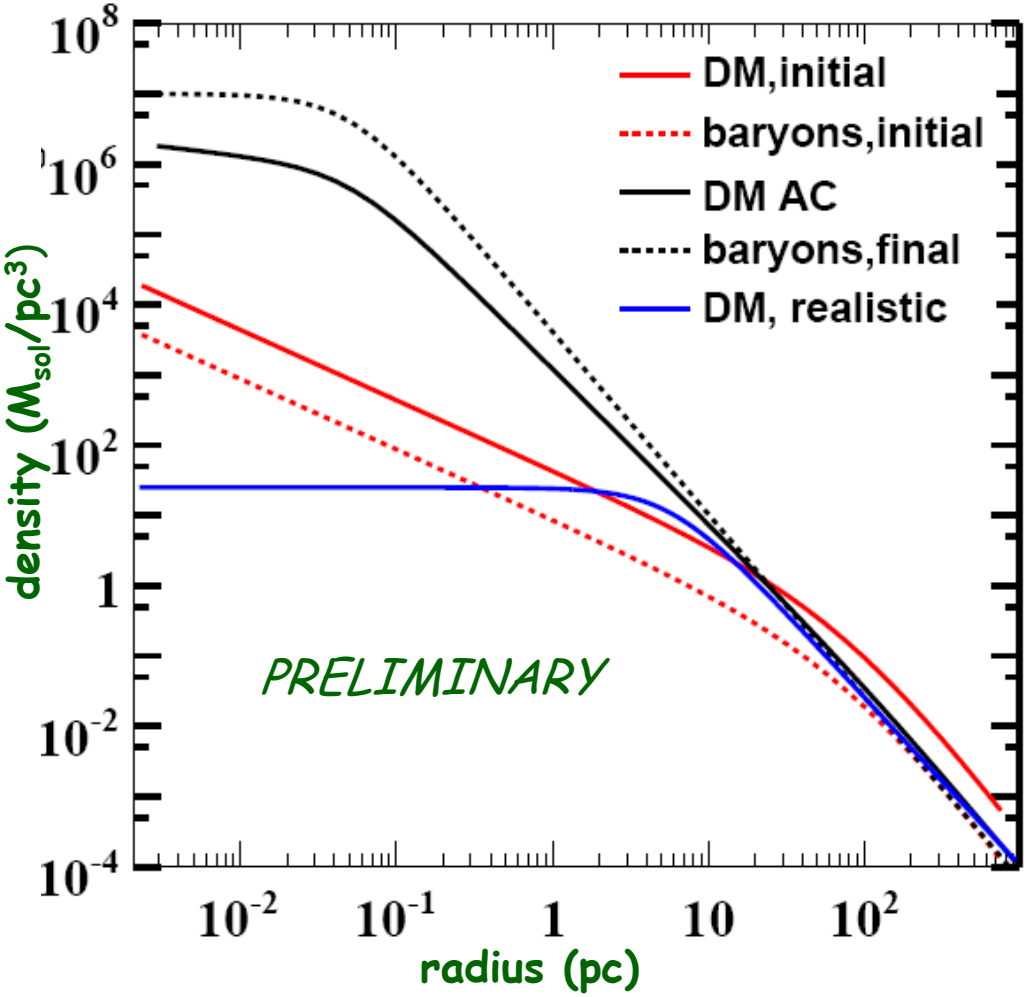
HESS data on M15

- Globular cluster, located at 10.1 kpc from Sun
- Estimated total mass: 10^5 M_{sol}
- Undergoing *core collapse*, with a very small r = 0.2 pc core



- 15.2 hours taken by HESS
- mean zenith angle: 37°
- No excess seen in 0.07° radius around source
  $\Rightarrow N\gamma < 35.7$ (95% C.L)

Dark matter modeling of M15



— initial DM halo with NFW profile (M_{vir} = 10^7 M_{sol}, c=50)

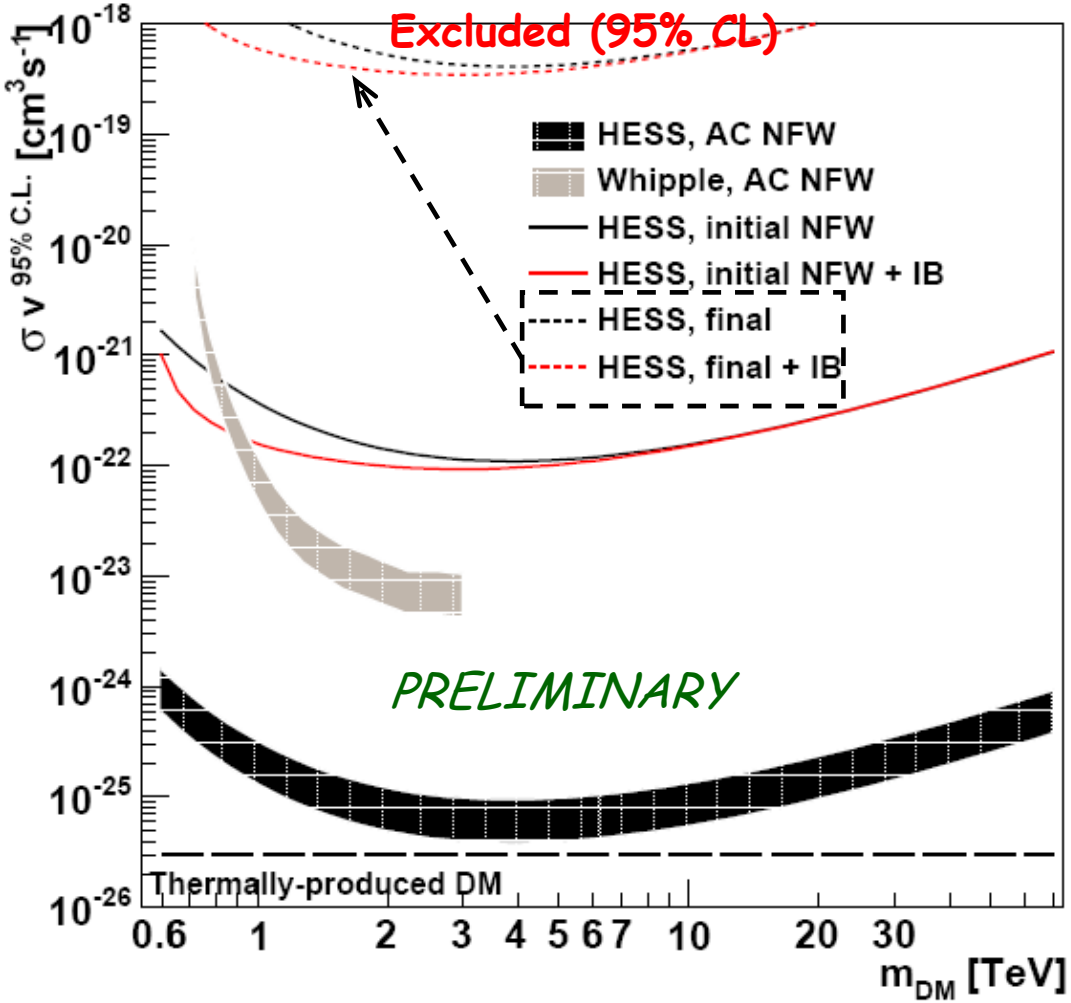
— adiabatic compression of dark matter following baryon collapse in core.
(same model as Woods et al 2008)

— heating of DM in core by baryons on timescale T_h=10^4 years

— Final DM density in core

$$\rho_{DM} = 25\, M_{sol} / \mathrm{pc}^3$$

HESS constraints on M15



— adiabatic compression only

$$\frac{\bar{J}_{\mathrm{M15}}}{\bar{J}^{\mathrm{GC}}_{\mathrm{NFW}}} = 110$$

— after DM heating by stars:

$$\frac{\bar{J}_{\mathrm{M15}}}{\bar{J}^{\mathrm{GC}}_{\mathrm{NFW}}} = 10^{-4}$$

— no significant DM constraint from M15

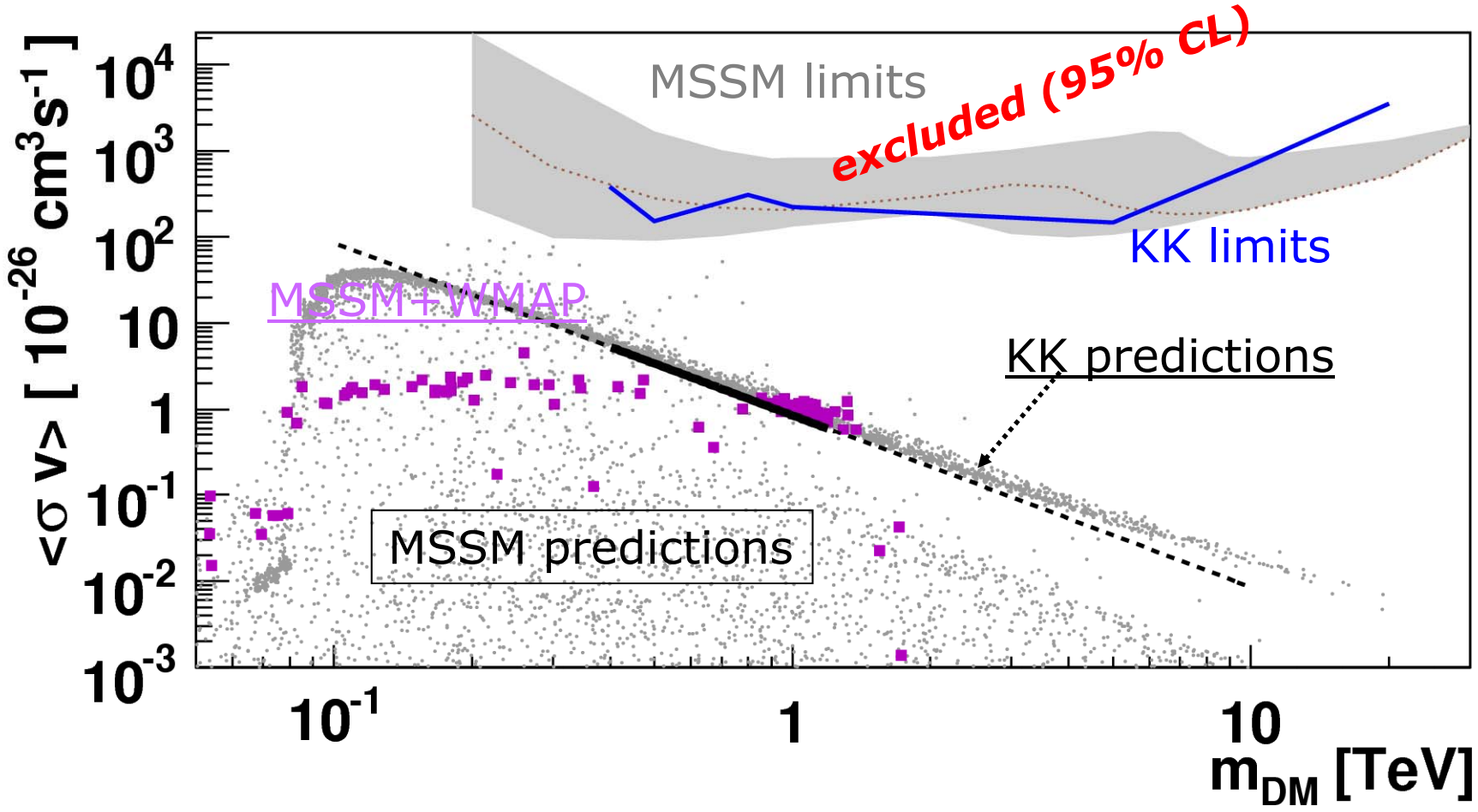
Summary

- new dark matter targets: Sculptor and Carina dwarf galaxies and M15 globular cluster have been studied by HESS.
- No signal was found towards any of these targets.
- Strong constraints from Sommerfeld effects in Carina/Sculptor

target	95% CL $\langle\sigma v\rangle$ limit (cm^3 /s)	Comment
Sgr dwarf	5 10^{-24} (NFW)	disrupted by Milky Way/ Model uncertain
Canis Major	5 10^{-24}	D~7 kpc, dwarf galaxy status uncertain
Carina	5 10^{-22}	D~100 kpc, tidal effects
Sculptor	5 10^{-22}	D~80 kpc
M15	5 10^{-19}	probably no DM, in spite of core collapse

BACKUP SLIDES

GC: exclusion plot



(p)MSSM predictions: DarkSusy 4.1

HESS high energy electron signal