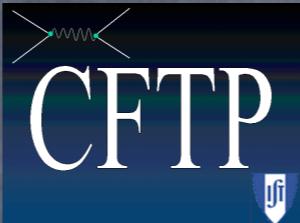


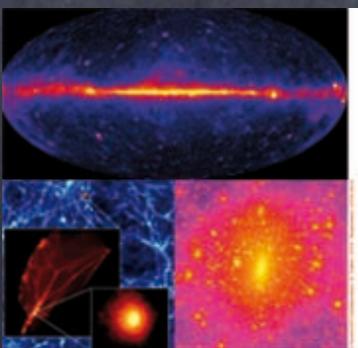
# Annihilation vs. Decay: Constraining Dark Matter Properties From A Gamma Ray Detection In Dwarf Galaxies

based on SPR and J. M. Siegal-Gaskins, JCAP 07:023, 2010

*Sergio Palomares-Ruiz*



Centro de Física Teórica de Partículas  
Instituto Superior Técnico, Lisbon



**IDM 2010**

8th International Workshop on  
**Identification of Dark Matter**

University of Montpellier 2  
26-30 July 2010

[www.ipta.univ-montp2.fr/idm2010](http://www.ipta.univ-montp2.fr/idm2010)



# Constraining DM properties

## ⦿ With gamma-rays

- S. Dodelson, D. Hooper and P. D. Serpico, *Phys. Rev. D*77:063512, 2008
- T. E. Jeltema and S. Profumo, *JCAP* 0811:003, 2008
- SPR and J. M. Siegal-Gaskins, *JCAP* 07:023, 2010
- N. Bernal and SPR, *arXiv:1006.0477*

## ⦿ With neutrinos from the Sun

- J. Edsjo and P. Gondolo, *Phys. Lett. B*357:595, 1995
- M. Cirelli *et al.*, *Nucl. Phys. B*727:99, 2005
- O. Mena, SPR and S. Pascoli, *Phys. Lett. B*664:92, 2008

## ⦿ With direct detection

- A. M. Green, *JCAP* 0708:022, 2007
- G. Bertone, D. G. Cerdeño, J. I. Collar and B. C. Odom, *Phys. Rev. Lett.* 99:151301, 2007
- M. Drees, C.-L. Shan, *JCAP* 0806:012, 2008
- A. M. Green, *JCAP* 0807:005, 2008
- C.-L. Shan, *New J. Phys.* 11:105013, 2009
- Y.-T. Chou and C.-L. Shan, *arXiv:1003.5277*

## ⦿ With colliders

- E. A. Baltz, M. Battaglia, M. E. Peskin and T. Wizansky, *Phys. Rev. D*74:103521, 2006
- W. S. Cho, K. Choi, Y. G. Kim and C. B. Park, *Phys. Rev. Lett.* 100:171801, 2008
- W. S. Cho, K. Choi, Y. G. Kim and C. B. Park, *Phys. Rev. D*79:031701, 2009

## ⦿ With a combination

- N. Bernal, A. Goudelis, Y. Mambrini and C. Muñoz, *JCAP* 0901:046, 2009
- G. Bertone, D. G. Cerdeño, M. Fornasa, R. Ruiz de Austri and R. Trotta, *arXiv:1005.4280*

# Indirect Detection in $\gamma$ -Rays

## ⦿ Extragalactic structures

Bergstrom, Edsjo, Ullio, Lacey, Pieri, Branchini, Belikov, Hooper, Profumo, Jeltema, Pohl, Eichler, Abazajian, Agrawal, Chacko, Kilic...

## ⦿ Galactic Center

Berezinsky, Gurevich, Zybin, Bottino, Mignola, Bergstrom, Ullio, Buckley, Cesarini, Fucito, Lionetto, Morselli, Baltz, MAGIC Collaboration, HESS Collaboration...

## ⦿ Milky Way Halo

Baltz, Calcano-Roldan, Moore, Stoher, White, Springel, Tormen, Yoshida, Springel, Pieri, Lavalle, Bertone, Branchini, Fermi-LAT Collaboration...

## ⦿ Milky Way subhalos

Baltz, Pieri, Lavalle, Bertone, Branchini, Tasitsiomi, Olinto, Koushiappas, Zentner, Walker, Hoffmann, Diemand, Kuhlen, Madau...

## ⦿ Dwarf Galaxies

Baltz, Briot, Salati, Taillet, Silk, Tyler, Tasitsiomi, Siegal-Gaskins, Olinto, Bergstrom, Hooper, Strigari, Koushiappas, Bullock, Kaplinghat, Bringmann, Doro, Fornasa, Pieri, Pizella, Corsini, Bonatá, Bertola, Martínez, Trotta, Scott, Conrad, Edsjo, Farnier, Akrani, Evans, Ferrer, Sarkar, Simon, Geha, Willman, Essig, Sehgal, MAGIC Collaboration, HESS Collaboration, VERITAS Collaboration, Fermi-LAT Collaboration...

# In case of a $\gamma$ -ray signal...

- Could annihilation and/or decay be identified as the origin of the signal?

Not with only the energy spectrum

Endpoint = M (annihilations) vs. M/2 (decays)

- What information about the particle properties could be obtained?

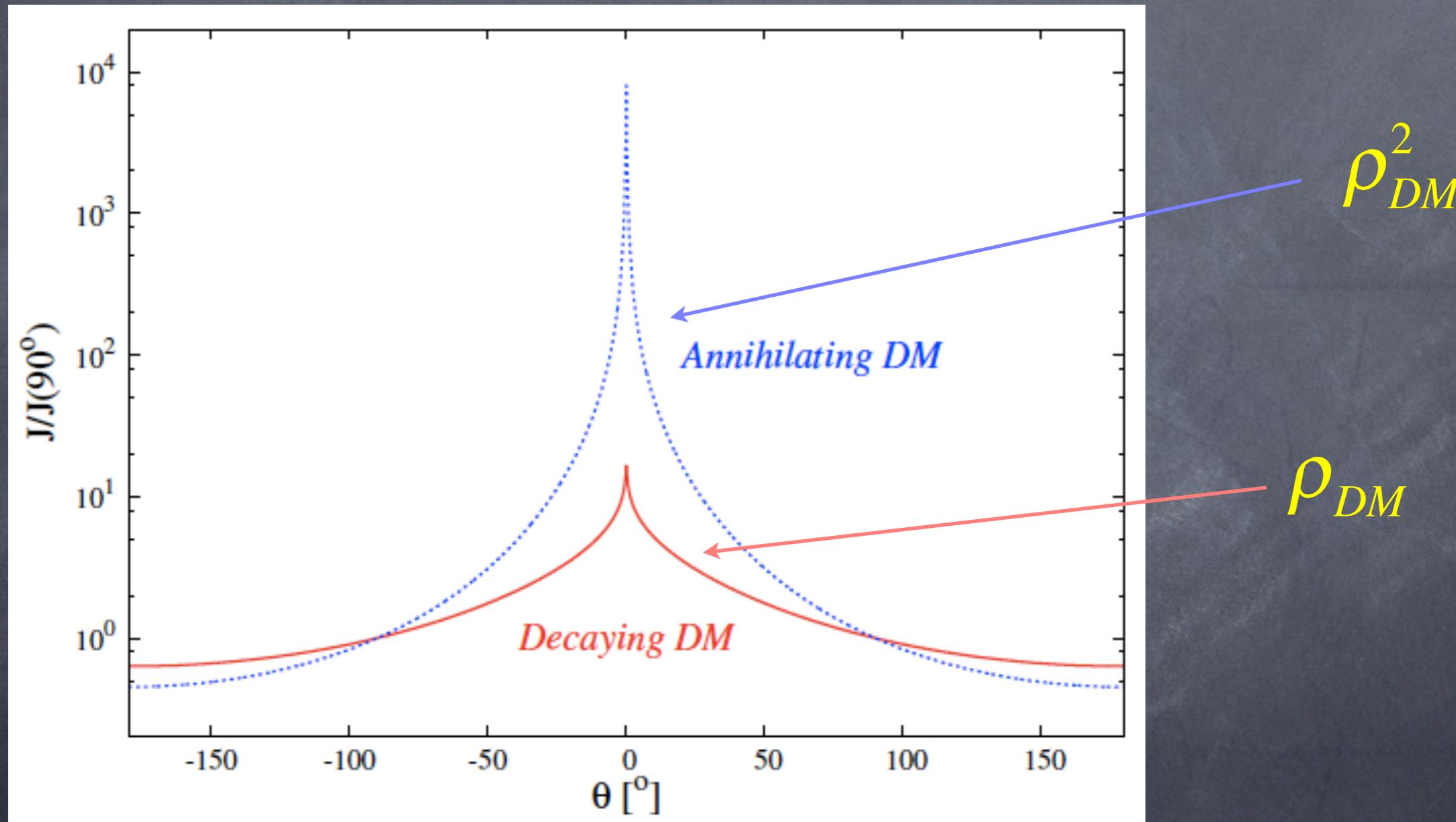
Mass, lifetime, annihilation cross section, annihilation/decay channels

See Talk by N. Bernal

# In case of a $\gamma$ -ray signal...

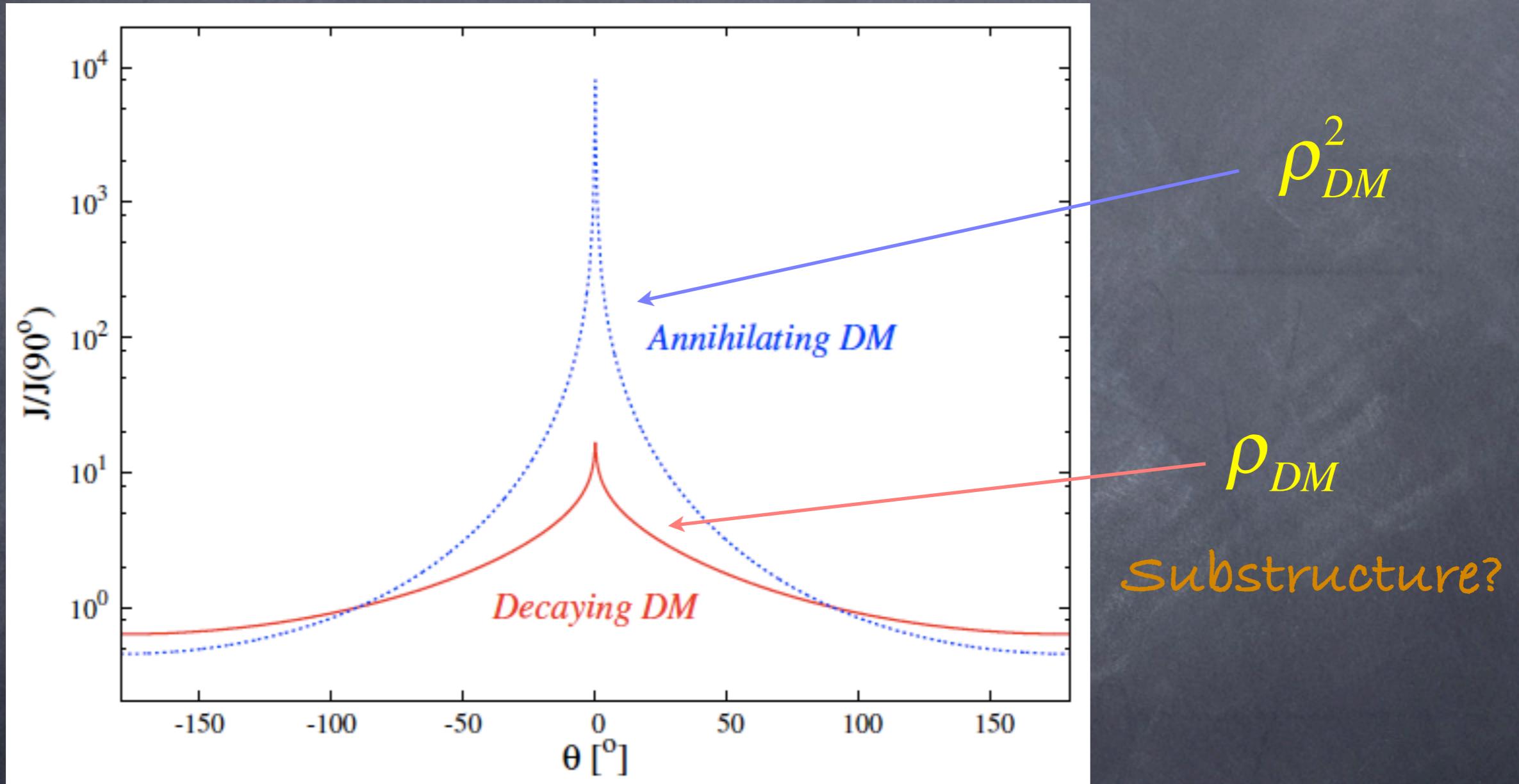
- If dark matter is unstable and produces an observable signal from decay, an annihilation signal might also be present
- There is a range of parameters for which this would occur
- We propose to use gamma-ray observations of Milky Way dwarf galaxies with current or future experiments

# Annihilation or Decay or ...?



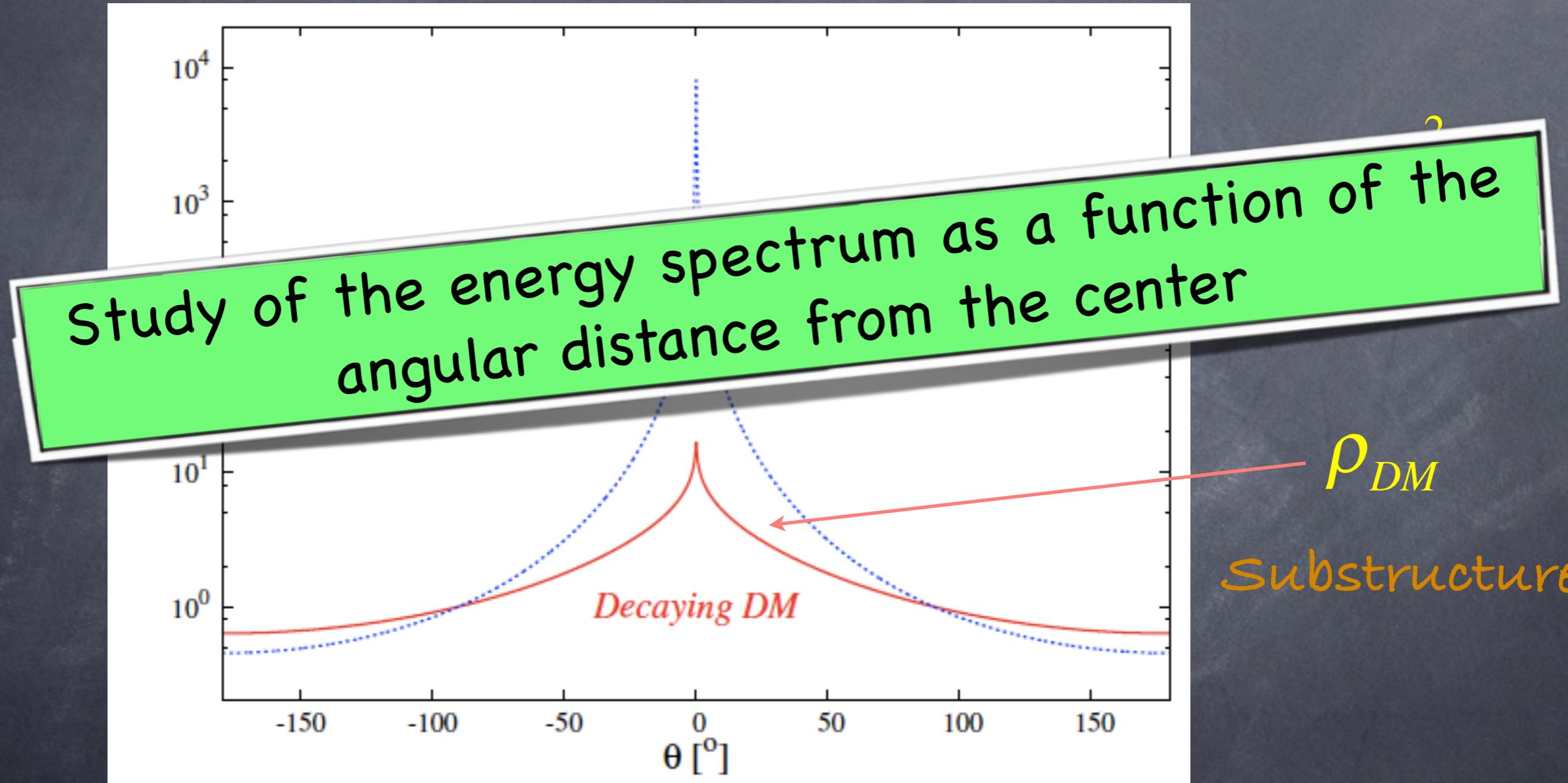
G. Bertone, W. Buchmuller, L. Covi and A. Ibarra, *JCAP* 0711:003, 2007

# Annihilation or Decay or ...?



G. Bertone, W. Buchmuller, L. Covi and A. Ibarra, *JCAP* 0711:003, 2007

# Annihilation or Decay or ...?



G. Bertone, W. Buchmuller, L. Covi and A. Ibarra, *JCAP* 0711:003, 2007

# General idea

$$P_D = \frac{1}{m_\chi \tau_\chi} \frac{dN_D}{dE}$$



$$\frac{I_D}{I_A}(\psi) = \frac{P_D}{P_A} \frac{\Phi_D(\psi)}{\Phi_A(\psi)} = \frac{2m_\chi}{\langle\sigma v\rangle \tau_\chi} \frac{(dN_D/dE)}{(dN_A/dE)} \frac{\Phi_D(\psi)}{\Phi_A(\psi)}$$



$$P_A = \frac{\langle\sigma v\rangle}{2m_\chi^2} \frac{dN_A}{dE}$$

$$\tau_\chi = \frac{2m_\chi}{\langle\sigma v\rangle} \frac{\int dE (dN_D/dE)}{\int dE (dN_A/dE)} \frac{\Phi_D(\psi_{\text{cross}})}{\Phi_A(\psi_{\text{cross}})}$$

Innermost region: annihilation

Outermost region: decay (or annihilation in substructure)

# General idea

$$P_D = \frac{1}{m_\chi \tau_\chi} \frac{dN_D}{dE}$$



$$\frac{I_D}{I_A}(\psi) = \frac{P_D}{P_A} \frac{\Phi_D(\psi)}{\Phi_A(\psi)} = \frac{2m_\chi}{\langle\sigma v\rangle \tau_\chi} \frac{(dN_D/dE)}{(dN_A/dE)} \frac{\Phi_D(\psi)}{\Phi_A(\psi)}$$



$$P_A = \frac{\langle\sigma v\rangle}{2m_\chi^2} \frac{dN_A}{dE}$$

$$\tau_\chi = \frac{2m_\chi}{\langle\sigma v\rangle} \frac{\int dE (dN_D/dE)}{\int dE (dN_A/dE)} \frac{\Phi_D(\psi_{\text{cross}})}{\Phi_A(\psi_{\text{cross}})}$$

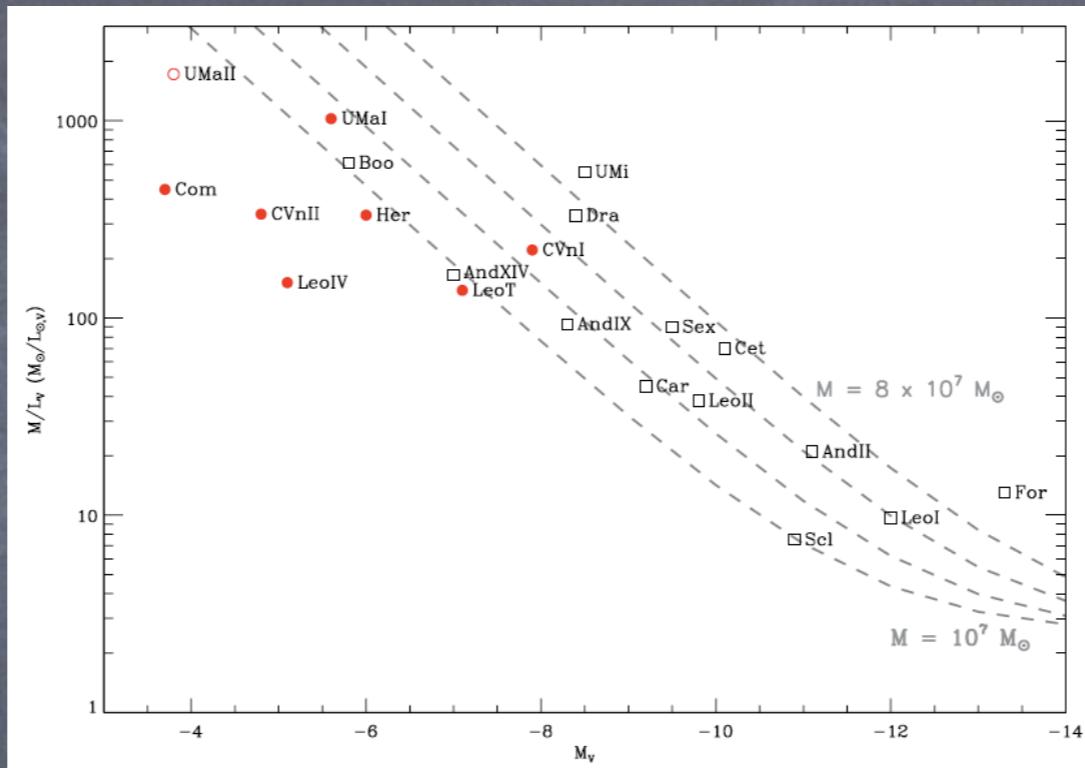
Innermost region: annihilation

Outermost region: decay (or annihilation in substructure)

Change of slope

# Dwarf Spheroidal Galaxies

- Highly dark matter dominated systems



"Mateo" plot

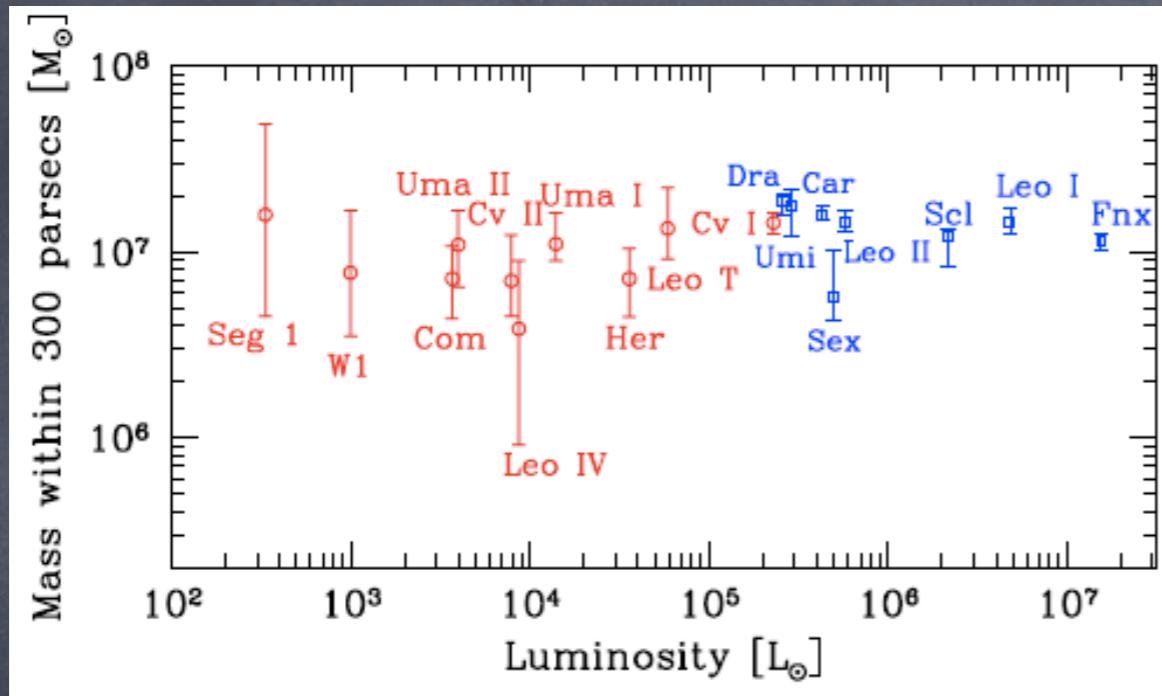
J. D. Simon and M. Geha, *Astrophys. J.* 670:313, 2007

- Relatively free from  $\gamma$ -ray emission from other astrophysical sources: no neutral or ionized gas and little or no recent star formation activity

M. Mateo, *Ann. Rev. Astron. Astrophys.* 36:435, 1998

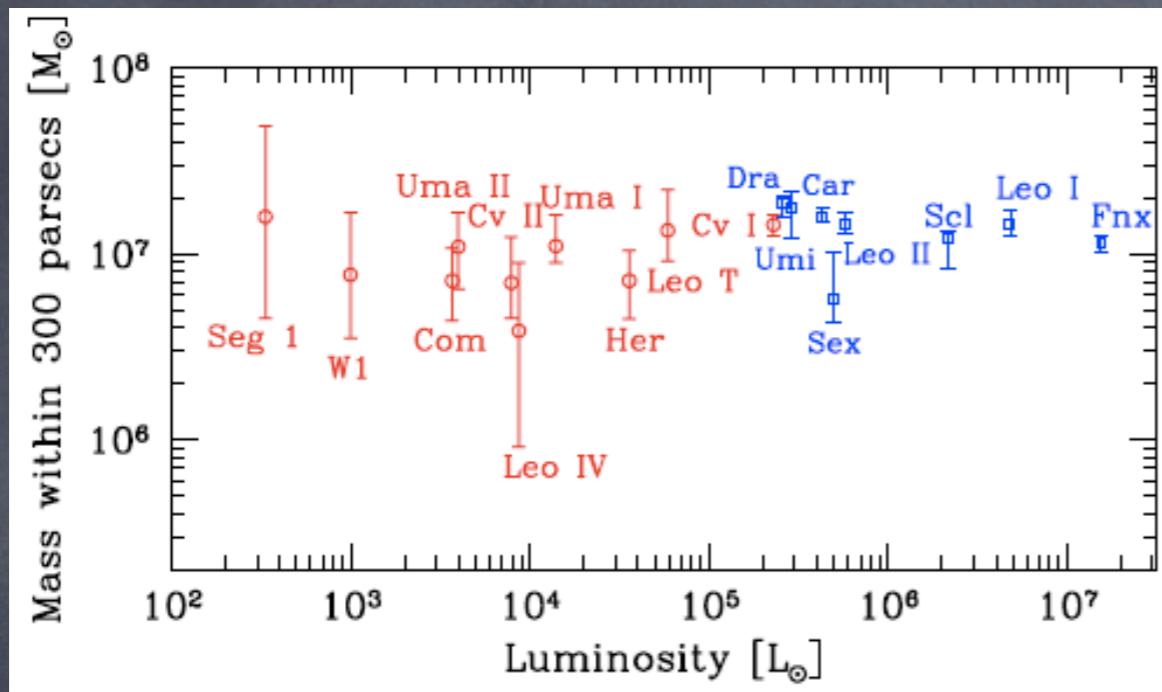
J. S. Gallagher, G. J. Madsen, R. J. Reynolds, E. K. Grebel and T. A. Smecker-Hane, *Astrophys. J.* 588:326, 2003  
J. Grcevich and M. E. Putman, *Astrophys. J.* 696:385, 2009

# Universal mass profile?

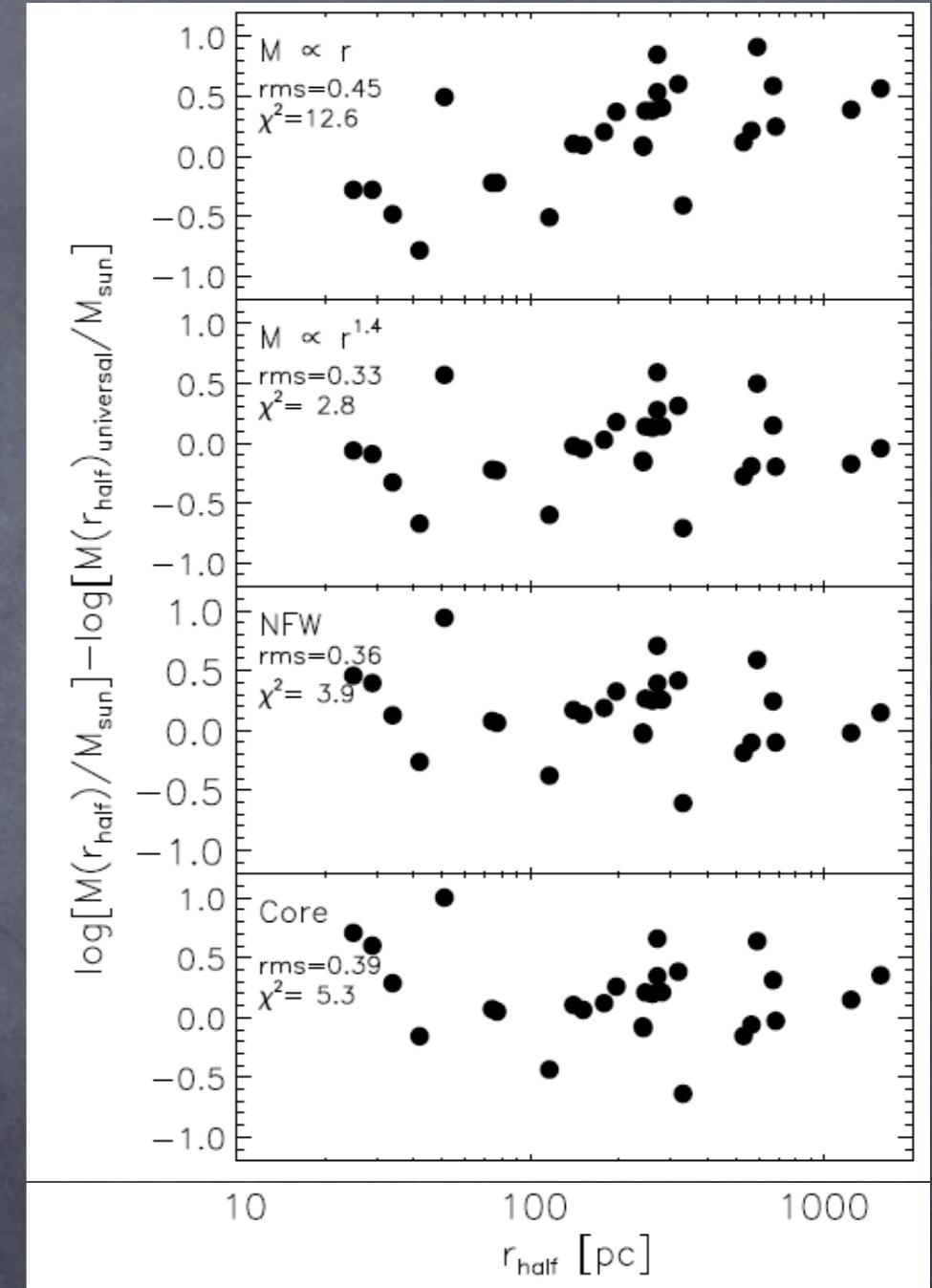


L. E. Strigari *et al.*, *Nature* 454:1096, 2008

# Universal mass profile?

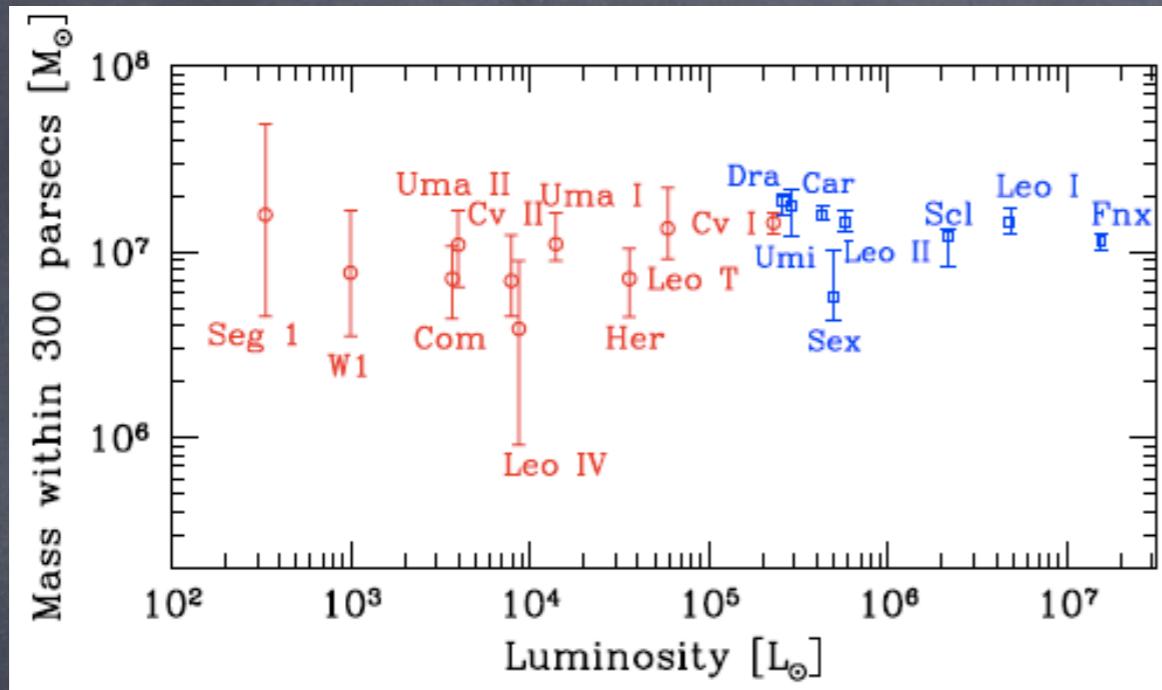


L. E. Strigari *et al.*, *Nature* 454:1096, 2008

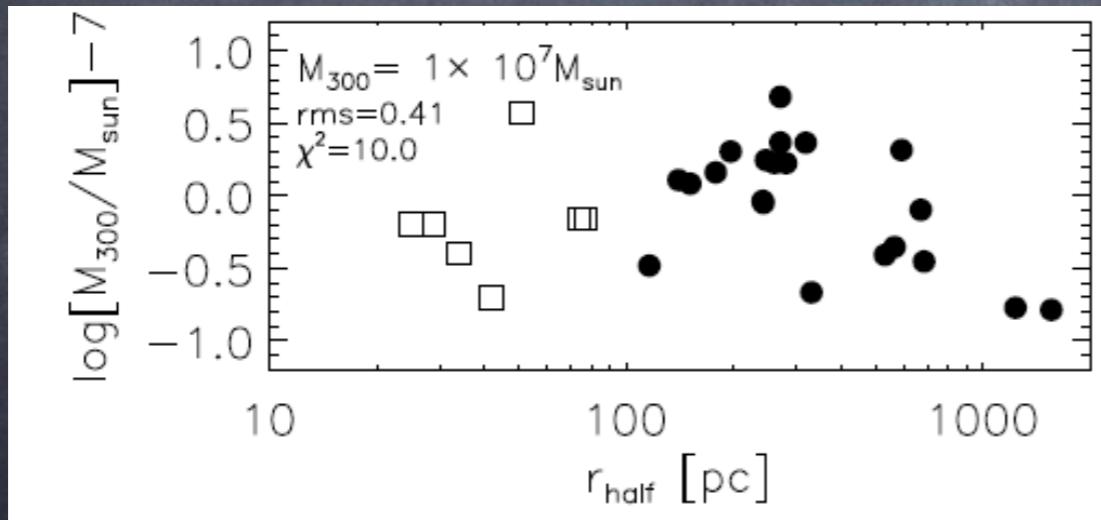


M. G. Walker *et al.*, *Astrophys. J.* 504:1274, 2009

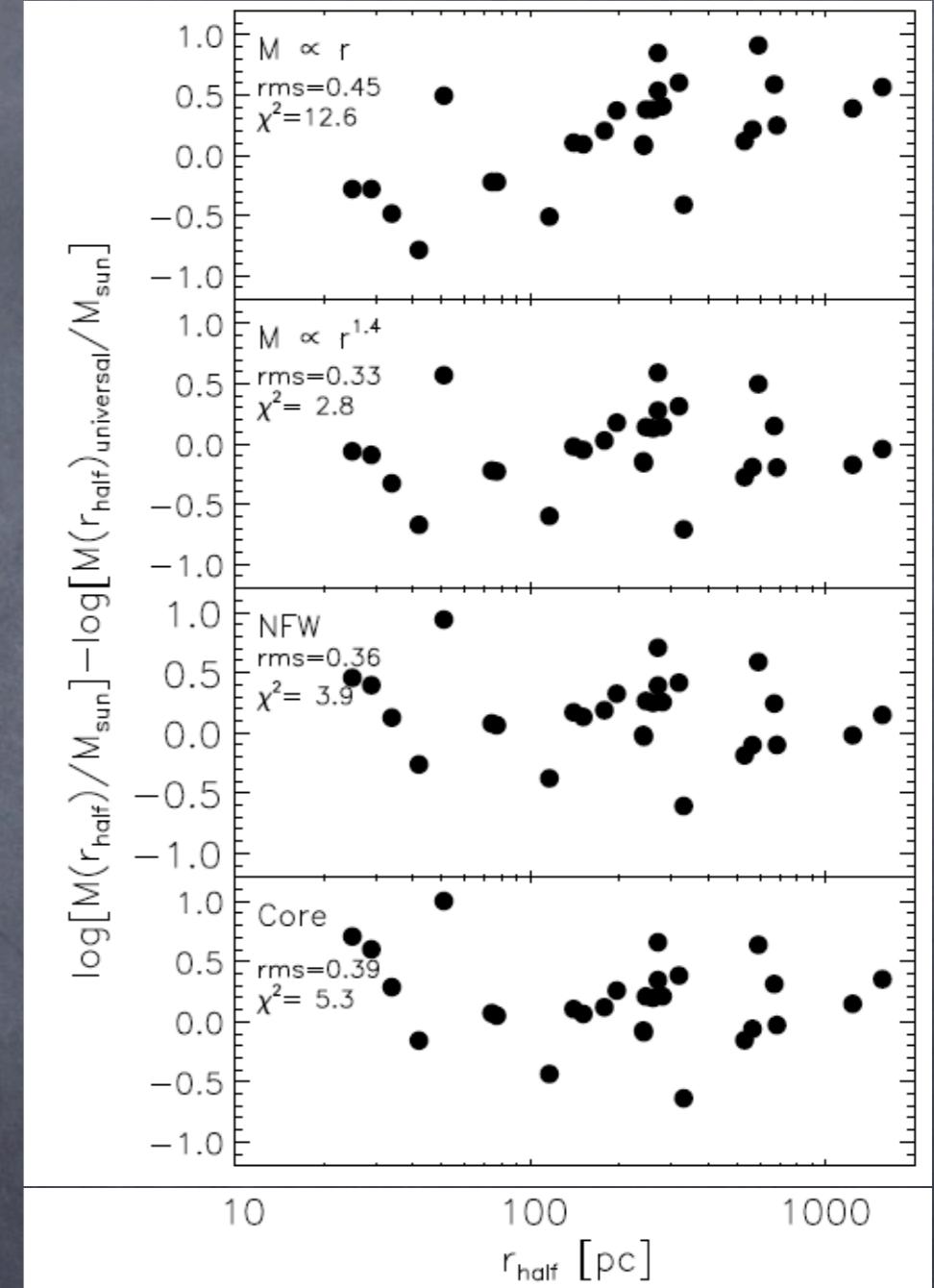
# Universal mass profile?



L. E. Strigari *et al.*, *Nature* 454:1096, 2008



M. G. Walker *et al.*, *Astrophys. J.* 504:1274, 2009



M. G. Walker *et al.*, *Astrophys. J.* 504:1274, 2009

Object	$d_\odot$ (kpc)	$d_{\text{GC}}$ (kpc)	$r_s$ (kpc)	$v_{\text{max}}$ (km/s)	$\rho_s$ ( $M_\odot \text{ kpc}^{-3}$ )	$r_{\text{cut}}$ (kpc)
Draco	76	76	0.795	22	$6.6 \times 10^7$	6.8
Ursa Minor (UMi)	66	68	0.795	21	$6.0 \times 10^7$	6.3
Sagittarius (Sgr)	24	16	0.795	22	$6.6 \times 10^7$	2.4



Draco

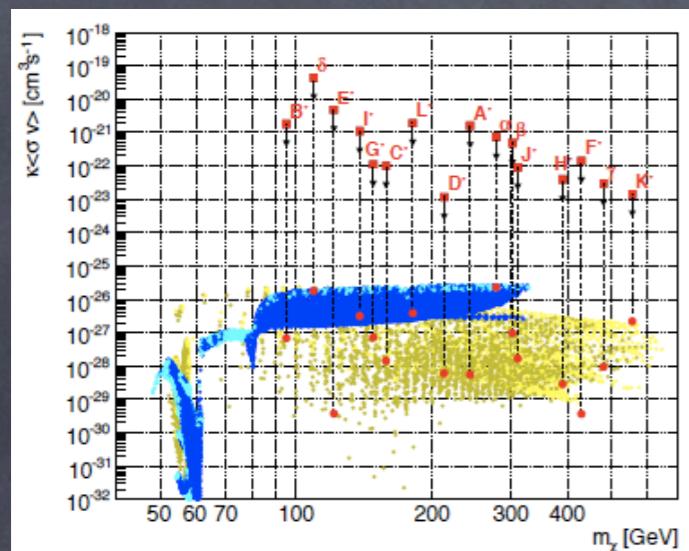


Sagittarius



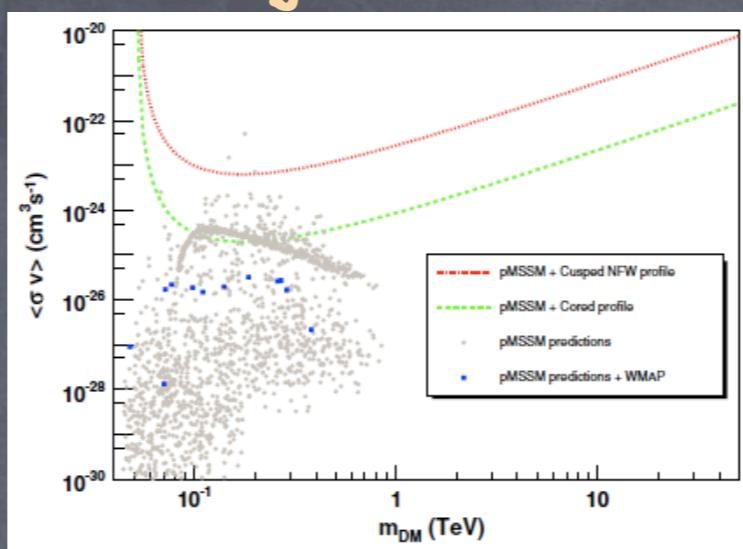
Ursa Minor

# Draco

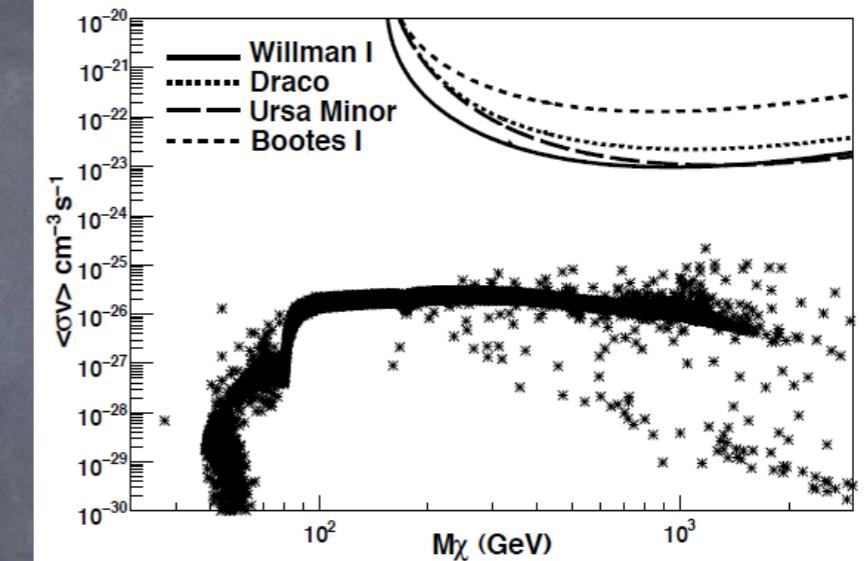


J. Albert *et al.* [MAGIC Collaboration],  
*Astrophys. J.* 679:428, 2008

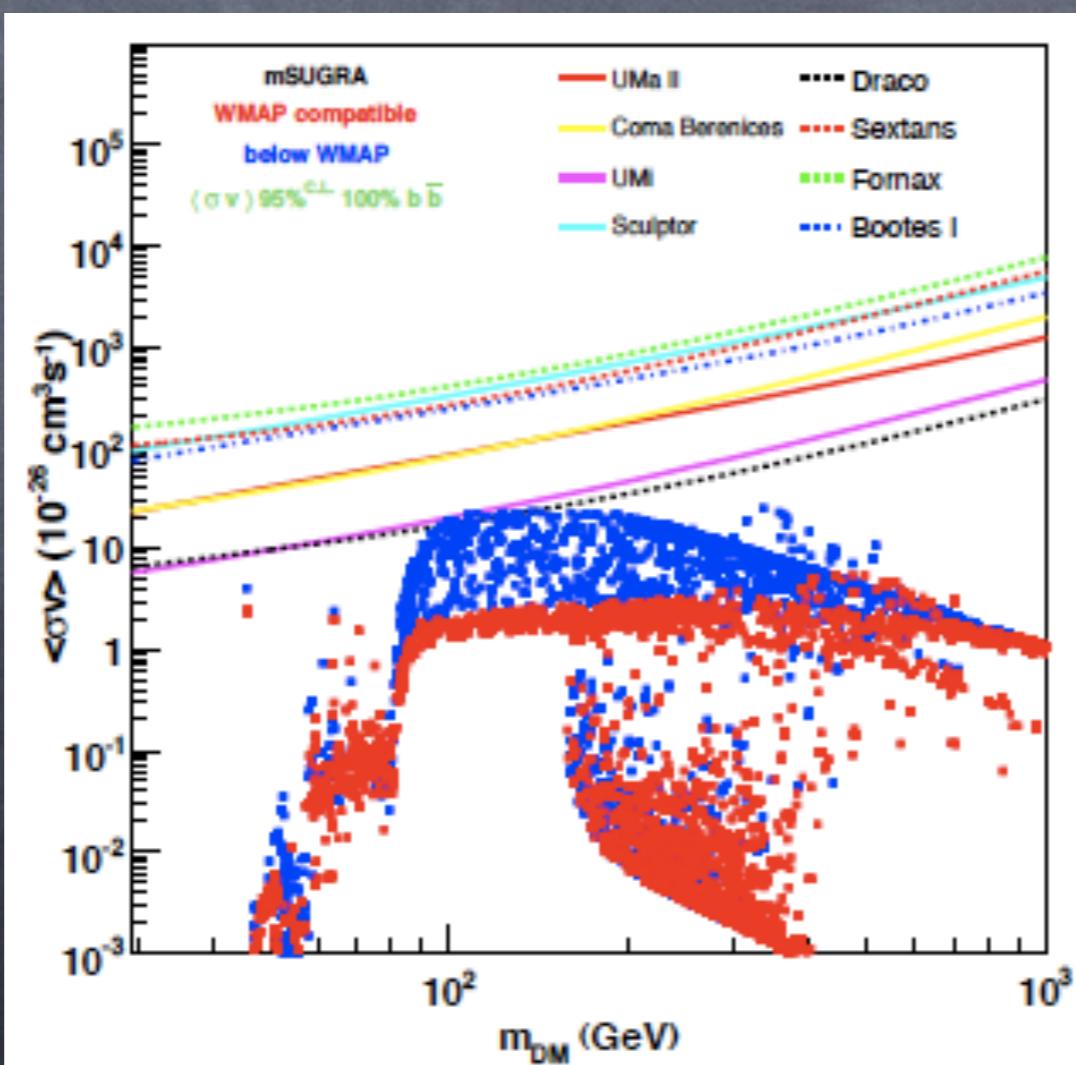
# Sagittarius



F. Aharonian *et al.* [HESS Collaboration],  
*Astropart. Phys.* 29:55, 2008

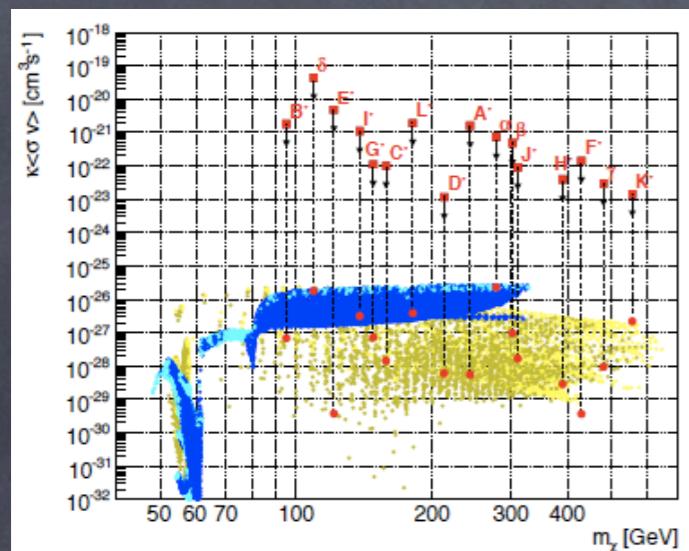


V. A. Acciari *et al.* [VERITAS Collaboration],  
*arXiv:1006.5995*



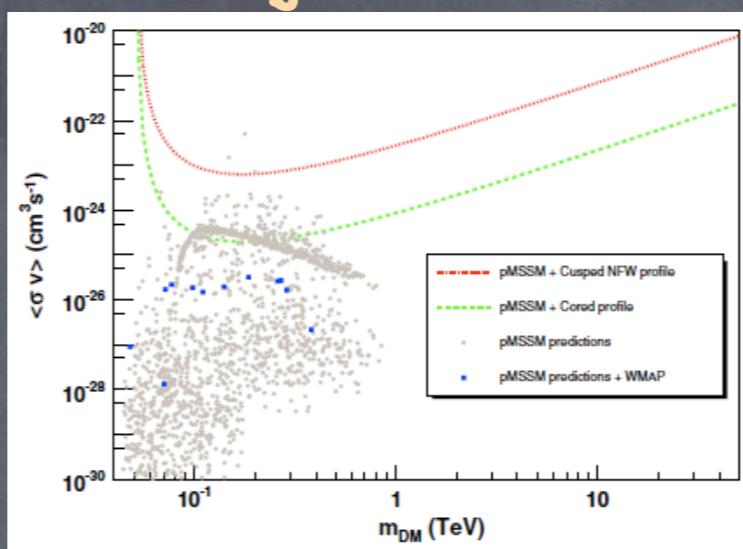
A. A. Abdo *et al.* [Fermi-LAT Collaboration],  
*Astrophys. J.* 712:147, 2010

# Draco

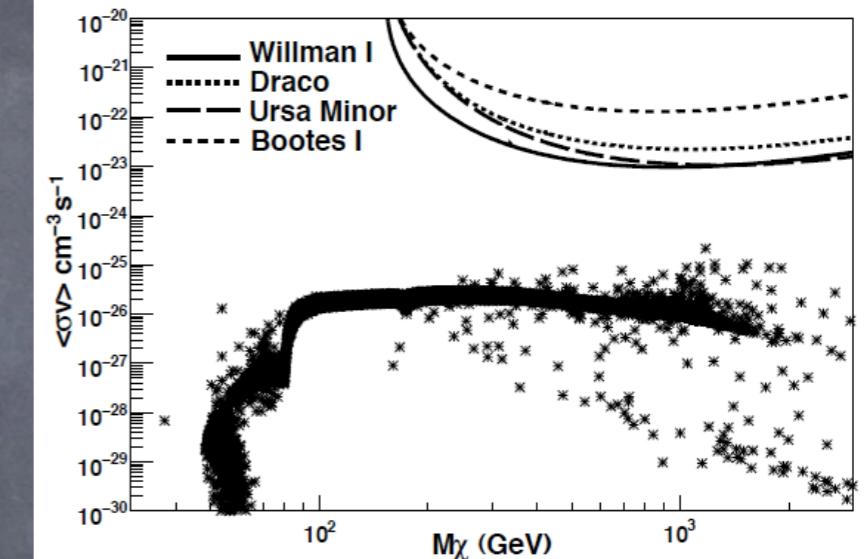


J. Albert *et al.* [MAGIC Collaboration],  
*Astrophys. J.* 679:428, 2008

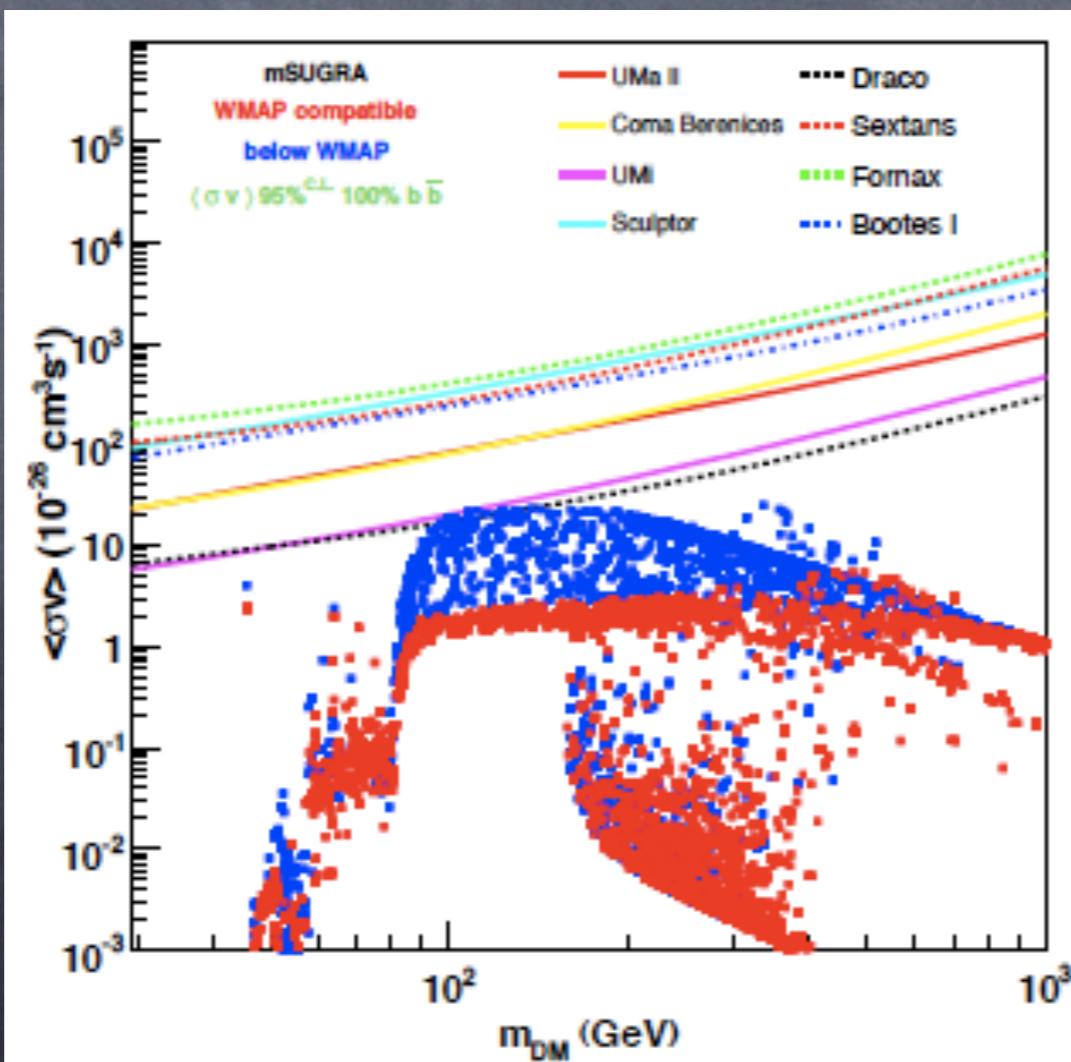
# Sagittarius



F. Aharonian *et al.* [HESS Collaboration],  
*Astropart. Phys.* 29:55, 2008



V. A. Acciari *et al.* [VERITAS Collaboration],  
*arXiv:1006.5995*



A. A. Abdo *et al.* [Fermi-LAT Collaboration],  
*Astrophys. J.* 712:147, 2010

# Smooth Halo

- We use a Navarro-Frenk-White density profile
- To account for tidal stripping we truncate the profile following the Roche-limit criterion

$$\rho_{\text{sm}}(r) = \frac{\rho_s}{r/r_s (1 + r/r_s)^2}$$

$$r_{\text{cut}} \simeq \left( \frac{GM_{\text{halo}}d_{\text{GC}}^2}{2\sigma_{\text{MW}}^2} \right)^{1/3}$$

$$I_{\text{sm},x}(\psi) = \frac{P_x}{4\pi} \int_{\text{los}} ds \rho_{\text{sm}}^i(r(s, \psi))$$

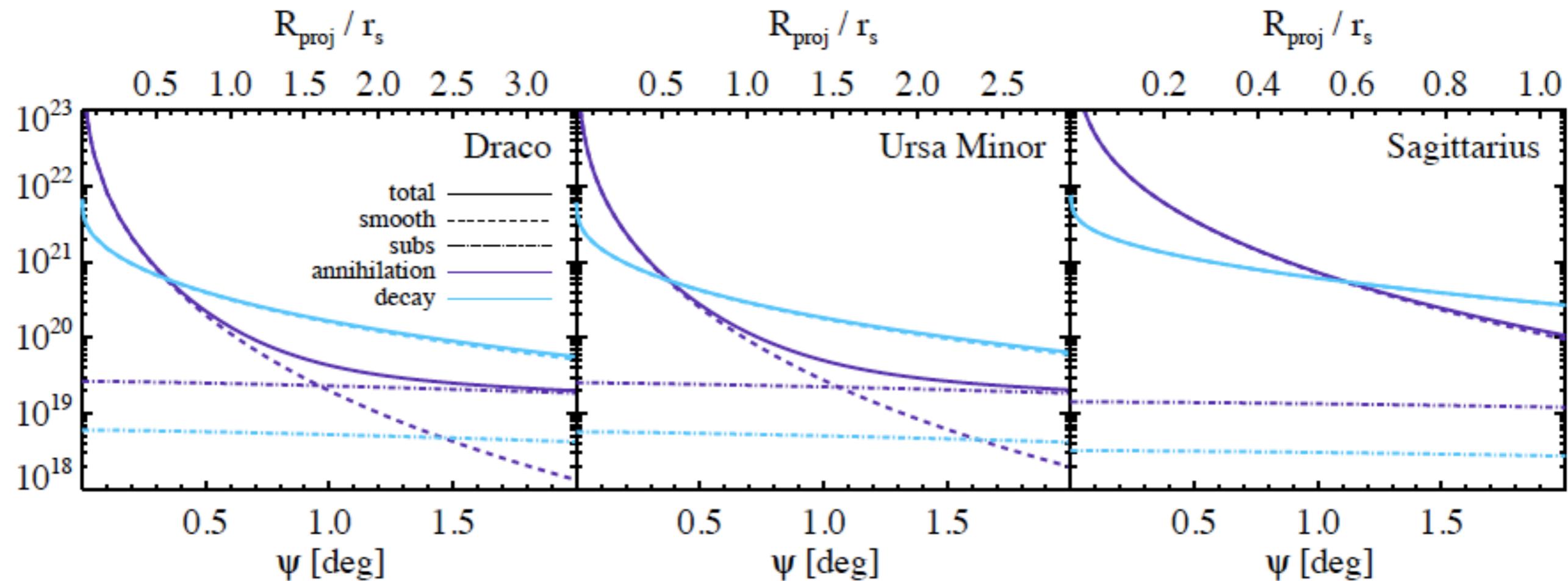
# Substructure

- We consider collectively the average emission from subhalos within the dwarf galaxy halo and sum over subhalos of all masses

$$I_{\text{subs},x}(\psi) = \frac{P_x}{4\pi} \int_{\text{los}} ds \mathcal{L}_{\text{subs},x} n_{\text{subs}}(r(s, \psi))$$

Radial distribution of subhalos

# Angular dependence of the intensity



SPR and J. M. Siegal-Gaskins, *JCAP* 07:023, 2010

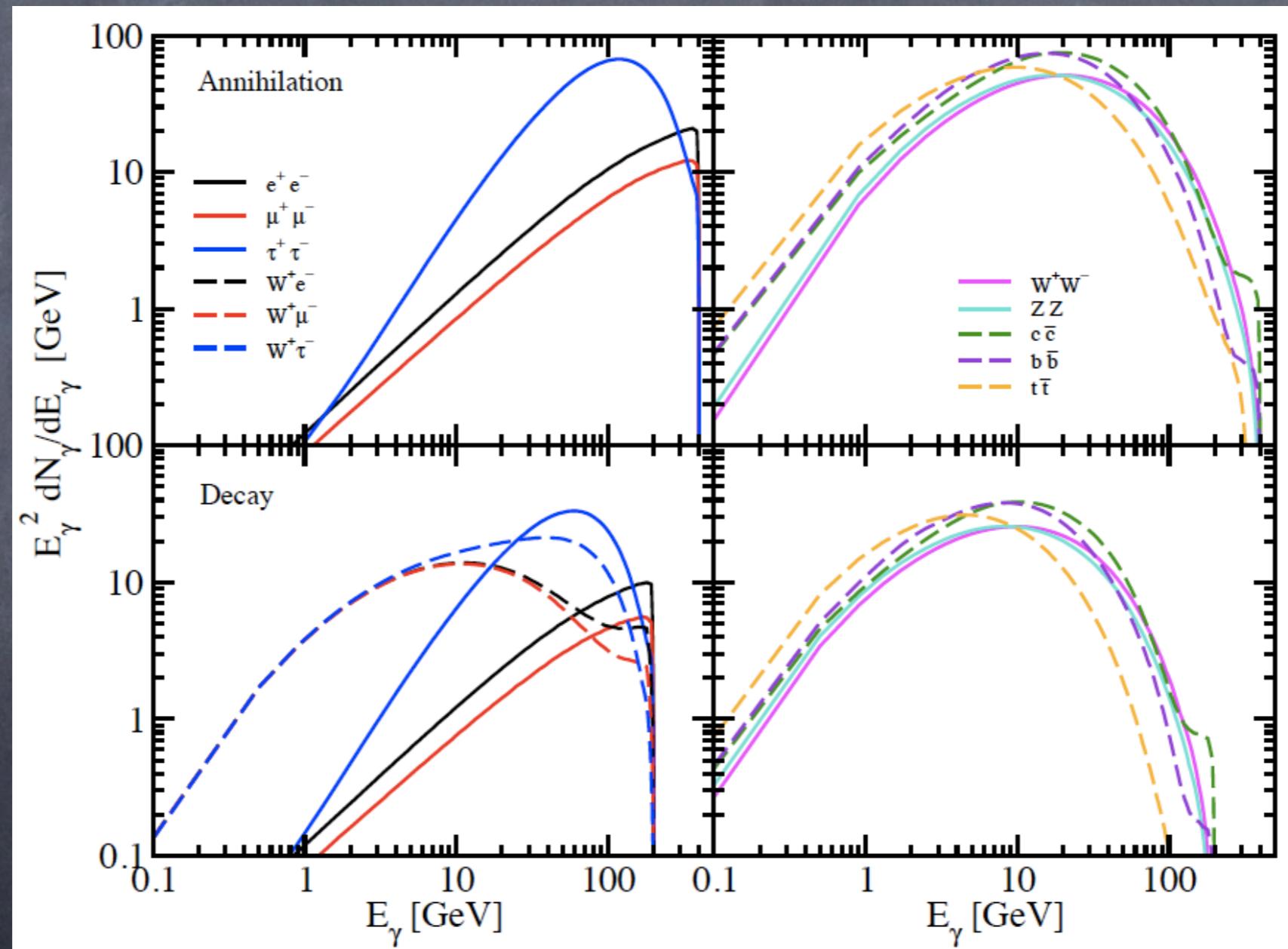
# $\gamma$ -Ray Spectra from DM annihilation/decay

We assume DM annihilates/decays into 2 SM particles and use PYTHIA 6.4

Only prompt photons as ICS photons are only significant at low energies

Hard  
Channels

Soft  
Channels

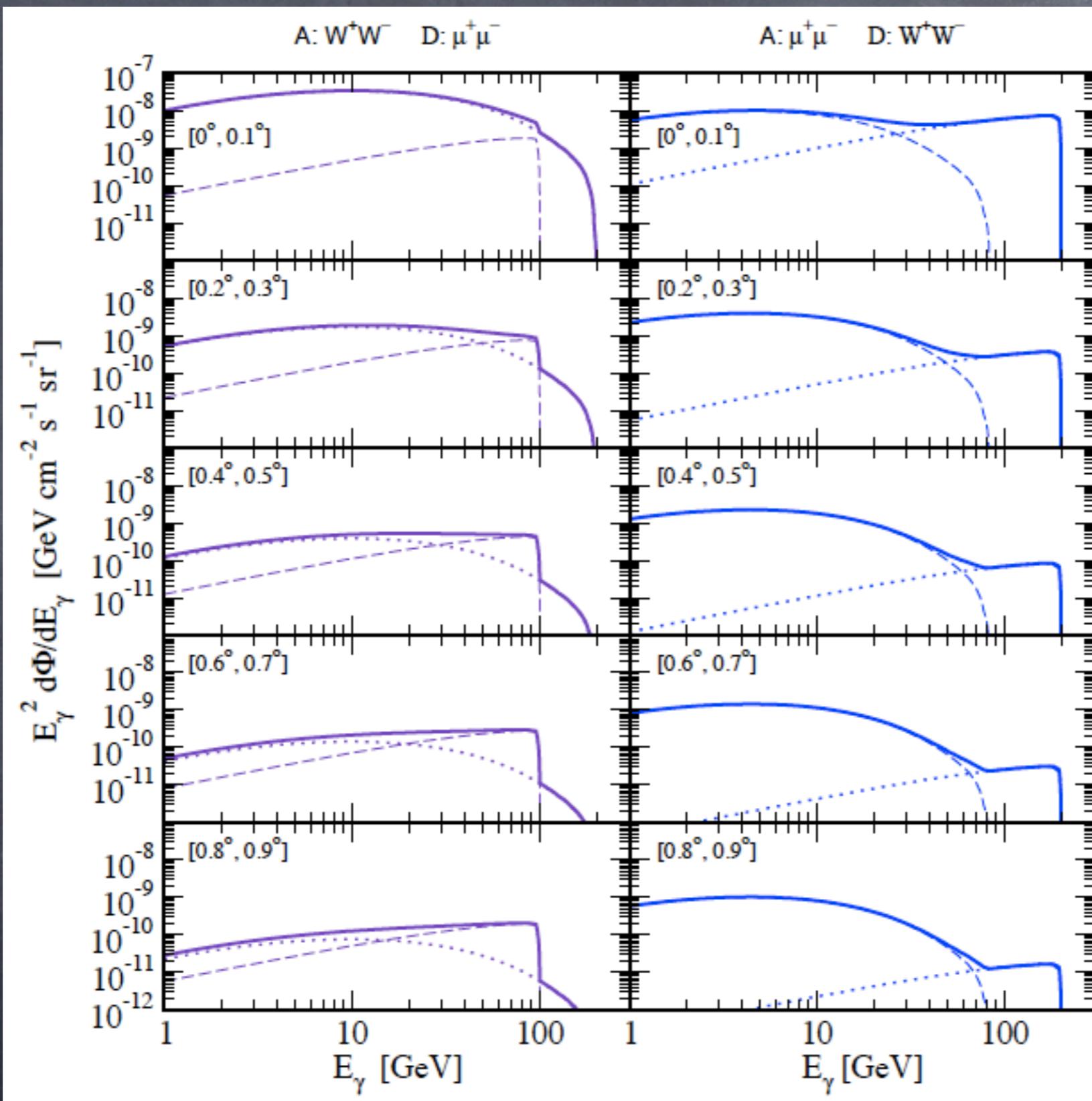


SPR and J. M. Siegal-Gaskins, *JCAP* 07:023, 2010

DM Annihilation vs. DM Decay, July 27, 2010

# Soft-Hard

# Hard-Soft



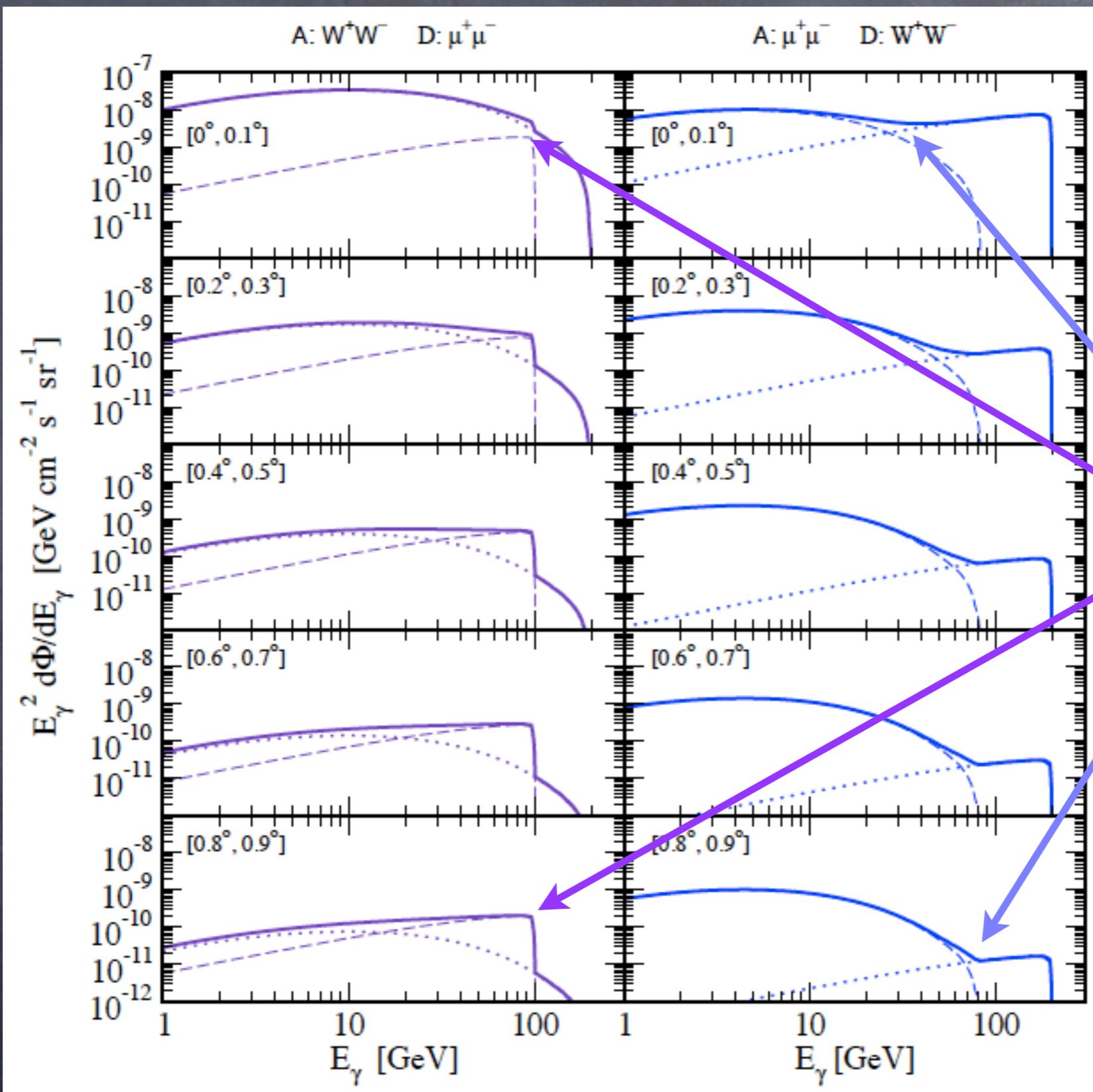
SPR and J. M. Siegal-Gaskins, *JCAP* 07:023, 2010

Sergio Palomares-Ruiz

DM Annihilation vs. DM Decay, July 27, 2010

# Soft-Hard

# Hard-Soft



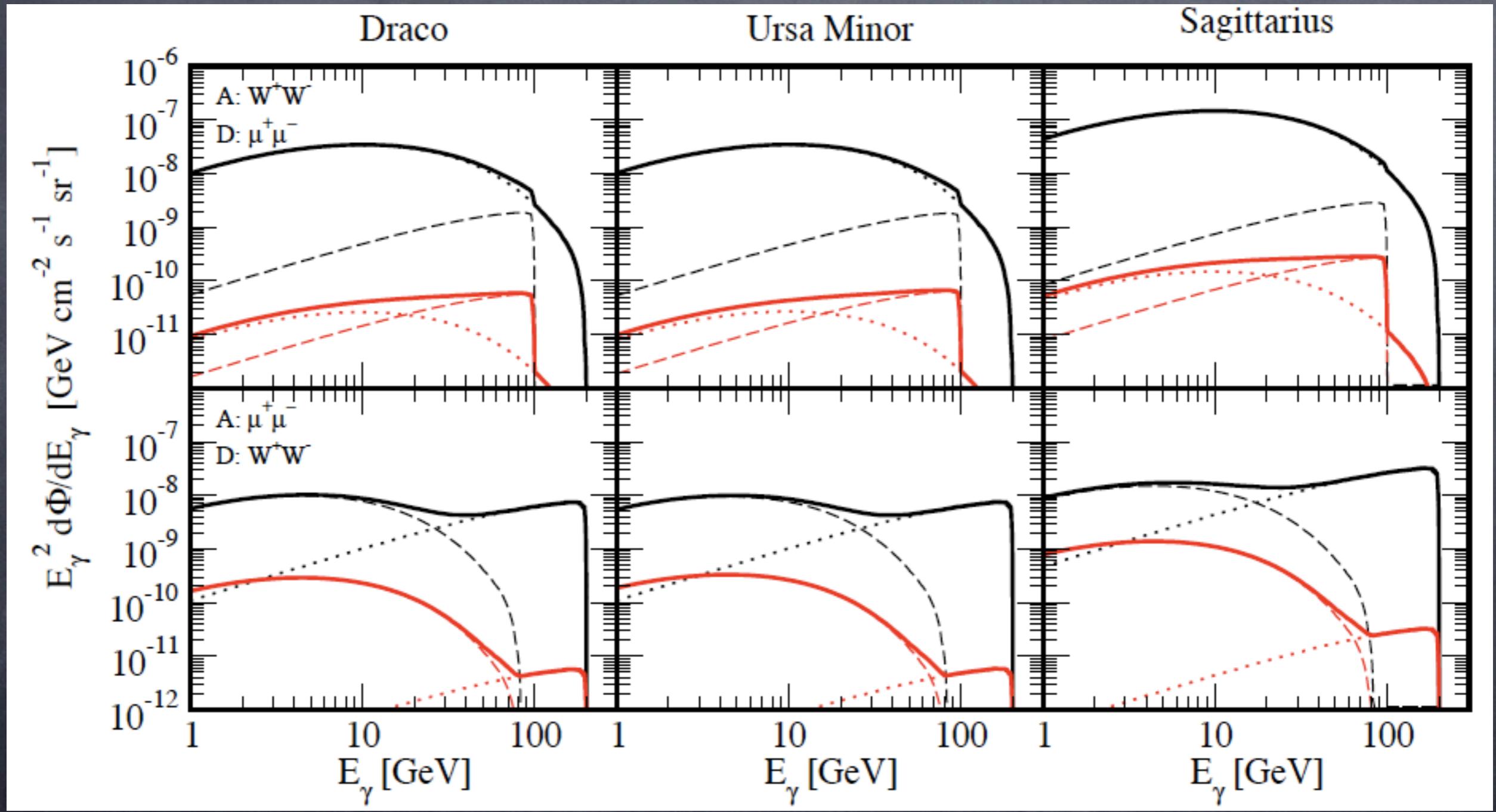
Spectral  
break

SPR and J. M. Siegal-Gaskins, *JCAP* 07:023, 2010

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DM Annihilation vs. DM Decay, July 27, 2010

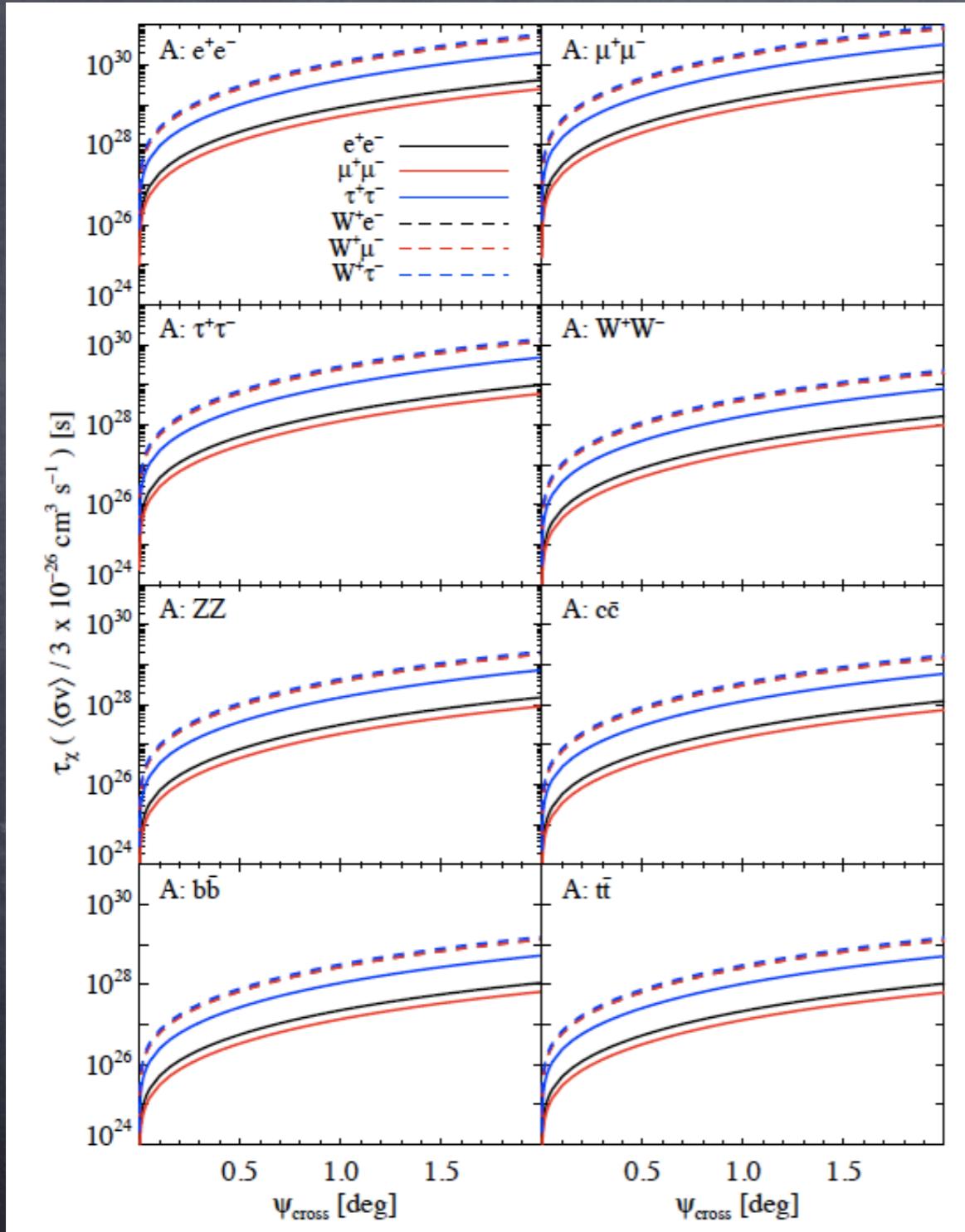
# Innermost vs. Outermost Annuli



SPR and J. M. Siegal-Gaskins, *JCAP* 07:023, 2010

DM Annihilation vs. DM Decay, July 27, 2010

# Range of interesting parameters



Here:  $m=200$  GeV and energy threshold=1 GeV

The normalization depends on the relative photon yields from annihilation and decay: for a given lifetime, the transition occurs further from the center when the ratio from annihilation to decay is larger.

The different amplitudes reflect the different photon yields for the various decay channels

In order for the transition to occur within 1-2 degrees:

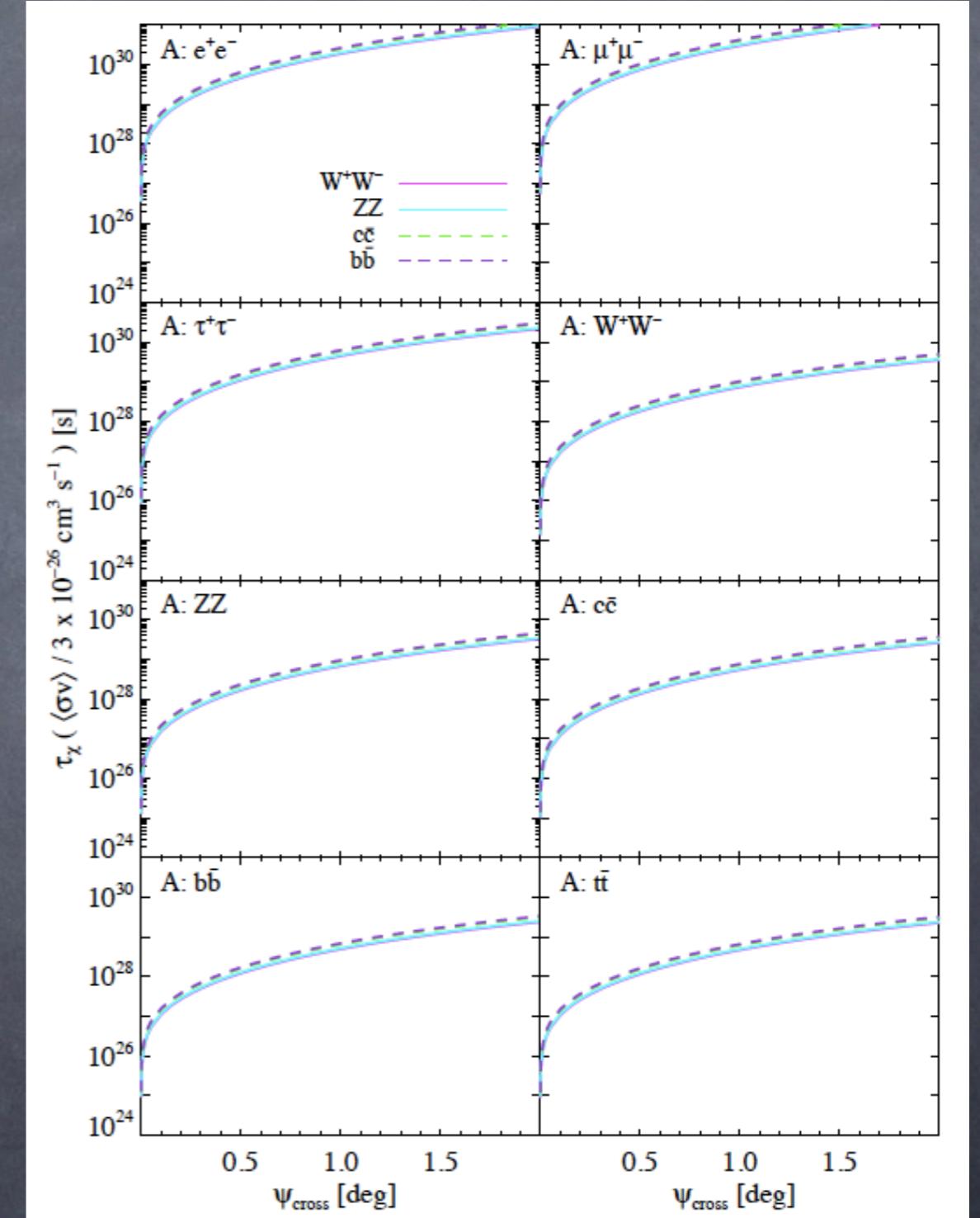
$$\tau_\chi \sim (10^{25} - 10^{31} \text{ s}) (3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1} / \langle \sigma v \rangle)$$

# Range of interesting parameters

for a threshold of 1 GeV, similar yields for all hadronic channels, which are the highest

In order for the transition to occur within 1-2 degrees:

$$\tau_\chi \sim (10^{25} - 10^{31} \text{ s}) (3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1} / \langle \sigma v \rangle)$$

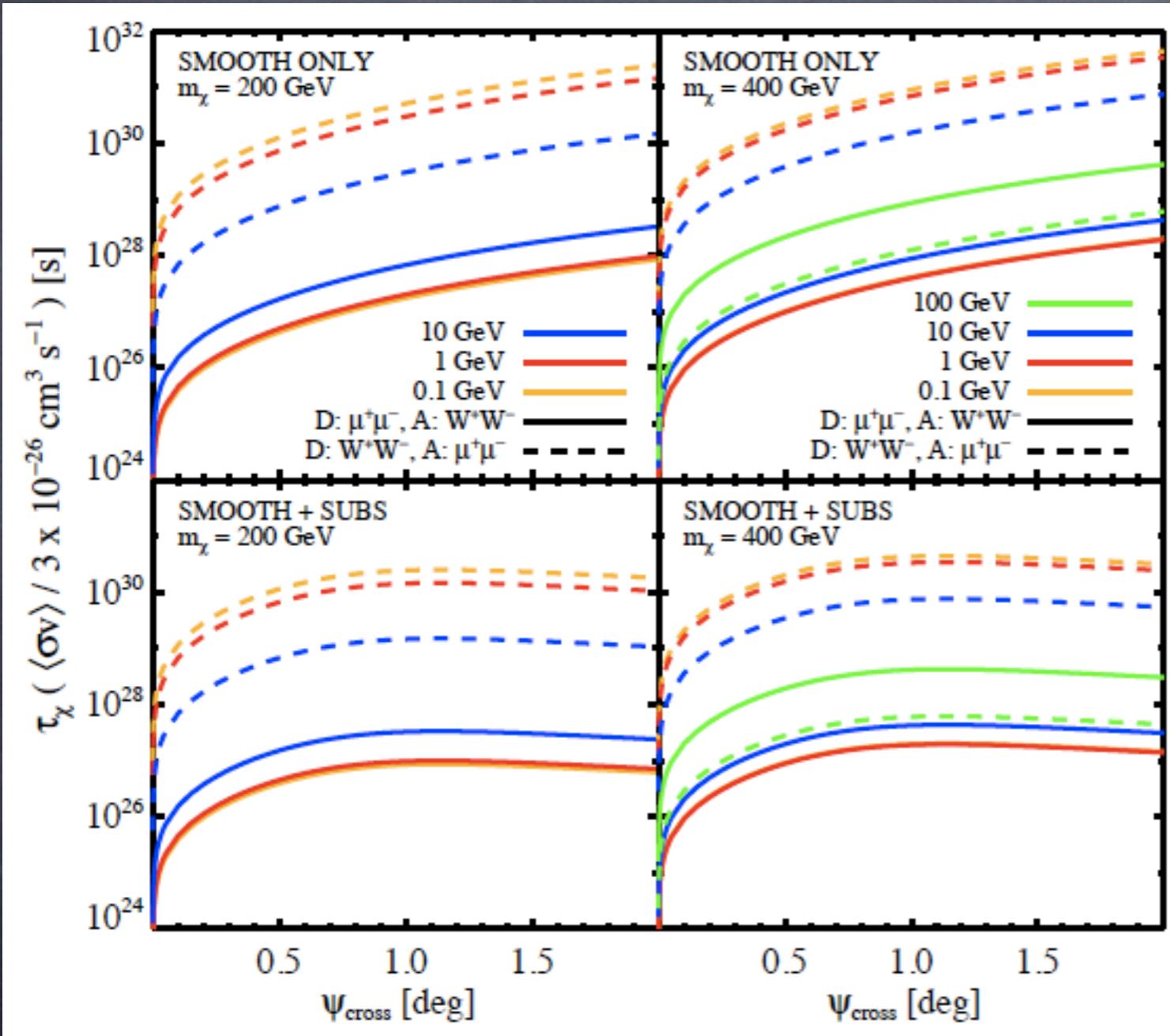


SPR and J. M. Siegal-Gaskins, *JCAP* 07:023, 2010

DM Annihilation vs. DM Decay, July 27, 2010

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# Effect of substructure, energy threshold and dark matter mass



Same trend: transition for soft-hard combinations occurs further from the center than for hard-soft

Higher threshold: soft channel is suppressed -> curves displaced upwards (downwards) if decay is into a hard (soft) channel and annihilation into a soft (hard) channel

The effect of substructure shows up at around 1 degree

# Conclusions

- We have outlined the way to constrain dark matter properties in the event of the clear detection of an indirect signal from gamma-ray observations of dwarf galaxies
- We have addressed the question of how scenarios of dark matter annihilation, decay, or both, could be distinguished, and what information could be obtained about the intrinsic properties of the dark matter particle (mass, annihilation cross section, lifetime and dominant annihilation/decay channels) and its small-scale distribution from this type of indirect measurement
- We have shown that spectral information alone is insufficient to identify the process that produced the signal
- The key: examining the dependence of the intensity and energy spectrum on the angular distribution of the emission
- This idea could in principle be applied to the Milky Way too: in this case an appropriate treatment of ICS is mandatory for annihilation/decay into leptonic channels (see also C. Boehm, T. Delahaye and J. Silk, arXiv:1003.1225)