Indirect dark matter searches

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[arXiv:1706.01843]
in collaboration with
E. Karaukes, P. Salucci

[arXiv:1708.04642]
in collaboration with
S. H. Cadena, R. Alfaro, A. Sandoval, E. Belmont, H. León, E. Karukes, P. Salucci
for the HAWC Collaboration

ASTRO@TS 2017- September 25, SISSA, Trieste, Italy

Outline

- Introduction: gravitational and cosmological evidences for Dark Matter (DM), Weakly Interacting Massive Particles (WIMPs), DM detection, indirect searches and targets

- Main question and motivations:

  Dwarf irregular galaxies as new targets

- Some technicality: angular dimension, astrophysical factor, gamma-ray telescopes, prospects and exclusion limits

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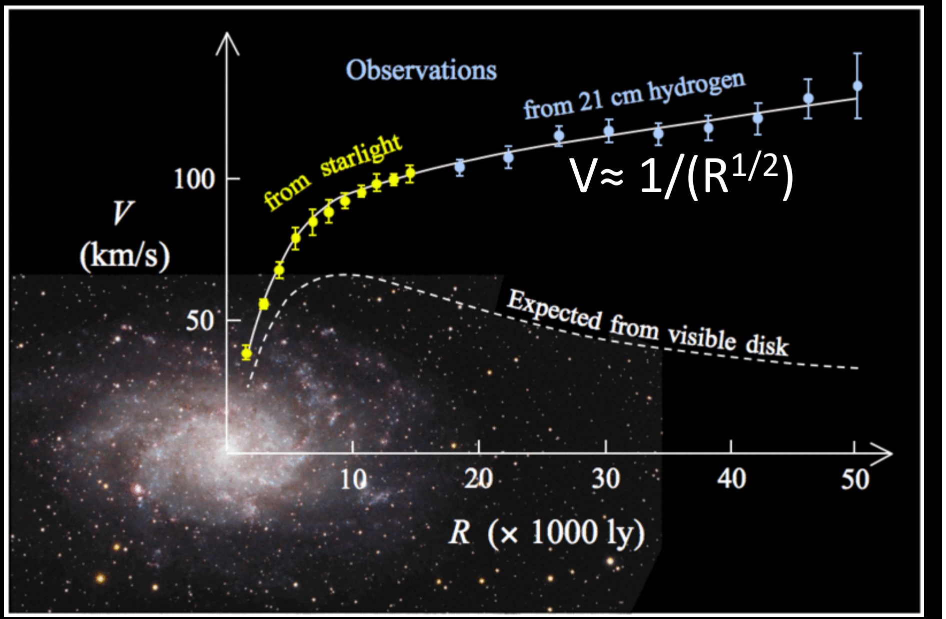
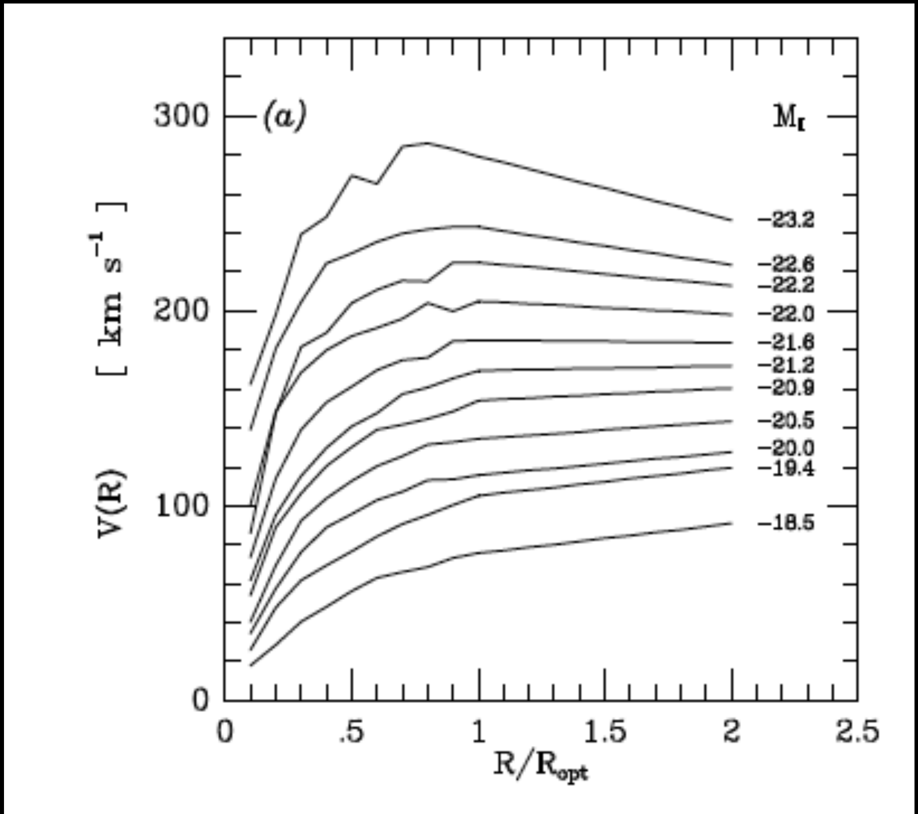
Rotation curves

The observations of the almost flat rotation curve in several spiral galaxy was one of the first motivation to hypothesize the existence of DM.





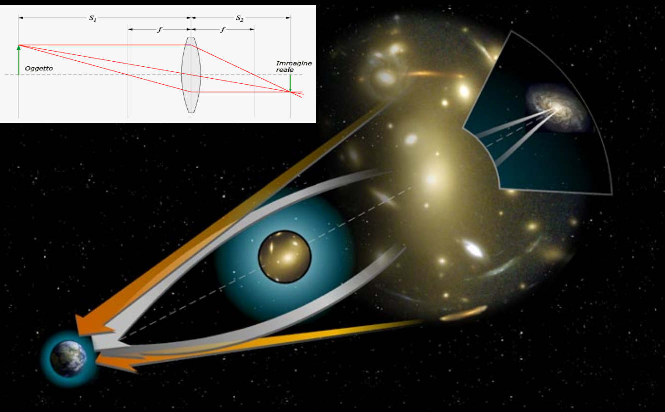
M.Persic, P.Salucci, F.Stel, MNRAS ;

$$\rho_{\rm NFW}(r) = \frac{A_s}{r(r+r_s)^2}$$

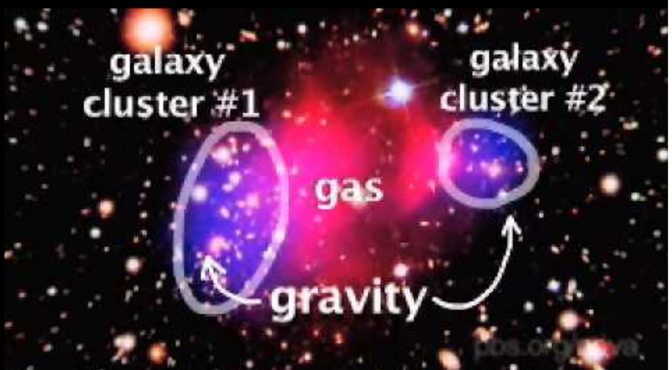
$$\rho_{\rm Einasto}(r) = \rho_s \exp\left\{-2n\left[\left(\frac{r}{r_s}\right)^{1/n} - 1\right]\right\}.$$

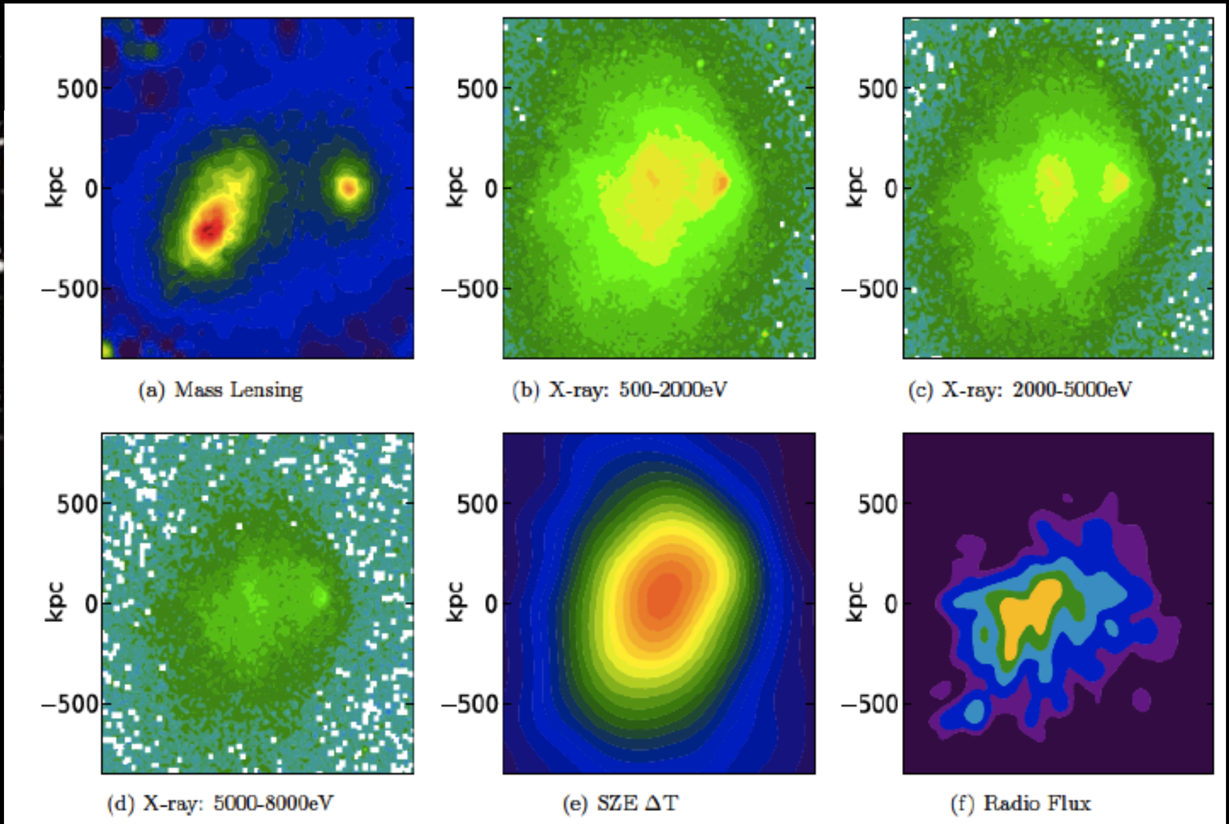
$$\rho_{\rm Burkert}(r) = \frac{\rho_0 r_0^3}{(r+r_0)(r^2+r_0^2)}$$

Gravitational Lensing: the Bullet Cluster



Light rays coming from more distant galaxies that pass close to a cluster may be distorted by its mass. In the first thin lens approximation the deflection of the light ray is proportional to the lens mass.





(a) Mass Lensing (b) X-ray: 500-2000eV (c) X-ray: 2000-5000eV

(d) X-ray: 5000-8000eV (e) SZE ΔT (f) Radio Flux

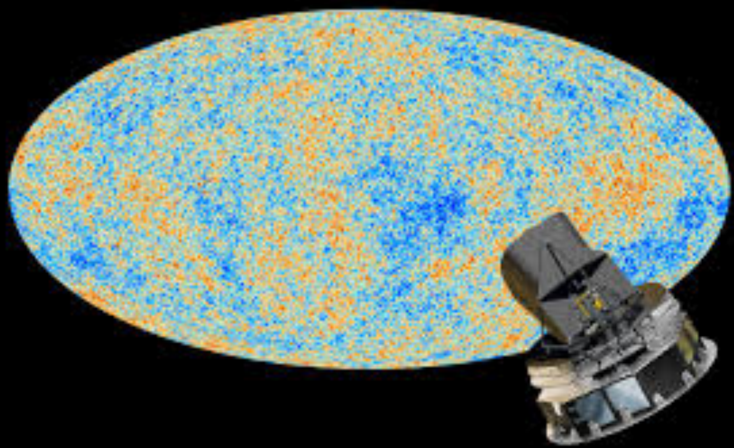
The mass distribution calculated with the gravitational lensing (figure (a)) does not match the luminous matter distribution showed in the other figures.

C. Lage and G. Farrar, Astro. J., 787:144(19pp) (2014).

Cosmological Standard Model ΛCDM

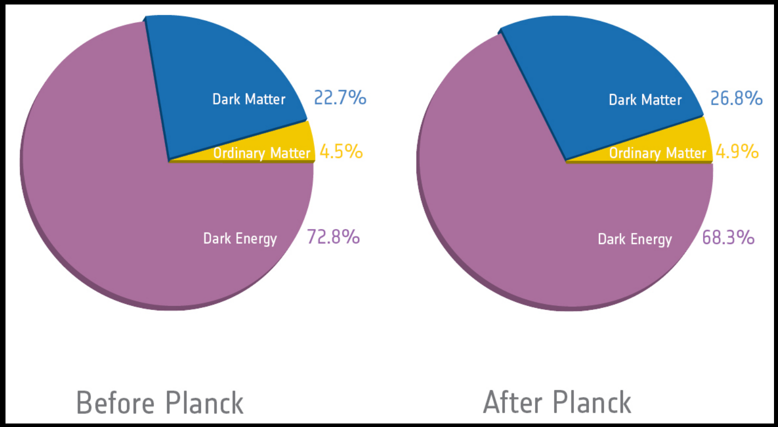
The Cosmological Standard Model assumes:

- general relativity as the correct theory of gravitation
- homogeneity and isotropy of space



It well explains:

- the existence and structure of the cosmic microwave background (CMB)
- the large-scale structure in the distribution of galaxies
- the abundances of hydrogen (including deuterium), helium, and lithium
- the accelerating expansion of the universe observed in supernovae data



Assuming:

- a cosmological constant Λ and a Cold DM component

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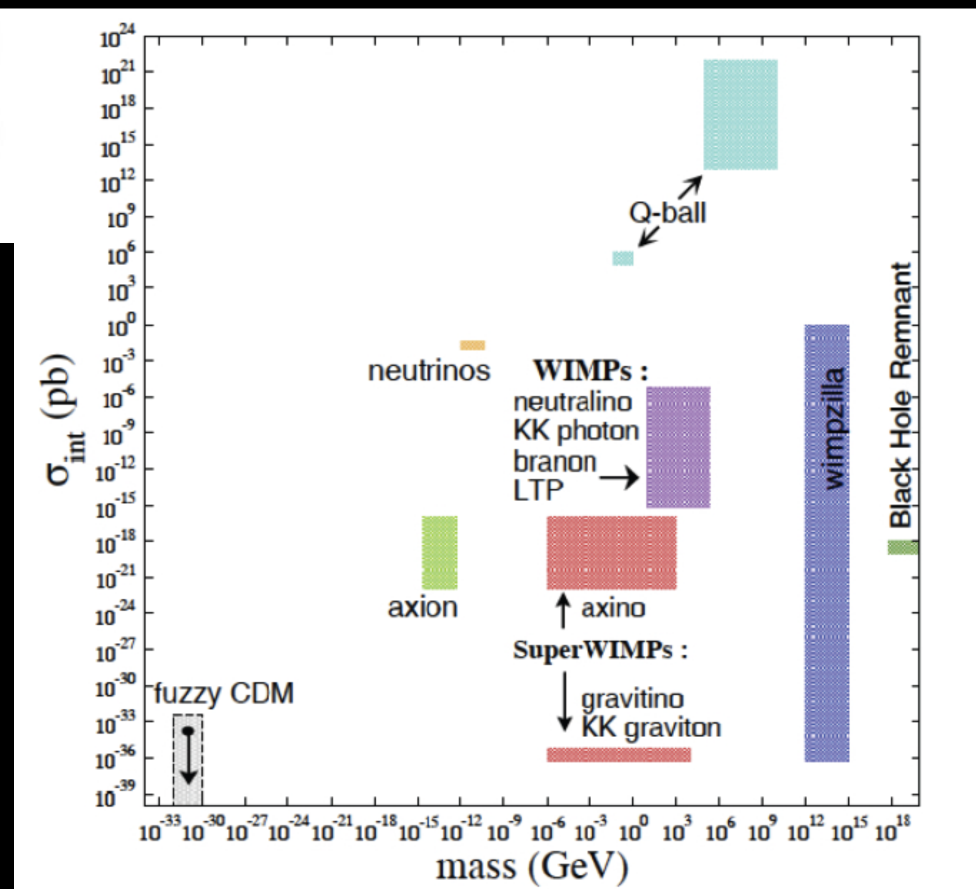
DM as a Particle: theory

Beyond the Standard Model of particles:
Super Symmetry (SUSY), Extra Dimensions,
Weakly Interacting Massive Particles (WIMPs), axions and so on…



S. Gardner and G. Fuller, Progress in Particle and Nuclear Physics 07/2013, [arXiv:1303.4758].

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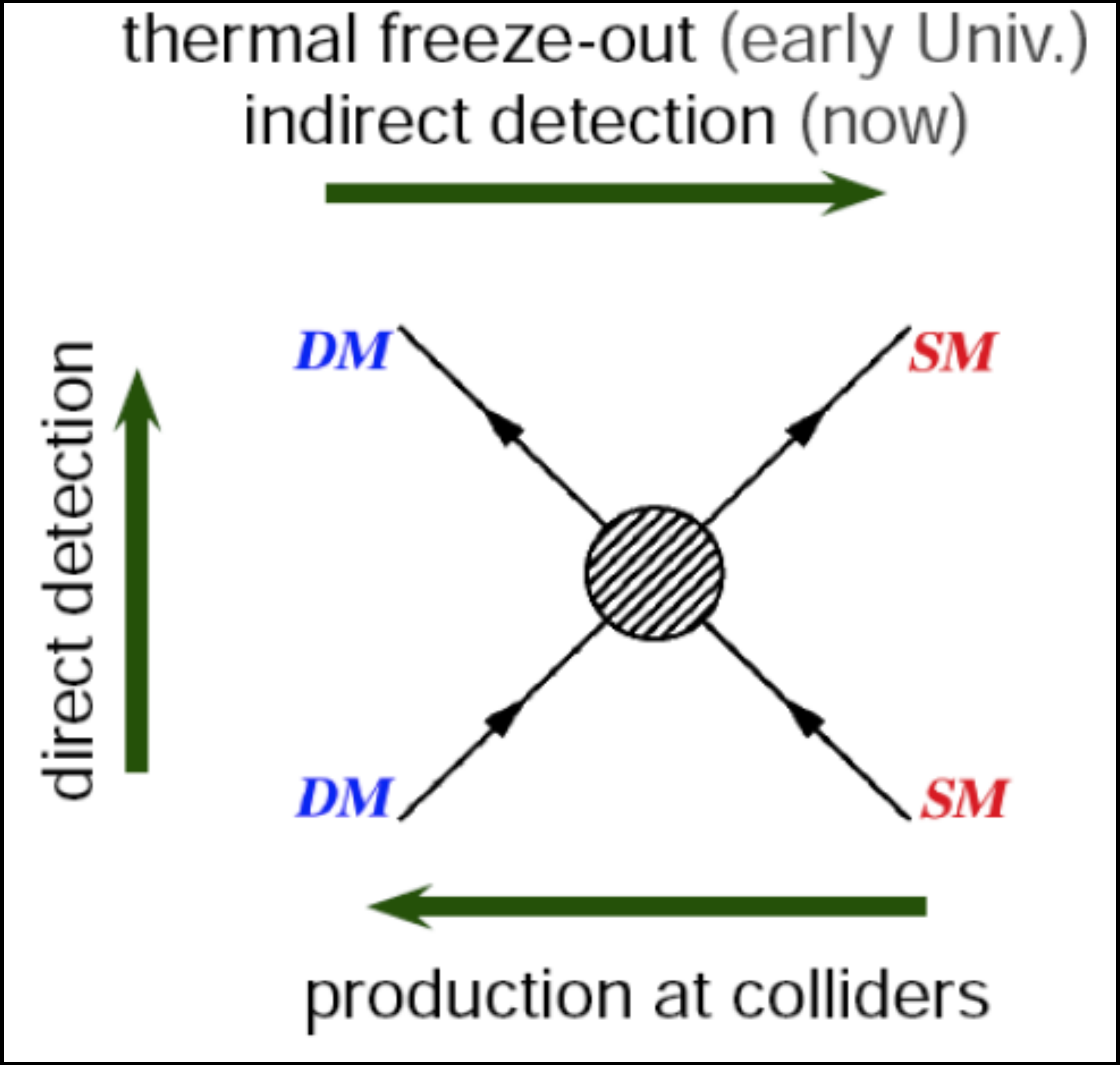
DM as a Particle: detection



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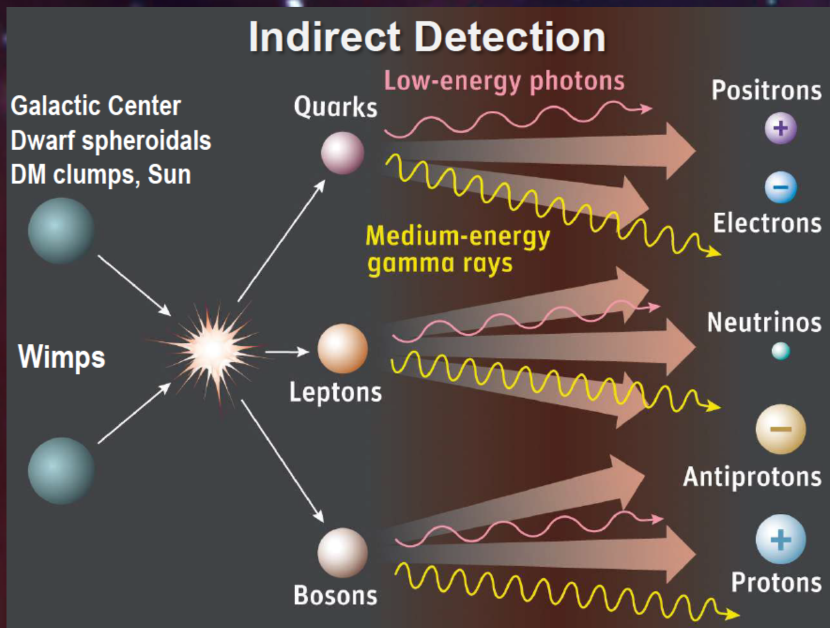
Indirect Dark Matter Searches



$$\frac{d\Phi_{\text{cr-DM}}}{dE} = \eta_{\text{cr}} \cdot \sum_{a=1}^{2} \sum_{i}^{\text{SM channels}} \frac{\zeta_i^{(a)}}{a} \frac{dN_i^{(\text{cr})}}{dE} \cdot \frac{\kappa_{\text{cr}}^{(a)}}{4\pi \; m_{\text{DM}}^{a}}$$

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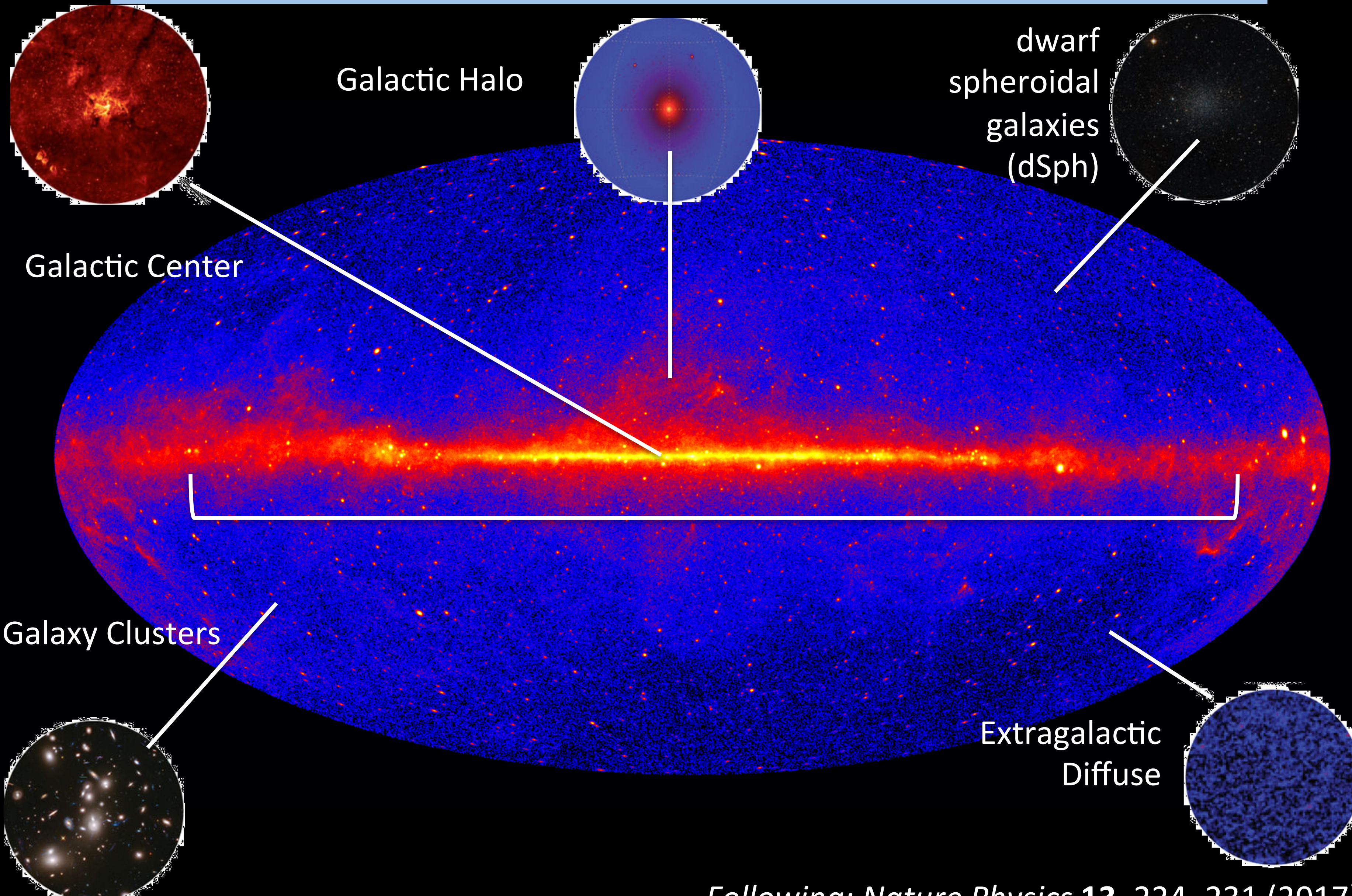
Indirect Dark Matter Searches: Targets



Following: Nature Physics **13**, 224–231 (2017)

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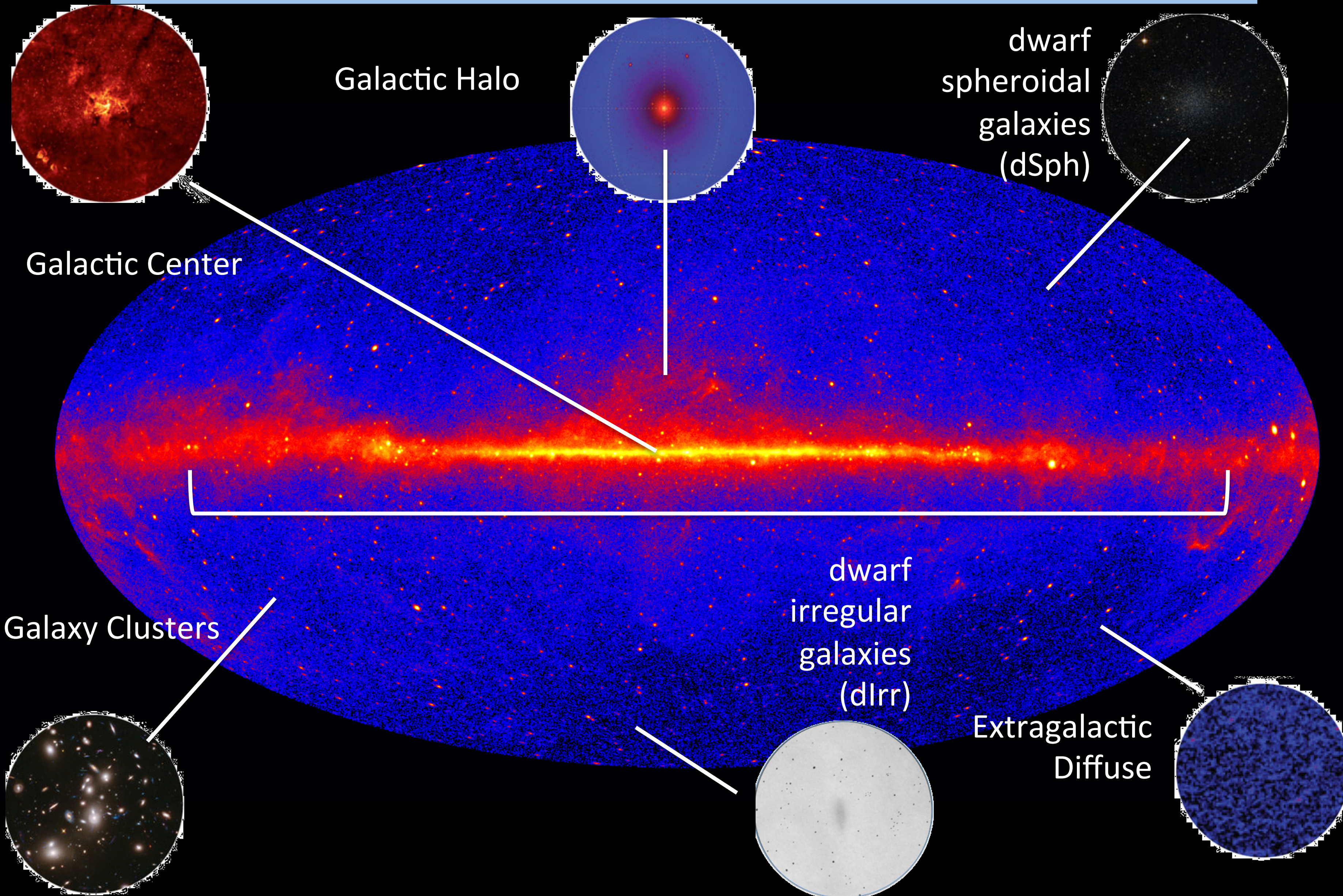


Question and Motivations

- Need to explore new sources

(No conclusive detection of dark matter (DM) signal so far);

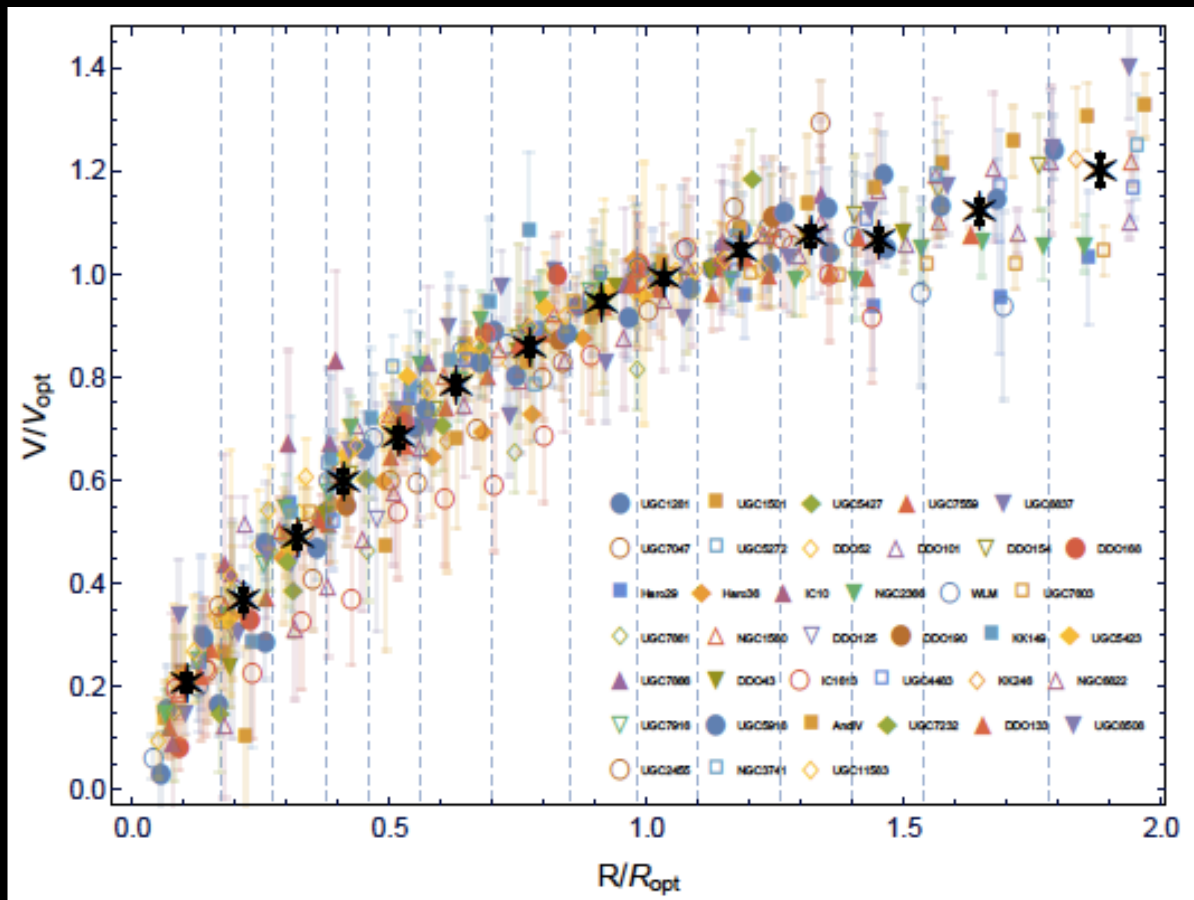
- Dwarf irregular galaxies (dIrrs) are rotationally supported objects

(high accuracy model for DM density distribution profile)

- dIrrs are DM dominated objects with extended halos

Synthetic RC

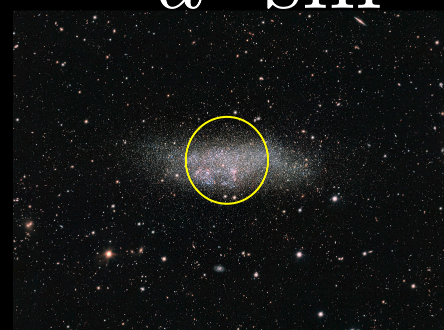
14 bin: Each bin is equally divided in two part. Each RC can contribute only with one data point to each semi bin. Extra data points concurring to the same semi bin are averaged accordingly. From N_i data in each radial bin *i* the average weighted rotation velocity is calculated, where the weights are taken from the uncertainties in the rotation velocity.



E. Karukes, P. Salucci, MNRAS 2017, 465, p4703-4722.

The extended halo

$$R^2 = d^2 \sin^2 \theta$$



$R_{vir} \approx 20 \times R_{opt}$

$\Theta_{opt} \approx 0.01$ - 0.2 degree

$\Theta_{vir} \approx 0.3$-5.3 degree

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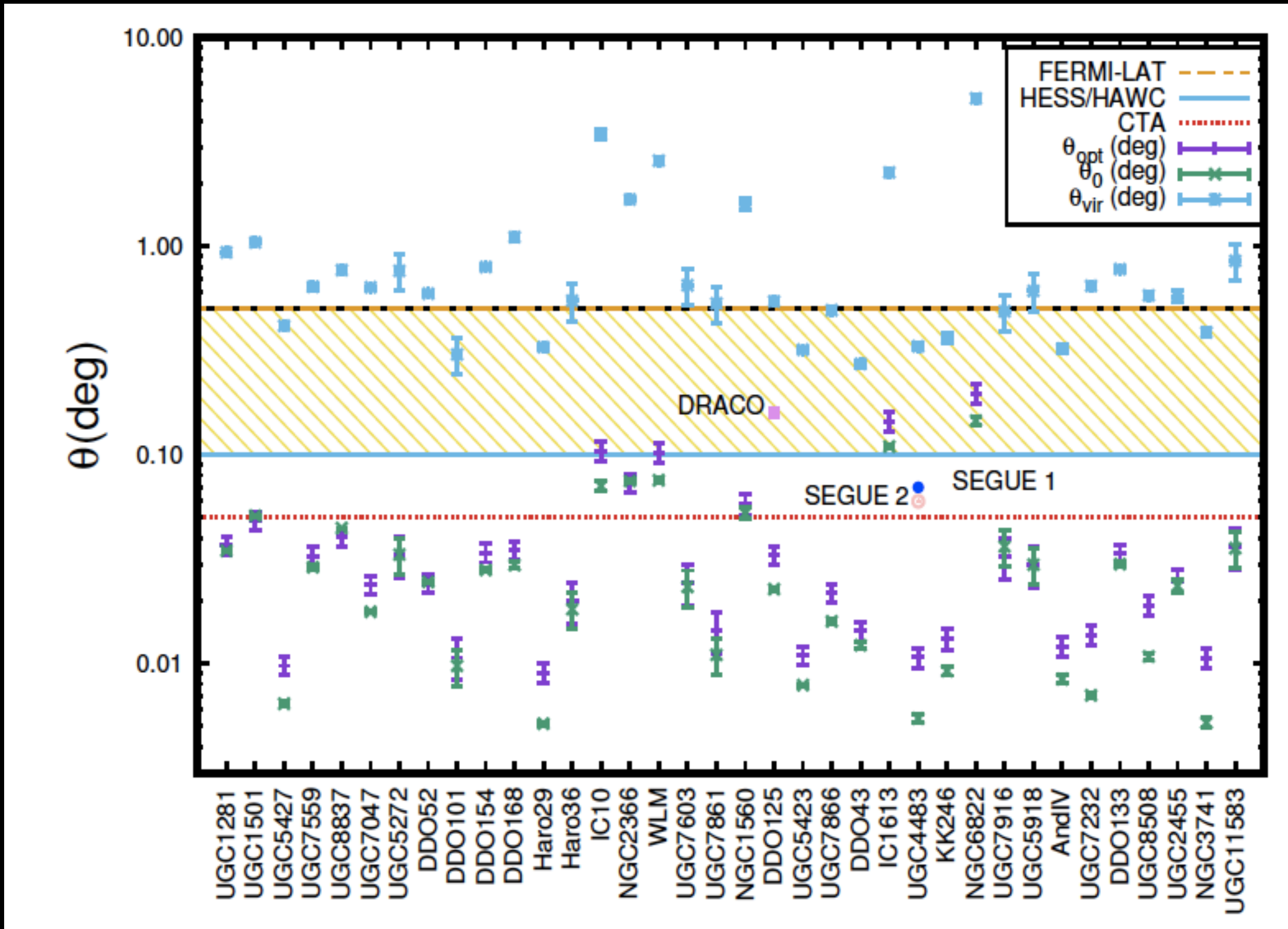
The angular resolution



V.G., E. Karukes, P. Salucci, arXiv:1706.01843

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DM indirect searches with gamma-rays

The differential gamma-ray flux expected by DM annihilation events in each dIrr galaxy is the usual combination of the particle physics and the astrophysical factor.

$$\frac{\mathrm{d}\,\Phi_{\gamma}^{\mathrm{DM}}}{\mathrm{d}\,E_{\gamma}} = \frac{dP(\mathrm{m_{DM}}, \langle\sigma_i v\rangle)}{dE} \times < J >_{\Delta\Omega}$$

The particle physics factor is the same as in any other source (dSph, Galctic Center etc…)

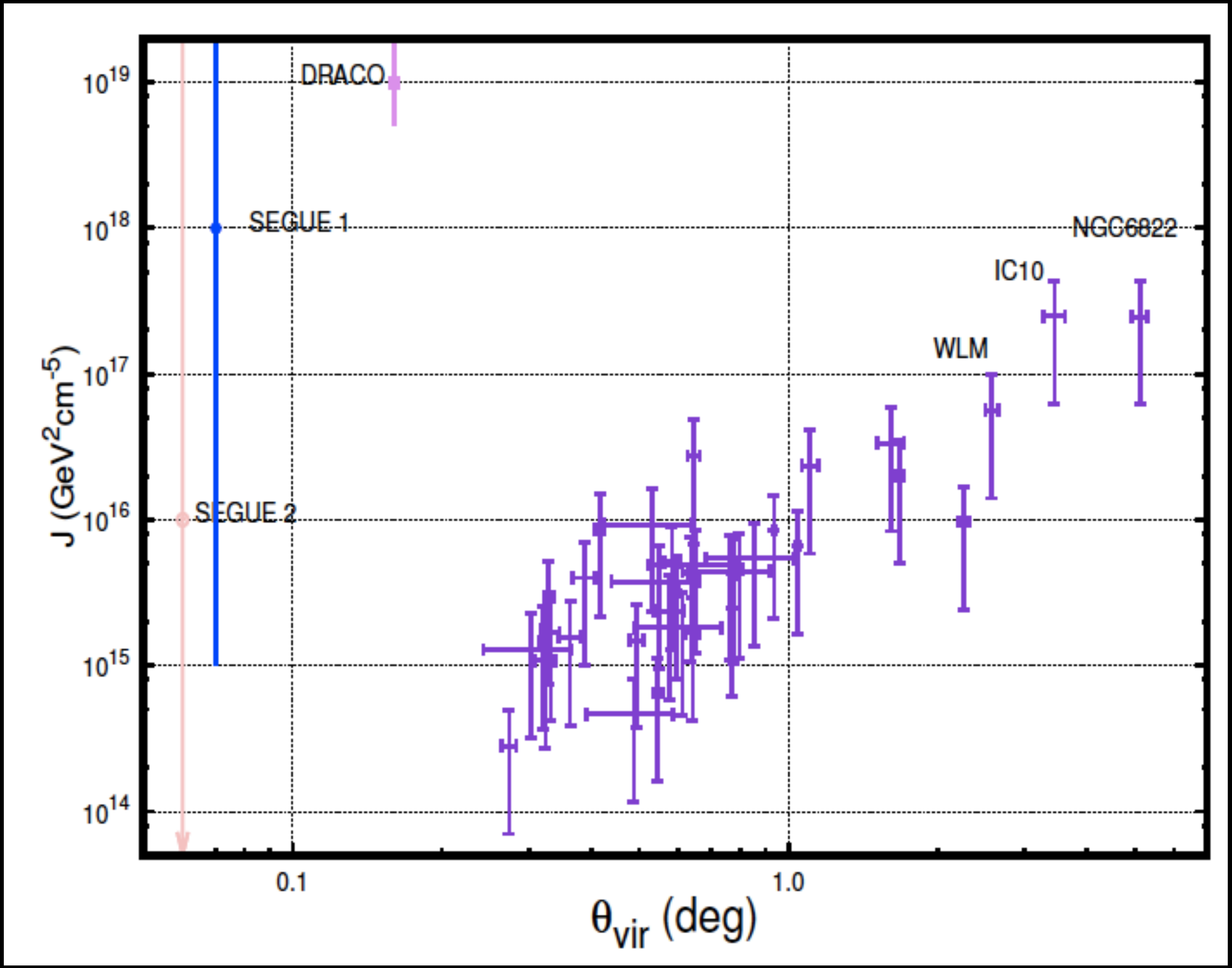
$$\frac{dP(\mathrm{m_{DM}}, \langle\sigma_i v\rangle)}{dE} = \frac{1}{4\pi \mathrm{m_{DM}^2}} \sum_i \langle\sigma_i v\rangle \frac{\mathrm{d}\,N_{\gamma}^{i}(\mathrm{m_{DM}})}{\mathrm{d}\,E_{\gamma}}$$

The astrophysical factor depend on the DM distribution profile, here Burkert profile.

$$< J >_{\Delta\Omega} = \frac{1}{\Delta\Omega} \int_{\Delta\Omega} \mathrm{d}\Omega \int_{l.o.s.} \rho^2[(s)]\mathrm{d}s$$

$$\rho_{\mathrm{Burkert}}(r) = \frac{\rho_0 r_0^3}{(r + r_0)(r^2 + r_0^2)}$$

The astrophysical factor



V.G., E. Karukes, P. Salucci, arXiv:1706.01843

The astrophysical background

- Star-forming region:

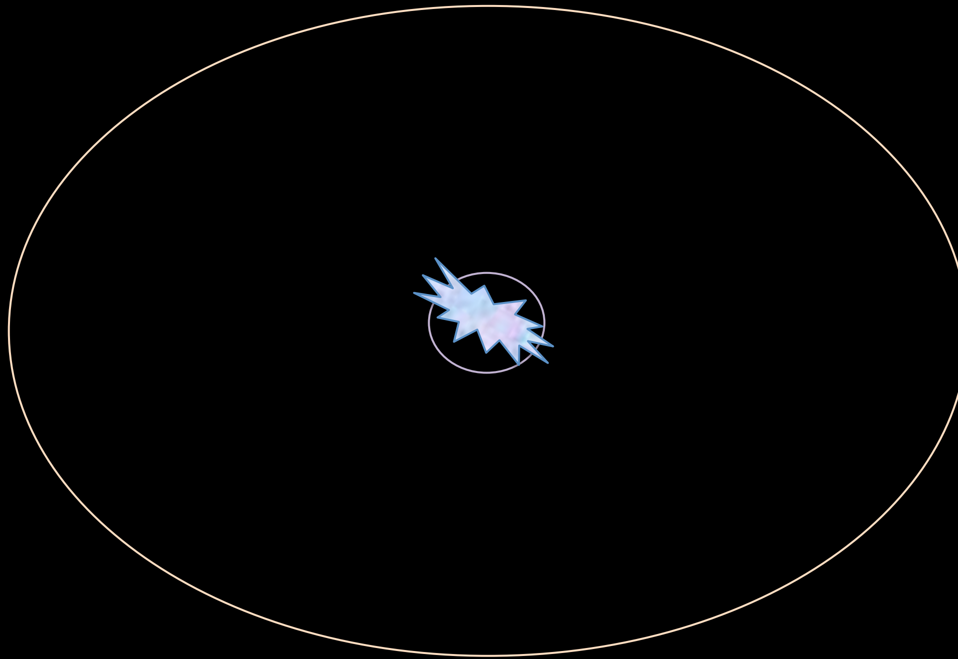
Supernovae Remnants, pulsars with nebulas, etc…

-> Star Formation Rate (SFR)

M.Tosi et al. , Astrophysics and Space Science 156 (1989)

- Emission from interstellar matter:

Pion Decay, Bremsstrahlung, Inverse Compton



$$L_\gamma^{diffuse} \approx 10^{36} \mathrm{ergs}^{-1} \quad L_\gamma^{HAWC} \approx 10^{-12} \mathrm{ergs}^{-1}$$

P. Martin, A&A 564 (2014) A61

Point-like analysis

- Active Galactic Nuclei (AGN) not observed In dIrrs

Optical region < 0.1º is not resolved by the current generation of gamma-ray telescopes

The astrophysical background

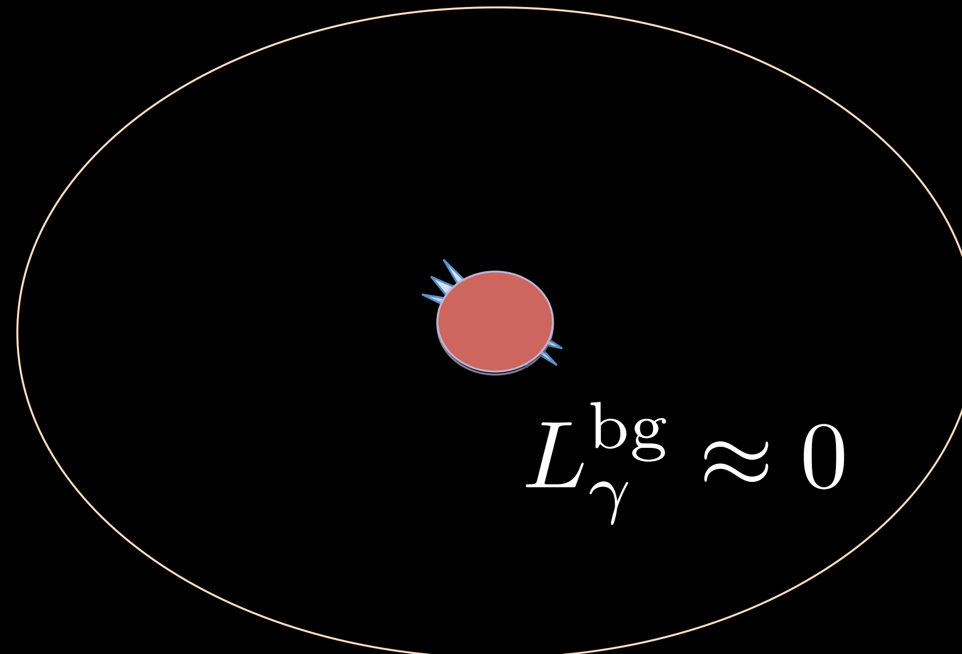
- Star-forming region:

  Supernovae Remnants, pulsars with nebulas, etc…

  -> SFR rate

- Emission from interstellar matter:

  Pion Decay, Bremsstrahlung, Inverse Compton



- AGN not observed In dIrrs

$$< J >_{\mathrm{Halo}} = < J >_{\mathrm{vir}} - < J >_{\mathrm{mask}} \quad (\mathrm{GeV}^2 \mathrm{cm}^{-5})$$

Optical region > 0.1º can be masked

Extended source analysis

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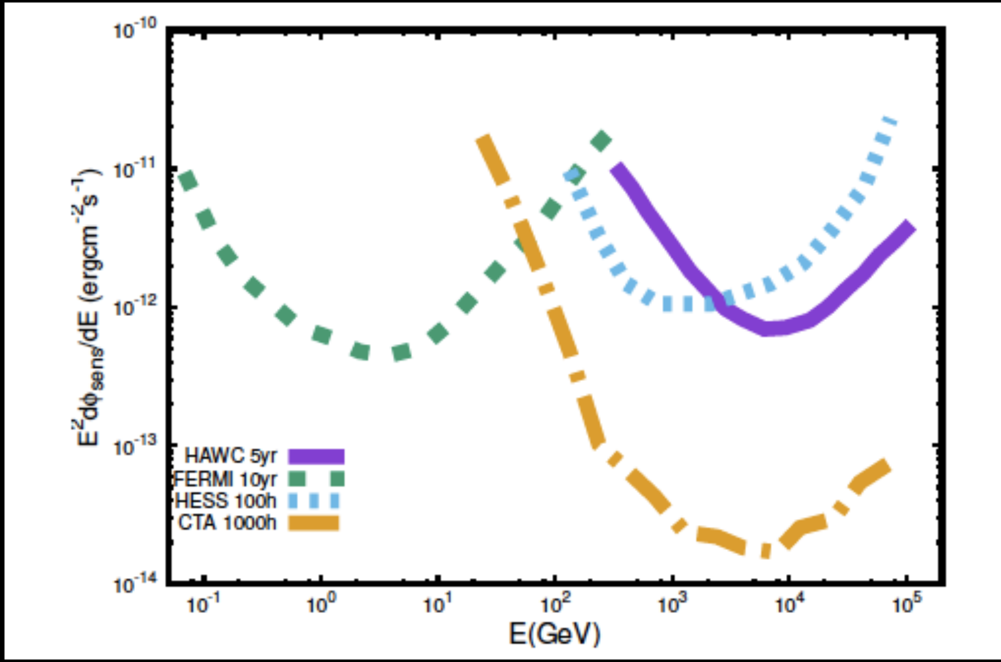
Gamma-ray telescopes

Experiment	FERMI-LAT	HESS I (II)	HAWC	CTA North/South
E range	20 Mev - 300 GeV	0.03- 100 TeV	0.1-100 TeV	0.02-200 TeV
Δ E	10%	15%	50%	10%
FoV (deg)	> 50	0.5	wilde	10
$\theta_{\rm PSF}$ (deg)	$0.1 - 0.5$	0.1	0.1	0.05
$A_{\rm eff}({\rm cm}^2)$	10^4	$1(6) \times 10^6$	10^5	10^{10}
$t_{\rm exp}$	10yr	100 h	5 yr	1000 h
$\phi_{\rm bg}^{\rm PSF}({\rm ph\,cm^{-2}s^{-1}})$	1.31×10^{-7}	7.65×10^{-11}	3.18×10^{-11}	3.09×10^{-10}



$$\chi = \frac{\phi_\gamma \sqrt{\Delta\Omega A_{\rm eff} t_{\rm exp}}}{\sqrt{\phi_\gamma + \phi_{\rm Bg}}}$$

V.G., E. Karukes, P. Salucci, arXiv:1706.01843

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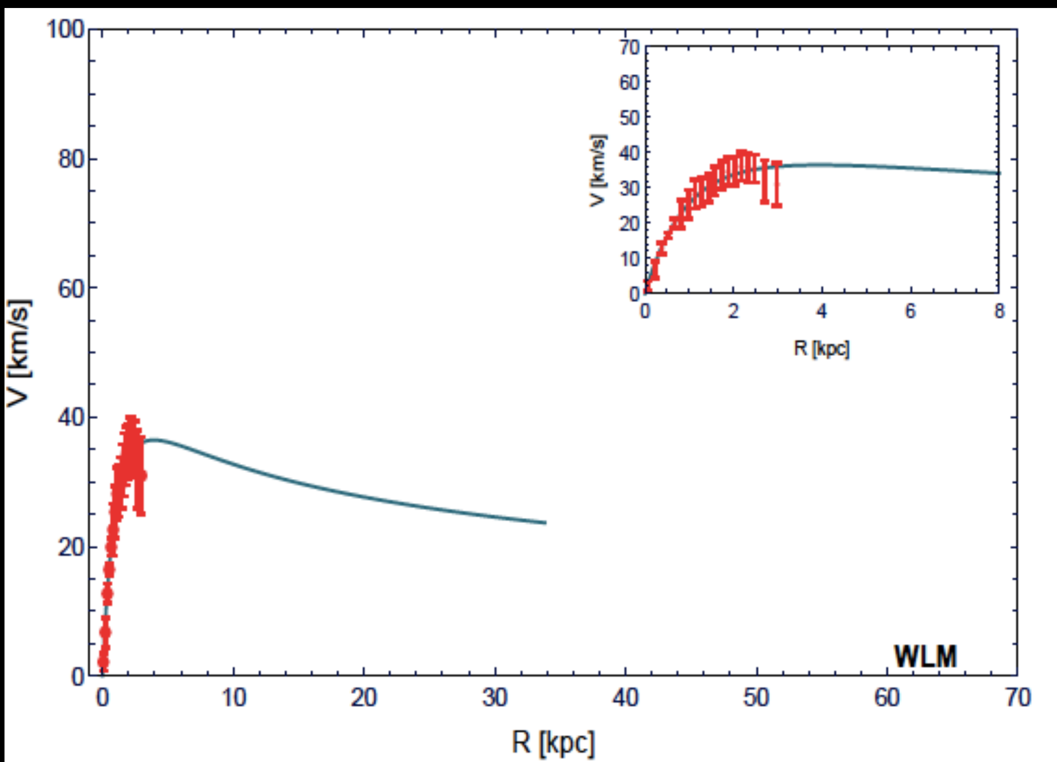
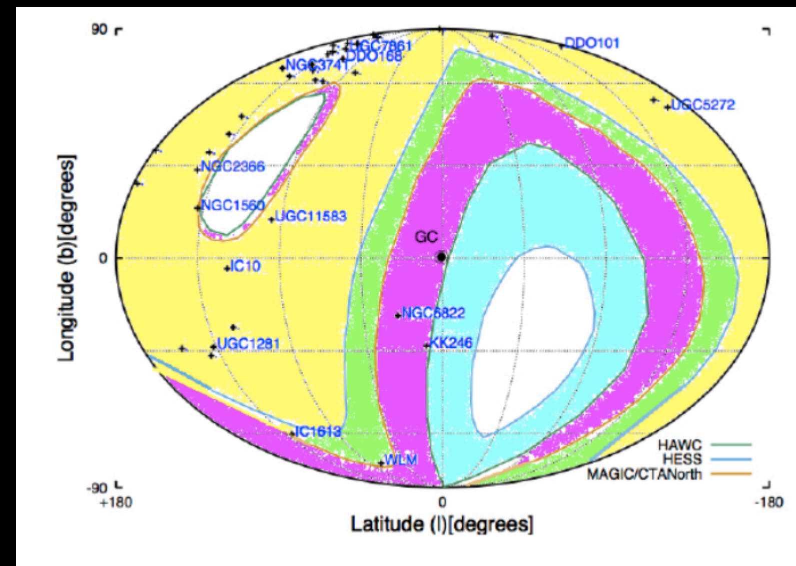
Wolf-Lundmark-Melotte (WLM)

- third-highest value of J-factor (≈10^{17}GeV^{2}cm^{-5}) and huge halo (≈3º)
- on the sky view of HESS, HAWC, CTA and FERMI
- zero background due to the high longitude
- well reproduced rotation curve





V.G., E. Karukes, P. Salucci, arXiv:1706.01843

Wolf-Lundmark-Melotte (WLM)

$$\chi = \frac{\phi_\gamma^{\text{Halo-DM}} \sqrt{\Delta\Omega_{\text{WLM}}^{\text{Halo}} A_{\text{eff}} t_{\text{exp}}}}{\sqrt{\phi_\gamma^{\text{Halo-DM}} + \phi_{\text{Bg}}^{\text{ext}}}} > 5$$

$$\phi_{\text{bg}}^{\text{ext}} = \phi_{\text{bg}}^{\text{PSF}} \sqrt{\Delta\Omega_{\text{PSF}}^2 + \Delta\Omega_{\text{Halo}}^2}$$

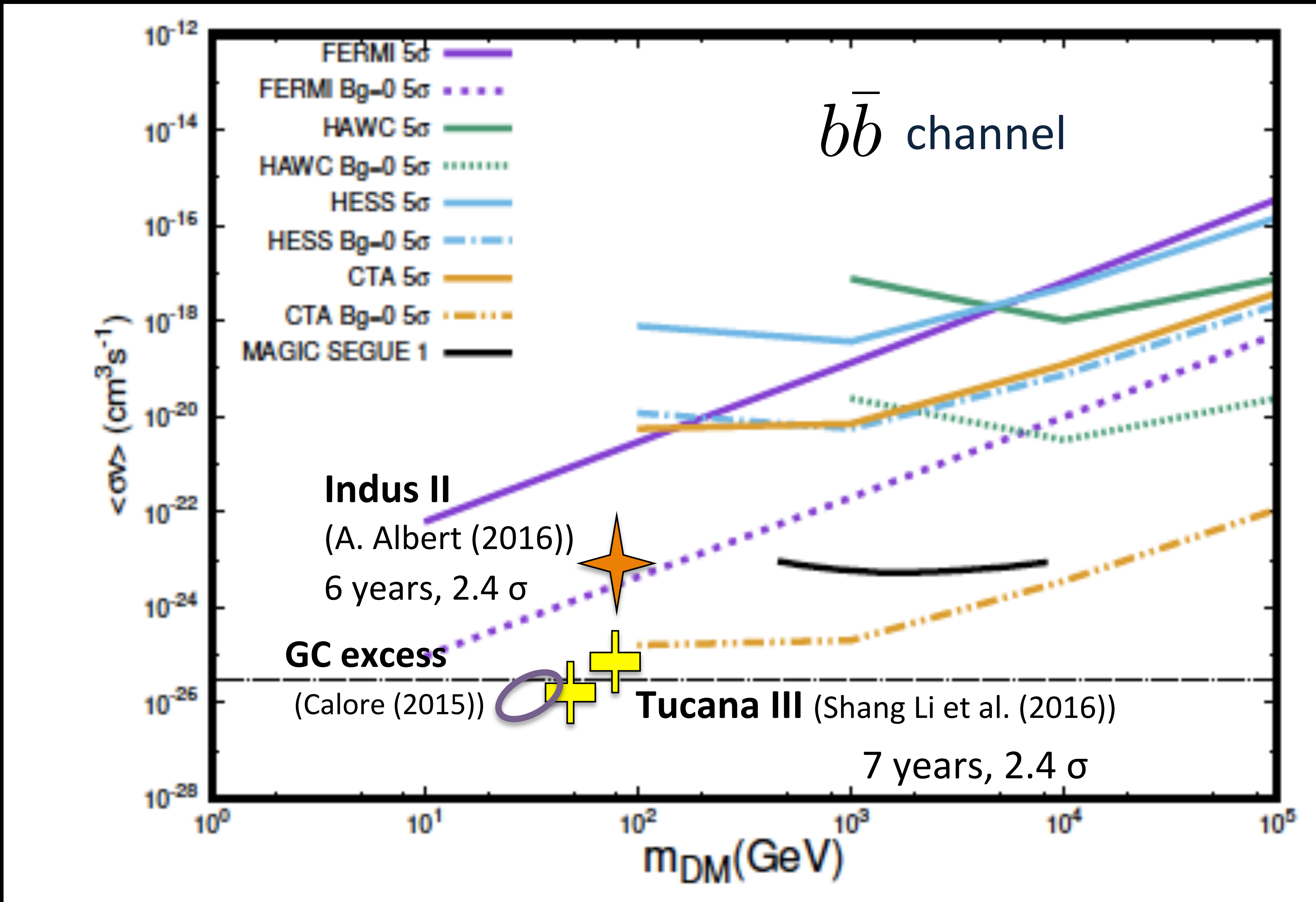
S. Funk, J. A. Hinton for the CTA Collaboration [arXiv:1205.0832v1]

Experiment	FERMI-LAT	HESS I (II)	HAWC	CTA North/South
$\phi_{\text{WLM}}^{\text{ext}}(\text{ph cm}^{-2}\text{s}^{-1})$	3.53×10^{-6}	5.12×10^{-8}	2.12×10^{-8}	8.27×10^{-7}

$\phi_{\text{bg}}^{\text{PSF}}(\text{ph cm}^{-2}\text{s}^{-1})$	1.31×10^{-7}	7.65×10^{-11}	3.18×10^{-11}	3.09×10^{-10}

V.G., E. Karukes, P. Salucci, arXiv:1706.01843

Wolf-Lundmark-Melotte (WLM)



V.G., E. Karukes, P. Salucci, arXiv:1706.01843

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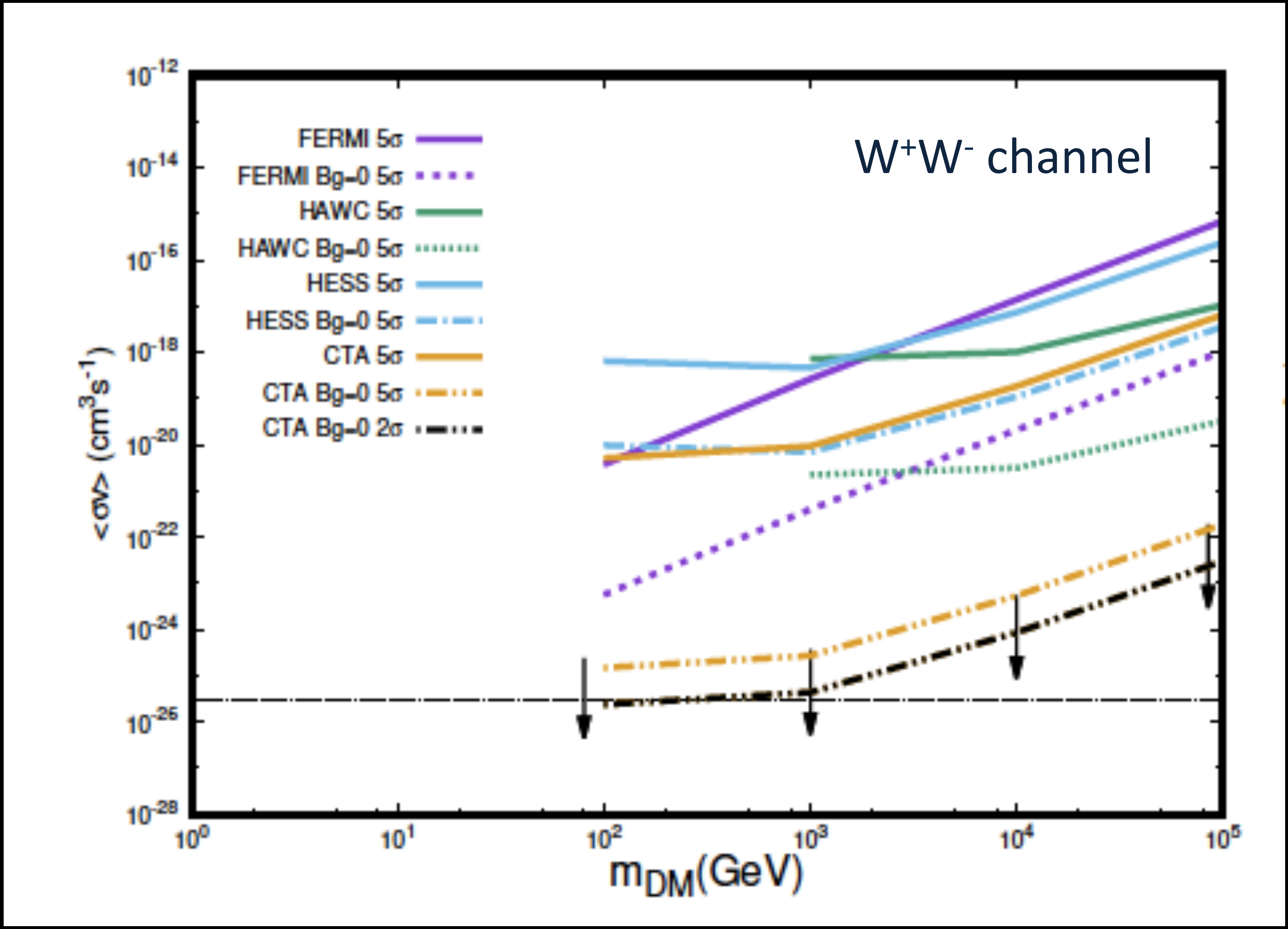
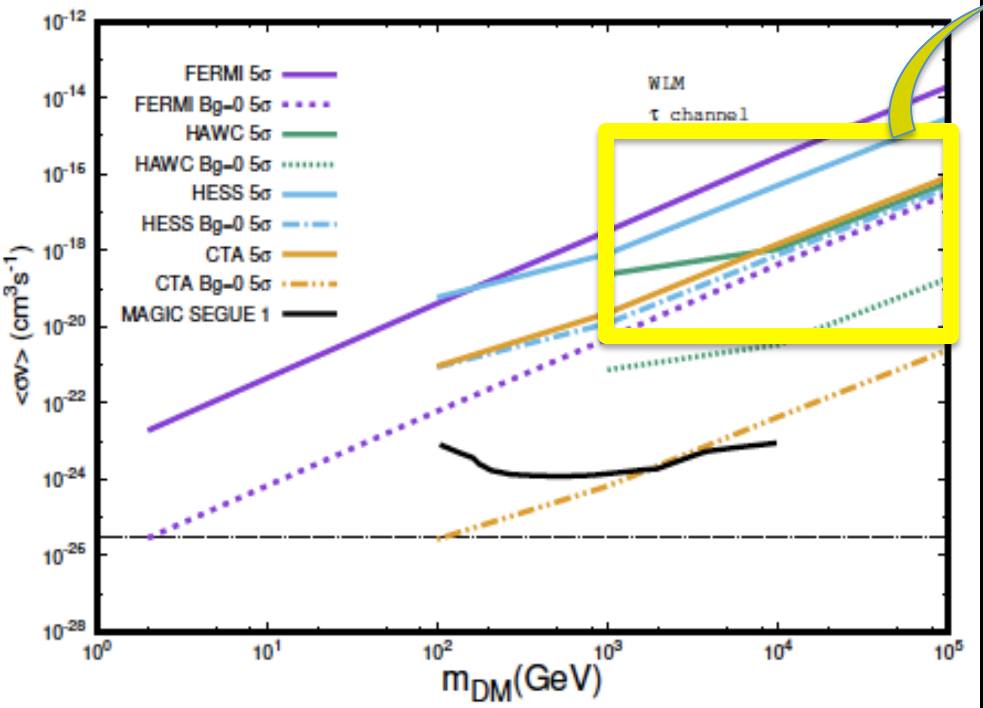


V.G., E. Karukes, P. Salucci, arXiv:1706.01843

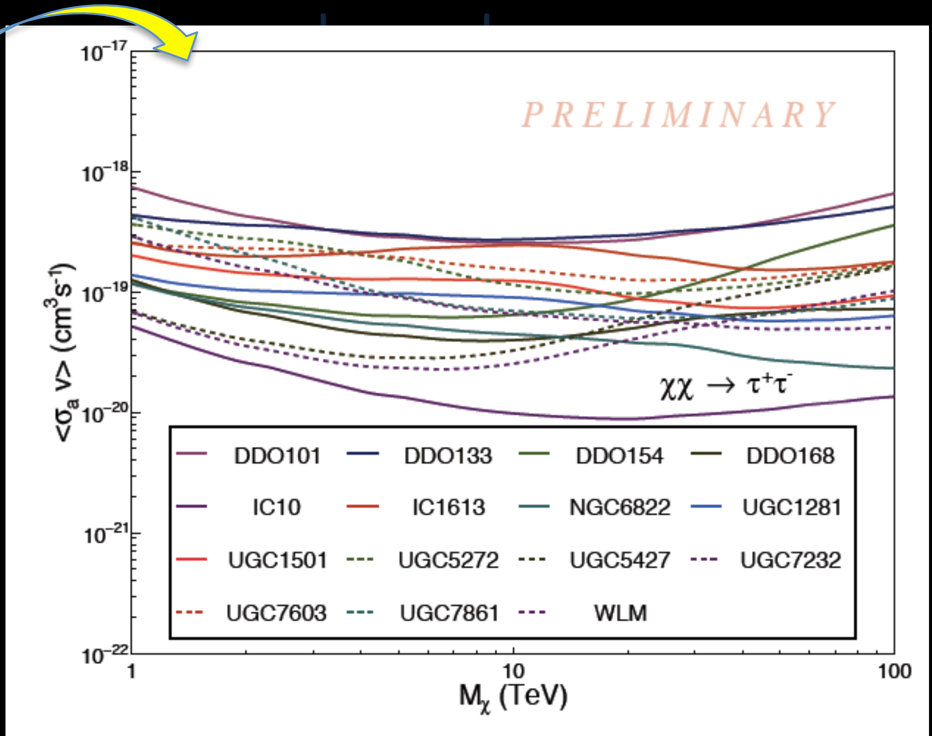
HAWC analysis

Extended halo: prospects



V.G., E. Karukes, P. Salucci, [arXiv:1706.01843]

Point-like analysis: preliminary results



S. H. Cadena, R. Alfaro, A. Sandoval, E. Belmont, H. León, V. G., E. Karukes, P. Salucci for the HAWC Collaboration, [arXiv:1708.04642]

Conclusion

- The astrophysical factor of dIrrs is comparable with a selection of dwarf spheroidal galaxies
  (dIrrs are prospective good candidates for DM indirect searches);

- The astrophysical gamma-ray background can be neglected (to first approximation, in point-like analysis)
  (S. H. Cadena, R. Alfaro, A. Sandoval, E. Belmont, H. León, V. G., E. Karukes, P. Salucci for the HAWC Collaboration, [arXiv:1708.04642]
  or masked (extended source analysis -> "smoking gun")

- Both new data analyses and next gamma-ray observations are expected to set new constraints on DM parameter space with dIrrs.

Thank you for your attention

Any questions ?