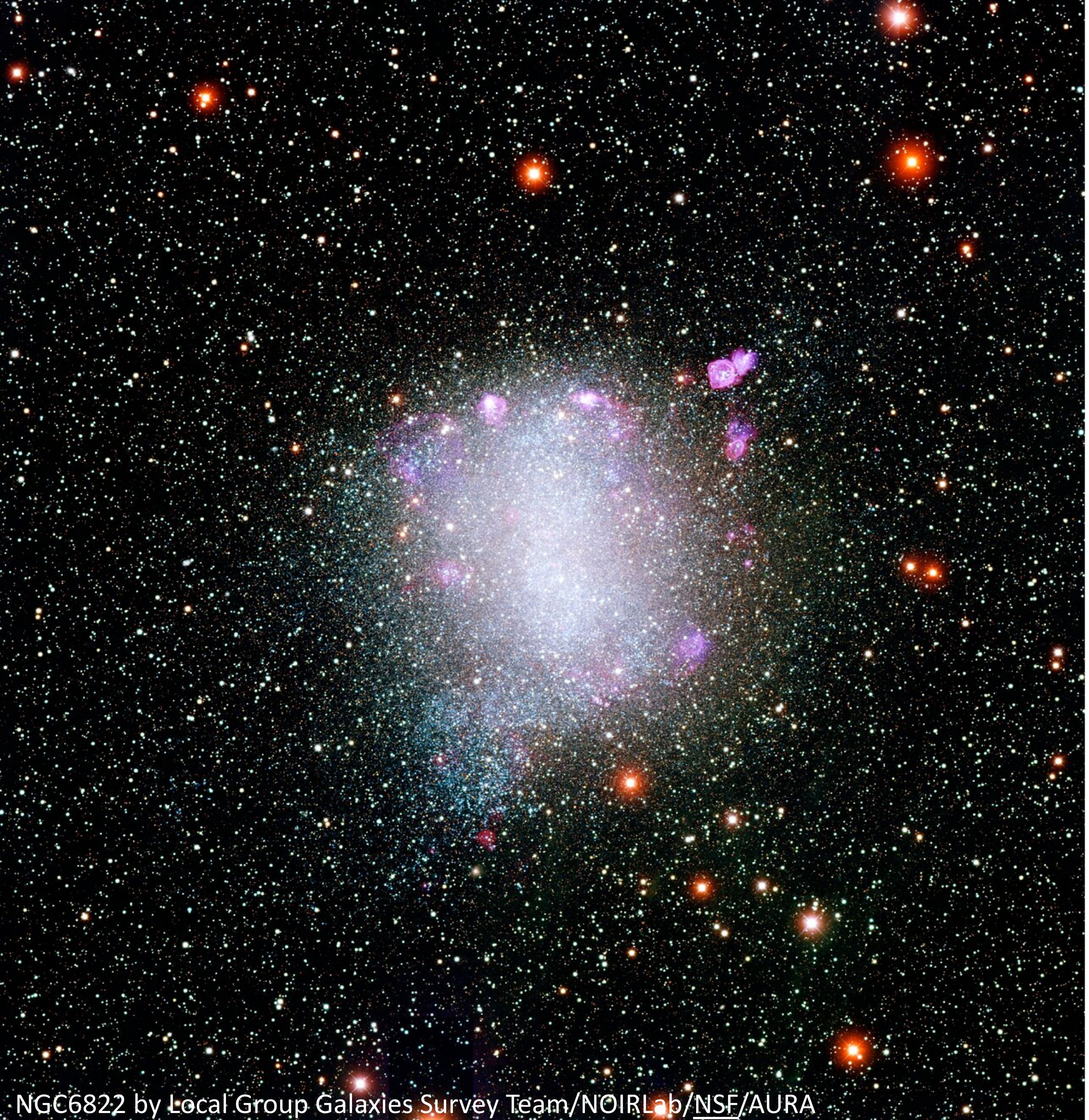


NGC6822 by Local Group Galaxies Survey Team/NOIRLab/NSF/AURA

Indirect Dark Matter Searches in Dwarf Irregular Galaxies

Mainly based on 2109.11291

Judit Pérez-Romero

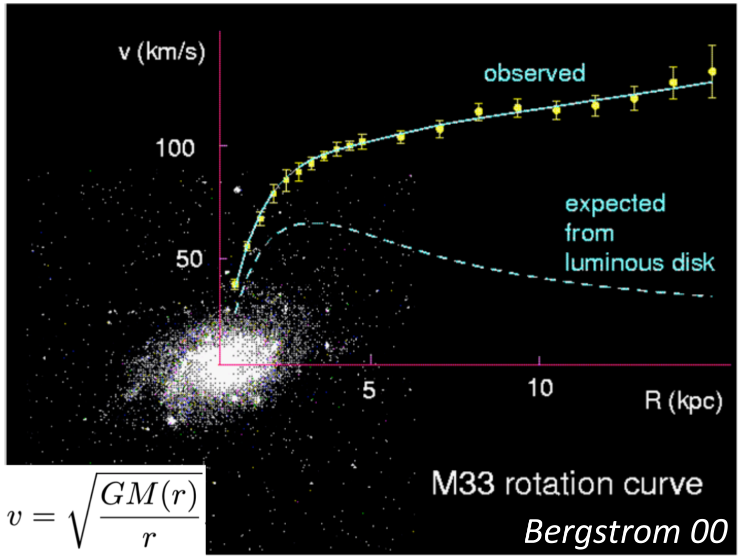
judit.perez@ung.si

30/08/2023

UNIVERZA V NOVI GORICI
SCIENTIA VINCES 1995

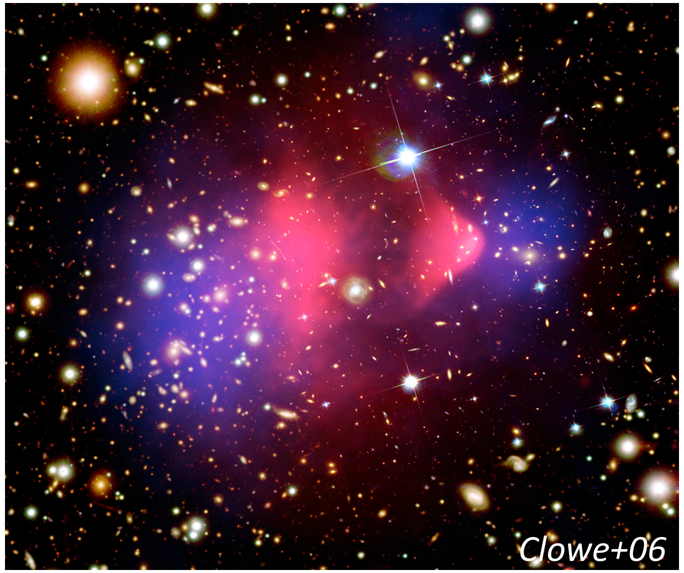
DARK MATTER (DM) EVIDENCE

Galactic scales



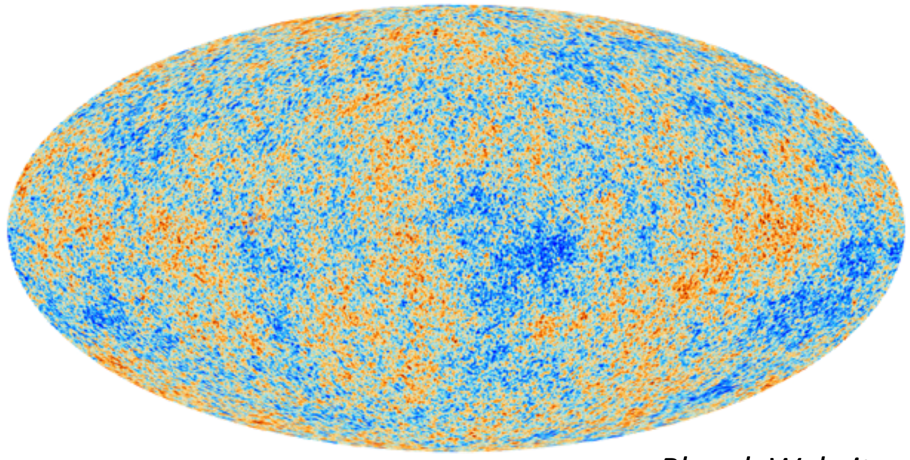
- Rotational curves
- Velocity dispersion

Galaxy cluster scales



- Peculiar velocity flows
- Mass tracers (X-rays, Sunyaev–Zeldovich, strong & weak lensing)
- Dynamical systems

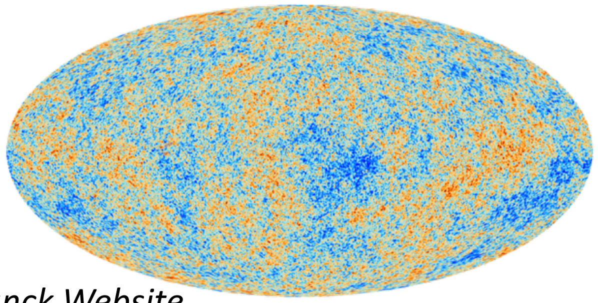
Cosmological scales



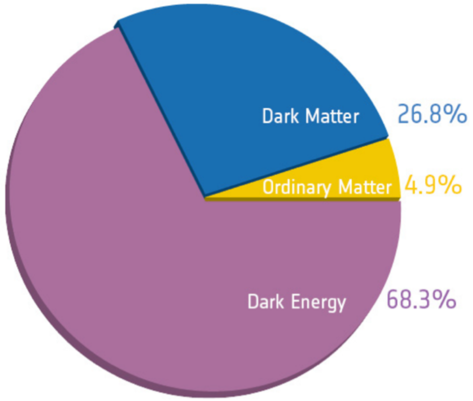
Planck Website

- Cosmic Microwave Background (CMB) anisotropies
- Large Scale Structure (LSS)

STANDARD COSMOLOGICAL MODEL: ΛCDM



Planck Website



$\Omega_\Lambda = 0.6889 \pm 0.056$

$\Omega_m = 0.3111 \pm 0.0056$

$\Omega_b h^2 = 0.02242 \pm 0.00014$

$\Omega_\chi h^2 = 0.11933 \pm 0.00091$

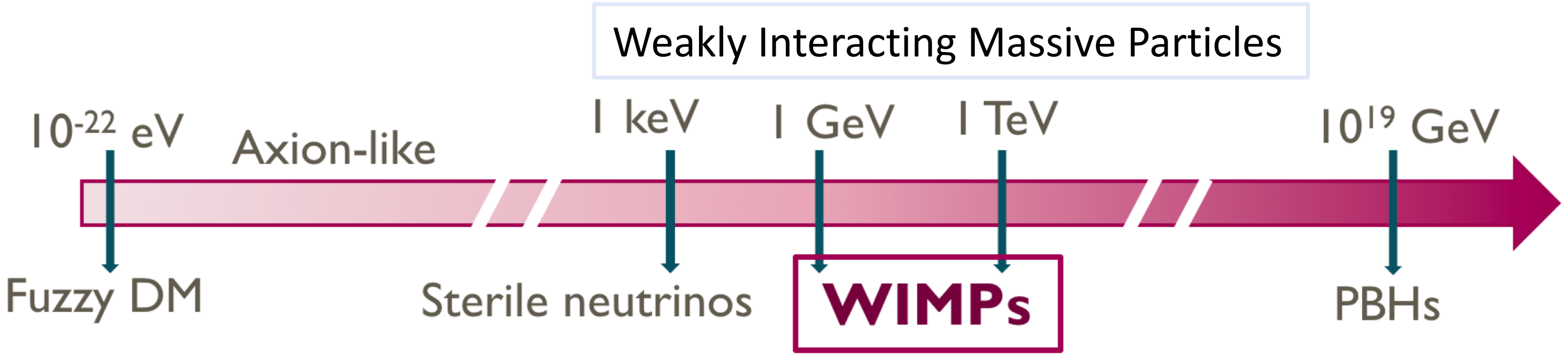
- **ΛCDM explains the formation of structures:**
  1. Inflation seeds perturbations in the field, creating curvature perturbation and when matter falls, **density perturbations**
  2. By hierarchical clustering the density perturbations form larger structures via merge, accretion or collapse
  3. The **driving component** of this process is collisionless, non-relativistic **DM**

     CDM
  4. The fundamental units of cosmic structures are **halos**, in which the baryonic matter gathers to form structures
  5. The later halos that do not get to merge with the rest, fall in the potential wells of main halos

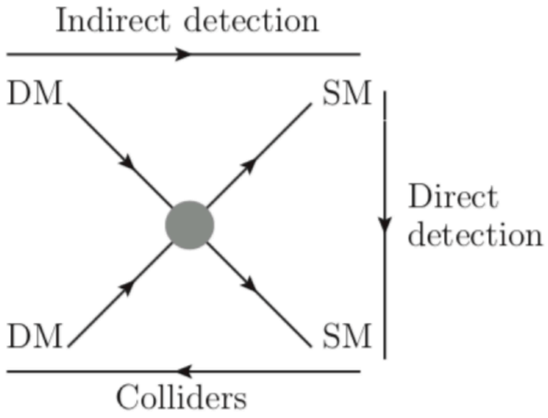
Halos and subhalos

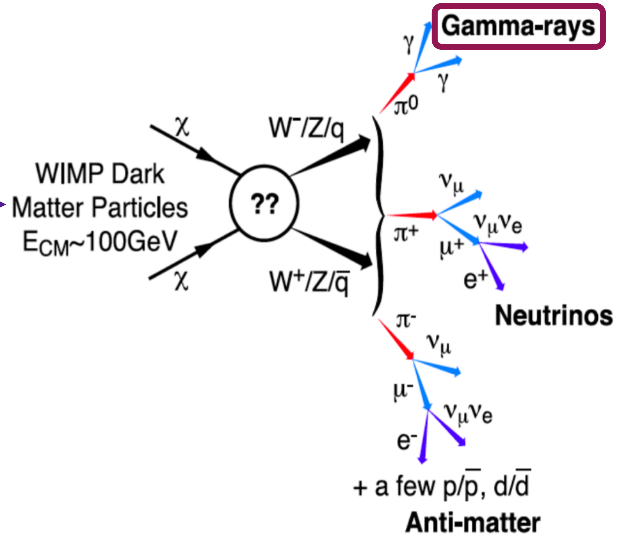
DM CANDIDATES: WIMPS

- **Different DM candidates:**
  - Non-baryonic
  - Electrically neutral
  - Non-relativistic & colissionless
  - Long-lived



- **The search for the WIMP**
  - **Annihilation/Decay** → **Indirect detection**
  - Collision → Direct detection
  - Production → Colliders detection

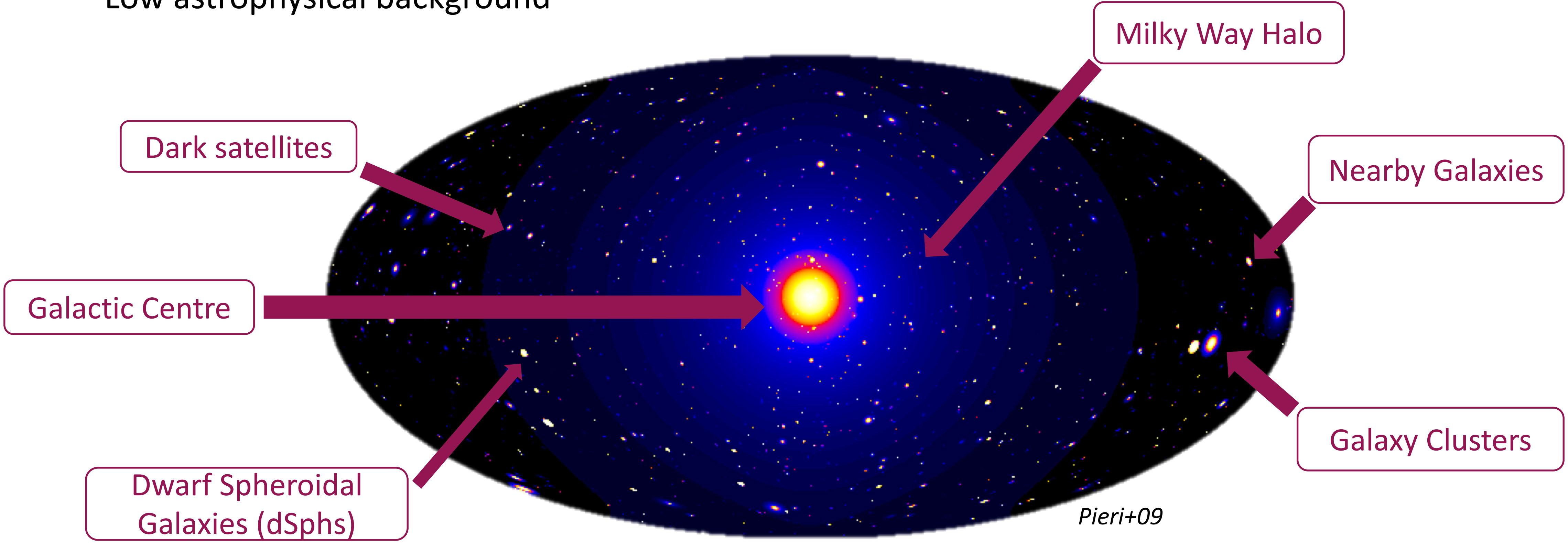




This γ-ray emission allows to perform Indirect DM Searches with current telescopes

γ-RAY DM SEARCHES

- Optimal conditions for indirect DM searches:
  - High DM density ($\phi_{DM} \propto \rho_{DM}^2$ for annihilation, $\phi_{DM} \propto \rho_{DM}$ for decay)
  - Massive nearby objects ($\phi_{DM} \propto M/d_{Earth}^2$)
  - Low astrophysical background



Pieri+09

γ-RAY DM SEARCHES

Clusters of galaxies

- Most massive - 10^{14}-10^{15} $M_\odot$
- Further – $z < 0.1$
- Large population of substructures
- Best targets for decay
- Astrophysical γ–ray emission

IllustrisTNG simulation – TNG100-1, https://www.tng-project.org/

dSphs

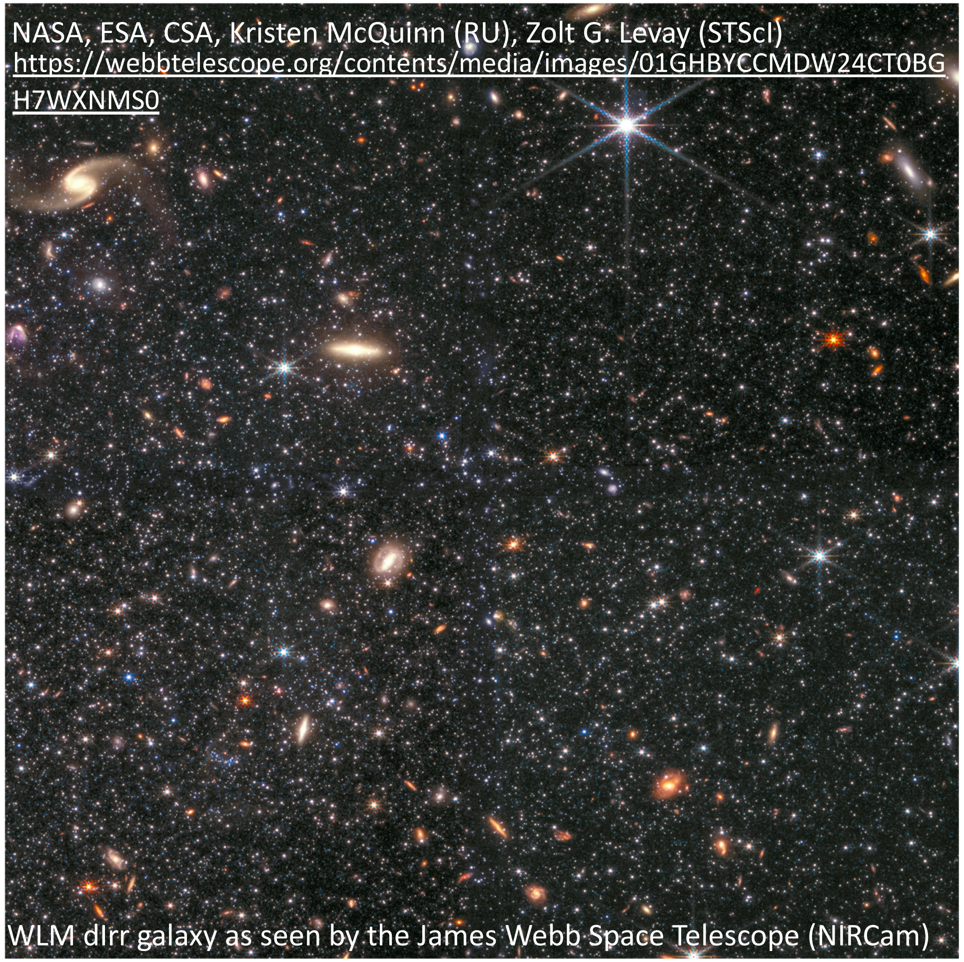
- Less massive - $10^7 – 10^9$ $M_\odot$
- Closer – $20 < d_L < 250$ kpc
- Pressure supported systems
- No substructures expected
- “Negligible” astrophysical γ–ray emission

ESO/G. Bono & CTIO – Carina dSph

DIRRS AS TARGETS FOR γ–RAYS DM SEARCHES

- Dwarf Irregular Galaxies (dIrrs):
  - Rotationally supported objects
  - Located in our Local Volume:

    $0.5 \text{ Mpc} < d_L < 10 \text{ Mpc}$
  - Have masses between $10^8 - 10^{10}$ $M_\odot$
  - Star-forming galaxies


NASA, ESA, CSA, Kristen McQuinn (RU), Zolt G. Levay (STScI)
https://webbtelescope.org/contents/media/images/01GHBYCCMDW24CT0BGH7WXNMS0
WLM dIrr galaxy as seen by the James Webb Space Telescope (NIRCam)

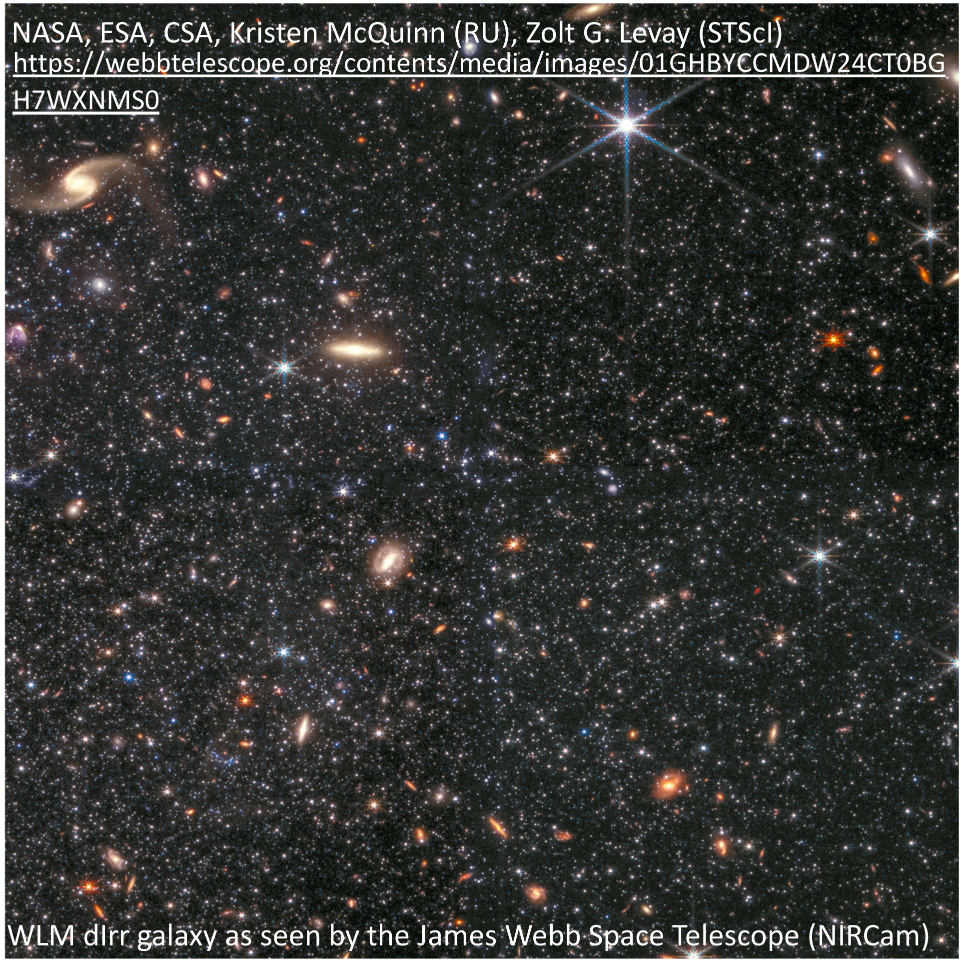
DIRRS AS TARGETS FOR γ–RAYS DM SEARCHES

- Dwarf Irregular Galaxies (dIrrs):
  - Rotationally supported objects
    - High DM density ✓
  - Located in our Local Volume:

    $0.5\ \text{Mpc} < d_L < 10\ \text{Mpc}$ ← Closeby ✓
  - Have masses between $10^8 – 10^{10}\ M_\odot$

    ↓

    ✓ Massive objects → Population of substructures expected
  - Caveat Star-forming galaxies



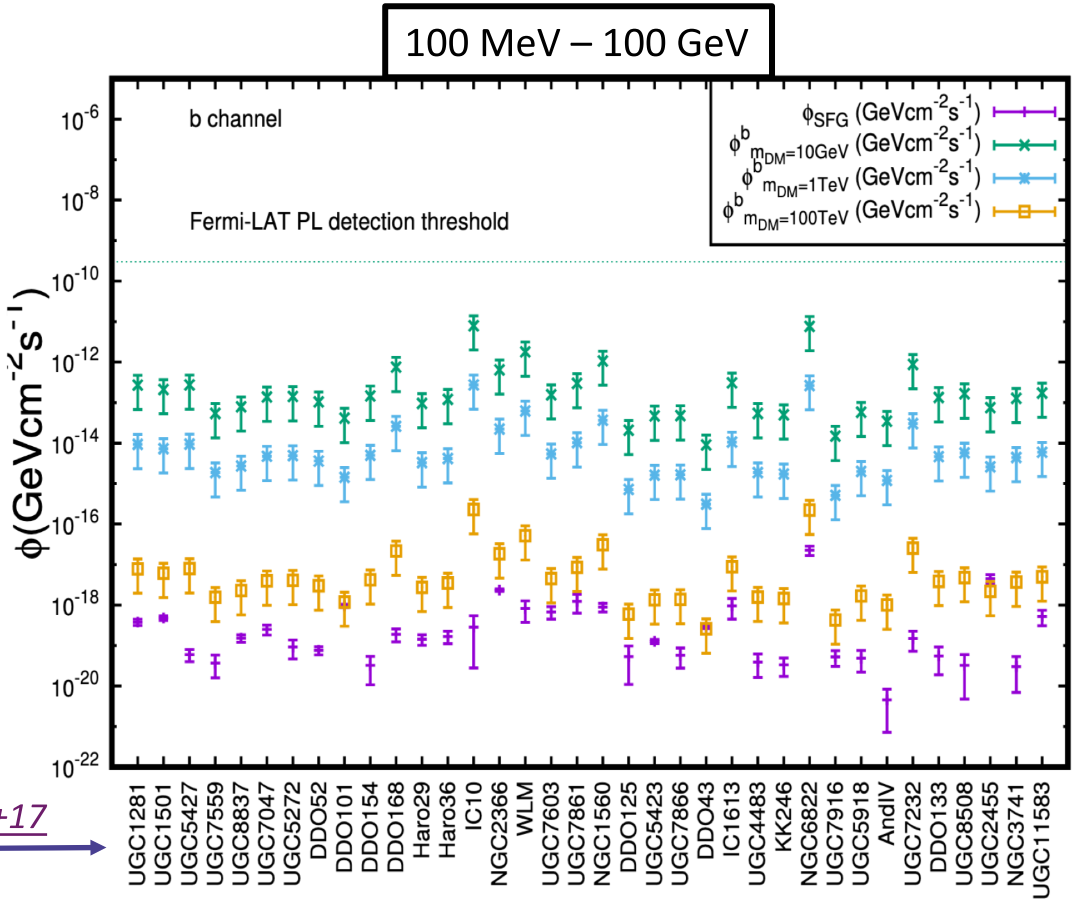
DIRRS AS TARGETS FOR γ–RAYS DM SEARCHES

- Dwarf Irregular Galaxies (dIrrs)
  - Rotationally supported objects
    - High DM density
  - Located in our Local Volume:

    0.5 Mpc < d_L < 10 Mpc ← Closeby
  - Have masses between $10^8 – 10^{10}$ M$_\odot$

    ↓

    Massive objects → Population of substructures expected
  - Star-forming galaxies (SFG) → Negligible γ–ray background → *Gammaldi+17*

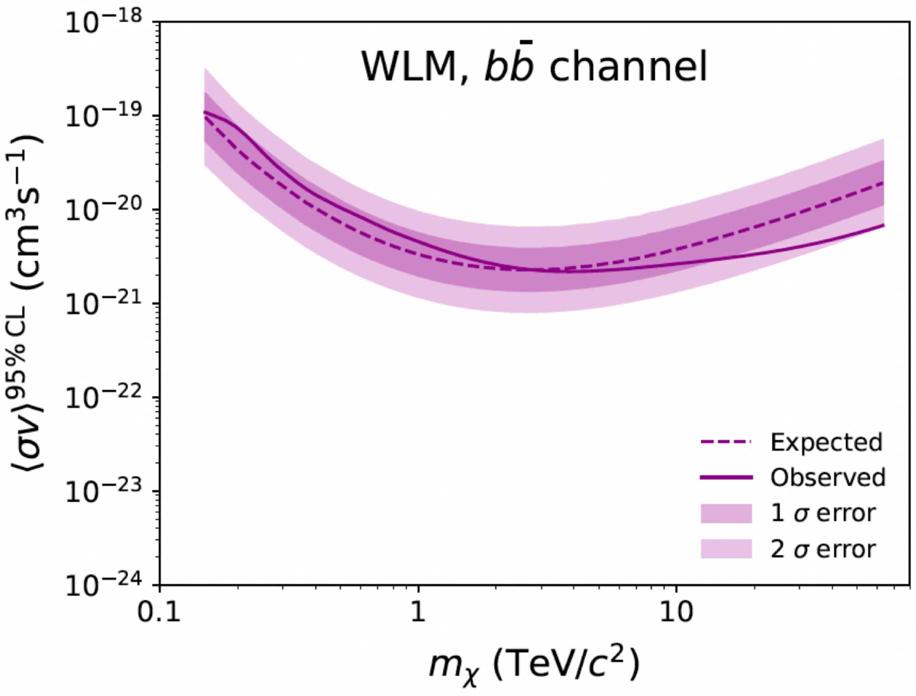


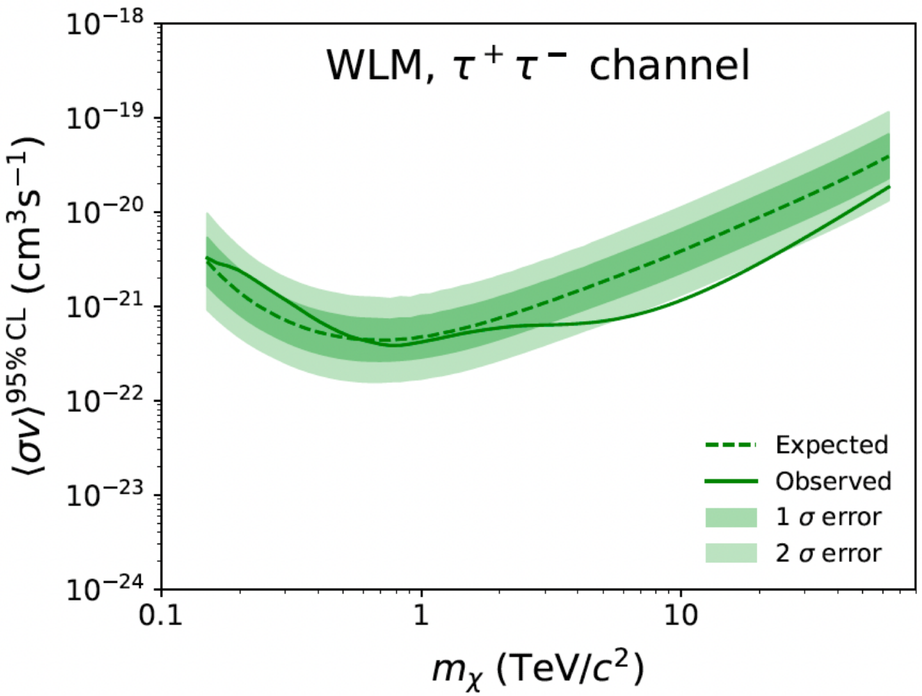
FIRST DM SEARCH IN DIRRS

- H.E.S.S observation of WLM dIrr: *H.E.S.S Collaboration* [2105.04325]
  - Characteristics

l [deg]	b [deg]	d_L [kpc]	ϕ_{SFG} [TeV cm^{-2} s^{-1}]
75.86	-73.83	175	10^{-15}

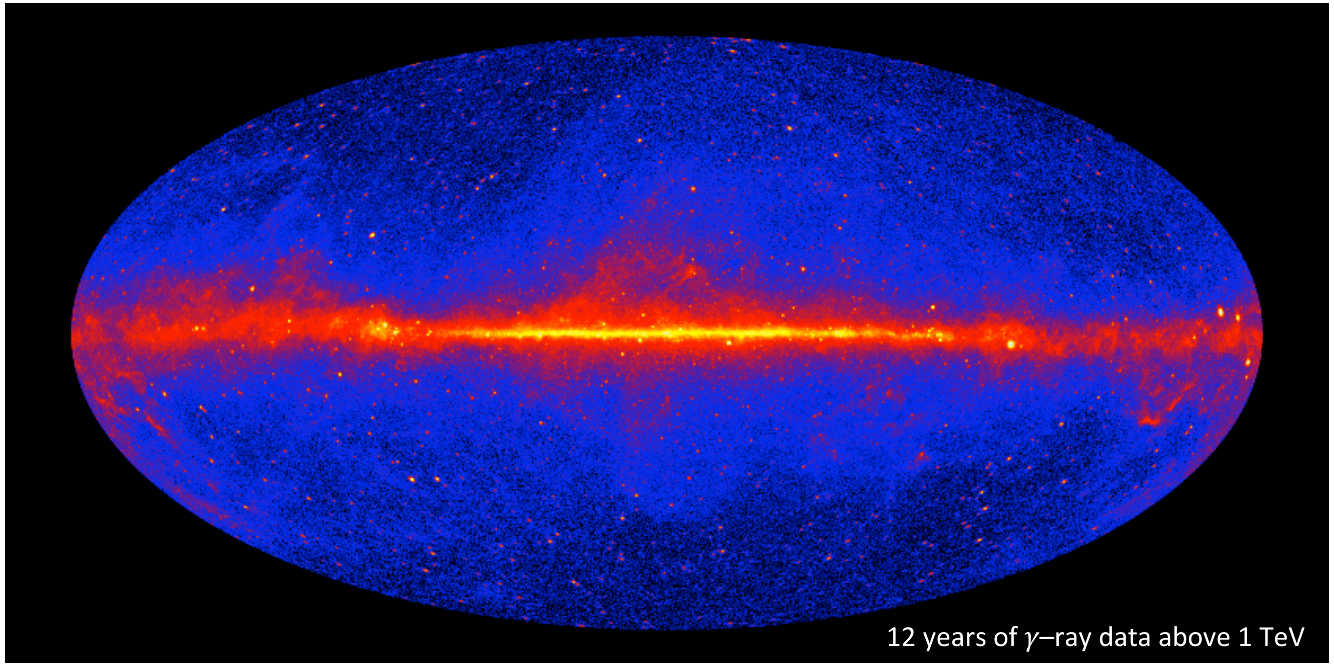
  - Observation: Wobble method, 18 hours, considered point-like source

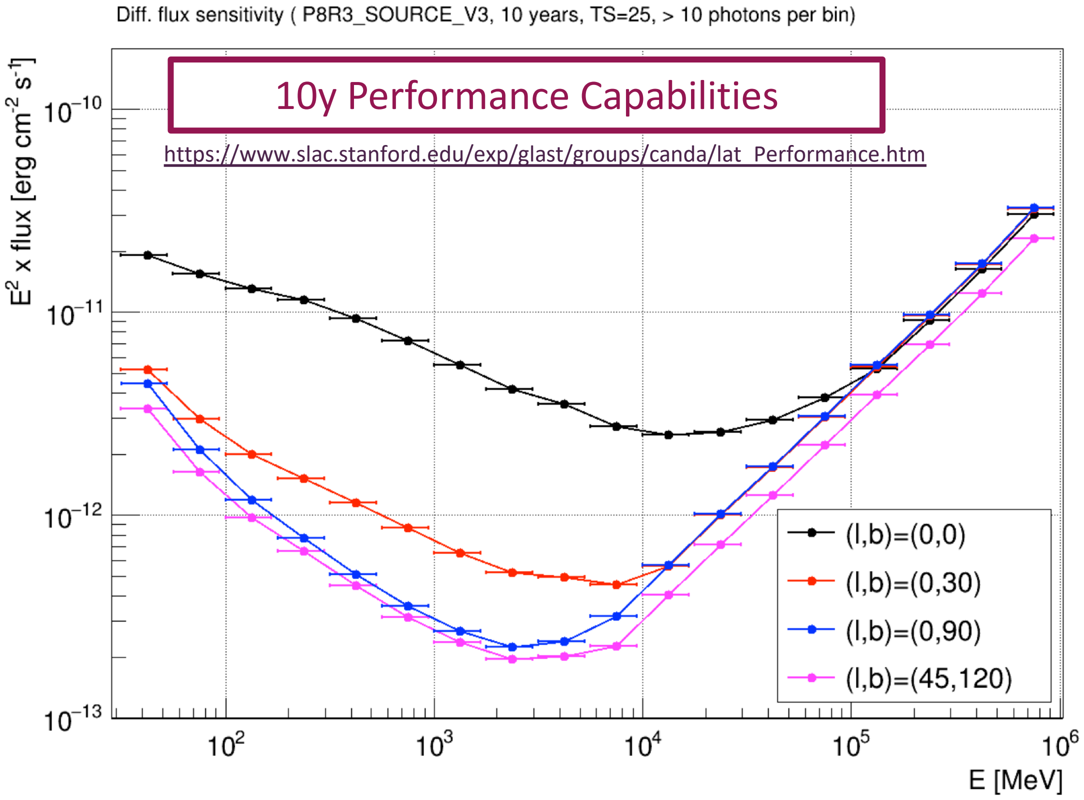




COMBINED DIRRS ANALYSIS WITH *FERMI*-LAT

- Satellite-based telescope launched in June 2008 – 14 years of γ-ray data
- All sky survey mode, image of whole sky every 3 hours
- We exploit this features to analyze several dIrrs to search for DM: *Gammaldi, JPR et al. 2021 [2109.11291]*



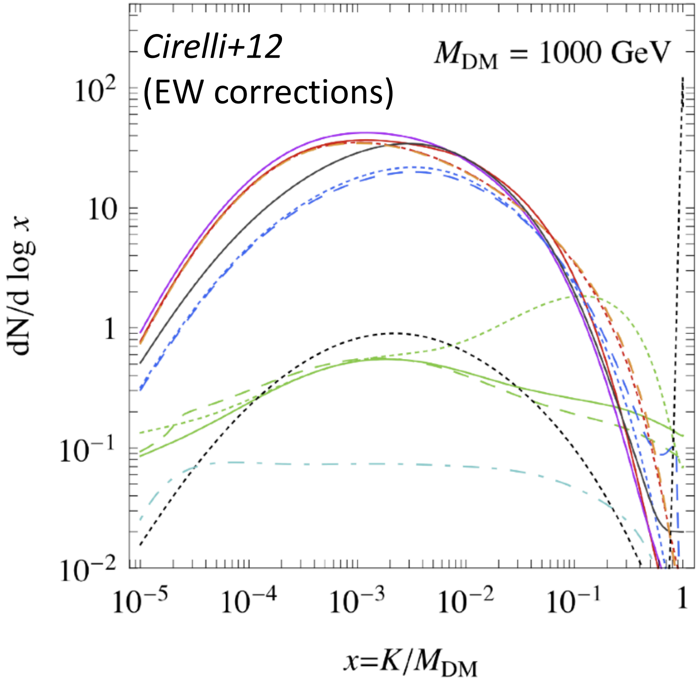


DM-INDUCED γ-RAY FROM WIMPS

- **Annihilation DM-induced $\boldsymbol{\gamma}$-ray flux from an astrophysical object**

$$\frac{d\Phi_{DM}}{dE}(E, l.o.s, \Delta\Omega, z) = \frac{d\phi}{dE}(E, z) \times \text{Astrophysical factor}$$

Particle Physics Model



$$\frac{d\phi}{dE}(E, z) = \frac{<\sigma v>}{8\pi m_{DM}^2}\frac{dN}{dE}$$

- DM mass
- Interaction channel

Quantifies the significance of the signal

$$J(l.o.s, \Delta\Omega, z) = \int_{\Delta\Omega}\int_{l.o.s} \rho_{DM}^2(r)dr$$

DM density profile

Main dependencies

$$J \propto \frac{M_{200}c_{200}^3}{D_{\rm Earth}^2}$$

DM MODELLING OF DIRRS

- Most promising candidates from *Gammaldi+17* are selected as targets

Name	d_L [Mpc]	R_D [kpc]	$\log_{10} M_D$ [$M_\odot$]	l [deg]	b [deg]	RC & M_D reference
NGC6822	0.48	0.66	7.0	23.3	-18.4	$Namumba+17$
IC10	0.79	0.79	8.1	119.0	-3.3	$Oh+15$
WLM	0.97	0.55	7.2	75.9	-73.6	$Oh+15$
IC1613	0.76	0.64	7.5	129.7	-60.6	$Oh+15$
Phoenix	0.44	0.23	6.8	272.2	-68.9	$Kacharov+16$, $Shao+18$
DDO210	0.9	0.17	5.8	34.0	-31.3	$Oh+15$
DDO216	1.1	0.54	7.2	61.5	-67.1	$Oh+15$

- State-of-the-art modelling of the DM density:
  I. Model the main halo;
  II. Model the substructure population defining benchmark models

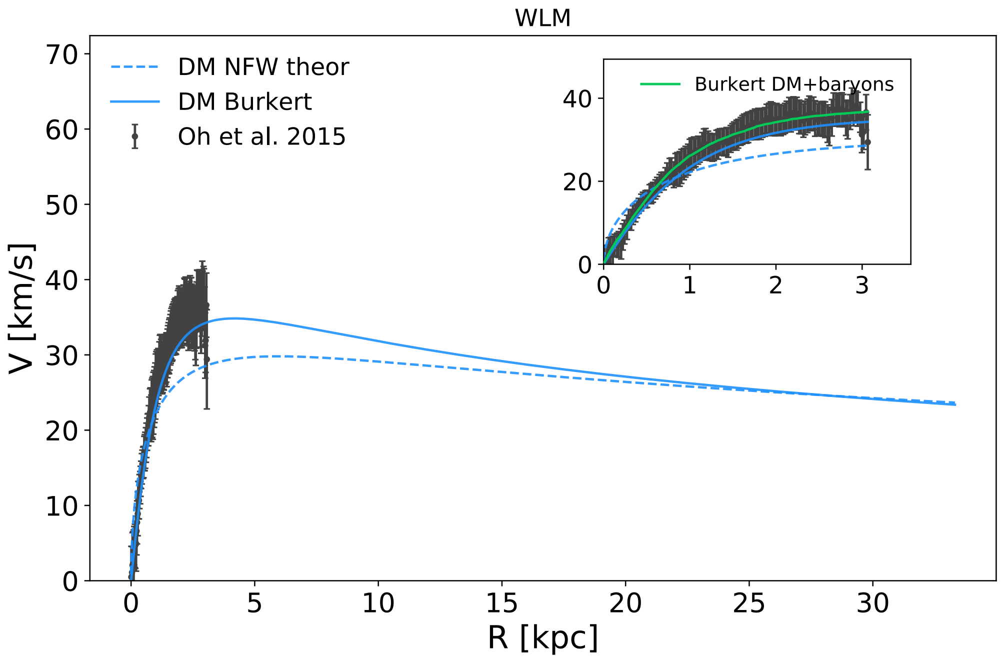
$$\langle\rho_{tot}\rangle(r) = \rho_{sm}(r) + \langle\rho_{subs}\rangle(r)$$

$$J(l.o.s, \Delta\Omega, z) = \int_{\Delta\Omega}\int_{l.o.s} \rho^2_{DM}(r)\,dr$$

DM MODELLING OF DIRRS (I): MAIN HALO

- State-of-the-art modelling of the DM density:
  - **I. Model the main halo;**
  - II. Model the substructure population defining benchmark models

$$\langle\rho_{\rm tot}\rangle(r) = \rho_{\rm sm}(r) + \langle\rho_{\rm subs}\rangle(r) \;\longrightarrow\; J(l.o.s, \Delta\Omega, z) = \int_{\Delta\Omega}\int_{l.o.s} \rho^2_{DM}(r)\,dr$$



- Two models for the main halo:
  - Fit likelihood to Burkert profile $\rho_{\rm Bur}(r) = \dfrac{\rho_c\, r_c^3}{(r+r_c)\,(r^2+r_c^2)}$
  - Build NFW from the fitted M_{200} assuming:

$$M_{200}^{\rm NFW} = M_{200}^{\rm Bur} \;+\; (c_{200} - M_{200})$$

Sánchez-Conde & Prada 14

$$\rho_{\rm NFW}(r) = \frac{\rho_0}{\left(\frac{r}{r_s}\right)\left(1+\frac{r}{r_s}\right)^2}$$

DM MODELLING OF DIRRS (II): SUBSTRUCTURES

- State-of-the-art modelling of the DM density:
  I. Model the main halo;
  II. Model the substructure population defining benchmark models

$$\langle\rho_{\mathrm{tot}}\rangle(r) = \rho_{\mathrm{sm}}(r) + \langle\rho_{\mathrm{subs}}\rangle(r)$$

$$\frac{\mathrm{d}^3 N}{\mathrm{d}V\mathrm{d}M\mathrm{d}c} = N_{\mathrm{tot}}\frac{\mathrm{d}\mathcal{P}_V}{\mathrm{d}V}(r)\cdot\frac{\mathrm{d}\mathcal{P}_M}{\mathrm{d}M}(M)\cdot\frac{\mathrm{d}\mathcal{P}_c}{\mathrm{d}c}(M,c)$$

DM subhalo profile: NFW

$$\rho_{\mathrm{NFW}}(r) = \frac{\rho_0}{\left(\frac{r}{r_s}\right)\left(1+\frac{r}{r_s}\right)^2}$$

DM MODELLING OF DIRRS (II): SUBSTRUCTURES

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$$\langle\rho_{\rm tot}\rangle(r) = \rho_{\rm sm}(r) + \langle\rho_{\rm subs}\rangle(r)$$

$$\frac{d^3N}{dV\,dM\,dc} = N_{\rm tot}\frac{d\mathcal{P}_V}{dV}(r)\cdot\frac{d\mathcal{P}_M}{dM}(M)\cdot\frac{d\mathcal{P}_c}{dc}(M,c)$$

DM subhalo profile: NFW

$$\rho_{\rm NFW}(r) = \frac{\rho_0}{\left(\frac{r}{r_s}\right)\left(1+\frac{r}{r_s}\right)^2}$$

Subhalo Radial Distribution (SRD)

- $$\rho_{\rm Bur}(r) = \frac{\rho_c\, r_c^3}{(r+r_c)(r^2+r_c^2)}$$
- $$\rho_{\rm NFW}(r) = \frac{\rho_0}{\left(\frac{r}{r_s}\right)\left(1+\frac{r}{r_s}\right)^2}$$

DM MODELLING OF DIRRS (II): SUBSTRUCTURES

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Subhalo Mass Function (SHMF)

$$dN/dm = A/M(m/M)^{-\alpha}$$

- α = 1.9 *Springel+08*
- α = 2.0 *Diemand+08*

DM MODELLING OF DIRRS (II): SUBSTRUCTURES

- State-of-the-art modelling of the DM density:
  I. Model the main halo;
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DM subhalo profile: NFW

$$\rho_{\rm NFW}(r) = \frac{\rho_0}{\left(\frac{r}{r_s}\right)\left(1+\frac{r}{r_s}\right)^2}$$

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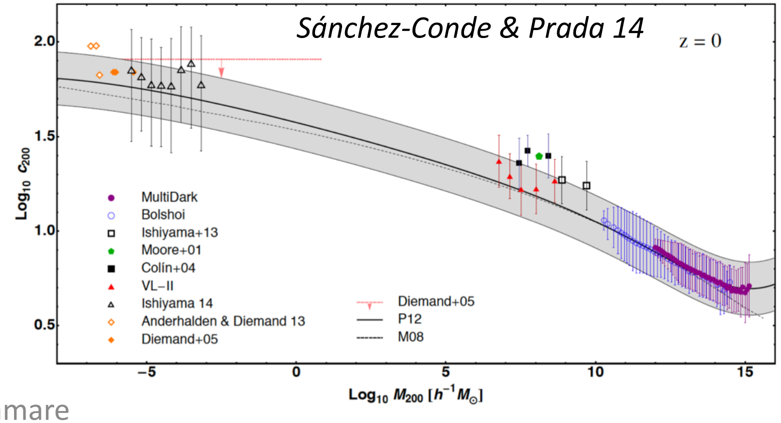
- $\rho_{\rm NFW}(r) = \dfrac{\rho_0}{\left(\frac{r}{r_s}\right)\left(1+\frac{r}{r_s}\right)^2}$

Subhalo Mass Function (SHMF)

$$dN/dm = A/M(m/M)^{-\alpha}$$

- α = 1.9 *Springel+08*
- α = 2.0 *Diemand+08*

Subhalo Concentration-Mass relation (c_{200}-M_{200})



DM MODELLING OF DIRRS: SUMMARY

- Most promising candidates from *Gammaldi+17* are selected as targets

Name	d_L [Mpc]	R_D [kpc]	$\log_{10} M_D$ [$M_\odot$]	l [deg]	b [deg]	RC & M_D reference
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DDO216	1.1	0.54	7.2	61.5	-67.1	*Oh + 15*

- Follow similar strategy:
  I. Model the main halo;
  II. Model the substructure population defining benchmark models

$$\langle\rho_{tot}\rangle(r) = \rho_{sm}(r) + \langle\rho_{subs}\rangle(r)$$

MIN → No substructure considered

MED → Best guess according to recent results

MAX → Educated upper bound

Model	ρ_{host}	ρ_{subs}	SRD	α
MIN	Burkert	-	-	-
MED	Burkert	NFW	Burkert	1.9
MAX-Bur	Burkert	NFW	Burkert	2
MAX-NFW	NFW	NFW	NFW	2

$$J(l.o.s, \Delta\Omega, z) = \int_{\Delta\Omega}\int_{l.o.s} \rho^2_{DM}(r)\,dr$$

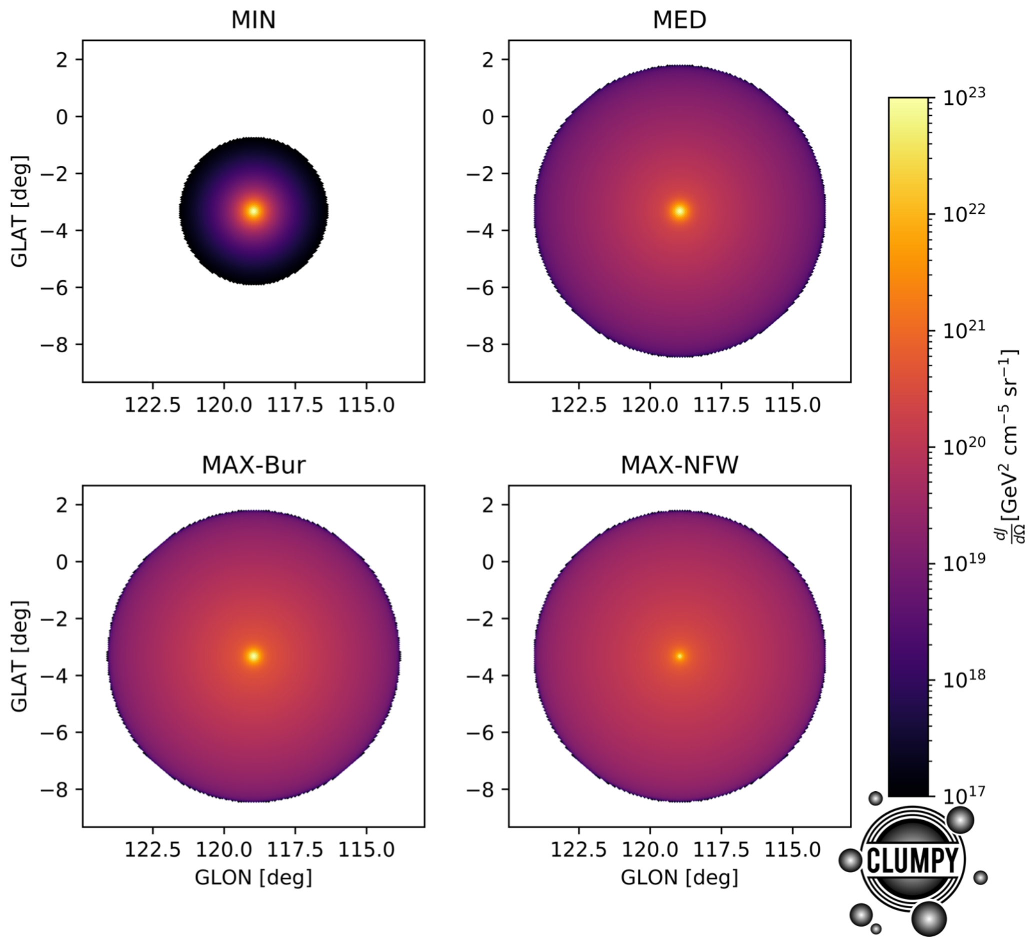
DM ANNIHILATION FLUXES FROM DIRRS

Name	$\log_{10} J_{\mathrm{MIN}}$	$\log_{10} J_{\mathrm{MED}}$	$\log_{10} J_{\mathrm{MAX-BUR}}$	$\log_{10} J_{\mathrm{MAX-NFW}}$
	$\mathrm{GeV^2cm^{-5}}$	$\mathrm{GeV^2cm^{-5}}$	$\mathrm{GeV^2cm^{-5}}$	$\mathrm{GeV^2cm^{-5}}$
NGC6822	17.86	18.40	18.62	18.63
IC10	18.21	18.40	18.53	18.33
WLM	16.72	17.10	17.27	17.24
IC1613	16.16	17.48	17.74	17.84
Phoenix	14.40	15.04	15.16	15.16
DDO210	15.90	16.20	16.32	16.27
DDO216	15.45	15.72	15.83	15.73

- Distributed, for all the benchmark models, according to $J \propto \frac{M_{200}^2}{d_L^2}$

B_{MED} = 0.6-3.4 (*B* ~1.2-2.0 – *Sánchez-Conde & Prada 14*)
$B_{\mathrm{MAX\text{-}BUR}}$ = 1.1-4.8 (*B* ~2.0-7.0 – *Sánchez-Conde & Prada 14*)

Example of IC10 skymaps of the J-factor



FERMI-LAT DATA ANALYSIS FOR DIRRS

Years of *Fermi* data	11
IRFs	P8R3_SOURCEVETO_V2
Energy range [GeV]	0.5 – 1000
Bins per decade	8
ROI [deg^2]	12 x 12
Pixel size [deg]	0.08
Catalogue	4FGL-DR1

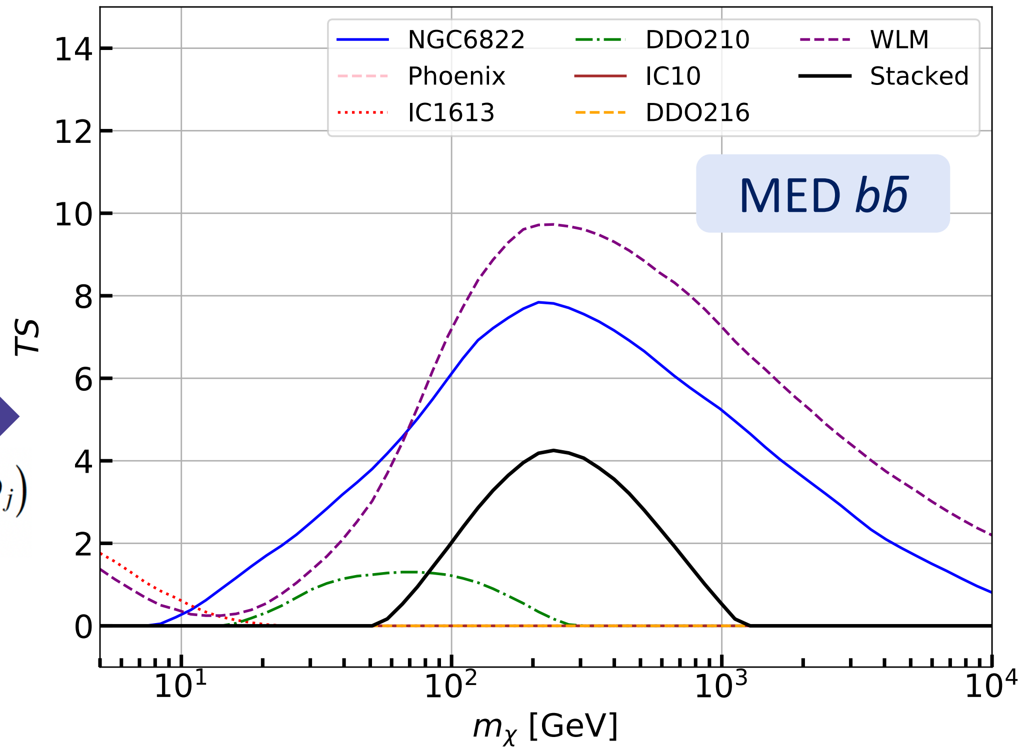
- Background components
  - Isotropic emission
  - Galactic IEM

Apply likelihood fit

$$\log\mathcal{L}(\mu,\theta|\mathcal{D}) = \sum_j \log\mathcal{L}_j\left(\mu,\theta_j|\mathcal{D}_j\right)$$

Is signal if

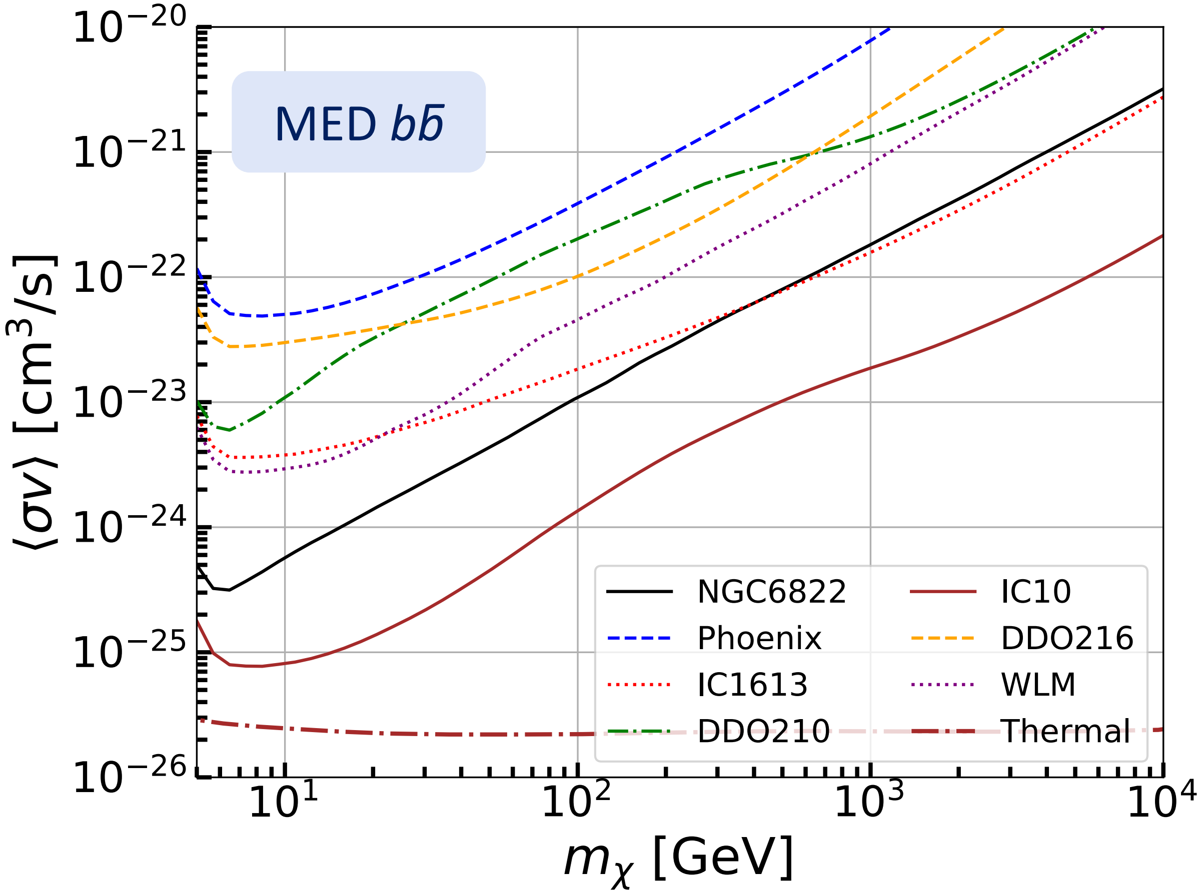
$$TS = 2\ln\frac{\mathcal{L}(\mu;\theta|\mathcal{D})}{\mathcal{L}_{null}(\theta|\mathcal{D})} \geq 25$$



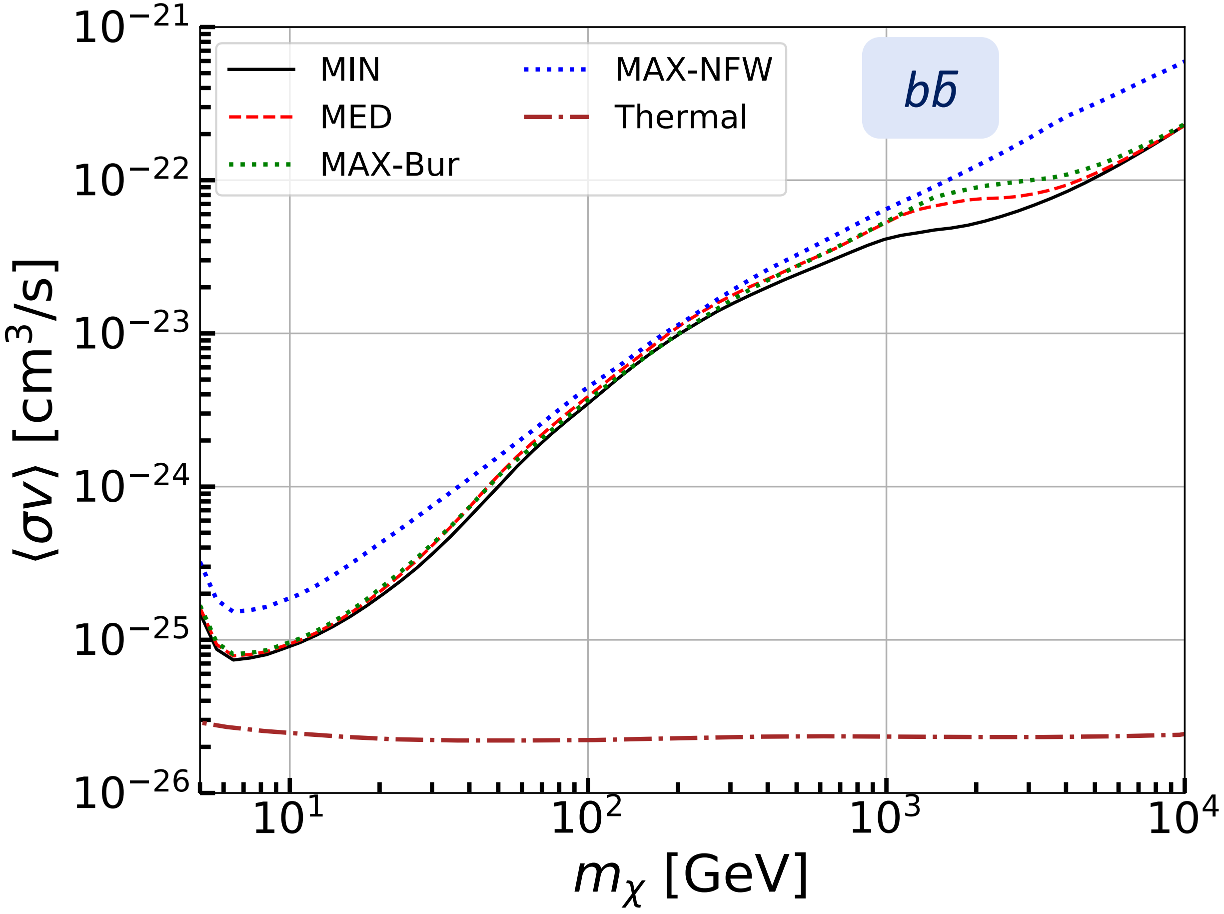
- Highest *TS* ~ 9-11 for WLM, depending on annihilation channel
- Very faint, most likely due to Galactic diffuse emission

DM CONSTRAINTS FROM DIRRS

- 95% C.L upper limits from individual dIrrs



- 95% C.L combined upper limits



MORE DM PREDICTIONS/SEARCHES WITH DIRRS

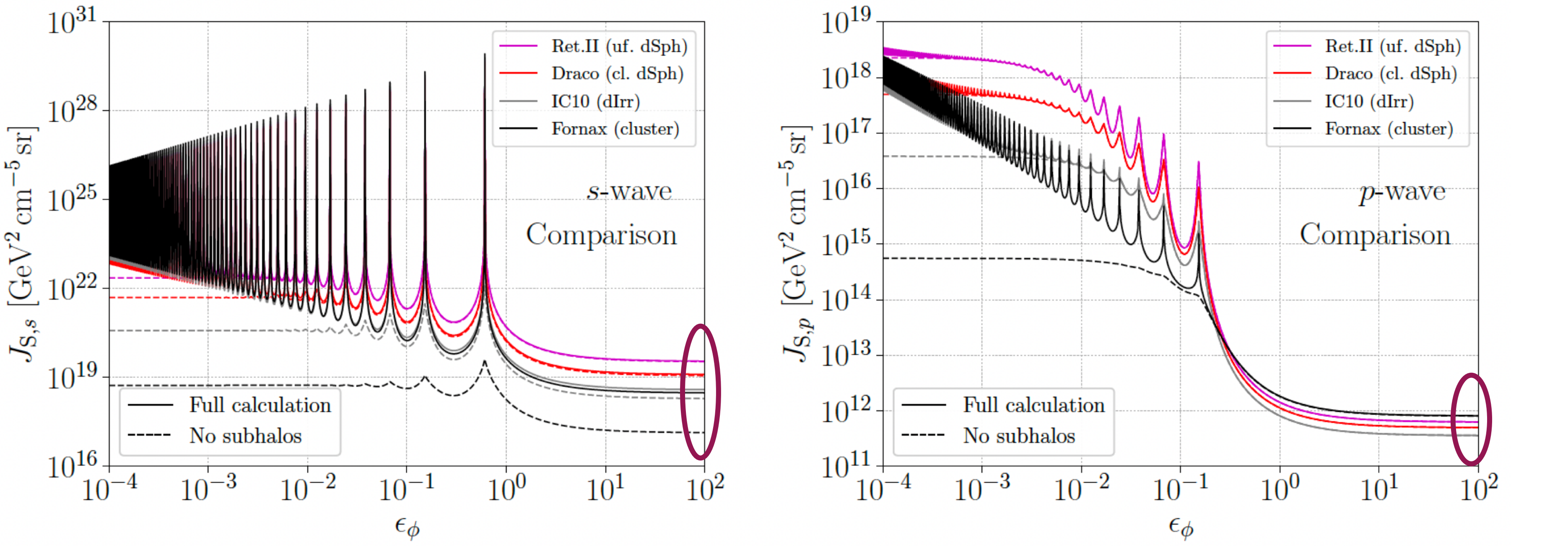
- **Classification of γ-ray targets for velocity-dependent and subhalo-boosted dark-matter annihilation**

Lacroix, Facchinetti, JPR et al. 2022 [2203.16440]

- Build intra- and inter-family ranking of targets for γ-ray DM searches
- Include *s*- and *p*-wave terms in the cross-section, Sommerfeld enhancement effect and boost due to substructures

Classification of targets is very dependent on the regime!

dSphs	dIrrs
Reticulum II	NGC6822
Sculptor	IC10
Draco	WLM
Galaxy clusters	
Coma	
Fornax	
Perseus	

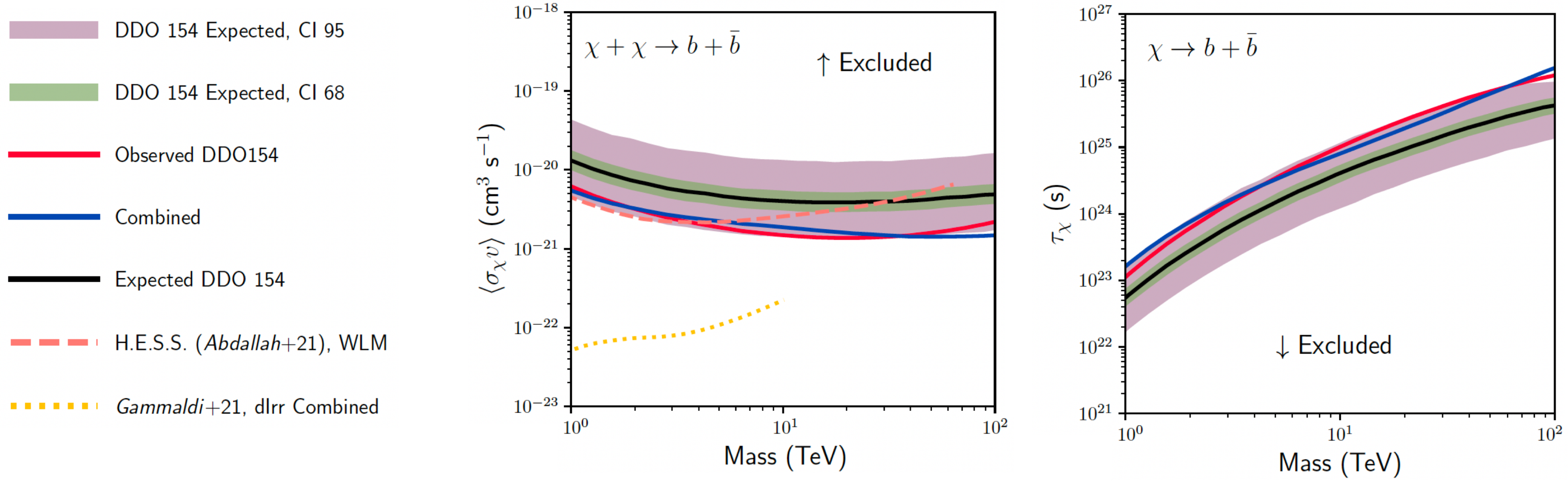


MORE DM PREDICTIONS/SEARCHES WITH DIRRS

- **Searching for TeV Dark Matter in Irregular dwarf galaxies with HAWC Observatory**

HAWC Collaboration & Gammaldi, Karukes, Salucci 2023 [2302.07929]

- Observation of 31 dIrrs and analysis including estimation of ϕ_{SFR} for the energy range from 1 – 100 TeV
- Limits for annihilation compared with previous searches and for decay for the first time!



DWARF IRREGULAR GALAXIES AS TARGETS FOR DM SEARCHES

- DIrrs are rotationally supported systems, we can obtain their DM density profiles directly from their rotational curves
- They have negligible γ-ray emission from their SFRs
- First DM search targeting dIrrs was in 2021, very young field!
- Neither individual analysis or combined have found a conclusive DM-induced γ–ray signal
- Best limits status:
  - up to 10 TeV are provided by *Gammaldi et al. 2021*, using 11 years of *Fermi*-LAT data
  - from 10 TeV are from *HAWC Collaboration et al. 2023*, using 31 dIrrs and also obtaining limits for decaying DM
- With future facilities, expect discovery of new dIrrs and better and more kinematical data

DIrrs stand as a firm complementary target to the most standard targets, need to be taken into account for the DM searches in the near future!

THANKS FOR YOUR ATTENTION!

BACK UP MATERIAL

STRUCTURE FORMATION IN ΛCDM

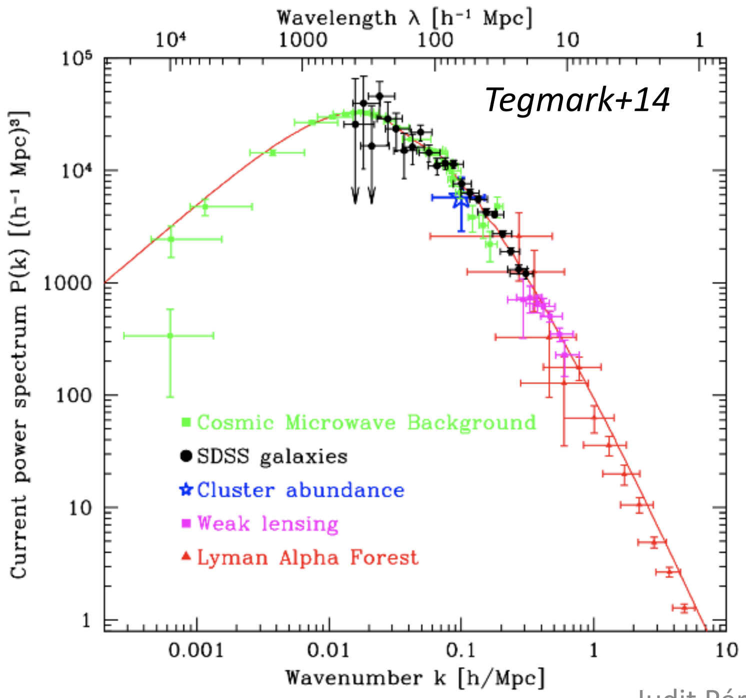
- **ΛCDM explains the formation of structures:**
  - Cosmological principle
    - Isotropy
    - Homogeneity

Need inhomogeneities to form structures

- Inflation seeds perturbations in the field, creating curvature perturbation and when matter falls, **density perturbations**

Linear growth

Matter power spectrum



- Dominant component is collisionless, non-relativistic dark matter

CDM

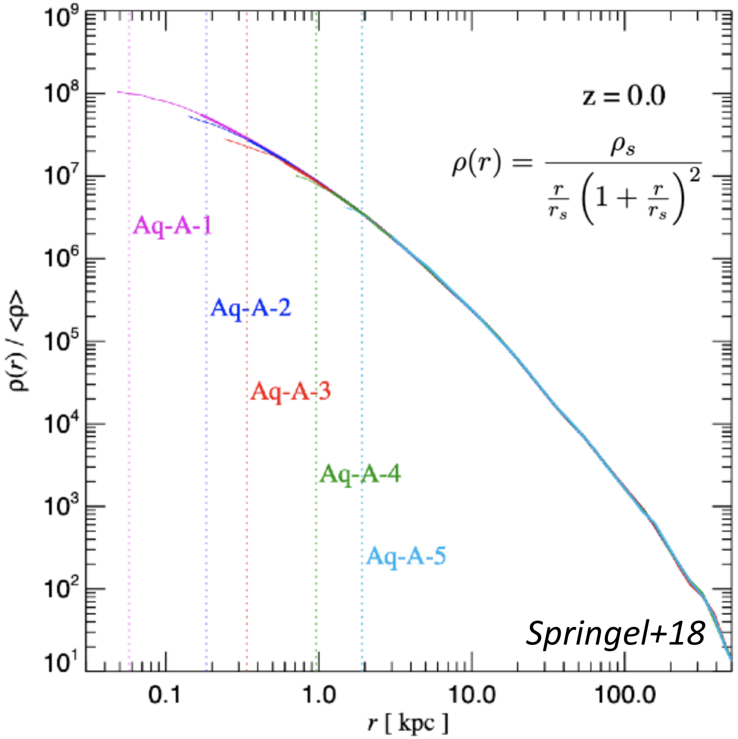
- Gathers gravitationally on small scales
- Seeds of larger structures by hierarchical clustering

Halos and subhalos

HALO AND SUBHALO PROPERTIES

Main halos

- Fundamental non-linear units of cosmic structures
- Inner density profile



Springel+18

- Mass distribution

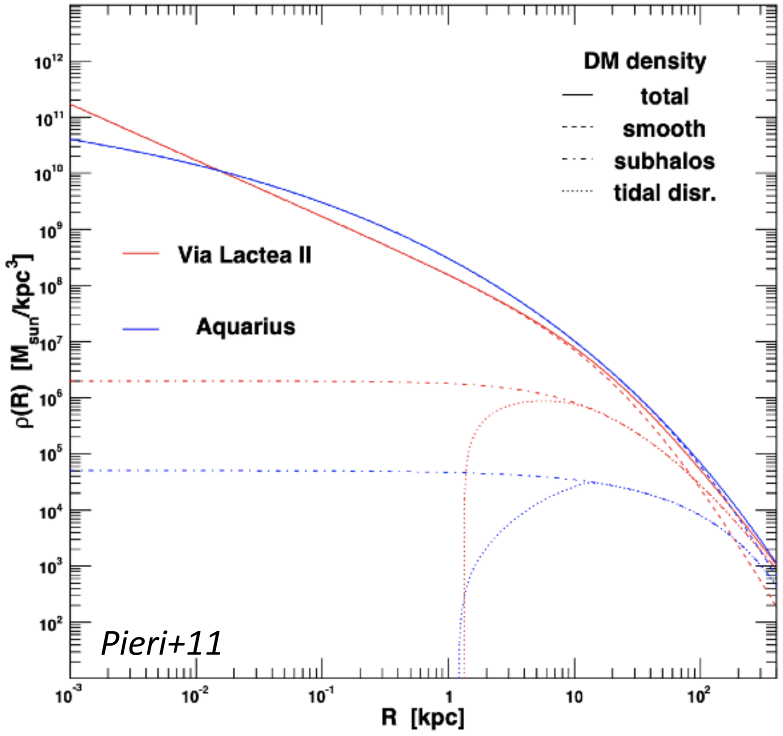
$$\frac{dn}{dM} \propto M^{\alpha}$$

- Concentration

$$c(M)$$

Subhalos

- The later halos that do not get to merge with the rest
- Fall in the potential wells of main halos



Pieri+11

- Mass distribution

$$\frac{dn_{sub}}{dM_{sub}} \propto M_{sub}^{\alpha}$$

$\alpha \in [1.9, 2.0]$

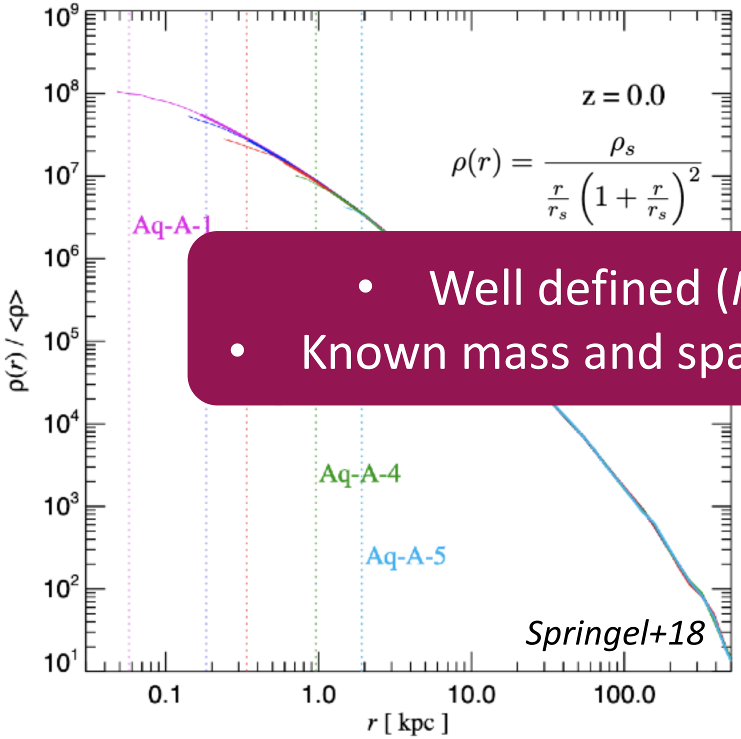
- Concentration

$$c_{sub}(M_{sub}, r_{sub})$$

HALO AND SUBHALO PROPERTIES

Main halos

- Fundamental non-linear units of cosmic structures
- Inner density profile



- Mass distribution

$\frac{dn}{\ldots} \propto M^{\alpha}$

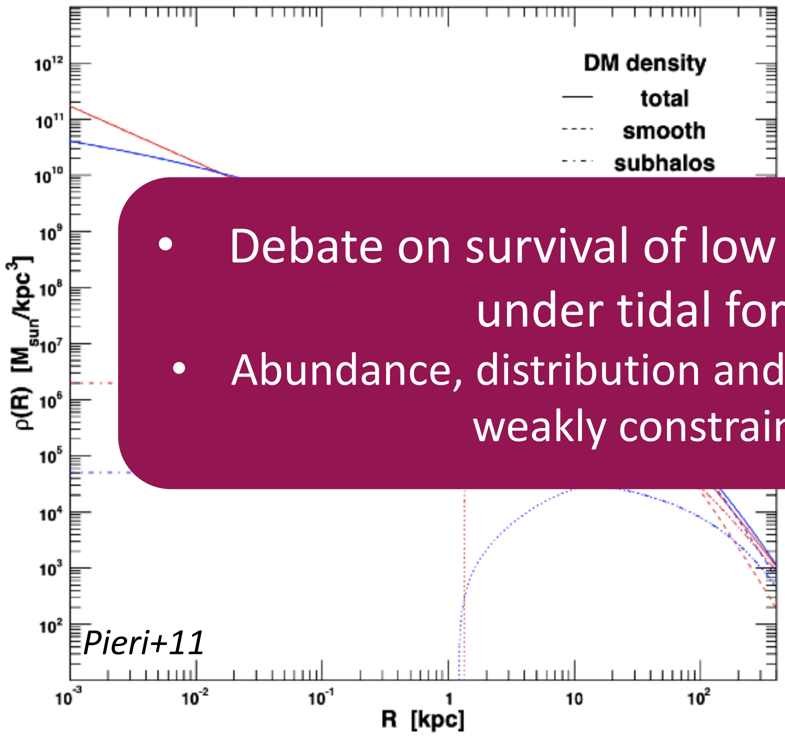
- Well defined (M_{200}, R_{200})
- Known mass and spatial distribution

- Concentration

$c(M)$

Subhalos

- The later halos that do not get to merge with the rest
- Fall in the potential wells of main halos



- Mass distribution

$\ldots M^{\alpha}_{sub}$

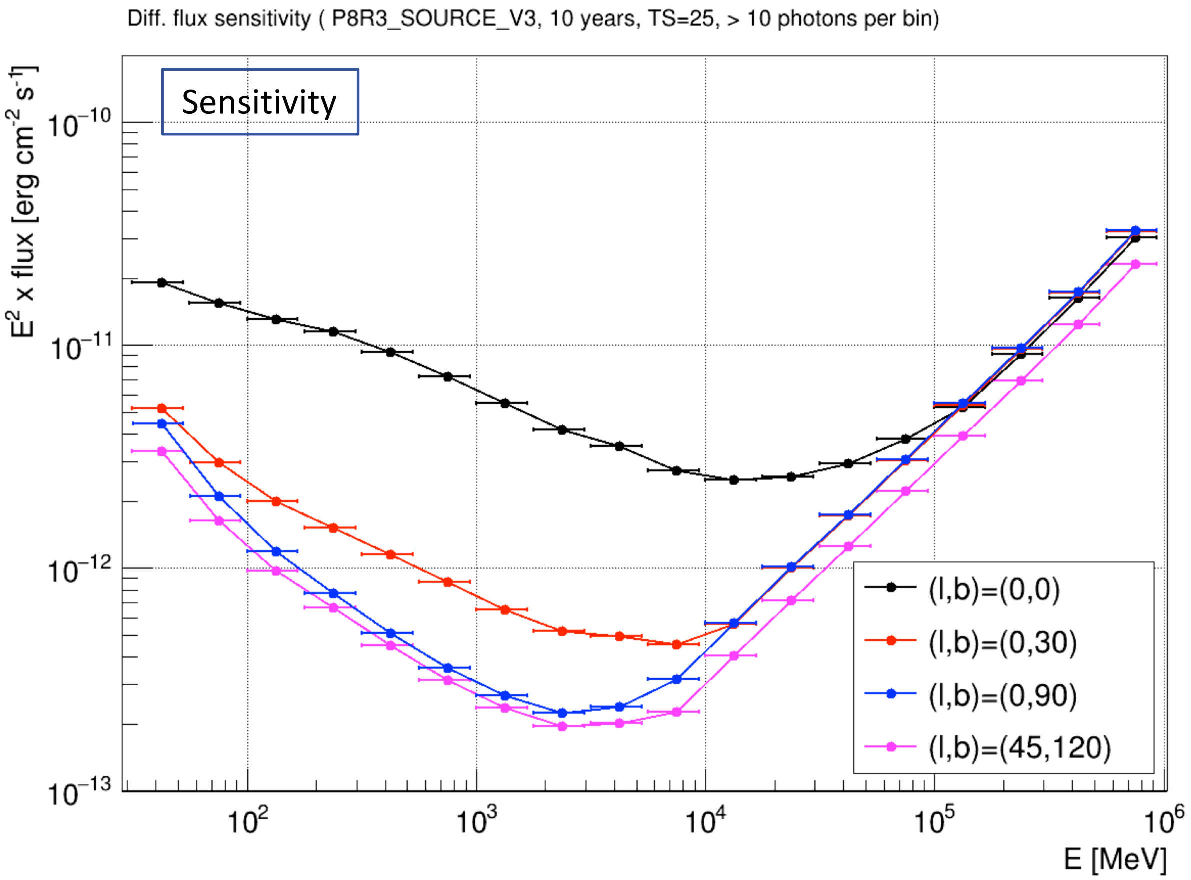
- Debate on survival of low mass subhalos under tidal forces
- Abundance, distribution and inner structure weakly constrained

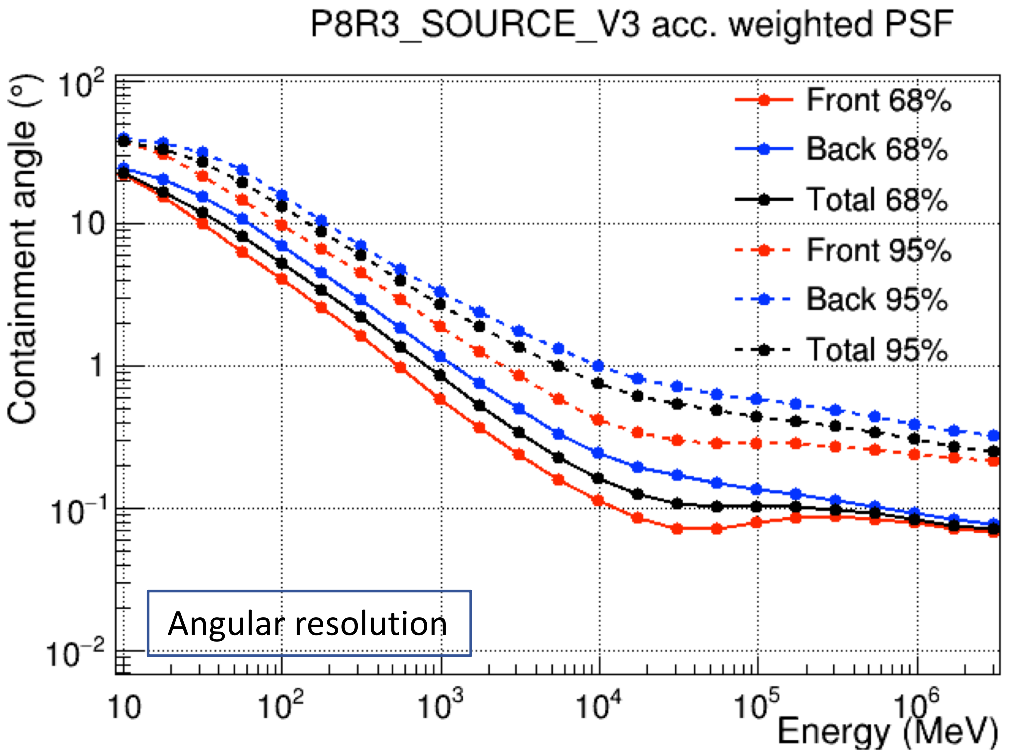
$c_{sub}(M_{sub}, r_{sub})$

FERMI-LAT PERFORMANCE

10y Performance Capabilities

https://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm





OBTENTION OF DM MODEL PARAMETERS

- State-of-the-art parametrization of the DM in galaxy clusters: $\langle\rho_{\mathrm{tot}}\rangle(r) = \rho_{\mathrm{sm}}(r) + \langle\rho_{\mathrm{subs}}\rangle(r)$

1 Assume a DM profile $\rho(r) = \frac{\rho_0}{(\frac{r}{r_s})[1+\frac{r}{r_s}]^2}$ NFW

2 Assume a concentration-mass relation ($c_{200} - M_{200}$): *Sánchez-Conde&Prada14* $c_{200}(M_{200}, z=0) = \sum_{i=0}^{5} c_i \times \left[\ln\left(\frac{M_{200}}{h^{-1}M_\odot}\right)\right]^i$

3 Assume spherical collapse from an overdensity Δ = 200 over the critical density $\Delta_{200} = \frac{3M_{200}}{4\pi R_{200}^3 \rho_{crit}}$

4 Compute remaining parameters

Scale density

$$\rho_0 := \frac{2\Delta_{200}\rho_{crit}c_{200}}{3F(c_{200})}$$

with

$$F(c_{200}) = \frac{2}{c_{200}^2}\left(\ln(1+c_{200}) - \frac{c_{200}}{1+c_{200}}\right)$$

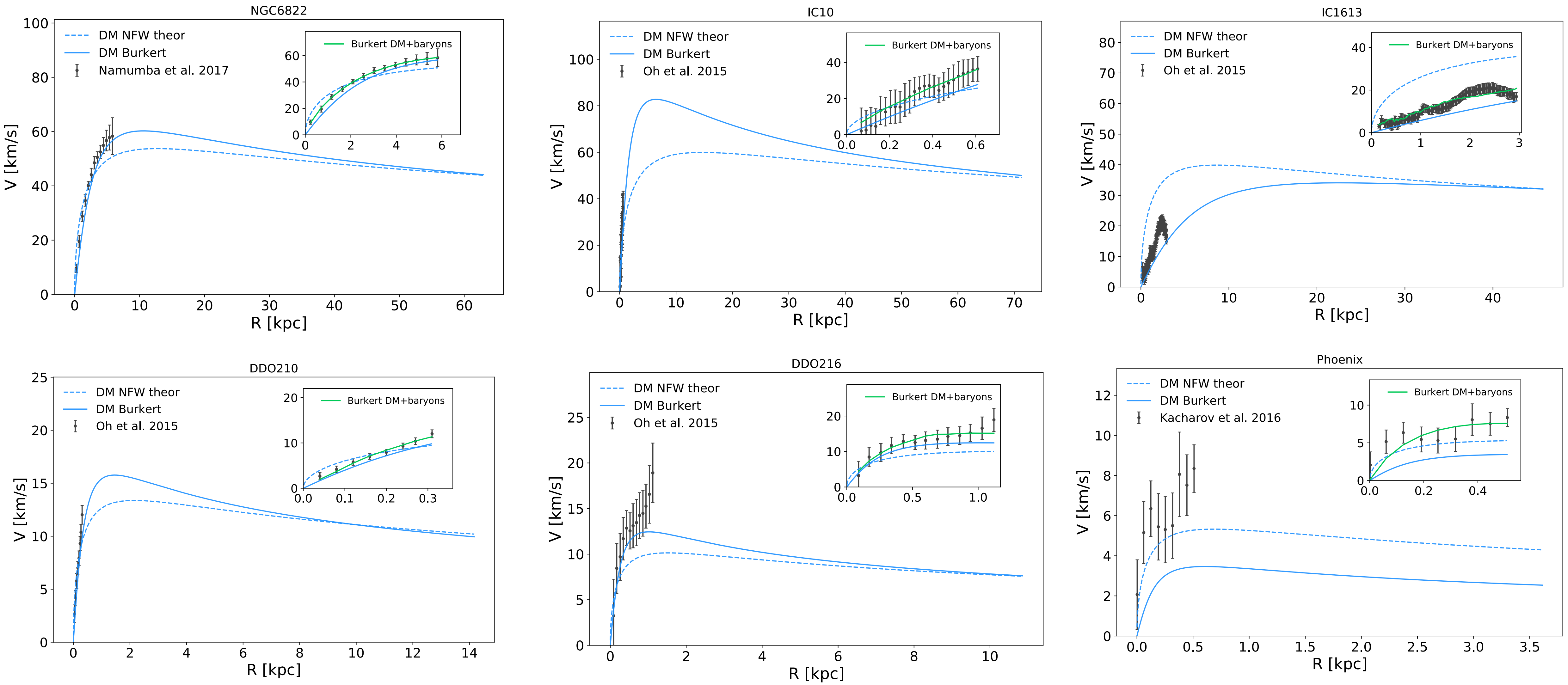
Scale radius

$$c_{200} = \frac{R_{200}}{r_s}$$

Angular extension

$$\theta_{200} = \tan\left(\frac{R_{200}}{d_L}\right)$$

DIRRS ROTATION CURVES



DIRRS BURKERT FIT VALUES AND NFW PROFILES

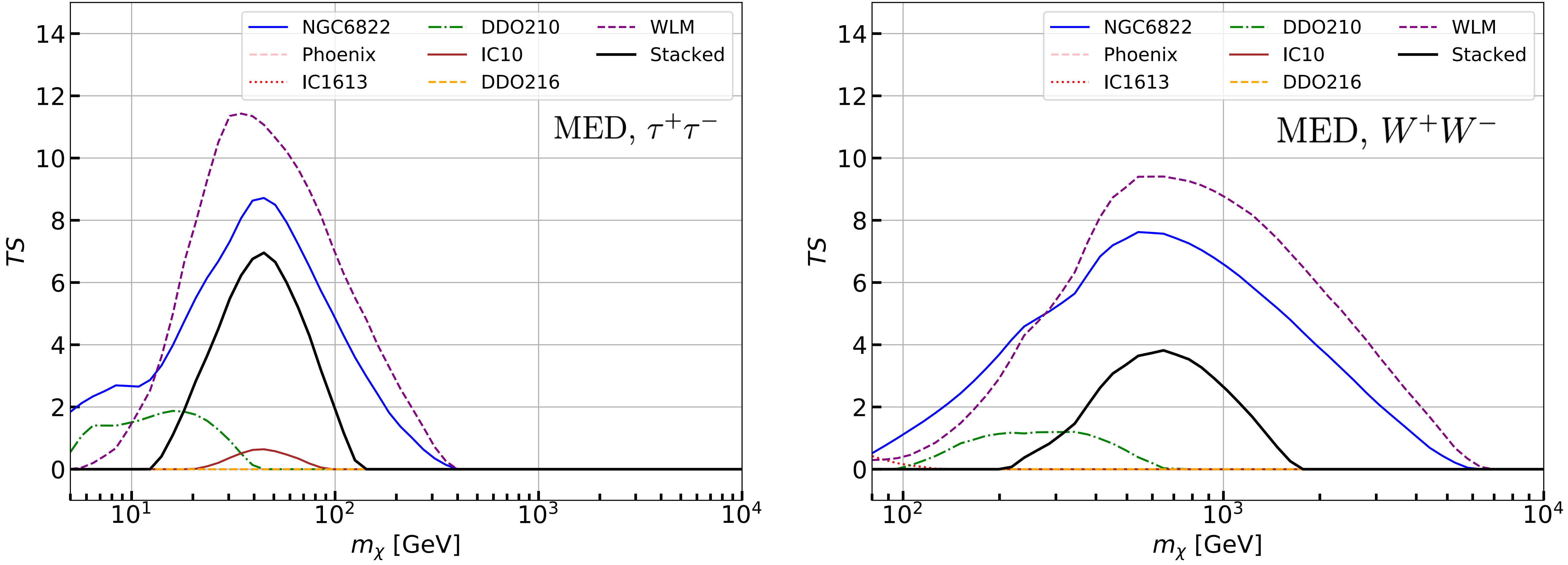
$$\rho_{\mathrm{Bur}}(r) = \frac{\rho_c\, r_c^3}{(r + r_c)\,(r^2 + r_c^2)}$$

Name	r_c [kpc]	$\log_{10}\rho_c$ [$M_\odot/\mathrm{kpc}^3$]	$\log_{10} M_D$ [$M_\odot$]	χ^2_{red} [ ]	R_{200} [kpc]	$\log_{10} M_{200}$ [$M_\odot$]	θ_{200} [deg]
NGC6822	$3.3^{+0.8}_{-0.7}$	7.5 ± 0.1	$7.9^{+0.2}_{-0.3}$	0.1	$62.9^{+8.4}_{-6.7}$	$10.5^{+0.2}_{-0.1}$	7.5
IC10	$2.0^{+0}_{-1.5}$	$8.2^{+0.4}_{-0.2}$	$^*8.1 \pm 0.1$	0.1	$71.3^{+7.1}_{-47.6}$	$10.6^{+0.1}_{-1.5}$	5.2
WLM	$1.3^{+0.2}_{-0.1}$	7.8 ± 0.1	$^*7.1^{+0.5}_{-0.9}$	0.1	$33.3^{+2.0}_{-1.5}$	9.6 ± 0.1	2.0
IC1613	$7.0^{+0}_{-1.2}$	6.3 ± 0.05	$^*7.1^{+0.07}_{-0.06}$	0.9	$45.7^{+1.7}_{-6.9}$	$10.0^{+0.05}_{-0.2}$	3.4
Phoenix	0.2	7.5	$^*6.8$	1.2	3.6	6.7	0.5
DDO210	$0.5^{+0.9}_{-0.2}$	$8.0^{+0.1}_{-0.2}$	$^*5.8 \pm 0.1$	0.5	$14.2^{+23.7}_{-4.6}$	$8.5^{+1.2}_{-0.5}$	0.9
DDO216	$0.3^{+0.3}_{-0.1}$	8.1 ± 0.3	$^*7.2 \pm 0.1$	0.3	$10.8^{+3.7}_{-2.7}$	8.2 ± 0.3	0.6

$$\rho_{\mathrm{NFW}}(r) = \frac{\rho_0}{\left(\frac{r}{r_s}\right)\left(1 + \frac{r}{r_s}\right)^2}$$

Name	c_{200}	r_s [kpc]	$\log_{10}\rho_0$ [$M_\odot/\mathrm{kpc}^3$]	R_{200} [kpc]	θ_{200} [deg]
NGC6822	10.7	5.9	6.9	62.6	7.4
IC10	10.4	6.8	6.8	70.3	5.1
WLM	12.2	2.8	7.0	33.6	2.0
IC1613	11.4	4.0	6.9	45.7	3.4
Phoenix	18.7	0.2	6.9	3.5	0.5
DDO210	14.5	1.0	7.2	14.5	0.9
DDO216	15.3	0.7	7.3	10.8	0.6

INSIGHT RESULTS: MORE CHANNELS AND MODELS



INSIGHT RESULTS: MORE CHANNELS AND MODELS

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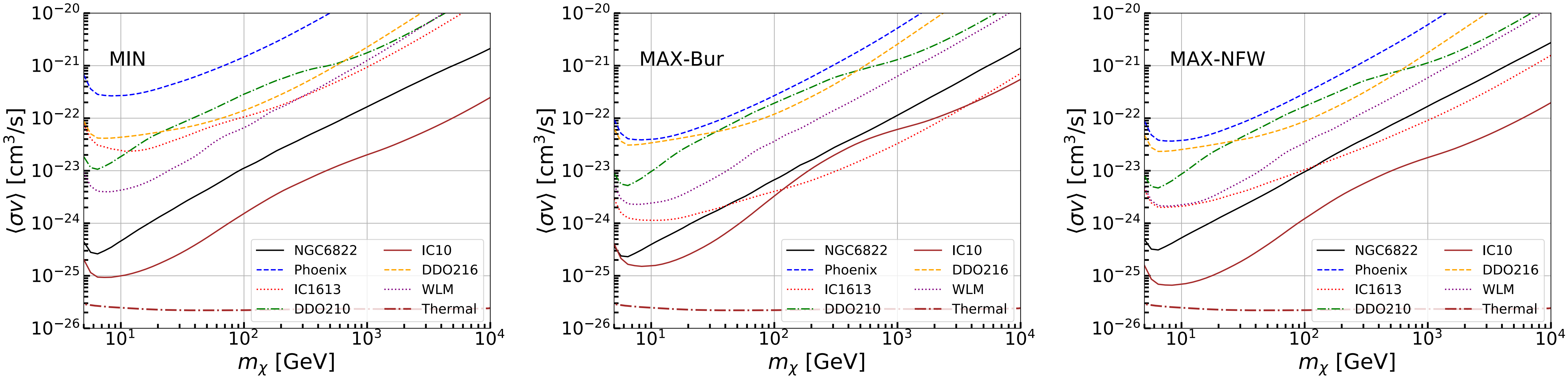
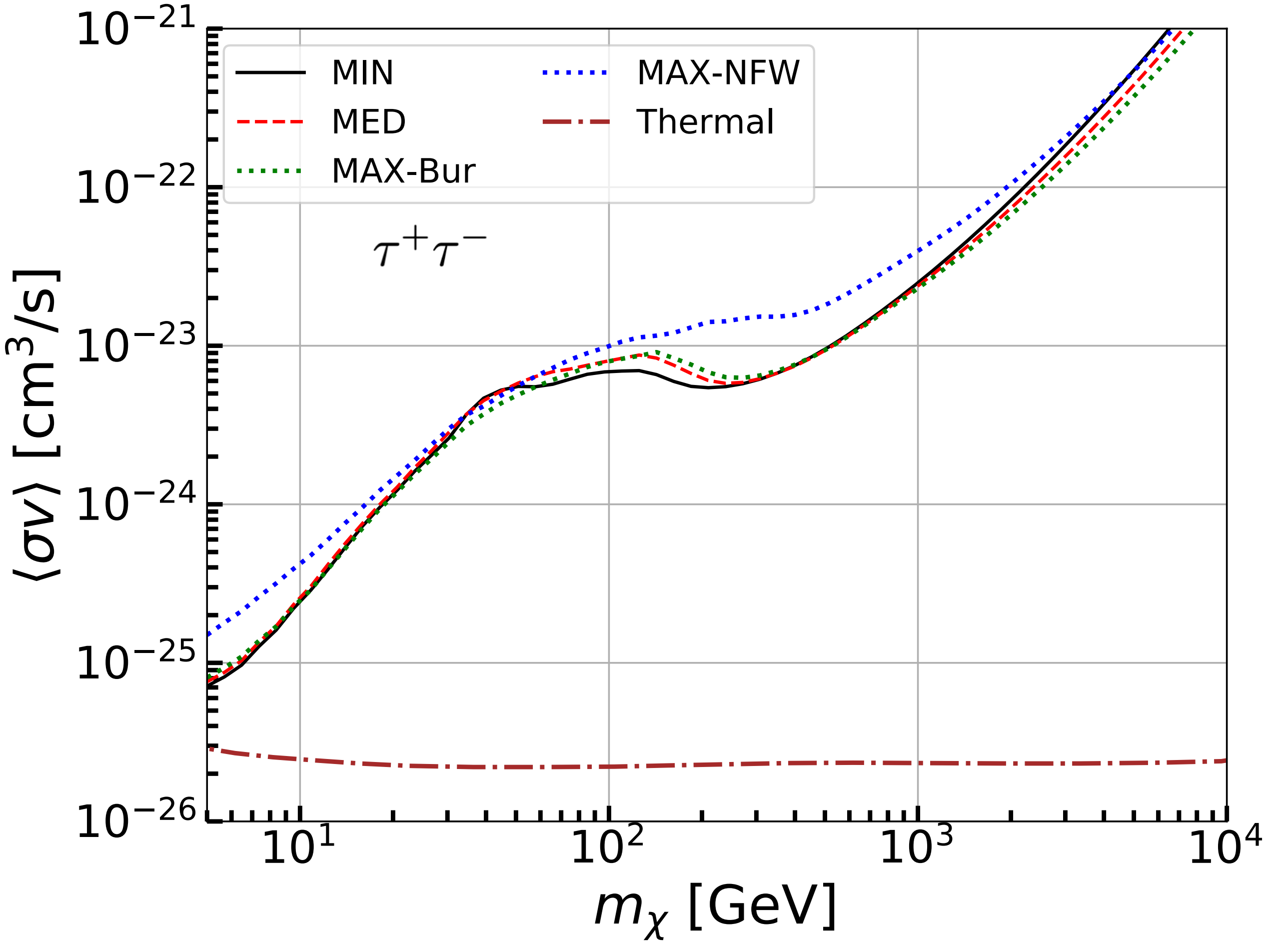
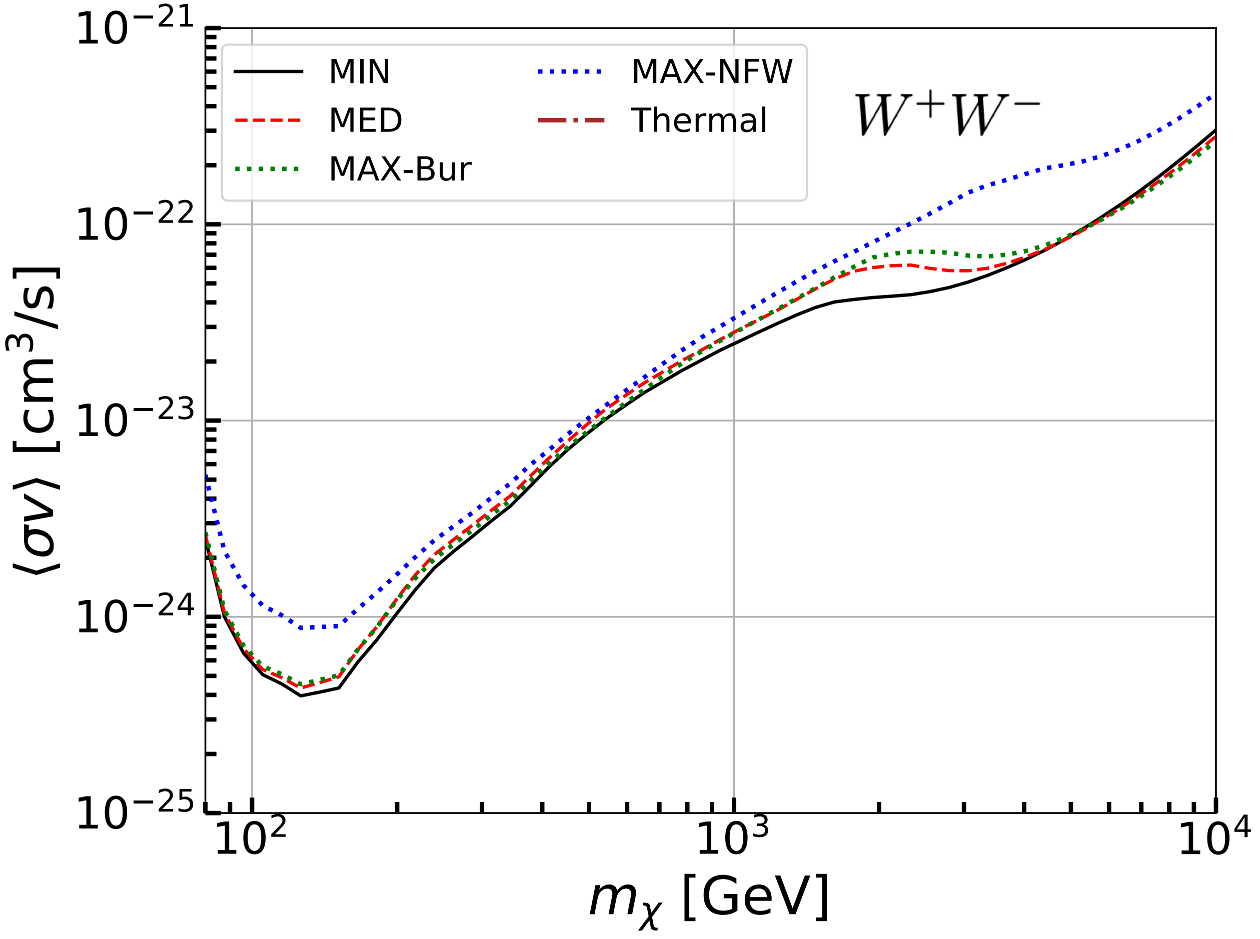
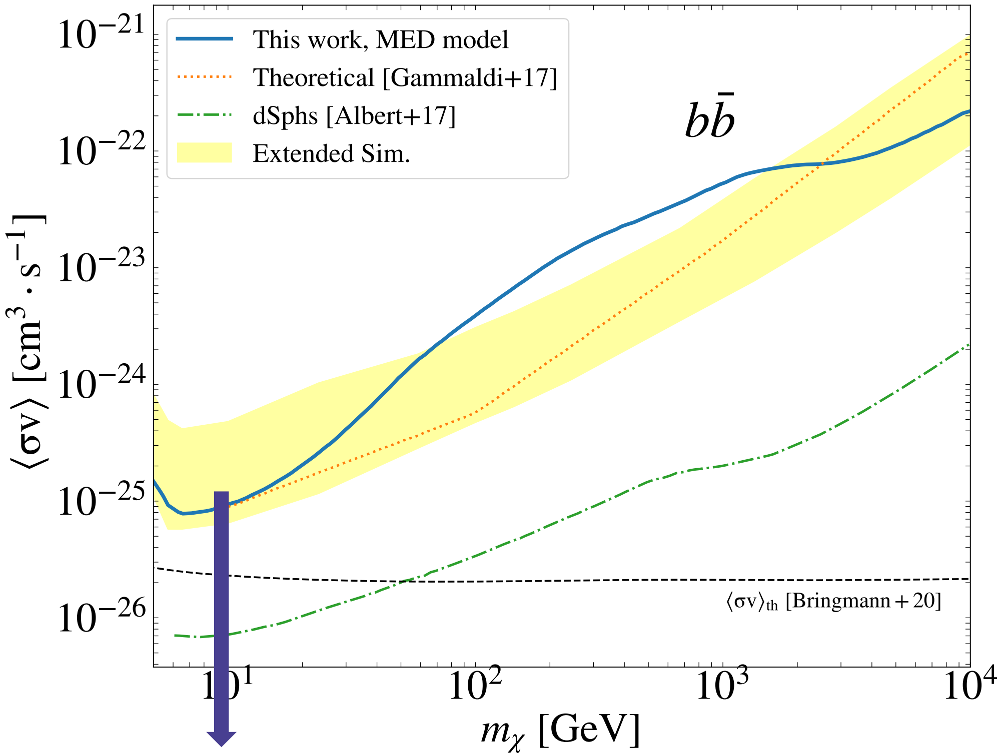


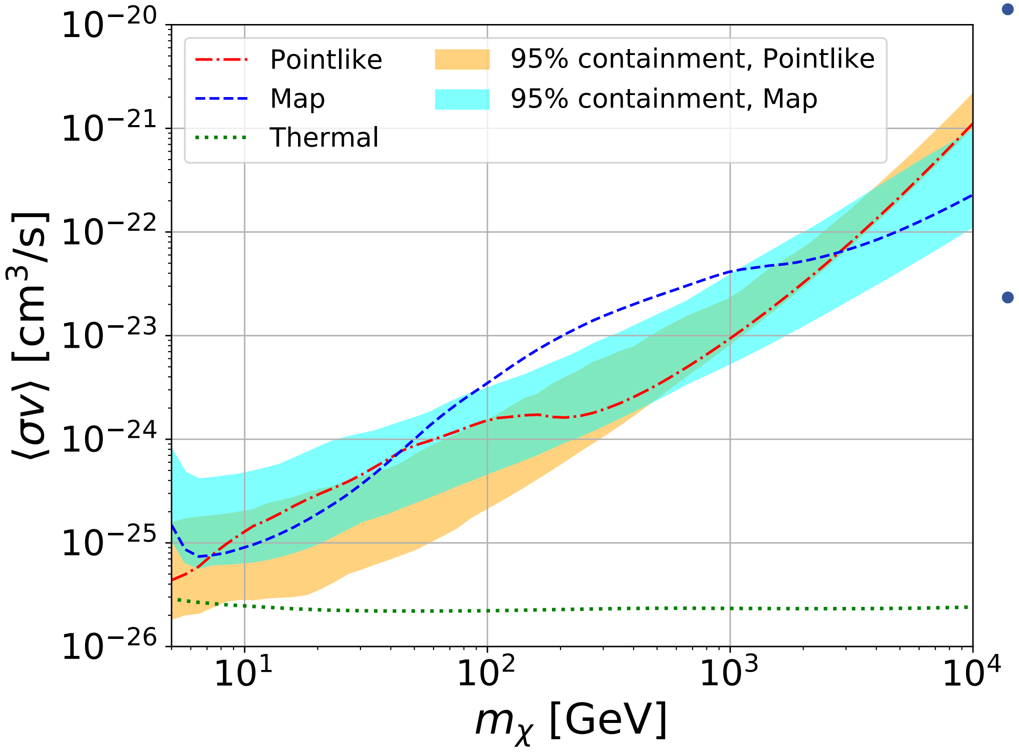
INSIGHT RESULTS: MORE CHANNELS AND MODELS





INSIGHT RESULTS: CONTROL SIMULATIONS





- Null simulations: no DM content but modeled with their spatial templates
- Blanck fields: random sky pointings assuming point-like sources without DM template

Both scenarios are repeated 100 times

- 95% C.L. containment band of 100 control simulations assuming no DM content, fitted to the DM spatial templates

FERMI-LAT SEARCHES IN DIRRS: SUMMARY

- Performed the first γ–ray DM search of dIrrs with *Fermi*-LAT using 11 years of data
- Agnostic modelling of the DM densities with the definition of benchmark models
- Inclusion of substructures, providing boosts values for the different benchmarks
- Neither individual analysis or combined find a DM-induced γ–ray signal:
  - The obtained 95% C.L. upper limits: best for m_χ~1 GeV, reaching $<\sigma v>$~10^{-25} $cm^3 s^{-1}$
  - Weakening around 100 GeV for $b\bar{b}$ and $\tau^+\tau^-$, probably due to mismodelling of BKGs
  - Above ~$O(1)$ of the thermal relic cross-section

Future work I: Better understanding of the kinematical data

Future work II: Discovery of new dIrrs and more data of their RCs will arrive

CAN WE CLASSIFY THE STUDIED TARGETS?

- Build intra- and inter-family ranking of targets for γ-ray DM searches
- The absence of firm detection of vanilla-WIMP DM

Let us broaden the theoretical particle framework…

Velocity dependence of $\langle\sigma v\rangle$	Canonical *s*-wave partial wave may be naturally suppressed	Mediator is a scalar	→ *p*-wave dominates $\sigma v_{\rm rel} \propto v_{\rm rel}^2$
Modification of the short-range $\langle\sigma v\rangle$	Exchange of light mediator induces a long-range interaction between DM particles	Complex dark sectors	→ Sommerfeld enhacement
Contribution of DM subhalos	Dependent on host halo mass and their structural properties	ΛCDM structure formation paradigm	→ Boost computation for velocity-dependent annihilations

DM MODELS FOR SELECTED DIRRS

- Use the DM models that just developed → V. Gammaldi, **JPR** *et al., Dark Matter search in dwarf irregular galaxies with the Fermi Large Area Telescope*, Phys. Rev. D 105, 083006, [arXiv:2204.00267]
- Select the most promising targets of the studied according to:
  - Highest J-factors
  - More available kinematic data
- Use core & cusp profiles to account for model uncertainties:

$$\rho_{\mathrm{Bur}}(r) = \frac{\rho_c\, r_c^3}{(r + r_c)\,(r^2 + r_c^2)}$$

$$\rho_{\mathrm{NFW}}(r) = \frac{\rho_0}{\left(\frac{r}{r_s}\right)\left(1 + \frac{r}{r_s}\right)^2}$$

dIrr	$(l,\, b)$ [deg]	D [kpc]	M_{200} $[10^{10}\ \mathrm{M}_\odot]$	Profile	ρ $[10^7\ \mathrm{M}_\odot\ \mathrm{kpc}^{-3}]$	r [kpc]	R_{200} [kpc]
NGC6822	(25.34, -18.40)	480	3.16	Burkert*	3.16	3.3	62.9
				NFW	0.79	5.9	62.6
IC10	(118.96, -3.33)	790	3.98	Burkert*	15.85	2.0	71.3
				NFW	0.63	6.8	70.3
WLM	(75.87, -73.86)	970	0.40	Burkert*	6.31	1.3	33.3
				NFW	1.00	2.8	33.6