Constraints on cross-section and lifetime of dark matter with HAWC Observations of dwarf Irregular galaxies

36th ICRC

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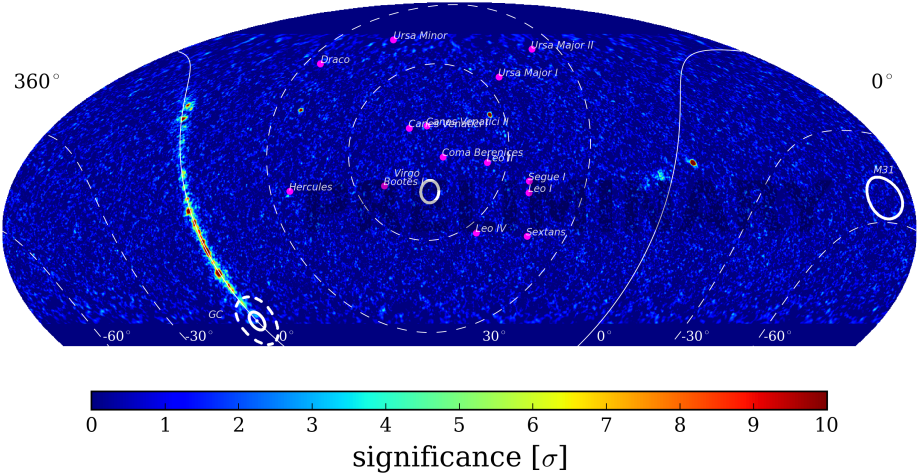
Indirect DM searches with HAWC



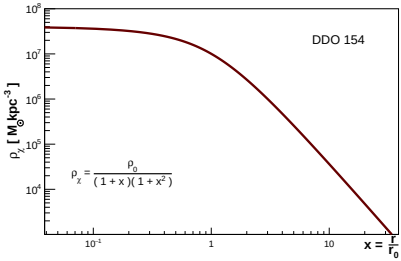
- 15 dSph galaxies, Virgo Cluster, Galaxy M31, Galactic Halo

dIrr galaxies

1. Gas-rich galaxies with low star-formation rates (SFRs)
2. With no defined disk shape
3. Weak magnetic fields
4. Negligible or null gamma-ray background
5. Dark matter (DM) dominated systems
6. Large number of dIrr galaxies within the local Volume ($d < 11$ Mpc)
   - Ground-based and Wide field-of-view experiments
   - Combined analysis

Dark Matter Profile for dIrr galaxies

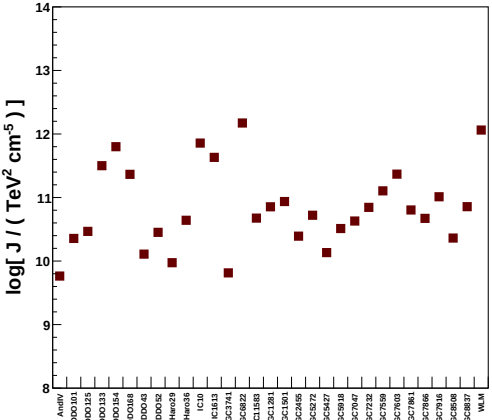
1. Halo parameters are constrained using kinematic data, see [astro-ph.GA/1609.06903v3]
2. Low-mass version of Universal Rotation Curve (URC) function
   - URC encodes the dark and luminous matter content of the galaxy
3. URC for dIrr galaxies
   - Exponential Freeman Disk (Stellar component)
   - Gaseous disk
   - Burkert Profile (DM component)
4. DM to baryionic mass ratio > 35
5. DM halo angular extension $\sim 1^\circ$
6. No Substructure
7. Astrophysical factors computed with CLUMPY package [arXiv:1506.07628 [astro-ph.CO]]

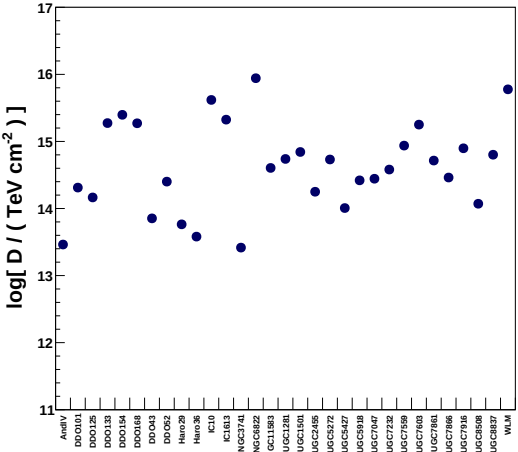


Astrophysical Factors for dIrr galaxies

$$J = \int_{\Delta\Omega} \int_{\text{l.o.s.}} [\rho_\chi(r(l))]^2 \, \mathrm{d}l \, \mathrm{d}\Omega$$

$$D = \int_{\Delta\Omega} \int_{\text{l.o.s.}} [\rho_\chi(r(l))] \, \mathrm{d}l \, \mathrm{d}\Omega$$



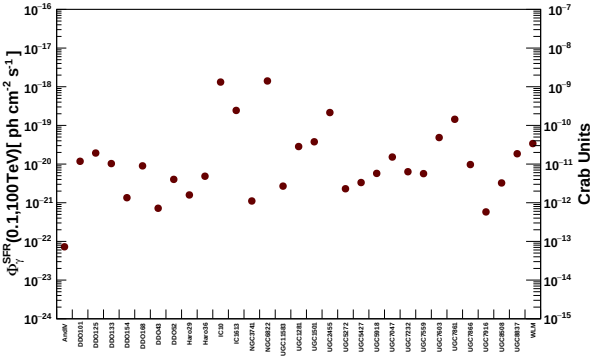


Gamma-ray background from star formation

We estimated an upper bound to the gamma-ray flux produced in SF regions @ dIrr galaxies

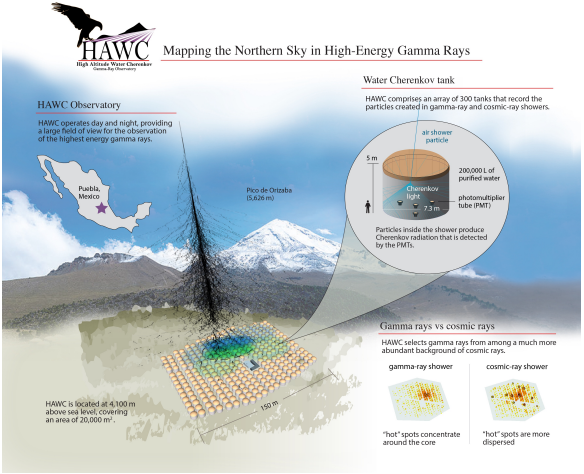
1. SFR estimated from stellar masses $\lesssim 1 \times 10^{-2} M_{\odot}\mathrm{yr}^{-1}$
2. Compute Injection Power of CR
3. Estimate the gamma-ray Luminosity L_{γ} and the energy flux φ_E^{γ} for energies between 0.1 and 100 TeV
4. Compute the integrated-photon flux Φ^{γ}
   - Diff. Photon flux ϕ^{γ} described by a Simple-Power Law with spectral index α
   - $\alpha = \alpha(SFR)$
   - Integrate ϕ^{γ} between 0.1 and 100 TeV

- V. Gammaldi & E. Karukes.
- See `arXiv:1402.0383 [astro-ph.HE]` & `arXiv:1710.11236 [astro-ph.GA]`

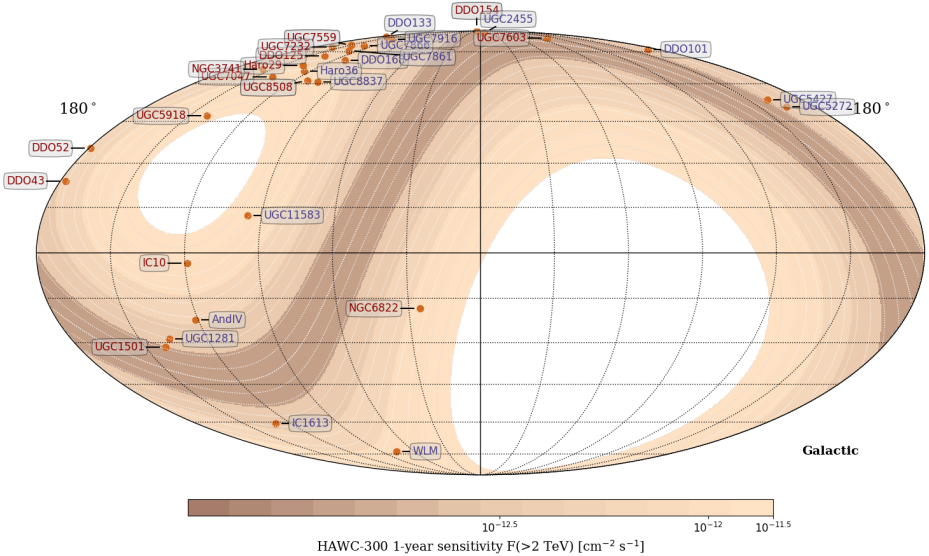


Why HAWC?

- All sky survey
  - Continuous observation
  - Multiple populations observed simultaneously
- Sample of 31 dIrr galaxies within the HAWC field-of-view
- HAWC observe these galaxies @ TeV energies by the first time



dIrr Sample


DDO154
UGC2455
DDO133
UGC7559
UGC7916
UGC7603
DDO101
UGC7232
UGC7861
DDO125
DDO161
NGC3741
Haro29
Haro36
UGC7047
UGC8837
UGC8508
180 °
UGC5427
UGC5272
180 °
UGC5918
DDO52
DDO43
UGC11583
IC10
NGC6822
AndIV
UGC1281
UGC1501
IC1613
WLM
Galactic
$10^{-12.5}$
10^{-12}
$10^{-11.5}$
HAWC-300 1-year sensitivity F(>2 TeV) [cm^{-2} s^{-1}]

Analysis

- HAWC Data $\rightarrow$ 1017 transits
- Dark matter candidate: WIMP with mass between 1 and 100 TeV
- Annihilation and decay to two channels
  - $b\bar{b}$ and $\tau^+\tau^-$
  - $\mathrm{d}N^\gamma/\mathrm{d}E$ computed with Pythia 8
- Point source analysis
- Maximum Likelihood to estimate significances and exclusion limits
- Individual and combined analysis

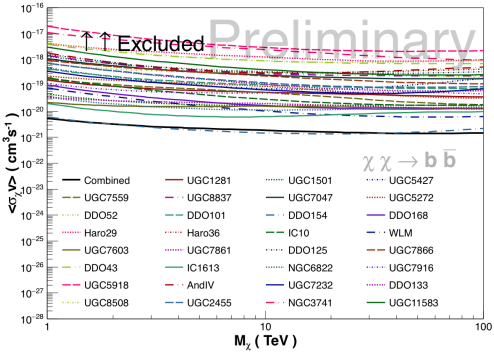
Combined Analysis

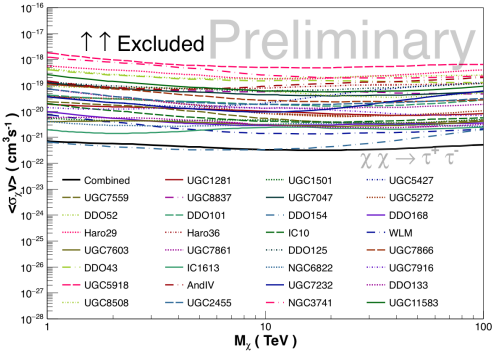
- Joint Likelihood approach
- Normalization common to all sources A. A is related to $\langle \sigma_\chi v \rangle$ or τ_χ

$$\log L_{\text{Joint}} = \sum_{i,m} [N_{i,m} \log(B_{i,m} + A \times S_{i,m}) - \log N_{i,m}! - (B_{i,m} + A \times S_{i,m})]$$

- We did not observe statistical excess therefore the significances are converted into exclusion Limits @ 95% C.L.

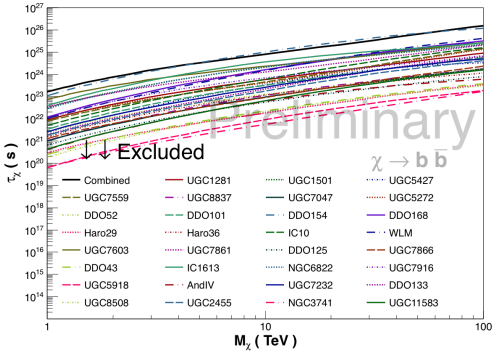
Exclusion Limits for DM annihilation

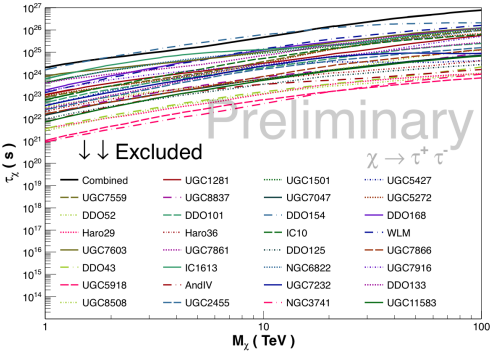




- Exclusion limits for 31 dIrr galaxies
- Galaxy DDO 154: $\langle\sigma_\chi v\rangle = 3.31 \times 10^{-22}$cm^{3}s^{-1} for 10 TeV WIMP ($\tau^+\tau^-$ channel)

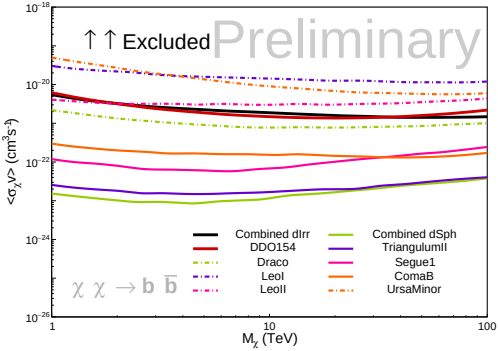
Exclusion Limits for DM decay

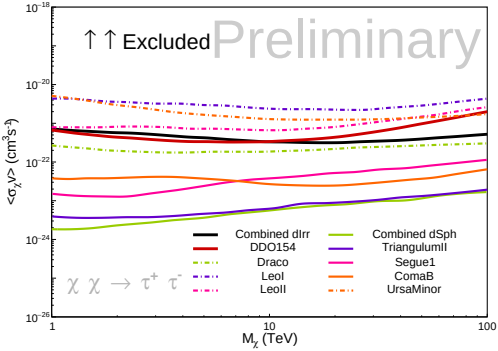




- Exclusion limits for 31 dIrr galaxies
- Galaxy DDO 154: $\tau_\chi = 6.16 \times 10^{25}$ s for 10 TeV WIMP ($\tau^+\tau^-$ channel)
- Exclusion limit close to theoretical lifetime, 10^{27} s

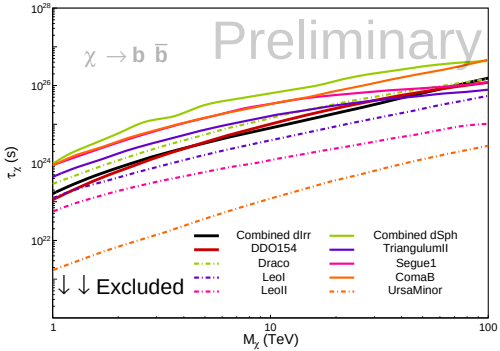
DM annihilation: Comparison with dSph Galaxies

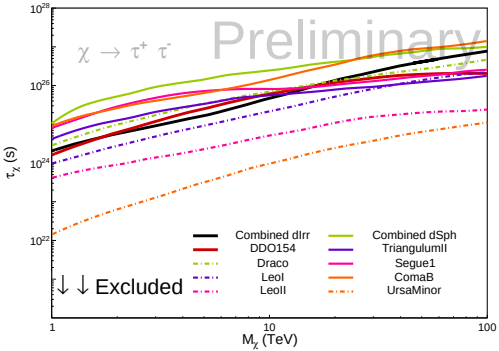




- Exclusion limits for dSph galaxies previously observed by HAWC
- Combined limit for dIrr galaxies comparable to classical dSphs but not to ultrafaint galaxies
  - Large J factors of ultrafaint galaxies
- dSph Combined limit for 15 galaxies within HAWC field-of-view

DM decay: Comparison with dSph Galaxies





- Exclusion limits for dSph galaxies previously observed by HAWC
- Combined limit for dIrr galaxies comparable to classical and ultrafaint dSph galaxies
  - D factors depend on the amount of DM
- dSph Combined limit for 15 galaxies within HAWC field-of-view

Summary

1. HAWC can perform Indirect DM searches in multiple populations simultaneously
   - HAWC can observe a large portion of the sky
   - Continuous operation
2. dIrr galaxies are a suitable population to search for DM signatures
3. For annihilation channels, ultrafaint galaxies are more suitable candidates
4. Combined analysis between dIrr and dSph populations will improve the limits (decay)
5. Improvement of dIrr exclusion limits:
   - Increase the number of dIrr galaxies used in the Joint likelihood
   - Re-shape of DM profile @ central regions, see [https://link.aps.org/doi/10.1103/PhysRevD.90.103508]

THANKS!