Sensitivity of CTA to dark matter annihilations in the Galactic Center

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L.Roszkowski, EMS, A.J.Williams, JHEP 1502 (2015) 014, 1411.5214
L.Roszkowski, EMS, A.J.Williams, JHEP 1408 (2014) 067, 1405.4289
Outline

1. Motivation
2. Summary of the calculation
2. Implications for SUSY
6. Summary
Direct detection: MSSM prospects

pMSSM $\chi^2$ analysis: $2\sigma$ regions

Color code gives neutralino composition: bino, higgsino, wino

1 tonne (2017)
Direct detection: MSSM prospects

\[ \text{pMSSM } \chi^2 \text{ analysis: } 2\sigma \text{ regions} \]

Area strongly favored after Higgs discovery (dark matter higgsino or wino) not entirely covered / even below neutrino background
Indirect detection is complementary

HIGGSINO just beyond reach

WINO possibly 90% CL excl. by HESS (Sommerfeld)

[First pointed out in Cohen, Lisanti, Pierce, Slatyer (2013); Fan, Reece (2013); Hryczuk et al. (2014)]
CTA – New guy in DM hunt race

- ground-based gamma-ray telescope
- Arrays in southern and northern hemisphere for full-sky coverage
- Energy range: tens of GeV to >100 TeV
- Sensitivity: more than an order of magnitude improvement in 100 GeV – 10 TeV

Galactic Center DM Halo

diffuse gamma radiation from WIMP pair annihilation

Search region!

HESS (112 hr)!

Fermi dSph !
(4 yrs +10 dsphs)!

CTA !
(NFW, 500 hr)!
The observational setup

- Mask galactic plane to reduce backgrounds
- OFF region rich in background
- ON region rich in signal
- Integrate over entire energy range or split into energy bins for spectral information.

BayesFIT (2014)
The backgrounds

1. Cosmic rays
   - Isotropic
   - Can discriminate based on shower
   - Estimated by MC from collaboration

2. Diffuse gamma-rays
   - Measured by FERMI-LAT below 100 GeV
   - Need to extrapolate to higher energies
   - Larger in ON region that OFF region! Can mimic DM signal

DGE background: Silverwood et al. arxiv:1408.4131
The signal

\[
\frac{d\Phi}{dE} = \frac{\sigma v}{8\pi m^2_\chi} \frac{dN_\gamma}{dE} \int_{\Delta \Omega} \int_{l.o.s.} \rho^2 [r(\theta)] dr(\theta) d\Omega
\]

\[
= \Phi_{PP} J
\]

Particle Physics Factor
Parameterises DM properties
Depends on annihilation final state

**J**
J factor
Parameterises DM halo and observation region
Astrophysical uncertainties
Halo model

**NFW:**
\[
\rho(r) = \rho_s \frac{(r/r_s)^{-\alpha}}{(1 + r/r_s)^{-3+\alpha}}
\]

**Einasto:**
\[
\rho(r) = \rho_s e^{-\frac{2}{\alpha} \left( (\frac{r}{r_s})^\alpha - 1 \right)}
\]
The observed signal

\[ N_i^{\text{ann}} = t_{\text{obs}} \cdot J \cdot \frac{\sigma v}{8\pi m_\chi^2} \int_{\Delta E_i} dE \left( \frac{1}{\sqrt{2\pi}\delta(E)^2} \int_{26\text{GeV}}^{m_\chi} d\tilde{E} \frac{dN_\gamma(\tilde{E})}{d\tilde{E}} A_{\text{eff}}(\tilde{E}) e^{-\frac{(E - \tilde{E})^2}{2\delta(E)^2}} \right) \]

- Separate into energy bins
- Marginalise over energy resolution
- Effective area is energy dependent

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Binned likelihood

\[ \mathcal{L} = \prod_{i,j} \frac{n_{i,j}^{\mu_{i,j}}}{n_{i,j}!} \]

- Likelihood function for poisson distribution
- Uses full spectral information
- Can be adapted to a full morphological analysis
Results: Projections for CTA

Below "thermal relic" level for many final states

Difference between $b\bar{b}$ and $WW$ mostly EW corrections

Excellent sensitivity to TeV scale DM candidates
Results: Projections for CTA

NFW profile:

\[ \rho(r) = \rho_s \left( \frac{r}{r_s} \right)^{-\alpha} \left( 1 + \frac{r}{r_s} \right)^{-3+\alpha} \]

Uncertainty due to parameterisation of halo

ON/OFF or morphological analysis allows halo profile to be constrained if a signal is seen
Impact in the MSSM

MSSM models yielding WW and $b\bar{b}^*$ final states will be tested.
Impact in the MSSM

Under Einasto and NFW profile all (or significant part) of higgsino region in reach with 500 hours.

Orthogonal and complementary to direct detection and the LHC

No problem w/ neutrino floor

Probes high mass neutralinos unreachable by LHC
The special case of CMSSM / mSUGRA

CTA key to covering entire parameter space of the CMSSM
To take home:

- LHC + Higgs point to multi-TeV SUSY:
  - heavier dark matter candidates emerge as likely
- CTA will improve limits on heavy annihilating dark matter
- CTA will provide complementarity to direct detection experiments and the LHC
- CTA can close the gaps on the parameter space of the CMSSM