Can SKA-Phase1 go much beyond the LHC in supersymmetry search?

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Main Points

- Square Kilometre Array (SKA) is the upcoming large radio telescope, more sensitive than any other existing radio telescope.
- We have studied the potential of the SKA in the first phase (SKA1) in detecting dark matter annihilation signals from dwarf spheroidal galaxies (dSPh) in the form of diffuse radio emission.
- We have taken Minimal supersymmetric standard model (MSSM) as illustration. Lightest neutralino (χ_1^0) as DM candidate.
- We found that it is possible to detect signals for dark matter masses about an order of magnitude beyond the reach of the LHC, with about 100 hrs of observation with the SKA1.

Reach of high luminosity LHC in SUSY search

- Predicted mass reach for integrated luminosity = 3000 fb^{-1} ($\sqrt{s}$ = 14 TeV):

LHC projection	$\tilde{g}$ (TeV)	$\tilde{q}$ (TeV)	$\tilde{t}_1$ (TeV)	$\tilde{b}_1$ (TeV)	$\chi_1^{\pm}$ (TeV)
$3000 fb^{-1}$	~ 2.5	~ 3.1	~ 1.4	~ 1.5	~ 1

- LHC is unlikely to see signatures of SUSY for $m_{\chi_1^0} \gtrsim 1$ TeV.

(Nuclear and Particle Physics Proceedings, **273-275**, (656 - 661) (2016))

(ATL-PHYS-PUB-2014-010 (2014); ATL-PHYS-PUB-2013-011 (2013); CMS-PAS-FTR-13-014 (2013))

Sensitivity of SKA in detecting radio signal

- SKA has comparatively lower threshold or higher sensitivity than other existing radio telescope in detecting extra-galactic radio signal.
- Due to large effective area its noise level is lower ($10^{-6} - 10^{-7}$ Jy),

$$N_{rms} \propto \frac{1}{\sqrt{\Delta t}\, A_{eff}} \tag{1}$$

- Radio signal coming from some source (dwarf galaxy) has to be above this threshold to be detected.

(1 Jy $= 10^{-23}$ erg cm^{-2}s^{-1}Hz^{-1}.)

Thompson *et al.* 1986

Diffuse radio signal from dSPh in terms of DM annihilation

- Nearby dwarf spheroidal galaxies (dSPh) are appropriate for studying DM induced diffuse radio signal due to:
  - high DM content (High mass to light ratio)
  - Absence of other astrophysical processes (star formation etc.)
- DM annihilation in dSPh produces large amount of $e^{\pm}$ flux determined by the source function:

$$Q_e(E, r) = \langle \sigma v \rangle_0 \frac{\rho_\chi^2(r)}{2m_\chi^2} \sum_f \frac{dN_f^e(E)}{dE} B_f \tag{2}$$

- B_f: weightage to various annihilation channel ($b\bar{b}, t\bar{t}, W^+W^-, \tau^+\tau^-$ etc.)

Diffuse radio signal from dSPh in terms of DM annihilation

- The spectra, produced in annihilation, diffuses and looses energy in the galactic medium to give a steady state distribution $\frac{dn}{dE}(E,r)$:

$$D(E)\nabla^2\left(\frac{dn}{dE}\right)+\frac{\partial}{\partial E}\left(b(E)\frac{dn}{dE}\right)+Q_e(E,r)=0 \qquad (3)$$

- Final flux (S_ν) or the radio synchrotron flux is obtained by folding with power spectrum (function of magnetic field B).

Diffuse radio signal from dSPh in terms of DM annihilation

- The radio flux decreases with diffusion coefficient D_0 ($D(E = 1$ GeV$)$) and increases with magnetic field B.
- Predicted values of these astrophysical parameters for a dSPh:

  $D_0 \sim 10^{26} - 10^{27} \mathrm{cm}^2 \mathrm{s}^{-1}$

  $B \sim 2\mu G$

  (Natarajan *et al.* 1308.4979, 1507.03589)
- We have taken conservative values of these astrophysical parameters.

  $D_0 \sim 10^{28} - 10^{29} \mathrm{cm}^2 \mathrm{s}^{-1}$

  $B \sim 1 - 0.1\mu G$

MSSM benchmark points

Cases	$\widetilde{l}$ (TeV)	$\widetilde{q}$ (TeV)	$\widetilde{t}$ (TeV)	$\widetilde{g}$ (TeV)
A	5	10	10	10
B	4	5	5	5
C	10	10	10	10

Cases	M_1(GeV)	M_2(GeV)	μ(GeV)	M_A(GeV)	$tan\beta$
A	4478	3977	4331	8294	20
B	-3885	3550	1133	3628	20
C	8600	10000	8500	17035	20

Case A: ($\chi_1^0 = 4091$ GeV), Case B: ($\chi_1^0 = 1153$ GeV), Case C: ($\chi_1^0 = 8498$ GeV).

MSSM benchmark points

Cases	annihilation channel	χ_1^0(GeV)	$\langle \sigma v \rangle_0$ (10^{-26}cm^{3}s^{-1})
A	$b\bar{b}$(53%), W^+W^-(35%), $\tau^+\tau^-$(11%)	4091	1.5
B	W^+W^-(55%), ZZ(45%)	1153	0.8
C	$b\bar{b}$(79%), $\tau^+\tau^-$(18%), $t\bar{t}$(3%)	8498	9.1

MSSM benchmark points

- All benchmarks satisfy the constraints coming from various experiments:
  - saturate observed relic density.
  - constraints from direct DM searches
  - lightest neutral Higgs mass
  - other constraints from collider search.

Results

- For the calculation of the radio flux we have taken Draco dSPh (with a NFW profile) as an illustration.

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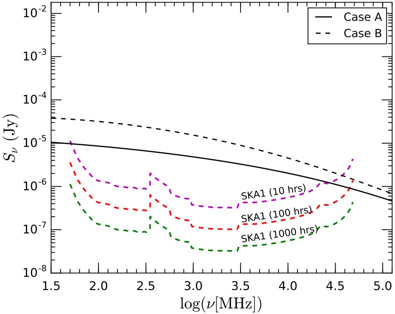


Figure : Synchrotron fluxes for Case A and B. ($D_0 = 3 \times 10^{28}\mathrm{cm}^2\mathrm{s}^{-1}$, $B = 1\ \mu G$).

- Case A: ($\chi_1^0 = 4091$ GeV), Case B: ($\chi_1^0 = 1153$ GeV),

Results

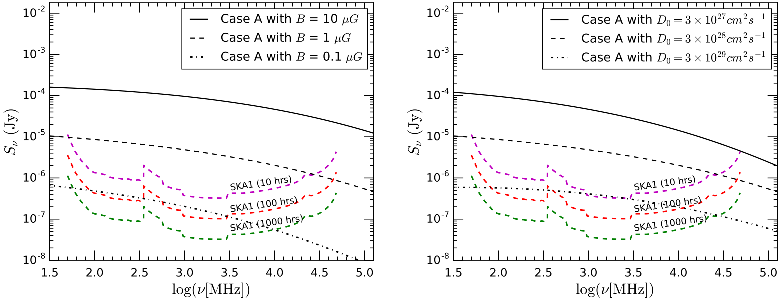


Figure : *left:* Variation of Flux with B ($D_0 = 3 \times 10^{28} \mathrm{cm}^2 \mathrm{s}^{-1}$); *right:* with D_0 ($B = 1\ \mu G$).

Case A: ($\chi_1^0 = 4091$ GeV).

Results (model independent constraints)

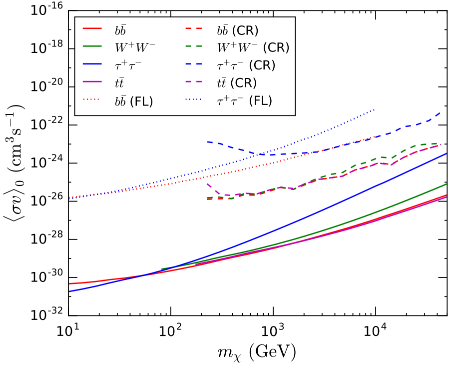
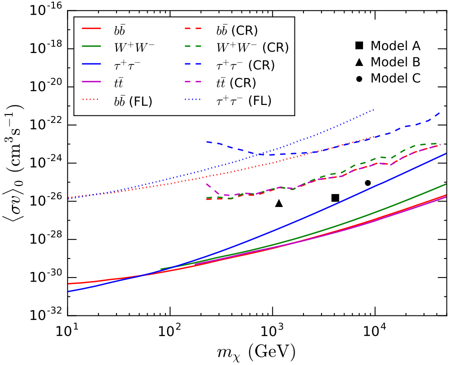


Figure : Lower limits (solid lines) of observability of radio flux from Draco in the $\langle\sigma v\rangle_0 - m_\chi$ plane at SKA1 with 100 hours, for various DM annihilation channels. Dashed and dotted lines denote the corresponding 95% C.L. upper limits from cosmic-ray (CR) antiproton observation (Cuoco *et al.* 1711.05274) and 6 years of Fermi LAT (FL) data respectively. $D_0 = 3 \times 10^{28} \text{cm}^2\text{s}^{-1}$, $B = 1$ μG.

Results

- Case A: $b\bar{b}$(53%), W^+W^-(35%). $\langle\sigma v\rangle_0 = 1.5 \times 10^{-26}\text{cm}^3\text{s}^{-1}$
- Case B: W^+W^-(55%), ZZ(45%). $\langle\sigma v\rangle_0 = 0.8 \times 10^{-26}\text{cm}^3\text{s}^{-1}$
- Case C: $b\bar{b}$(79%), $\tau^+\tau^-$(18%), $t\bar{t}$(3%). $\langle\sigma v\rangle_0 = 9.1 \times 10^{-26}\text{cm}^3\text{s}^{-1}$



- It is possible to probe and constrain the unexplored region of MSSM parameter space.

Conclusion

- SKA1 can play a crucial role in detecting DM induced signal in the from of diffuse radio synchrotron radiation.
- Taking MSSM as an example we have shown that SKA1 with about 100 hrs of observation is capable to detect the signal for super-symmetric DM mass which is well beyond the reach of high luminosity LHC.
- Even with the conservative choices of astrophysical parameters it is sensitive to the SUSY mass scale which is about an order magnitude higher than the LHC reach.
- Apart from MSSM, we have also shown the parameter space which can be probed or constrained by SKA in a model independent way up-to such a mass scale way beyond the reach of LHC.

THANK YOU

Backup

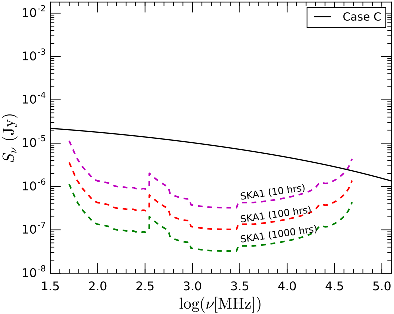


Figure : Synchrotron flux for Case C for Draco ($D_0 = 3 \times 10^{28} \mathrm{cm}^2\mathrm{s}^{-1}$, $B = 1$ μG).

Case C: ($\chi_1^0 = 8498$ GeV).