Constraints on particle properties from astrophysical sources

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DECLARATION

I ***Mr. Soumya Rao****, S/o Dr. B. G. Anandarao, resident of 3/6, Aashray apartments, Judges Bungalows road, Ahmedabad 380015, hereby declare that the work incorporated in the present thesis entitled,* ***"Constraints on particle properties from astrophysical sources"*** *is my own and original. This work (in part or in full) has not been submitted to any University for the award of a Degree or a Diploma.*

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I feel great pleasure in certifying that the thesis entitled, **"Constraints on particle properties from astrophysical sources"** embodies a record of the results of investigations carried out by Mr. Soumya Rao under my guidance.

He has completed the following requirements as per Ph.D. regulations of the University.

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I am satisfied with the analysis of data, interpretation of results and conclusions drawn.

I recommend the submission of thesis.

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Dedicated to my parents

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Abstract

As the thesis title indicates this work is about studying properties of exotic particles whose existence is supported by astrophysical observations. The presence of Dark Matter(DM) has been supported by a variety of evidence. At galactic and sub-galactic scales, this evidence includes galactic rotation curves, the weak gravitational lensing of distant galaxies by foreground structure, and the weak modulation of strong lensing around individual massive elliptical galaxies. On cosmological scales, observations of the anisotropies in the cosmic microwave background and large scale structure strongly lead us to the conclusion that $80 - 85\%$ of the matter in the universe (by mass) consists of non-luminous and non-baryonic material.

The experimental constraints on DM include relic density measurement from WMAP, direct detection of DM and indirect detection of DM. The mass and cross section of the DM is probed by direct detection experiments like XENON, CDMS, DAMA and COGENT. Of these experiments, the DAMA experiment observed an annual modulation in its signal which could have been due to DM scattering. However none of the other experiments conducting direct DM searches are able to confirm the DAMA result. In the work presented here we consider dipolar interactions of DM to analyse results from these experiments and find that there is a valid parameter space where DAMA and the null experiments can be explained. In addition we also improve previous bounds on the dipole moments of DM. We do not assume any particular candidate of DM for this purpose, except that its a weakly interacting massive particle (WIMP).

We also consider an extension of Standard Model where such a dipolar DM can be realised. And we find that the right handed neutrino added to the SM particle content, can be such a candidate. In particular we find that for a mass of the order of 100 GeV can explain the direct detection experiments. We also test the candidate for indirect detection experiments like PAMELA and FERMI which measure cosmic ray fluxes of positrons/electrons and find reasonably good agreement with the data.

The indirect detection experiments like PAMELA and FERMI rely on the ob-

servations of DM annihilation products such as positrons, antiprotons and photons which might indicate the existence of DM. The PAMELA experiment has reported results indicating a sharp upturn in the positron fraction ($e^+/(e^+ + e)$) from $10-100$ GeV, counter to what is expected from high-energy cosmic rays interacting with the interstellar medium (ISM). This result confirms excesses seen in previous experiments. One possible explanation for this is dark matter annihilation into e^+e, but this requires a large cross section. However no such increase in the antiprotons has been seen.

Here we consider a supersymmetric model with a heavy wino as the DM candidate. In order to obtain the correct relic density for such a DM candidate, in addition to getting the required annihilation cross section to explain the PAMELA positron anomaly keeping the antiproton flux undisturbed by the DM signal, we use the concept of Sommerfeld enhancement. In a consistent manner, Sommerfeld enhancement is incorporated in the relic density calculation and near the Sommerfeld resonant mass one obtains the correct relic abundance as measured by WMAP, while at the same time one gets a sufficiently large boost factor in the annihilation cross section to explain the PAMELA positron excess.

List of Publications

1. *Dipolar Dark Matter,* E. Masso, S. Mohanty and **S. Rao**, Phys. Rev. D **80**, 036009 (2009) [arXiv:0906.1979 [hep-ph]].

2. *Reconciling heavy wino dark matter model with the relic density and PAMELA data using Sommerfeld effect,*
   S. Mohanty, **S. Rao** and D. P. Roy, arXiv:1009.5058 [hep-ph] (accepted in Int. J. Mod. Phys. A).

3. *A simple model for magnetic inelastic dark matter (MiDM),*
   S. Patra and **S. Rao**, arXiv:1112.3454 [hep-ph] (communicated for publication).

4. *Constraint on super-luminal neutrinos from vacuum Cerenkov processes,*
   S. Mohanty and **S. Rao**, arXiv:1111.2725 [hep-ph] (communicated for publication).

5. *Neutrino processes with power law dispersion in the light of OPERA observations,*
   S. Mohanty and **S. Rao**, arXiv:1112.2981 [hep-ph] (communicated for publication).

Publications (1), (2) and (3) have been included in this thesis.

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