Constraints on decaying dark matter and anomalous kolar events

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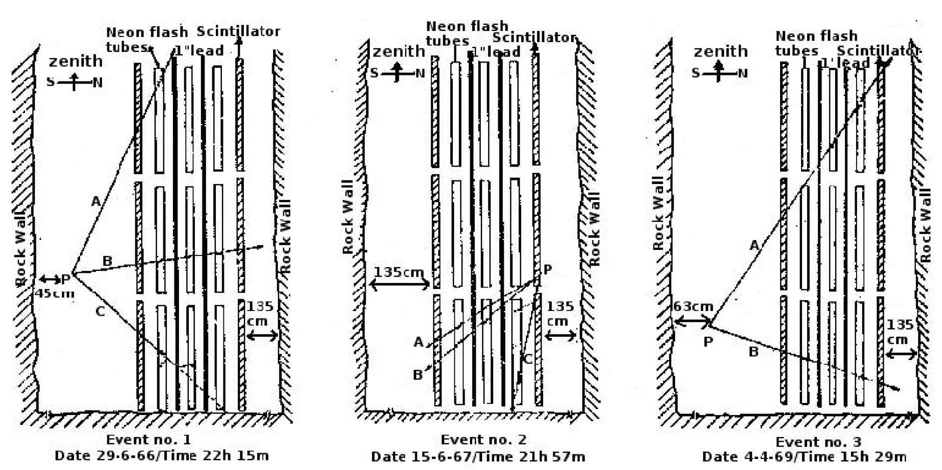
Abstract

Using the Fermi LAT data on the gamma ray emission from dwarf spheroidal galaxies, we get the upper bound on the probability of gamma rays from dark matter decay for the validity of explanation of the anomalous Kolar events as dark matter decay.

Anomalous Kolar events

At the Kolar gold fields (KGF) in India, deep under ground particle physics experiments were carried out from 1960 to 1992. During two separate periods of these experiments, some anomalous events were seen. Five such events was reported during the cosmic ray neutrino experiments and three events during proton decay studies. In total, there were eight events which are not understandable with known physics. These events are now known as anomalous Kolar events.



Few Multitrack (Kolar) events recorded in KGF neutrino detectors in the first period [1].

Dark matter particles decay hypothesis of anomalous Kolar events

The possibility of explaining the anomalous Kolar events via decay of dark matter was pointed out in [1]. Decay of neutral dark matter particle at rest in the mass range of 5 to 10 GeV with life time of order around the age of the universe ($10^{17}s$) could explain these events.

If the local number density of dark matter particle (DMP) in the solar system is n, the decay rate of DMP is Γ, the effective volume of the cavern is V and the branching ratio to the decay into visible channels is B, then the rate of events seen in the cavern is given by,

$$R = n\Gamma V B$$

If we take n to be the range of one per cc, Γ to be $10^{-17}\ s^{-1}$ (with DMP life time roughly around the age of the universe), V to be $10\ m \times 10\ m \times 10\ m \approx 10^9\ cm^3$ and $B \approx 1$, we get $R \approx 0.1$ events per year. All these numbers are very approximate. Especially the volume V, since the cavern does not exist now. It was remarkable that such a crude estimate agreed roughly with the rate of the anomalous events seen at Kolar.

Model independent constraints for dark matter decay

Among various astrophysical sources, dwarf spheroidal galaxies (dSphs) are favourable for indirect detection of dark matter since they comparatively have smaller astrophysics background for gamma ray observation. They also have large mass to luminosity ratio ($\sim 1000\ order$) which shows that they have large dark matter content.

The Large Area Telescope is one of the instrument in Fermi Gamma-ray Space Telescope (Fermi LAT). It has produced important results for indirect dark matter detection in variety of astrophysical sources including dSphs. In this work, we considered a set of 27 dSphs to calculate model independent constraints on particle physics model for dark matter decay using the gamma rays observation data given in [2] which were obtained from Fermi-LAT Pass 8 data set.

FermiLAT observation of gamma rays from dSph

The number of photons expected from dark matter decay in a dSph can be expressed as

$$N = \frac{\Gamma}{m_\chi} \times \Phi_P \times\ J_d \times (A_{eff}T_{obs}) \tag{1}$$

where,

Γ is the decay rate of dark matter.
m_χ is the mass of the dark matter particle.
A_{eff} is the effective area (ignoring energy dependence) of the detector.
T_{obs} is the observation time.
J_d corresponds to the dark matter distribution in dSph for the decay to an opening angle of 0.5^0 by assuming Navarro Frenk White (NFW) profile with spherically symmetric dark matter density distribution.

$$J_d = \int_{\Delta\Omega}\int \rho_{DM}(r,\Omega) dr d\Omega \tag{2}$$

r is the distance from the detector to the dSph along the line of sight.
ρ_{DM} is the dark matter density distribution within the region of interest ($\Delta\Omega$).
Φ_P is a factor proportional to the production of gamma rays in dark matter decay.

$$\Phi_P = \frac{1}{4\pi}\int_{E_{th}}^{E_{max}} \sum_f B_f \frac{dN_f}{dE} dE \tag{3}$$

$\frac{dN_f}{dE}$ is the gamma ray spectrum for the decay channel f with branching factor B_f.

The total gamma ray photons emitted per decay are calculated from summing the spectral flux $\left(\frac{dN_f}{dE}\right)$ over all the possible final states and integrating in the energy range of E_{th} - threshold energy to E_{max} - maximum energy.

Constraining particle physics models from dSphs data

The factor Φ_P is independent of astrophysics. Fermi LAT observation data provides number of observed photons (N_{obs}) and ($A_{eff}T_{obs}$) for various dSphs. We have calculated the number of expected average number of photons (N) from decaying dark matter over astrophysical background distribution with confidence level (β) for a set of dSphs. Since, Φ_P only depends on the model under consideration, the calculated bound on N directly provides bound on Φ_P.

$$\Phi_P(\beta) = \frac{m_\chi \times N(\beta)}{\Gamma \times \sum\limits_{i\in\{dSphs\}} \left[J_d^i(\Delta\Omega)\left(A_{eff}T_{obs}\right)^i\right]} \tag{4}$$

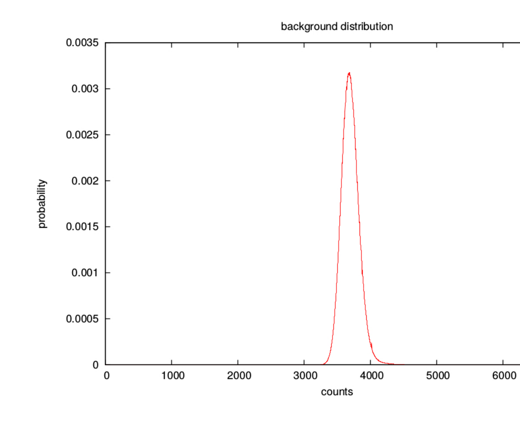
The uncertainties associated with J_d's of dSphs are treated as systematic uncertainties in the analysis.

We assume Poisson distribution for N. We create distribution tables with mean value for various expected number of photons N_{DM}^{exp}. If total of N_{DM}^{exp} photons are coming from dark matter decay, then the probability distribution for N_{DM} signals is, from the corresponding signal distribution function $P\left(N_{DM}; N_{DM}^{exp}\right)$.

$$P\left(N_{DM}; N_{DM}^{exp}\right) = e^{-N_{DM}^{exp}} \frac{\left(N_{DM}^{exp}\right)^{N_{DM}}}{N_{DM}!} \tag{5}$$

The normalized total background probability distribution for our set is calculated from convolution of individual empirical background distributions corresponding to each FermiLAT gamma ray observations of dSphs.

$$P_{bgd}\left(N_{bgd}\right) = \sum_{\sum\limits_i N_{bgd}^i = N_{bgd}} \prod_i P_{bgd}^i\left(N_{bgd}^i\right)$$



Total background distribution for our set of 27 dSphs.

Properties and Fermi LAT data of dSphs [2]

dSph Name	$log_{10}\left[\frac{J_d}{GeV\,cm^{-2}}\right]$	$A_{eff}T_{obs}\ (cm^2s)$	N_{bgd}	N_{obs}
Bootes I	$17.28^{+0.64}_{-0.38}$	4.042 * E11	137	128
Canes Venatici I	$17.78^{+0.11}_{-0.11}$	4.27 * E11	102	72
Canes Venatici II	$17.37^{+0.4}_{-0.4}$	4.259 * E11	103	91
Carina	$17.98^{+0.34}_{-0.34}$	4.363 * E11	203	159
Coma Berenices	$18.06^{+0.32}_{-0.32}$	4.046 * E11	115	151
Draco	$18.39^{+0.25}_{-0.25}$	5.366 * E11	175	150
Fornax	$18.26^{+0.17}_{-0.17}$	3.993 * E11	92	125
Grus I	$17.59^{+0.46}_{-0.96}$	4.191 * E11	109	105
Hercules	$17.38^{+0.45}_{-0.45}$	4.33 * E11	234	222
Horologium I	$17.78^{+0.47}_{-0.2}$	4.394 * E11	110	132
Hydra II	$16.89^{+0.44}_{-0.92}$	4.012 * E11	205	162
Leo I	$17.89^{+0.28}_{-0.28}$	3.879 * E11	128	138
Leo II	$17.62^{+0.25}_{-0.25}$	3.996 * E11	111	83
Leo IV	$17.22^{+0.9}_{-0.9}$	3.67 * E11	131	133
Leo T	$17.35^{+0.37}_{-0.37}$	3.993 * E11	130	122
Leo V	$17.23^{+1.05}_{-0.7}$	3.682 * E11	130	145
Pisces II	$17.41^{+0.57}_{-0.4}$	3.718 * E11	152	137
Reticulum II	$17.93^{+0.85}_{-0.32}$	4.423 * E11	108	128
Sculptor	$18.33^{+0.29}_{-0.29}$	3.897 * E11	88	114
Segue 1	$18.17^{+0.39}_{-0.39}$	3.947 * E11	128	154
Segue 2	$17.08^{+0.86}_{-1.75}$	4.072 * E11	210	246
Sextans	$18.07^{+0.29}_{-0.29}$	3.699 * E11	131	139
Tucana II	$18.45^{+0.88}_{-0.58}$	4.518 * E11	121	128
Ursa Major I	$18.15^{+0.25}_{-0.25}$	4.823 * E11	110	108
Ursa Major II	$18.48^{+0.39}_{-0.39}$	5.594 * E11	182	225
Ursa Minor	$18.45^{+0.24}_{-0.24}$	5.701 * E11	146	123
Willman 1	$18.03^{+0.91}_{-0.62}$	4.771 * E11	108	113

The probability for N_{DM}^{exp} (Expected photons from dark matter decay) to be more than N_{obs}^{Tot} (observed number of photons) is

$$\sum_{(N_{bgd}+N_{DM})>N_{obs}^{Tot}} P_{bgd}\left(N_{bgd}\right) \times P\left(N_{DM}; N_{DM}^{exp}\right) \tag{6}$$

The bound on number of photons $N(\beta)$ originated from dark matter decay to the confidence level β is calculated from

$$\sum_{(N_{bgd}+N_{DM})>N_{obs}^{Tot}} P_{bgd}\left(N_{bgd}\right) \times P\left(N_{DM}; N(\beta)\right) = \beta. \tag{7}$$

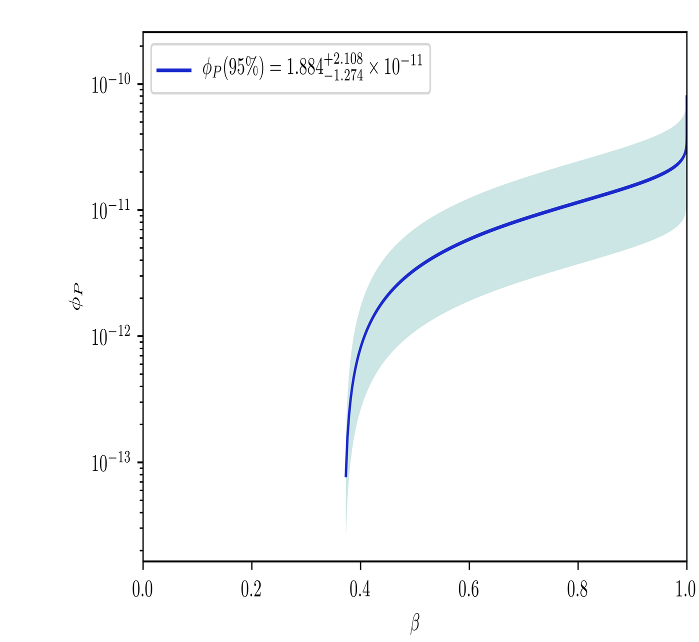
For β confidence level, we get the upper limit on N_{DM}^{exp} as,

$$N_{DM}^{exp} < N(\beta)$$

We set $m_\chi = 10\ GeV$ & $\Gamma \approx 10^{-17}s^{-1}$, for the explanation of anomalous Kolar events as dark matter decay. For $\beta = 0.95$ - (95% confidence level), we obtained the bound on the factor ϕ_P as,

$$\boldsymbol{\phi_P(95\%) = 1.88^{+2.11}_{-1.27} \times 10^{-11}}$$

The upper bound $\phi_\mathbf{P}$ for decaying dark matter with different mass m_χ (in GeV units) can be calculated by multiplying with a scale factor $\left(\frac{m_\chi}{10}\right)$.



Upper bound on Φ_P for dark matter decay. The solid line and its band correspond to the central value and their $\pm1\sigma$ variations in J_d's.

References

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[2] Kimberly K. Boddy, Jason Kumar, Danny Marfatia, and Pearl Sandick. Model-independent constraints on dark matter annihilation in dwarf spheroidal galaxies. *Phys. Rev. D*, 97:095031, May 2018. doi: 10.1103/PhysRevD.97.095031.