Dark Matter (WS 2018/19) - Problem sheet 11

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Remark: This is the final exercise sheet of the course!

Indirect detection of dark matter with Imaging Air Cherenkov Telescopes (IACTs)

This problem sheet gives a brief view into detecting dark matter annihilation products with IACTs. As an example, the H.E.S.S. telescope array has been looking at the Galactic center (arXiv:1607.08142) for potential gamma ray signals, deriving limits for the dark matter annihilation cross-section in the process.

11.1 Signal estimation *5 Points*

Let us assume dark matter to consist of neutralinos which annihilate into photons ($\chi\chi \to \gamma\gamma$). When looking at a potential source of gamma rays produced by dark matter annihilation, like the Galactic center, the expected flux along the line of sight given by the directional vector $\hat{n}$ can be expressed as (arXiv:astro-ph/9712318):

$$\Phi(\hat{n}) = \frac{N_\gamma \langle \sigma v \rangle}{4\pi m_\chi^2} \int_{line\ of\ sight} \rho_\chi(l)^2 dl(\hat{n}),$$

with n_χ being the neutralino mass, ρ_χ the dark matter density, N_γ the number of photons in the final state and $\langle \sigma v \rangle$ the thermally averaged annihilation cross-section. A more convenient form for calculations is:

$$\Phi(\hat{n}) \approx \left(\frac{1.87 \cdot 10^{-11}}{\mathrm{cm}^2\ \mathrm{s}\ \mathrm{sr}} \right) \left(\frac{N_\gamma \langle \sigma v \rangle}{10^{-29}\ \mathrm{cm}^3/\mathrm{s}} \right) \left(\frac{10\ \mathrm{GeV}}{m_\chi} \right)^2 J(\hat{n}),$$

with the J-factor:

$$J(\hat{n}) \propto \int_{line\ of\ sight} \rho_\chi(l)^2 dl(\hat{n}),$$

whose exact definition seems to slightly differ between references, but always contains the line of sight integral. Figure 1 shows the J-factor averaged over the solid angle $\Delta\Omega$ of a cone centered at the galactic center as a function of $\Delta\Omega$ for different dark matter density profiles.

a) Which density profile gives, based on Figure 1, the highest dark matter density in the Galactic center, and why?

b) Which value for $\langle J(0) \rangle$ do you get for a solid angle of $\Delta\Omega = 10^{-3}\,\mathrm{sr}$ (typical for an IACT) when assuming an NFW profile and a distance of 8.5 kpc between source and observer?

c) Using the extracted value for $\langle J(0)\rangle$ and $\Delta\Omega = 10^{-3}\,\mathrm{sr}$, calculate the expected number of gamma rays for a typical IACT measurement. Assume an effective detection area of $A_{eff} = 10^5\,\mathrm{m}^2$, a measurement duration of $t = 100\,\mathrm{h}$, and the neutralino parameters to be $\langle\sigma v\rangle = 10^{-31}\,\mathrm{cm}^3/\mathrm{s}$ and $m_\chi = 250\,\mathrm{GeV/c}^2$.

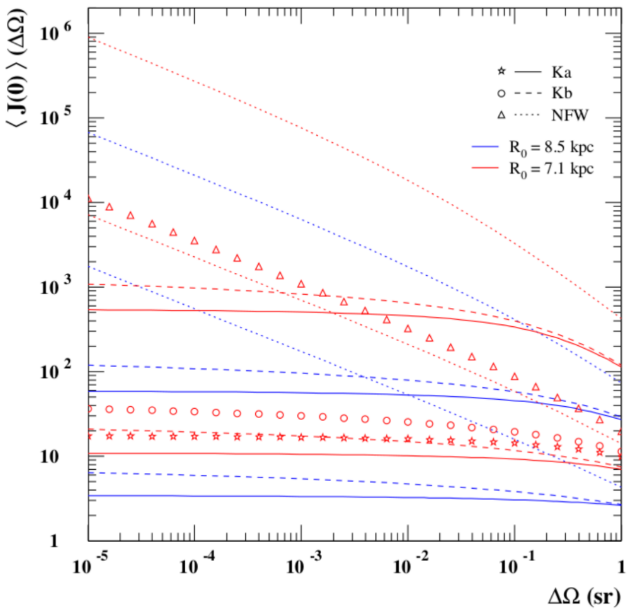

Figure 1: J-factor averaged over $\Delta\Omega$ as a function of $\Delta\Omega$ for different halo profiles (Ka, Kb and-NFW), taken from arXiv:astro-ph/9712318. Markers indicate that standard values of the respective density profile parameters have been used, while the (dashed) lines correspond to the most extreme values for the profile parameters still allowed by data having been used.

11.2 Background estimation *5 Points*

Hadronic showers contribute to the background of a gamma ray measurement, as both cannot be perfectly distinguished. The background rate can be modeled via:

$$\frac{dR_{had}}{d\Omega} = \left(\frac{6.1 \cdot 10^{-3}}{\mathrm{cm}^2\ \mathrm{s\ sr}}\right)\left(\frac{E_0}{1\,\mathrm{GeV}}\right)^{-1.7} \epsilon_{had},$$

we assume that $\epsilon_{had} = 0.3\%$, which corresponds to the fraction of hadronic shower events after applying selection criteria.

a) Using the same parameters as before, calculate the expected number of background events due to hadronic showers at $E_0 = 250\,\mathrm{GeV}$.

b) Which kind of cosmic rays could also induce background? How well can the showers caused by them be distinguished from gamma ray showers?

c) Assume, that 10 signal events are expected to be detected within the above measurement period. Given the number of expected background events that you just calculated, would a measurement with this exposure be sufficient to statistically reject the background-only hypothesis?

Detecting dark matter with colliders

As a preparation for the lecture, we want to have a look at the ATLAS detector at the Large Hadron Collider (LHC). For answering the questions, you are encouraged to research information on your own. However you can also have a look at arXiv:1411.1559 as a starting point.

11.3 Particle detection with ATLAS *3 Bonus Points*

First we need to understand the very basics of how ATLAS is detecting particles. Besides general available resources, the following link might prove to be useful:
`http://atlas.physicsmasterclasses.org/en/zpath_playwithatlas.htm`

a) Describe the purpose of the solenoid magnet, the tracking systems, the two different calorimeter types and the muon spectrometer.

b) Explain how the detector sub-systems respond when a proton/neutron is detected. Explain how the detector sub-systems respond when an electron/muon/photon is detected.

c) What is the transverse missing energy E_T^{miss}? For the "identification" of which particles is it useful? Why is not the total missing energy being used?

d) Which dark matter signature is being searched for in the above given paper?