Dark Matter (WS 2017/18) - Problem sheet 8

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Time: Wd. 09:15 - 11:00

Venue: Philosphenweg 12, kHS

Deadline for this sheet: 24.01.2018

1 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.

1.1 Basics *3.5 Points*

1. How are gamma rays able to cause Cherenkov radiation in Earth's atmosphere?
2. Provide a brief description of how IACTs detect gamma rays and how they are able to determine the direction a gamma ray came from.
3. How does the expected gamma ray flux depend on the dark matter density?
4. Why is the Galactic center an interesting region for observing potential dark matter signals?
5. How do dwarf spheroidal galaxies compare to the Galactic center as a source for dark matter signals, and what are the reasons for the differences?

1.2 Signal estimation *2.5 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):

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

with m_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:

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

with the J-factor:

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

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.

1. Which density profile gives, based on Figure 1, the highest dark matter density in the Galactic center, and why?
2. Which value for $\langle J(0) \rangle$ do you get for a solid angle of $\Delta\Omega = 10^{-3}$ sr (typical for an IACT) when assuming an NFW profile and a distance of 8.5 kpc between source and observer?
3. Using the extracted value for $\langle J(0) \rangle$ and $\Delta\Omega = 10^{-3}$ sr, calculate the expected number of gamma rays for a typical IACT measurement. Assume an effective detection area of $A_{\text{eff}} = 10^5$ m^2, a measurement duration of $t = 100$ h, and the neutralino parameters to be $\langle \sigma v \rangle = 10^{-31}$ cm^3/s and $m_\chi = 250$ GeV.

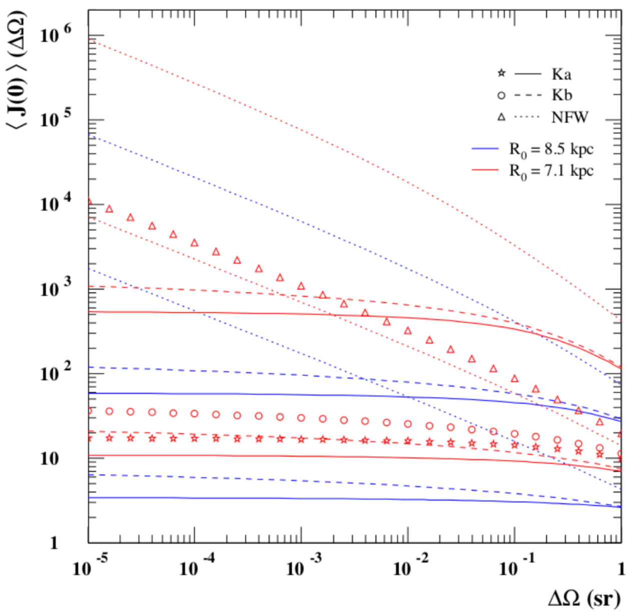

Figure 1: J-factor averaged over $\Delta\Omega$ as a function of $\Delta\Omega$ for different halo profiles (Ka, Kb and NFW), taken from arXiv:astro-ph/9712318. Markers indicate that standard values of the respective density profile parameters have been used, while the (dashed) lines correspond to the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

1.3 Background estimation *3 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:

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

with ϵ_{had} corresponding to the fraction of hadronic shower events after applying selection criteria to discriminate them against gamma ray showers. For our calculations, we assume it to be $\sim 15\%$.

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

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

3. You now have both an expected number of events for gamma rays and hadronic background. Would a measurement where the number of measured events is equal to the sum of both expected values (rounded to the next integer) be statistically compatible with the background-only case?