Exercises GRASPA
Astroparticle physics and Astrophysics

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1 Detection of an astrophysical source

1. The ESA astrometry mission, Gaia, is able to measure the parallax of remote stars up to 10 micro-arcsec $= 10^{-5\prime\prime}$. What is the corresponding distance? How does it compare with the radius of the Galaxy?
   Answer: 100 kpc vs $\sim$ 20 kpc

2. Suppose a sun-like star is sitting far from us, at a distance of 1/10 of the previously computed one. Astronomers use the magnitude to measure the brightness of an object, usually in a given bandwidth. The apparent magnitude of a star $m_\star$ in the V(visible) band can be defined with respect to the Sun for which $m_\odot = -27$, it reads:
$$m_\star - m_\odot = -2.5 \log_{10} \left(\frac{\mathcal{F}_\star}{\mathcal{F}_\odot} \right) , \quad (1)$$
   with $\mathcal{F}_\odot$ and $\mathcal{F}_\star$ the flux of the sun and of the star measured at Earth. You can notice that the dimmer the star, the larger its magnitude. Given that, on a relatively clear sky, the limiting visibility is about 6th magnitude with the naked eye ($m_{\rm lim} \simeq +6$), is it possible to distinguish this star?
   Answer: $m_\star = +19.5 > +6$ so it is not visible

3. Now imagine that, instead of the star, there is a supernova at this specific distance. A typical supernova releases gravitational energy of 10^{53} erg, with $\sim$99% carried by neutrinos, about $\sim$1% released as kinetic energy of the ejecta, and $\sim$0.01% into photons. Assuming that this energy is released within the first several months (say 100 days) of its life, estimate the photon flux at Earth. Would such a supernova be visible with naked eye during a night sky? How does it compare with the magnitude of Jupiter of -2.7?
   (The solar flux outside the atmosphere, so-called *solar constant* is $\mathcal{F}_\odot = 1372$ W m^{-2}.)
   Answer: $F_{\rm SN} \simeq 10^{-4}\,{\rm erg\,s^{-1}\,cm^{-2}} = 10^{-7}\,{\rm W\,m^{-2}}$ and $m_{\rm SN} = -1.7$ namely slightly less bright than Jupiter

4. (**Bonus**) Cosmic rays (CRs) may be accelerated in supernova shocks, converting $\sim$10% of the kinetic energy of the SN. When accelerated, CRs interact with the ambient medium and produce secondary particles, charged pions $\pi^+\pi^-$ which subsequently decay into leptons and neutrinos, and neutral pions π^0 that decay into γ rays. γ rays and neutrinos are among the secondary particles that are stable and propagate over large distances. Assume that the luminosity in γ rays is constant during 10 kyr and that they carry approximately 10^{-7} of the energy of the accelerated CRs. Would Fermi-LAT be able to detect a γ-ray flux at 1 GeV within the first 100 days of a Galactic SN at 10 kpc? Use the following Fig. 1 to compare your result with the Fermi-LAT point source sensitivity, assuming that the threshold flux scales as:
$$F(t) = F_0 \left(\frac{\Delta t}{T_0} \right)^{1/2} , \quad (2)$$
   where F is the threshold flux for an event duration Δt. T_0 is the full data taking period which is according to Fig. 1, 10 years. In fact, the γ-rays luminosity of a SN is probably several orders of magnitude higher at such an early stage.
   Answer: for $\Delta T = 100$ d and $T_0 = 10$ yr the threshold flux is a factor of 0.2 less compared to the one given in the plot (in other words the sensitivity curve of the plot has increased by a factor of 5), and the flux from the SN is $10^{-14}\,{\rm erg\,s^{-1}\,cm^{-2}}$ and the Fermi sensitivity $\sim 10^{-12}\,{\rm erg\,cm^{-2}\,s^{-1}}$, so it will not be detected within the first 100 d

5. (**Bonus**) Assuming that the neutrinos produced by inelastic collisions carry equal amounts of power as the γ rays, would IceCube be able to detect any at neutrino energies of 1 TeV? Use the following graph (Fig. 2).

   Answer: the neutrino flux is $10^{-5}\,{\rm erg\,s^{-1}\,cm^{-2}}$ at 1 GeV, and $6 \times 10^{-18}\,{\rm TeV^{-1}\,s^{-1}\,cm^{-2}}$ at 1 TeV assuming a flux dependence of E^{-2}

2 Detection of an exotic source

Simulation of the γ-ray flux from dark matter particles annihilation in a dark Galactic subhalo in Fermi-LAT data. You will run it on the computers provided by us, where all relevant software is already installed. In this tutorial you will learn how to model the γ-ray flux from dark matter particle annihilation, make a simulation of this signal for Fermi-LAT γ-ray observations, understand how we can look for this signal in real Fermi-LAT data.

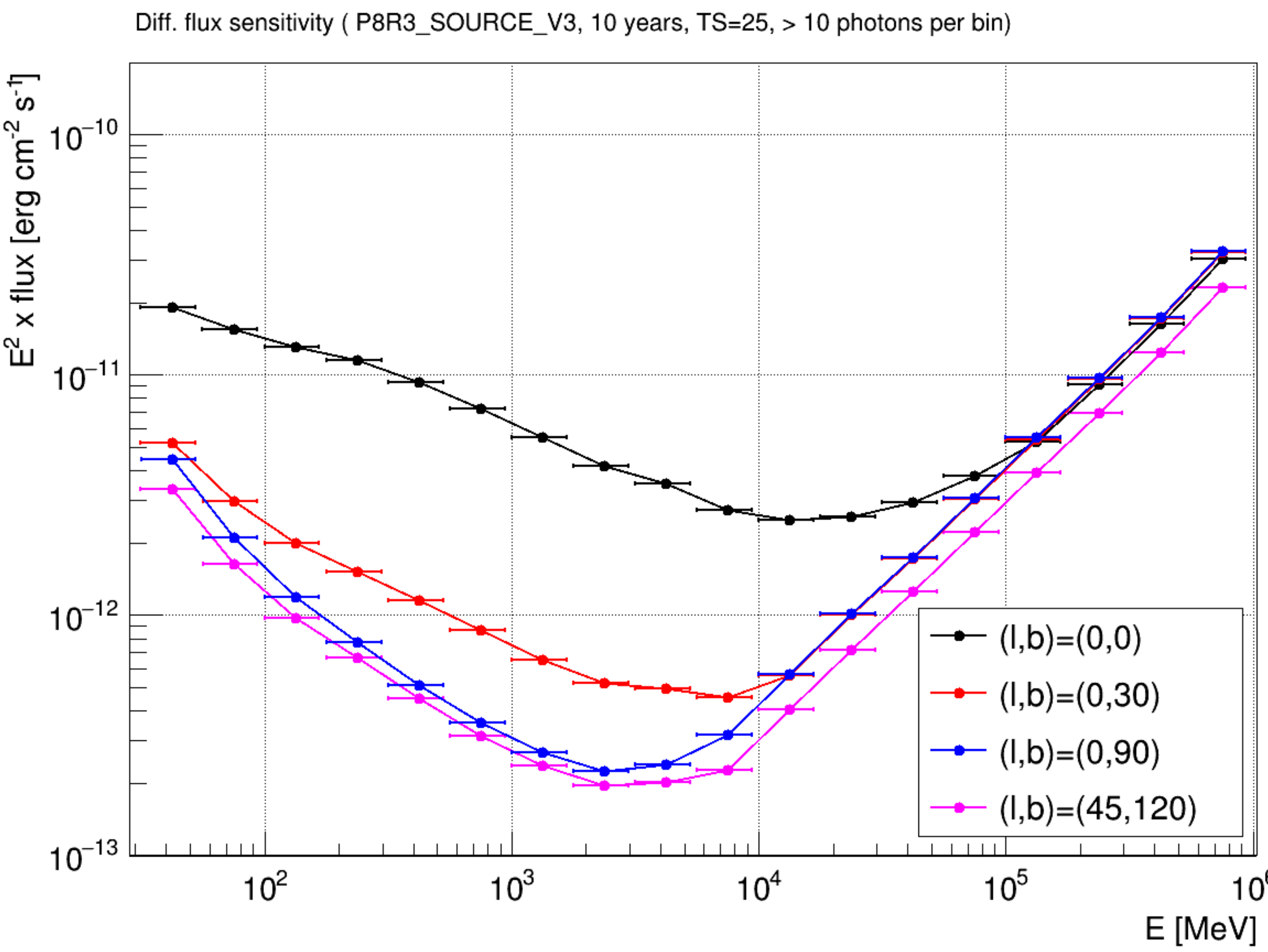

Figure 1: The Fermi-LAT point source sensitivity after 10 years of observations.
Adapted from https://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

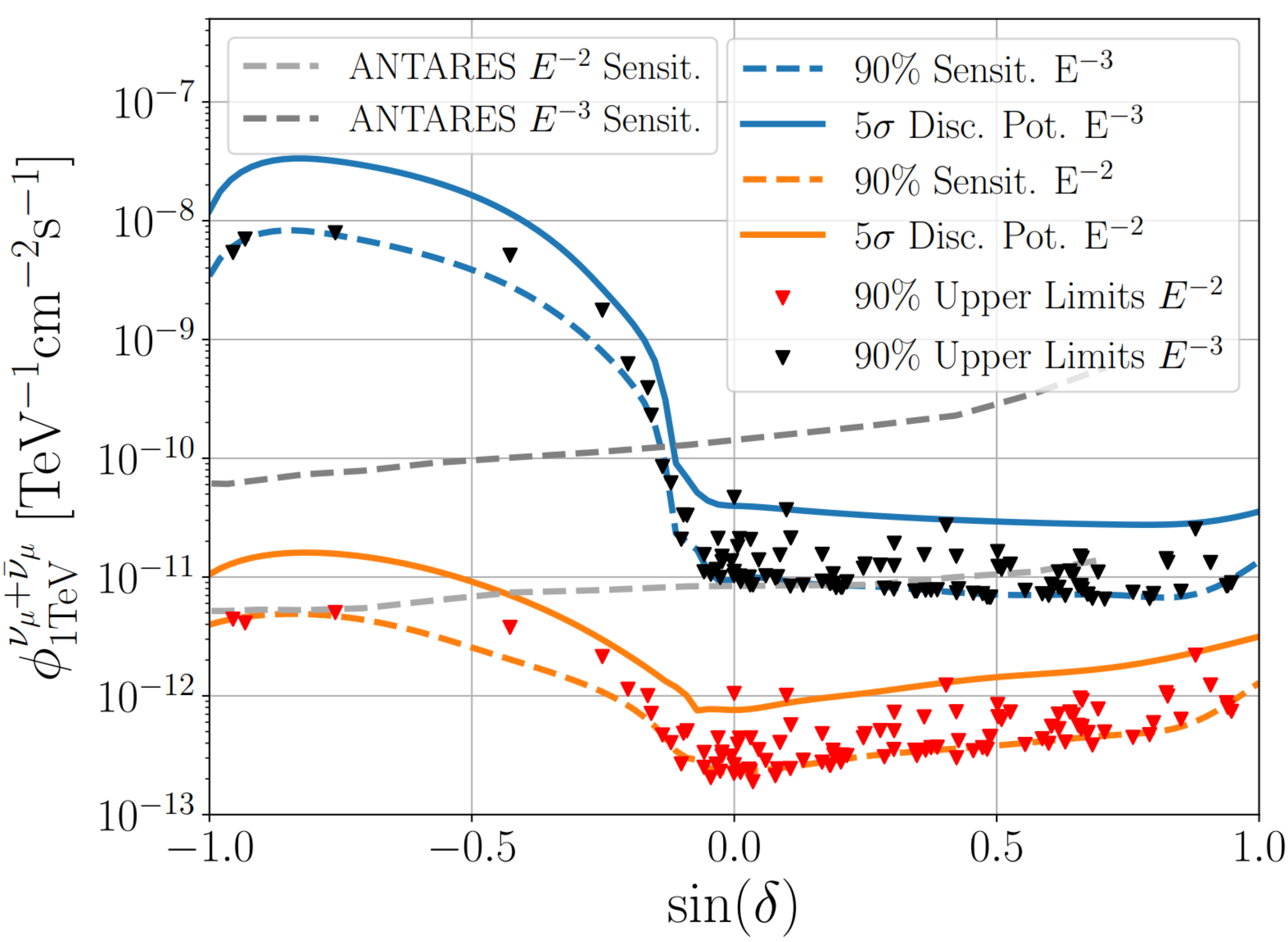

Figure 2: The IceCube point source sensitivity at neutrino energy of 1 TeV after 10 years of operations. Extracted from https://arxiv.org/pdf/1910.08488.pdf