# Exercises GRASPA
# Astroparticle physics and Astrophysics

Dimitrios Kantzas, Silvia Manconi, Francesca Calore, Yoann Génolini

July 2023

## 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 $\sim$ 30 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:
$$m_\star - m_\odot = -2.5 \log_{10} \left( \frac{\mathcal{F}_\star}{\mathcal{F}_\odot} \right) , \tag{1}$$
   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, 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 $\mathcal{F}_\odot = 1372\ \mathrm{W\,m^{-2}}$.)
   Answer: $F_{\rm SN} \simeq 10^{-4}\,\mathrm{erg\,s^{-1}\,cm^{-2}} = 10^{-7}\,\mathrm{W\,m^{-2}}$ 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 $\pi^0$ that decay into $\gamma$ rays. $\gamma$ rays and neutrinos are among the secondary particles that are stable and propagate over large distances. Assume that the luminosity in $\gamma$ 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 them at 1 GeV within the first 100 days? Use the following figure (Fig. 1) to compare your result with the Fermi-LAT point source sensitivity, assuming that the threshold flux scales as:
$$F(t) = F_0 \left( \frac{\Delta t}{T_0} \right)^{-1/2} , \tag{2}$$
   where $F$ is the threshold flux for an event duration $\Delta t$. $T_0$ is the full data taking period which is according to Fig. 1, 10 years. In fact, the $\gamma$-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 $10^{-14}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$ and the Fermi sensitivity $\sim 10^{-12}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$, 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 $\gamma$ 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 $10^{-5}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$ at 1 GeV, and $6 \times 10^{-18}\,\mathrm{TeV^{-1}\,s^{-1}\,cm^{-2}}$ at 1 TeV assuming a flux dependence of $E^{-2}$

## 2 Detection of an exotic source

Simulation of the $\gamma$-ray flux from dark matter particles annihilation in a dark Galactic subhalo in Fermi-LAT data. Please download the material (zip file) from the indico page. 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 $\gamma$-ray flux from dark matter particle annihilation, make a simulation of this signal for Fermi-LAT $\gamma$-ray observations, understand how we can look for this signal in real Fermi-LAT data.

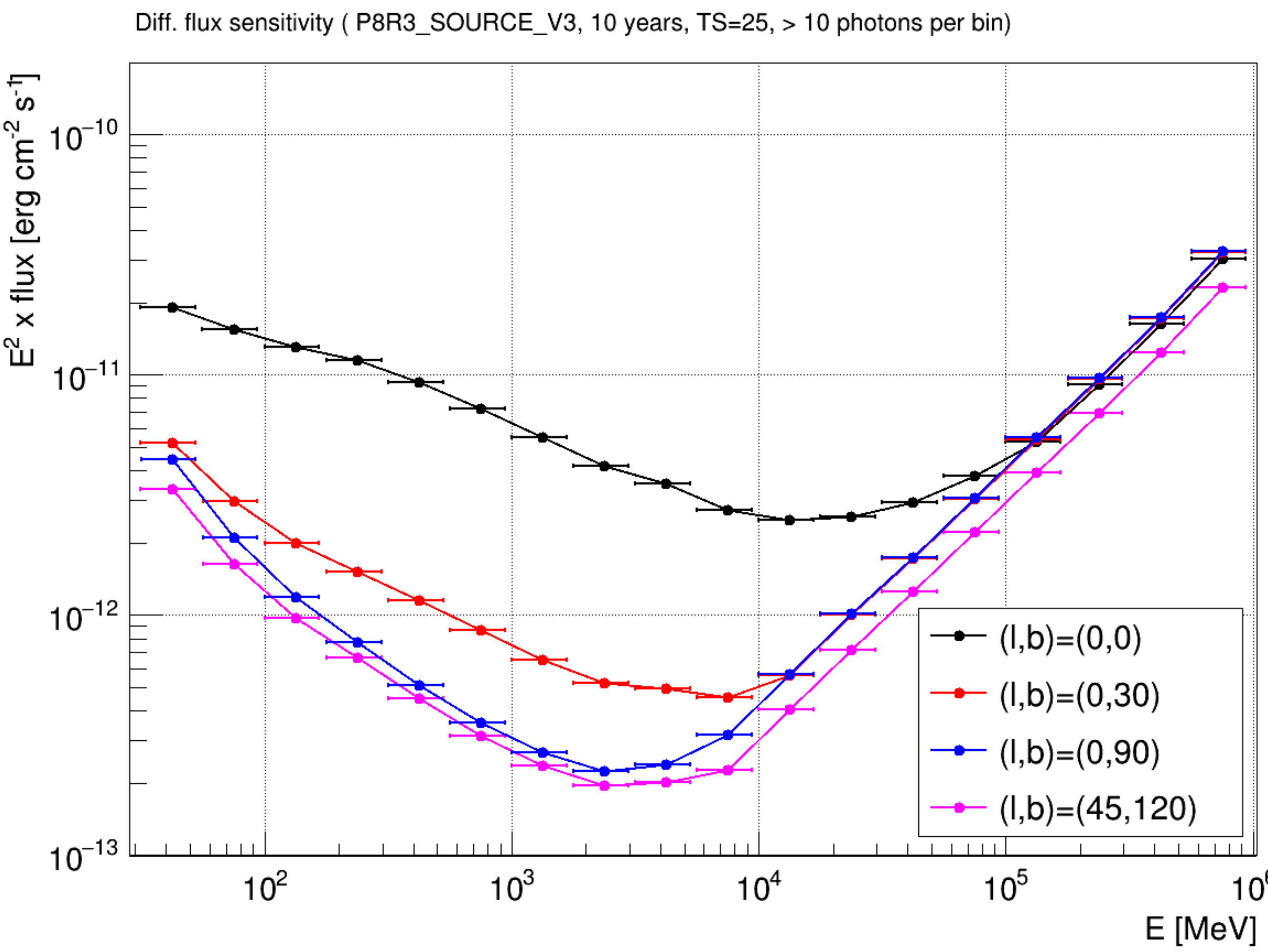


Figure 1: The Fermi-LAT point source sensitivity after 10 years of observations.
Adapted from https://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

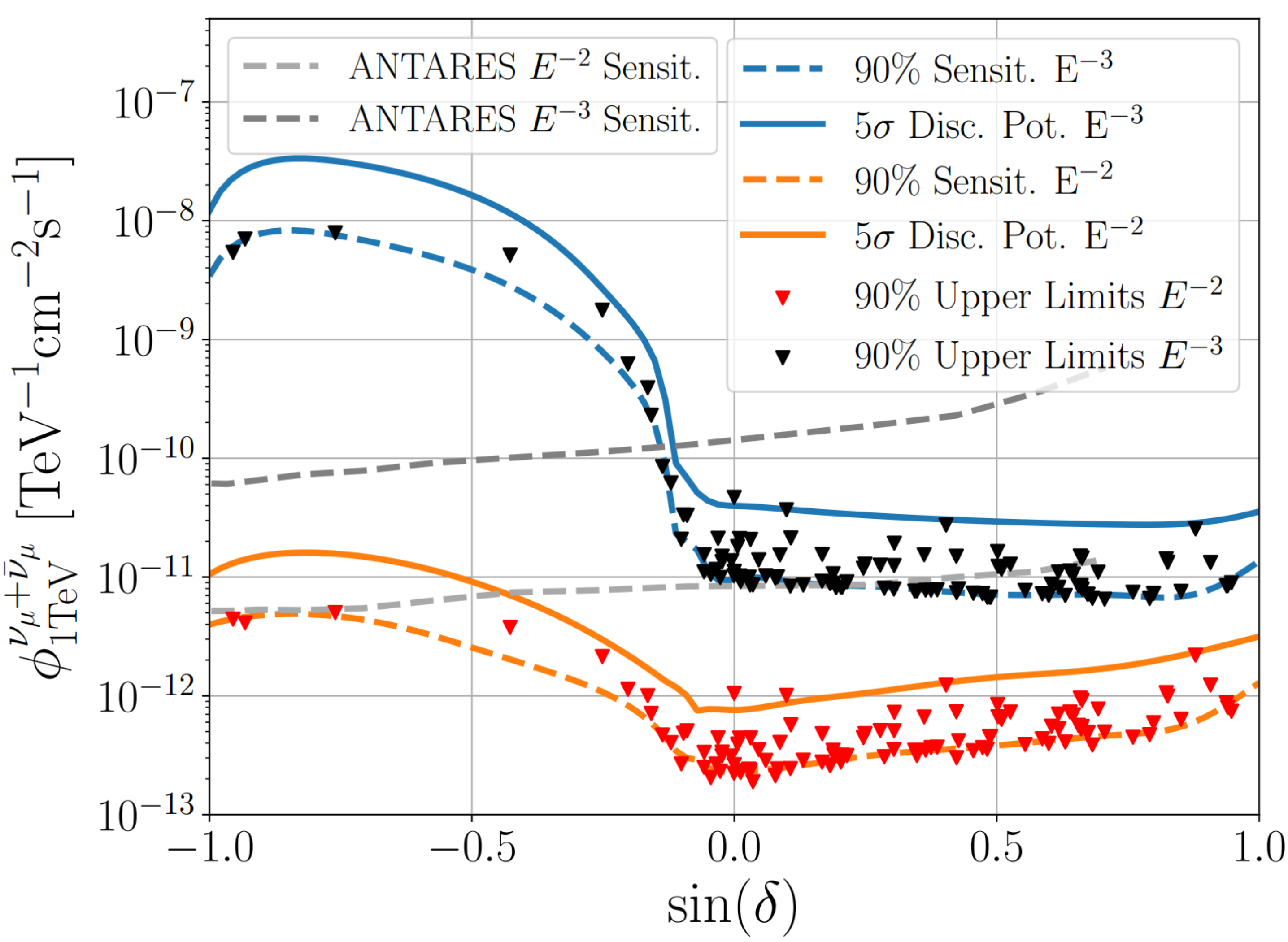


Figure 2: The IceCube point source sensitivity at neutrino energy of 1 TeV after 10 years of operations. Extracted from https://arxiv.org/pdf/1910.08488.pdf