Summary about 1st year of PhD and *perspectives* on 2nd year

<u>*Politecnico di Bari, Università di Padova*</u>

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S. Camposeo, September **2024**,
PhD in Technologies for Physics and Astronomy,
Curriculum *Detectors, optics and lasers*

Graduated in Physics (Astrophysics curriculum, 2023, Lecce)

General resume about activities of 1°year

- **Courses**:

  Particle detectors in space (S.Loporchio), **exam** given in April 2024

  New technologies for Cherenkov telescopes (S.Loporchio), **exam** given in July 2024

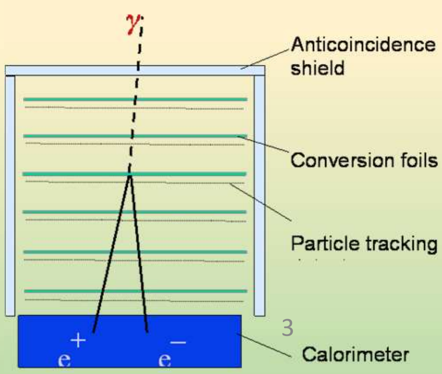
  Scintillators and Silicon photomultipliers (E.Bissaldi), **exam** given in July 2024

  Simulation of opt. photon propagation for scintillator-based detectors (D.Serini)

General resume about activities of 1°year

- **Research**:
  - Analysis of **Fermi** Space Telescope Data (in particular, currently, study of Jupiter as hypothetical source)
  - Study of high-energy astrophysics through 30+ papers

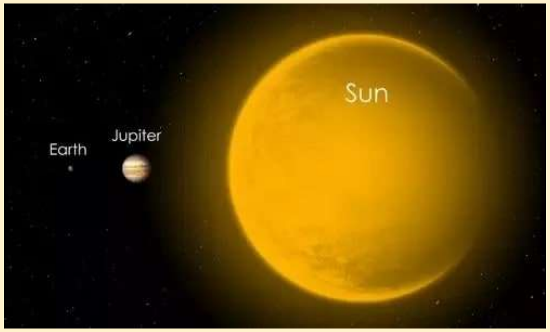
- **Other activites**:
  - INFN kids: Science outreach in elementary schools (29th of May, 2024, Bari)
  - Kick-off Meeting of PhD students in Padova, July, 2024



Research Activity

Research activity is focused on **high energy astrophysics**.
In particular the project consists in studying **solar system** sources by exploiting data of Fermi telescope (and also other high-energy-photon telescopes).

Data should be compared with **simulation** results (approaching High Performance Computing platforms).

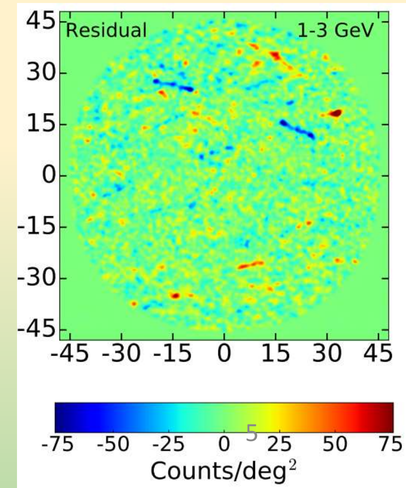


Also attention to **detector technologies** will be paid during final stages of research, in order to describe hypothetical new instruments for improving observations.

Research Activity

First source I decided to study is **Jupiter**.
One of inspiring documents for this research has been the following paper:
First Analysis of Jupiter in Gamma Rays and a New Search for Dark Matter,
Rebecca K. Leane and Tim Linden.

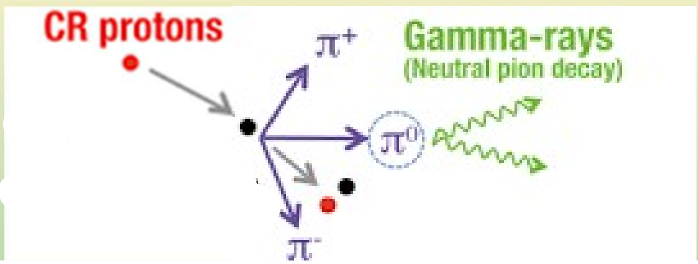
These γ-rays could potentially be produced through the **active acceleration** of cosmic rays in Jovian magnetic fields, through the **passive interaction of galactic cosmic rays** with Jupiter's atmosphere (similar to Solar models), or from **Dark Matter (DM) annihilation.**



The Physics

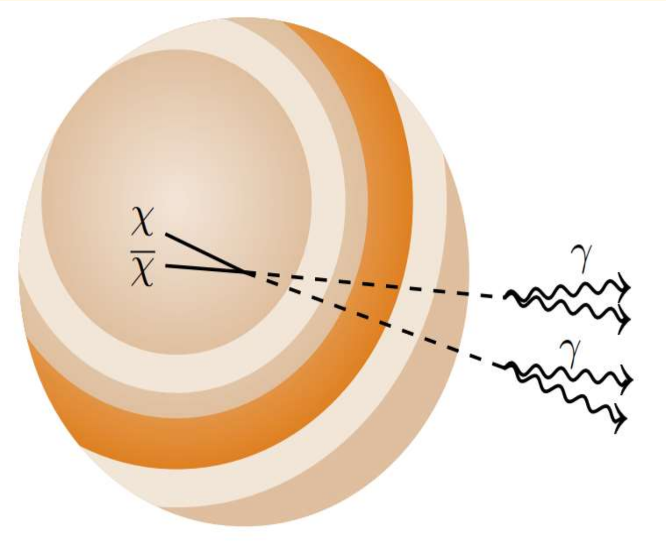
First mechanism we expect to be accountable for eventual gamma ray emission is INTERACTION OF **COSMIC RAYS WITH JOVIAN ATMOSPHERE** (‘hadronic mechanism’).

When a fastly moving **proton** interacts with matter (i.e the atmosphere or the surface of a planet/star), a **neutral pion** gets generated by part of its kinetic energy,
and this pion decays into two gamma rays.



The Physics

If we observed an **excess of gamma ray** production in relation to expected hadronic production, we would consider «**exotic**» mechanisms related to **dark matter.**



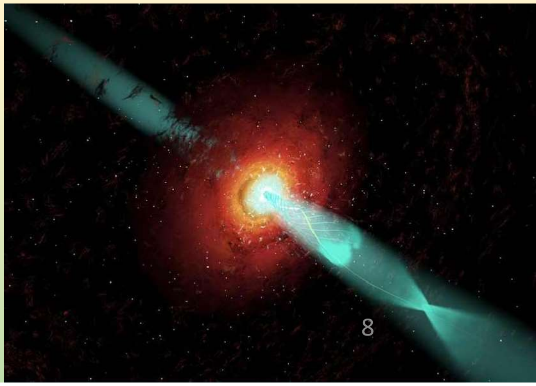
In this framework (the «WIMP» scenario) different emission mechanisms could be hypothesized:

- emission related to **annihilation** between DM particles (**if** a DM particle is the antiparticle of itself);
- emission related to **decay**/fragmentation of DM particle **following** its interaction with slow ordinary matter.

PREPARATION

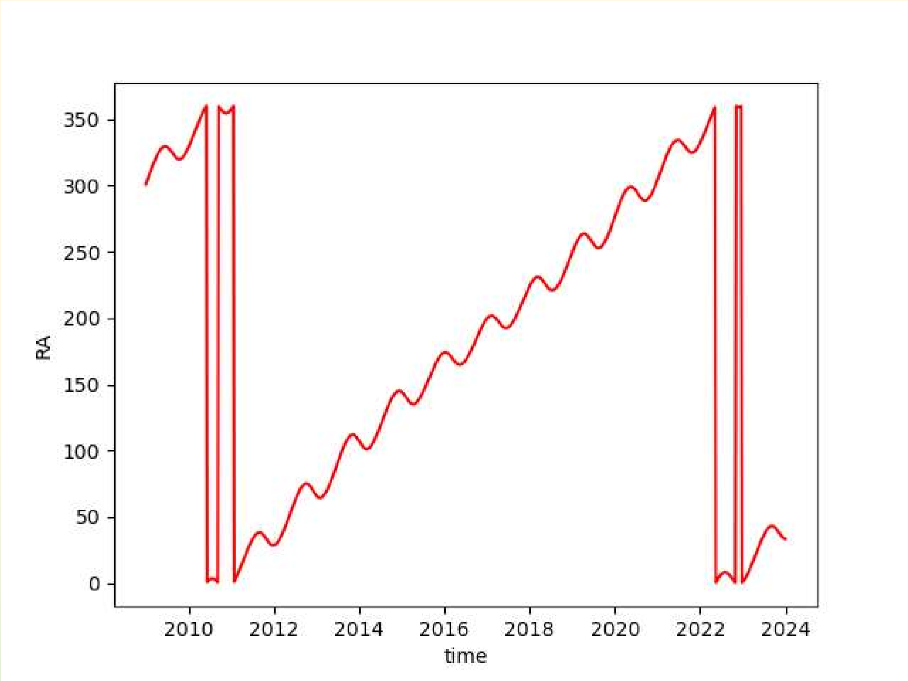
In order to start research activities, first months of PhD year have been dedicated to:

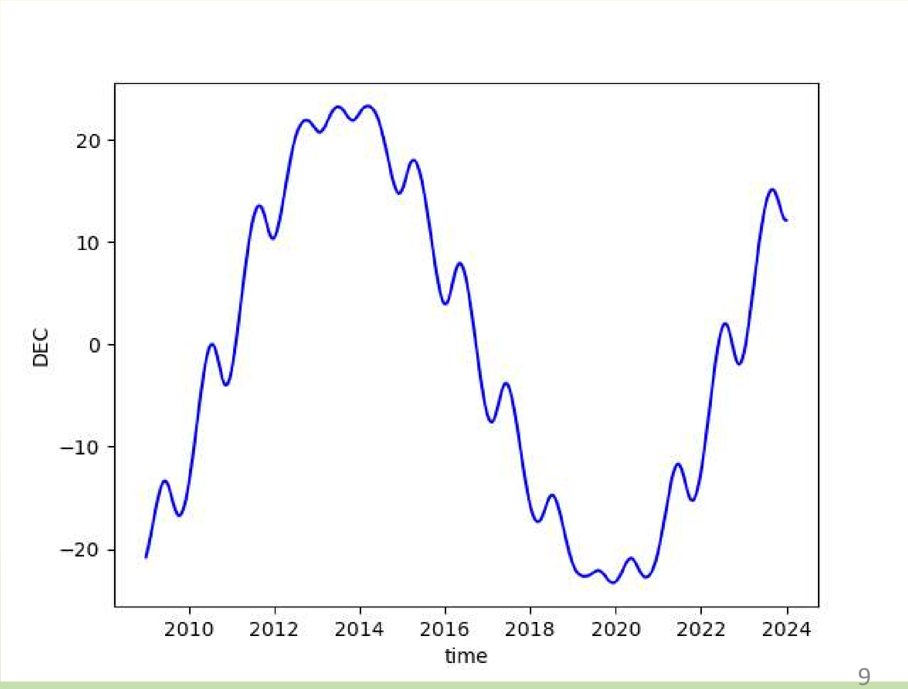
- training on **Python** programming;
- training on **Fermipy**;
- deepening on **high energy astrophysics;**
- deepening on particle detectors and photon **detectors**
- deepening on ReCas **HPC** platform of University of Bari, which will be used for all analysis.



RESEARCH: is Jupiter a source of Gamma Rays?

First object to be studied has been Jupiter (same work could be strongly intersting for Sun and for other planets).
Jupiter is obviously a **moving source** in the Celestial-Equator-System (idem for Sun and other planets).





Research Activity

LAT's field of view is **20%** of sky, and every 3 hours FermiLat observes the entire sky.
The idea is to exploit **15 years** of observation (2008-2023).

If we consider a **brief** time interval, Jupiter can be considered as a **steady source**.
So the software **FermiPy** (used for LAT analysis) can be questioned about that time interval, with Jupiter in the center of the ROI.

Research activity

In particular, initially chosen idea is the following:
to **divide the sky-path** of Jupiter along 15 years in many steps in which Jupiter has «travelled» **exactly 2 deg**.
335 steps have been obtained.

Time centre	ra.jup	dec.jup	distanza UA	ra.lun	dec.lun	ra.sun	dec.sun	sep lun	sep sun	time step	step start	step end
2454836,85	302,068462	-20,597656	6,056749523	22,1626056	13,79879571	286,2868323	-22,59594238	85,86784206	14,8019611	8,7	2454832,5	2454841,2
2454845,55	304,189063	-20,166368	6,081461571	155,174082	7,352310398	295,7464196	-21,33170234	147,3794192	7,979601311	8,7	2454841,2	2454849,9
2454854,2	306,305812	-19,709703	6,09017217	261,822979	-27,5879472	304,9530639	-19,56361383	41,28185319	1,282431587	8,6	2454849,9	2454858,5
2454862,8	308,403686	-19,231396	6,083028643	6,35641459	6,729381646	313,8768655	-17,35648094	62,70388073	5,524012471	8,6	2454858,5	2454867,1
2454871,45	310,489712	-18,730903	6,060086036	133,582129	16,71849034	322,5910205	-14,75635728	176,4355779	12,24647918	8,7	2454867,1	2454875,8
2454880,2	312,562324	-18,210021	6,021149118	244,953393	-26,57301872	331,1591377	-11,81359001	62,39302332	19,05141324	8,8	2454875,8	2454884,6
2454889,1	314,617481	-17,670704	5,965804346	354,701207	1,230299561	339,6546154	-8,573429767	43,75383496	25,98766823	9	2454884,6	2454893,6
2454898,3	316,667984	-17,110826	5,892726859	126,117649	19,32107693	348,2425148	-5,049824833	169,7651901	33,17675593	9,4	2454893,6	2454903
2454907,9	318,710653	-16,532951	5,800460763	249,420778	-27,18630098	357,0611726	-1,276002502	64,43300285	40,71565938	9,8	2454903	2454912,8
2454918,05	320,741977	-15,939095	5,686739473	14,5401829	10,80304287	6,308374215	2,725585161	59,60008995	48,77419077	10,5	2454912,8	2454923,3
2454929,05	322,767173	-15,330639	5,547021905	171,479813	-0,793745763	16,34022756	6,952128618	147,3630942	57,58159073	11,5	2454923,3	2454934,8
2454941,4	324,787916	-14,710253	5,373652307	327,495138	-11,92995547	27,73804624	11,40594033	3,829944372	67,63141364	13,2	2454934,8	2454948

Research activity

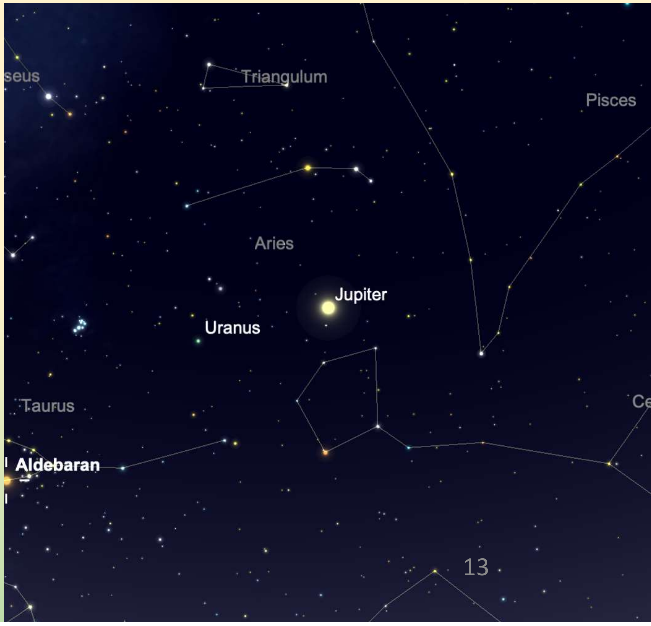
```
from astropy.coordinates import SkyCoord  # High-level coordinates
from astropy.coordinates import ICRS, Galactic, FK4, FK5  # Low-level frames
from astropy.coordinates import Angle, Latitude, Longitude  # Angles
import astropy.units as u
import numpy as np
from astropy.time import Time
from astropy.coordinates import solar_system_ephemeris, EarthLocation
from astropy.coordinates import get_body_barycentric, get_body
a = Time(2454832.5, format='jd', scale='utc')
loc = EarthLocation.of_site('greenwich') 
with solar_system_ephemeris.set('builtin'):
    jup = get_body('jupiter', a, loc) 
jup  
t=[0.]*54780
#creiamo il vettore dei tempi
i=0
while (i<54780):
    t[i]=2454832.5+i*0.1
    i=i+1
#creiamo il vettore delle coordinate
i=0
ra=[0.]*54780
dec=[0.]*54780
d=[0.]*54780
while (i<54780):
    a = Time(t[i], format='jd', scale='utc')
    with solar_system_ephemeris.set('builtin'):
        jup = get_body('jupiter', a, loc)
    ra[i]=jup.ra
    dec[i]=jup.dec
    d[i]=jup.distance
    i=i+1
```

Research Activity

Time duration of 2deg-step variated from **8 days to 90 days**.

Choice of 2 deg as single-step-path is due to a **compromise** between accuracy on coordinates and Fermi Angular Resolution.

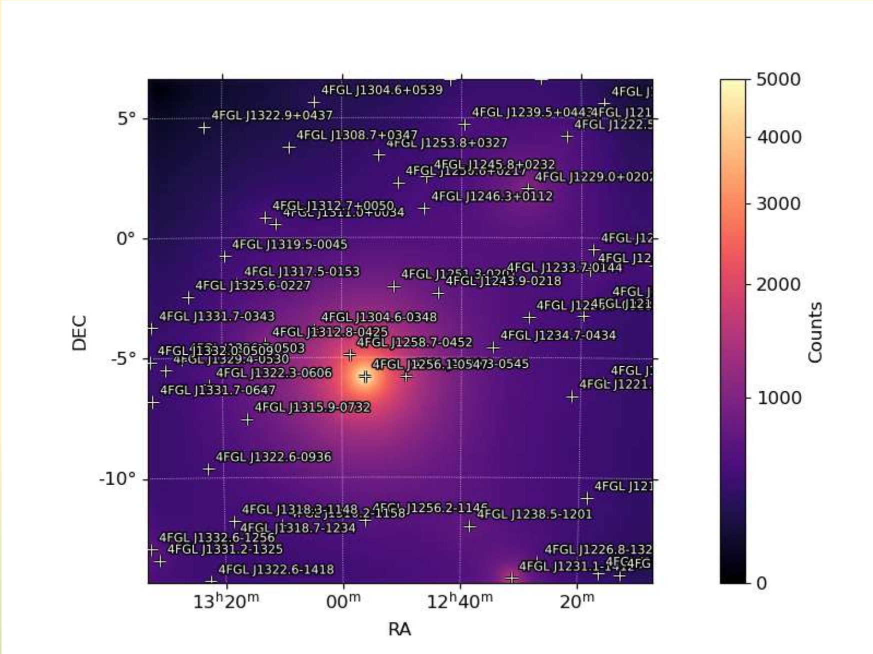
I also asked the calculation of **Moon and Sun's** average coordinates in same time intervals,
because in the analysis, a cut will be given
(these sources are disturbing to us!).



Research Activity

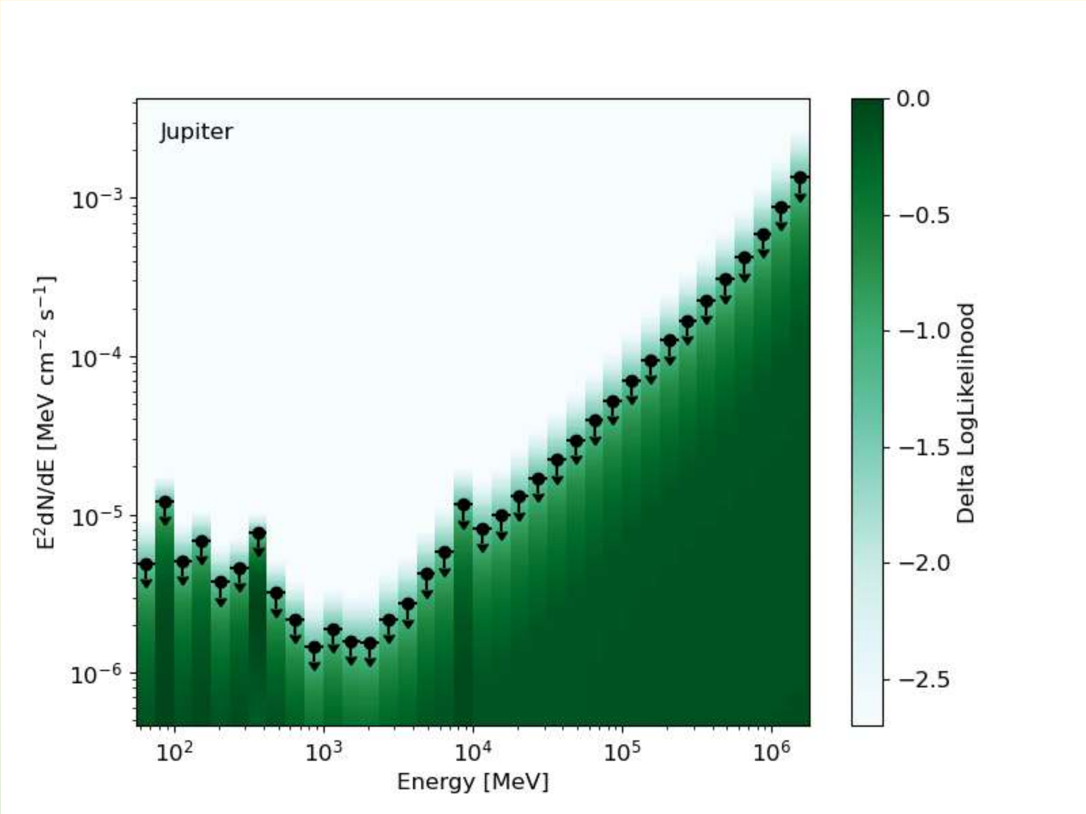
Fermi data are analyzed by the tool **FermiPy.**
When you point to a source, you try to characterize this object **above** a known **background** (made of **known sources**).

Usually the considered **ROI** (region of interest) is a **20 deg square**,
in which the studied source is in the centre.
Usually you free parameters of all objects inside a **5 deg circle** around the centre.



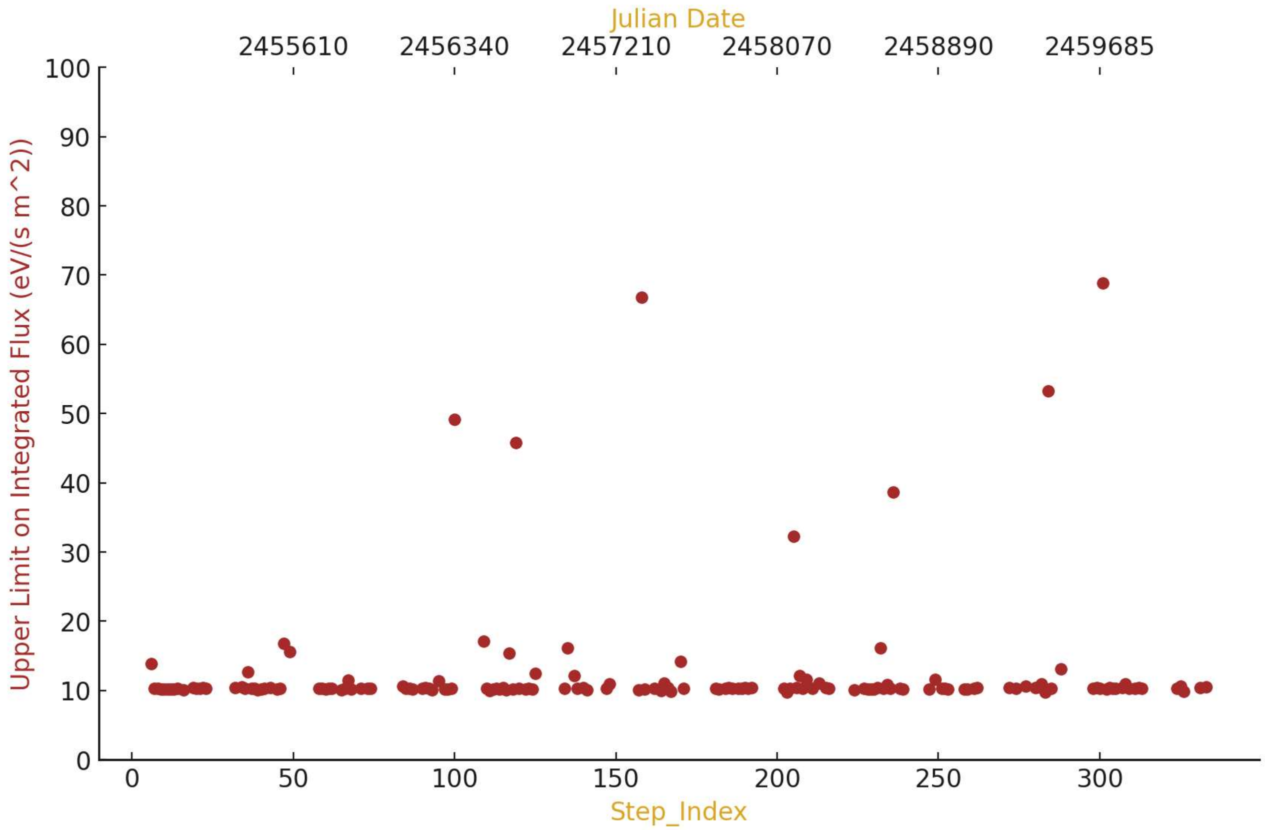
Research Activity

The analysis of **slowest** step (2 deg in 90 days) is showed below. It is the **188°** step.
Upper limits (of 2σ significance) **on counts from Jupiter** are drawn **for each** energy bin.

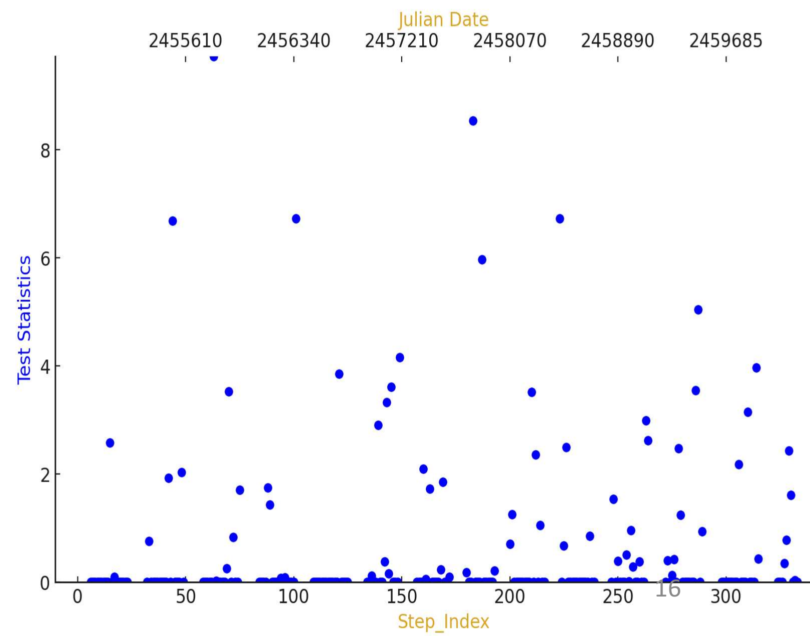


Research Activity

Upper Limits (2σ significance) **VS time date** (or step index), *from Output_fermipy.fits*



These upper limits refer to ***integrated flux*** *from 50 MeV to 300 GeV.*



Research activity

INTERPRETATION

For each step (i.e. for each ROI) **upper limits** on integrated flux have been computed, because **NO additional source** (i.e. Jupiter) over the backgr. has been detected. Backgr. is **specific** to the step, i.e to the ROI.

A **conventional true detection** should be a measure with $5\sigma_{background}$ surplus over the predicted background.
Predicted backgr. is **given by models** for diffuse light and known sources in the ROI.

Research activity

INTERPRETATION

Roughly speaking, the **upper limit on Jupiter flux** for a given step (ROI) with a **95.4%** confidence level (i.e 2σ significance) is **twice** the $\sigma_{predicted\ backgr.}$ for that step (ROI).

Bigger is the confidence level, bigger is the upper limit.
If you break through the wall of $5\sigma_{predicted\ backgr.}$,
i.e if you find a flux bigger than this upper limit, you have a **detection**.

STACKING OF STEPS (to be achieved very soon)

Single-step results will be **joint**.
This corresponds to maximize the following log.likelyhood:

$$\ln L = \sum_s \sum_i \ln {}_i^s L$$

where ${}_i^s L$ is the lik. function for the i-th energy bin and the s-th step.

Count measure is a **poissonian** phen. (Flux is derived from Counts/time_interval).
So $Flux_{backgr}$ is expected to be constant with increasing time of obs.,
but $\sigma_{backgr} \propto \mathbf{1/\sqrt{time\_interval}}$ so that an increas of obs. time interval **will give us** a **smaller** upper limit, with fixed conf. level, i.e. we'll have a **stronger constraint**.

Perspectives on 2° Year

- To perform analysis also:
  - with **1 deg-steps**;
  - on other sources (Sun?)
  - for x-rays

- To **simulate** emissions from Jovian environment, exploiting ReCas and its **HPC** sub-cloud.

- To attend International **Physics School** «Francesco Romano» in Monopoli, October 2024

- To complete **compulsory** schedule of PhD with one additional course

- **Soft** activities inside Physics department of Bari (such as INFN kids program).