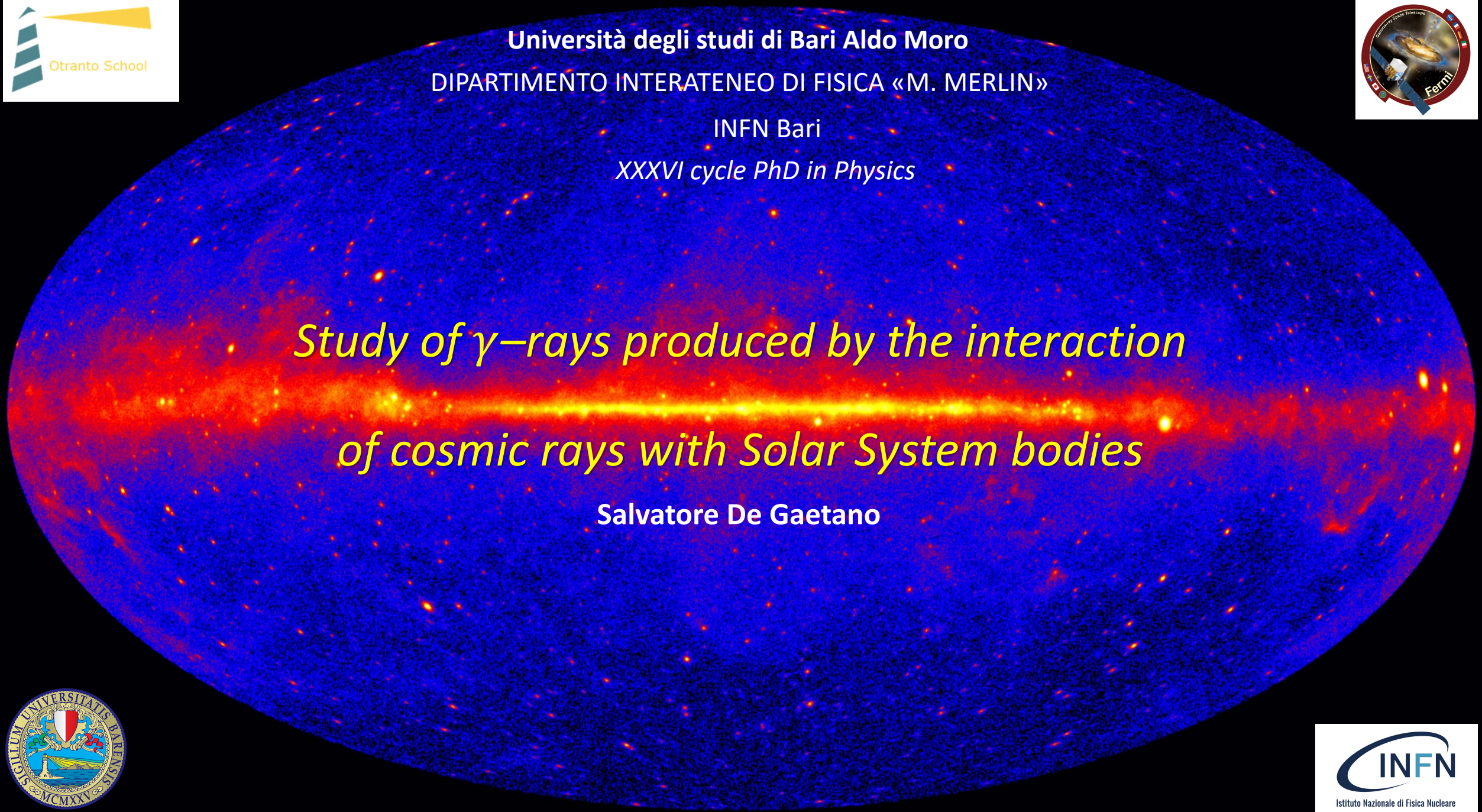



**Università degli studi di Bari Aldo Moro**

DIPARTIMENTO INTERATENEO DI FISICA «M. MERLIN»

INFN Bari


*XXXVI cycle PhD in Physics*

# *Study of γ–rays produced by the interaction of cosmic rays with Solar System bodies*

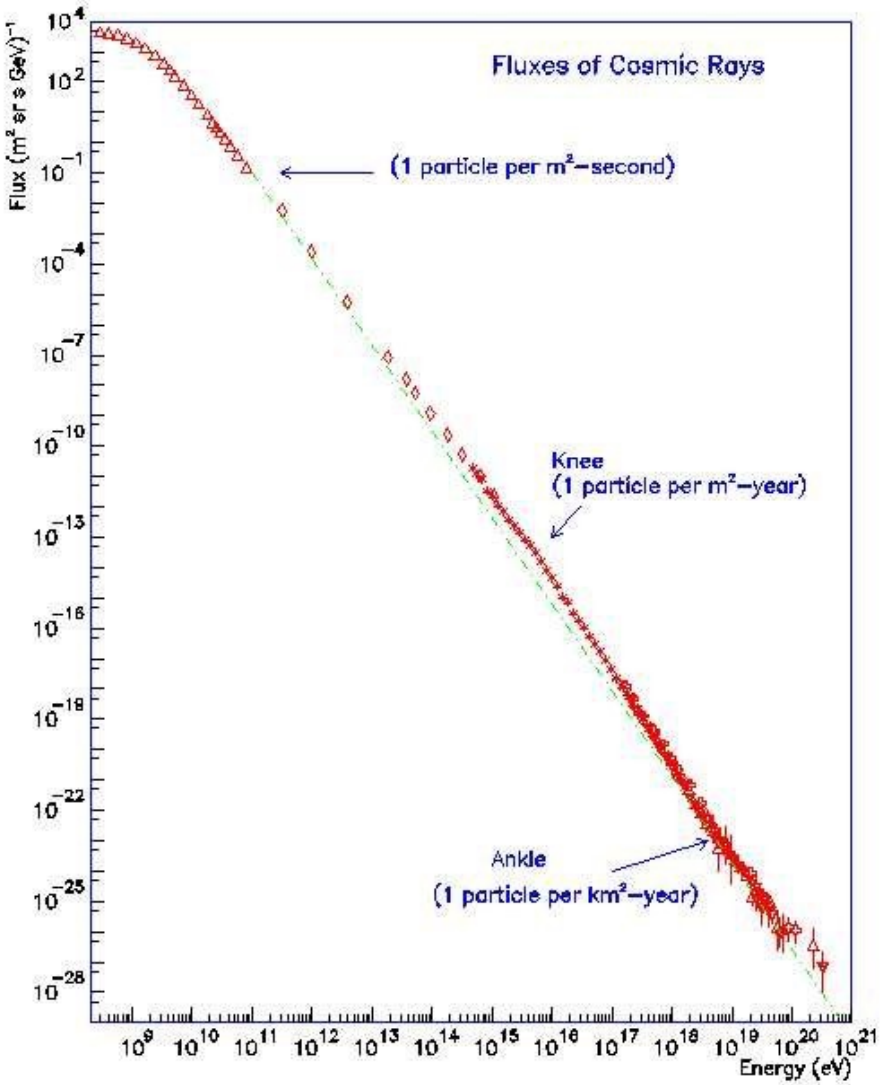

**Salvatore De Gaetano**

# 1. Cosmic $\gamma$−rays

- Cosmic rays are energetic particles coming from the outer space
  - mainly composed of protons, He nuclei, $e^-$ , $e^+$
  - $\gamma$−rays are a tiny fraction of cosmic radiation

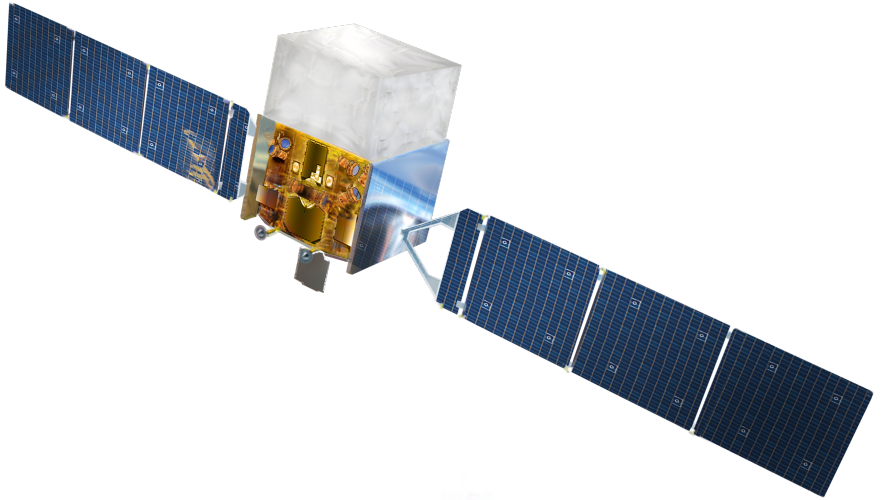
- Celestial bodies can act as $\gamma$−ray sources due to cosmic rays interacting with them
  - $p + N \rightarrow \pi^0 \rightarrow \gamma\gamma$
  - $p + N \rightarrow N^* \rightarrow N + \gamma$
  - $e^+ - e^-$ bremsstrahlung with matter nuclei
  - $e^+ - e^-$ annihilation
  - inverse-Compton effect between cosmic $e^+$ / $e^-$ and a low energy photon
  - synchrotron radiation from $e^+$ or $e^-$ bent into circular orbits (e.g. in magnetic fields)

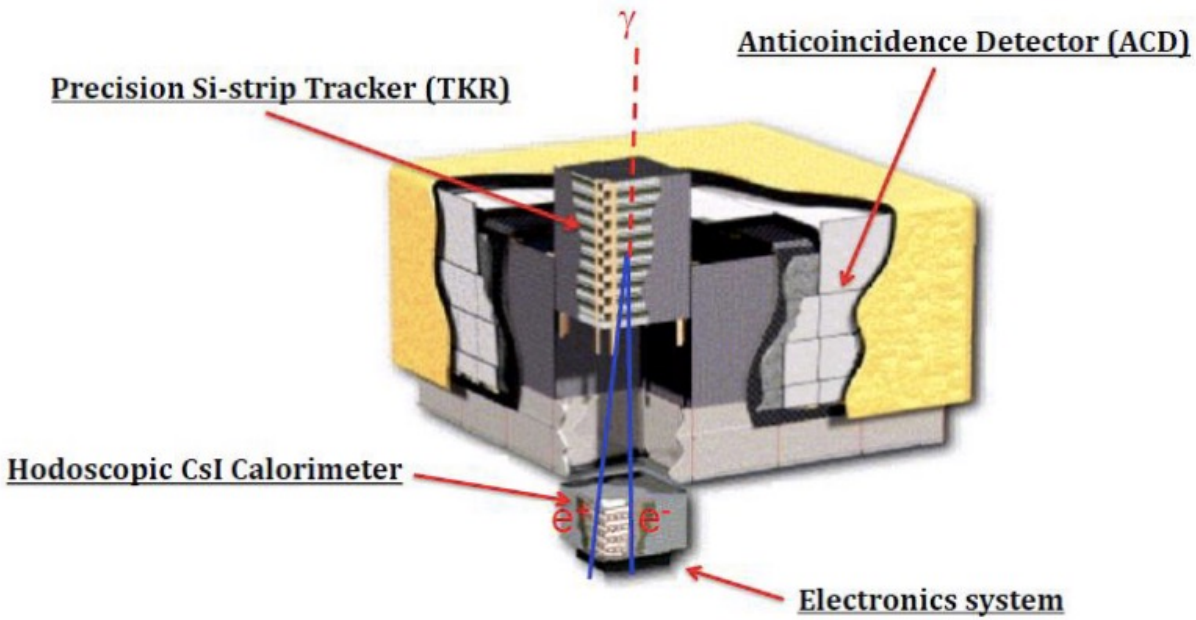
- The goal of this project is to study this $\gamma$−ray emission
  - probing the interaction models at the base of the $\gamma$−ray production
  - measuring the spectra of cosmic rays
  - studying the chemical composition of the bodies surface



# 2. Fermi experiment

- Fermi is a satellite observatory for photon energies from 8 keV to over 300 GeV
- Its main instrument is the LAT (Large Area Telescope)
  - allowing a scan of the entire $\gamma$–ray sky every two orbits around the Earth
  - based on $\gamma \rightarrow e^+ e^-$ conversion
  - 16 tracker (TKR) modules, 16 calorimeter (CAL) modules and a segmented anti-coincidence detector (ACD)
  - TKR allows for $\gamma$ direction reconstruction, CAL measures the energy of the shower produced by the $\gamma$, ACD rejects charged cosmic rays
- The LAT performs long-term high-sensitivity $\gamma$–ray observations of celestial sources from $\sim$ 20 MeV to > 300 GeV
- The data of Fermi are publicly available and they can be processed by the Fermitools
  - set of software packages used to select and study the data from a given portion of sky

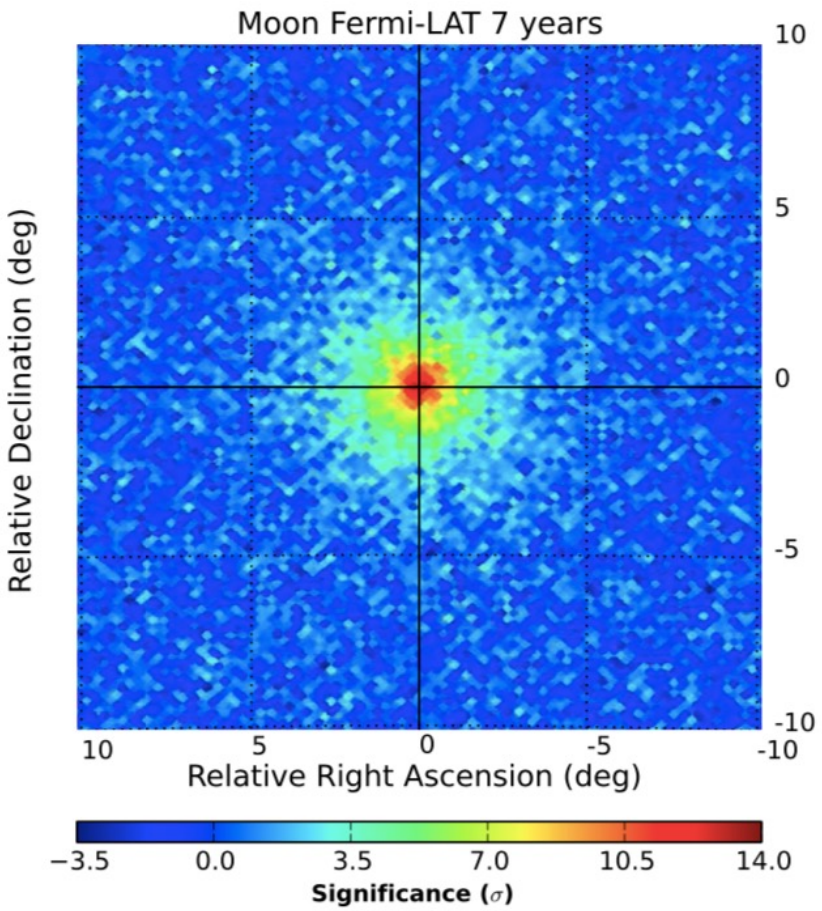


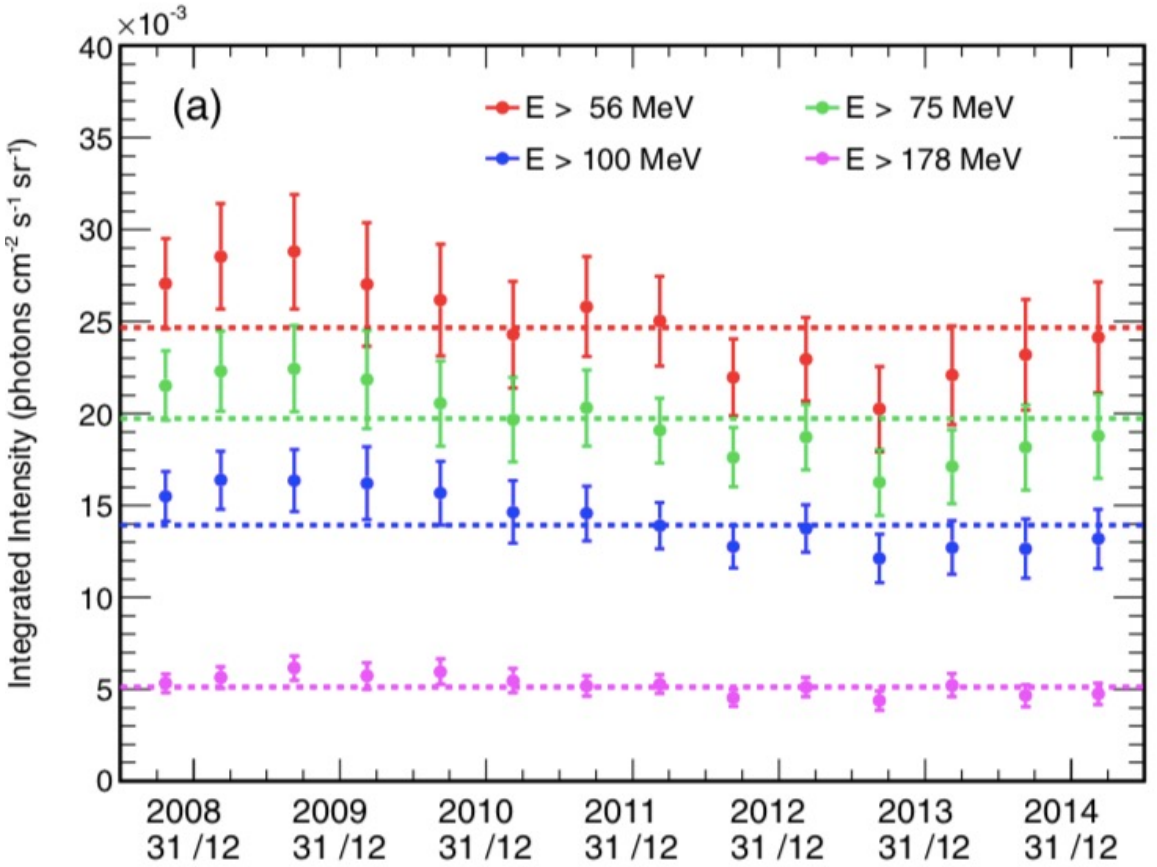


# 3. Moon analysis

- First 7 years of Fermi data
- E = [ 30 MeV ÷ few GeV ]

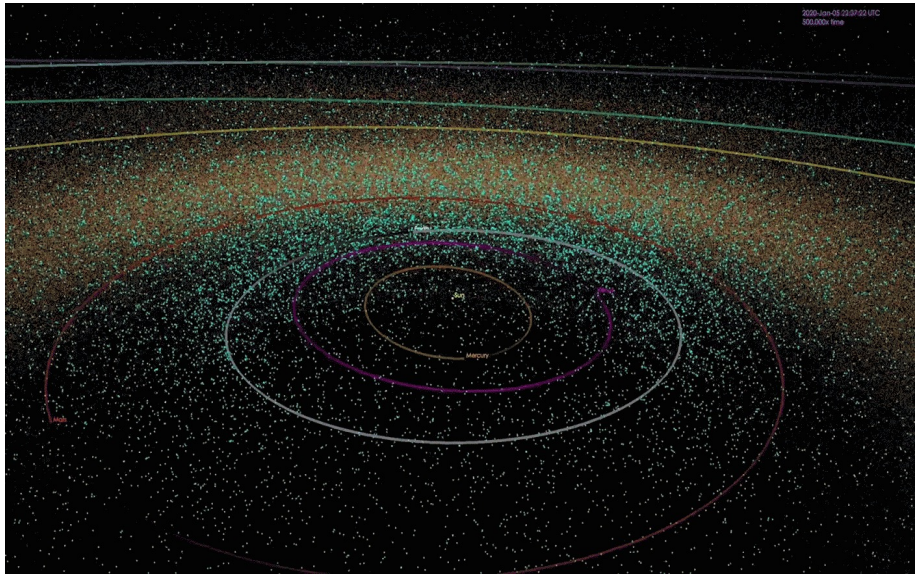
- Cosmic rays flux must be affected by solar modulation
- Time evolution of the Moon flux: found a correlation with the solar activity



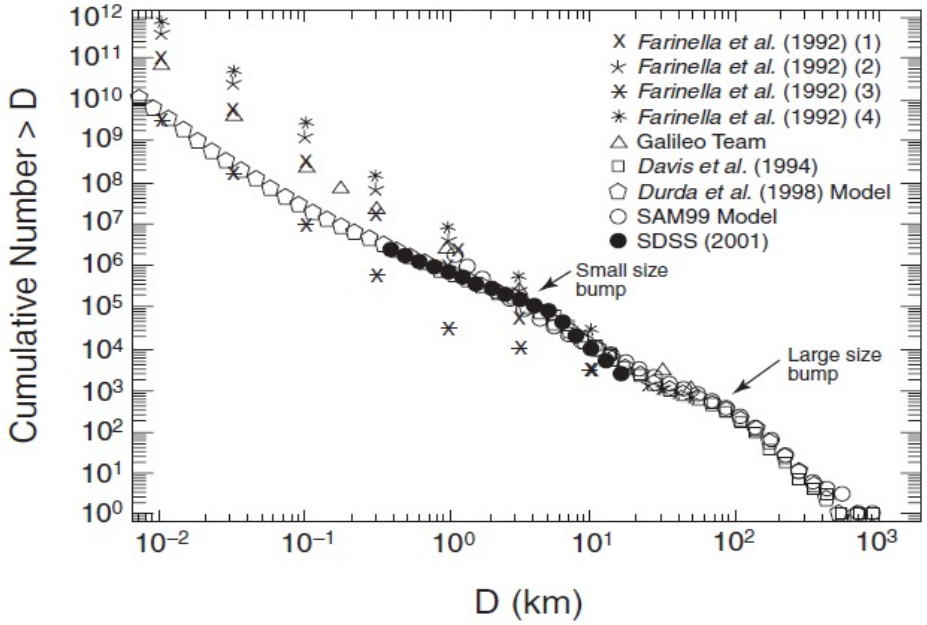

- New update: first 12 years of data
- The Sun activity has now reached its maximum
- The lunar flux is expected to start decreasing

# 4. Solar System Small Bodies analysis



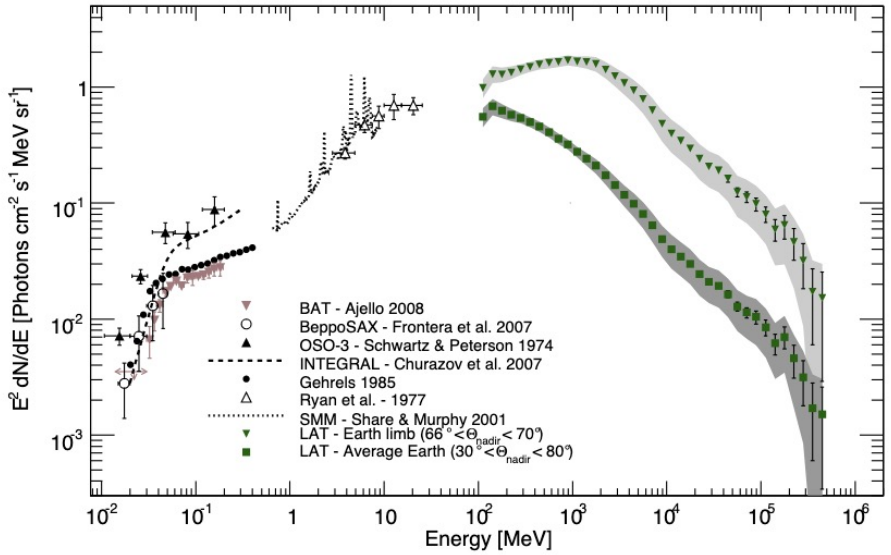
- Small solar system bodies should produce a diffuse emission close to the ecliptic plane
- The JPL database provides a catalog of about $10^6$ small bodies of radius > 10 cm
- Several models predict the existence of a number of SSSB greater than in the JPL catalog

- Calculating emission spectrum of a spherical body of a given material: FLUKA code
- Emission spectrum + population model (right) = diffuse source emission
- Compare Fermi data with the theoretical flux, put upper limits
- Constraints on the population given by the model



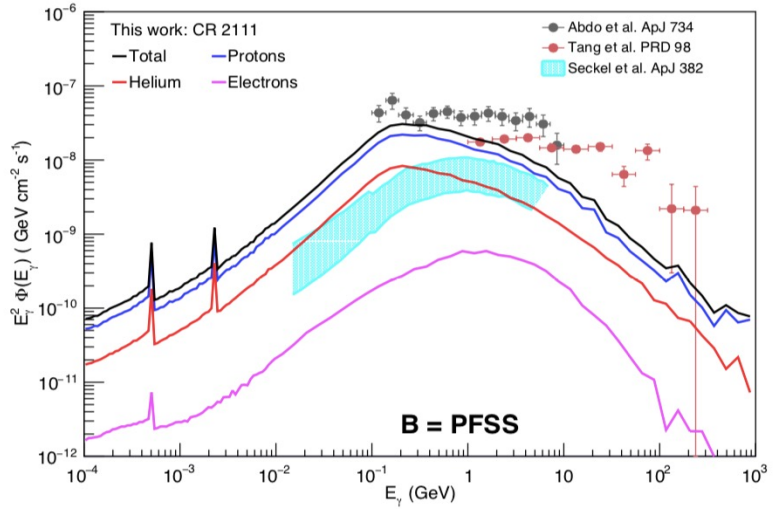
# 5. Future work

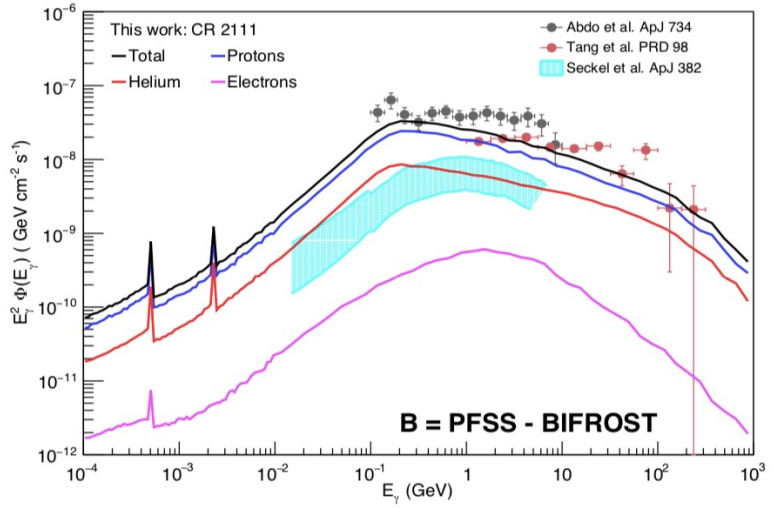
## Earth atmosphere




- One-year LAT data
- Analysed two different portions of atmosphere
- Lacking a model describing the Earth atmosphere $\gamma$−ray spectrum

## Sun




- Simulations obtained with two different values of the Sun inner magnetic field
- Time of measurements (LAT data) ≠ time of simulations
- Find the best model for the Sun inner magnetic field
- Do measurements and simulations over the same periods of time

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