12th INTEGRAL Conference & 1st AHEAD Gamma-ray Workshop

Background of gamma-ray telescopes in low-Earth orbit

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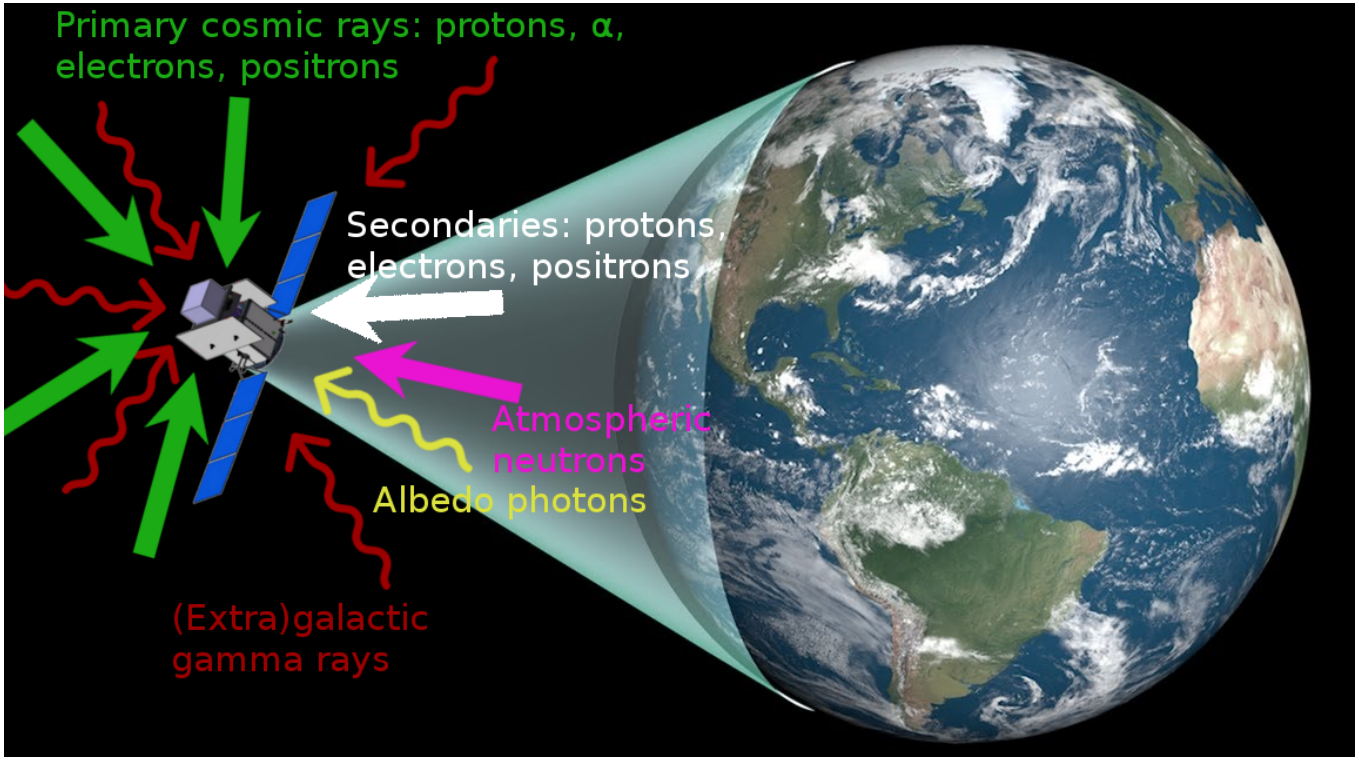
Introduction



All missions suffer from background:

- Restrict observation
- Deteriorate on-board instrumentation

Model

The proposed model is intended to be used for gamma-ray experiments on LEOs at different

- inclinations
- altitudes
- solar activity

over a wide energy range (4 to 9 decades depending on the component).

Geomagnetic cutoff value is calculated starting from the input orbit parameters (Smart and Shea (2005))

Model

Every component is modeled starting from experimental data and existing models:

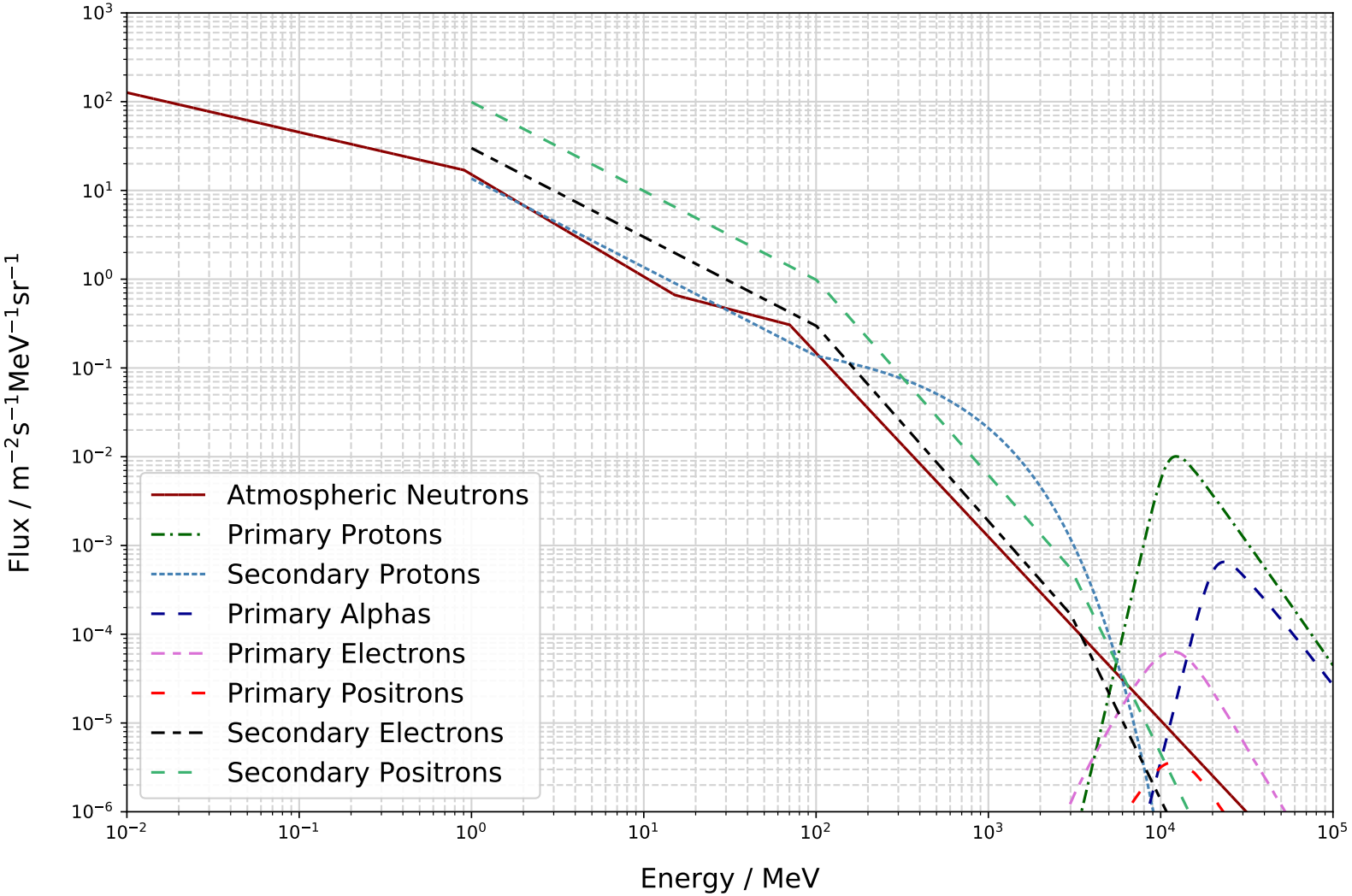
- INTEGRAL (photons)
- Fermi-LAT (photons)
- AMS-01 (secondary charged cosmic rays)
- AMS-02 (primary charged cosmic rays)
- Two different models for the atmospheric neutrons (Kole et al. 2015 and Lingenfelter 1963, down to 0.01 eV)

General Parameters

If not differently specified, the spectrum (in $m^{-2}s^{-1}MeV^{-1}sr^{-1}$) is calculated for:

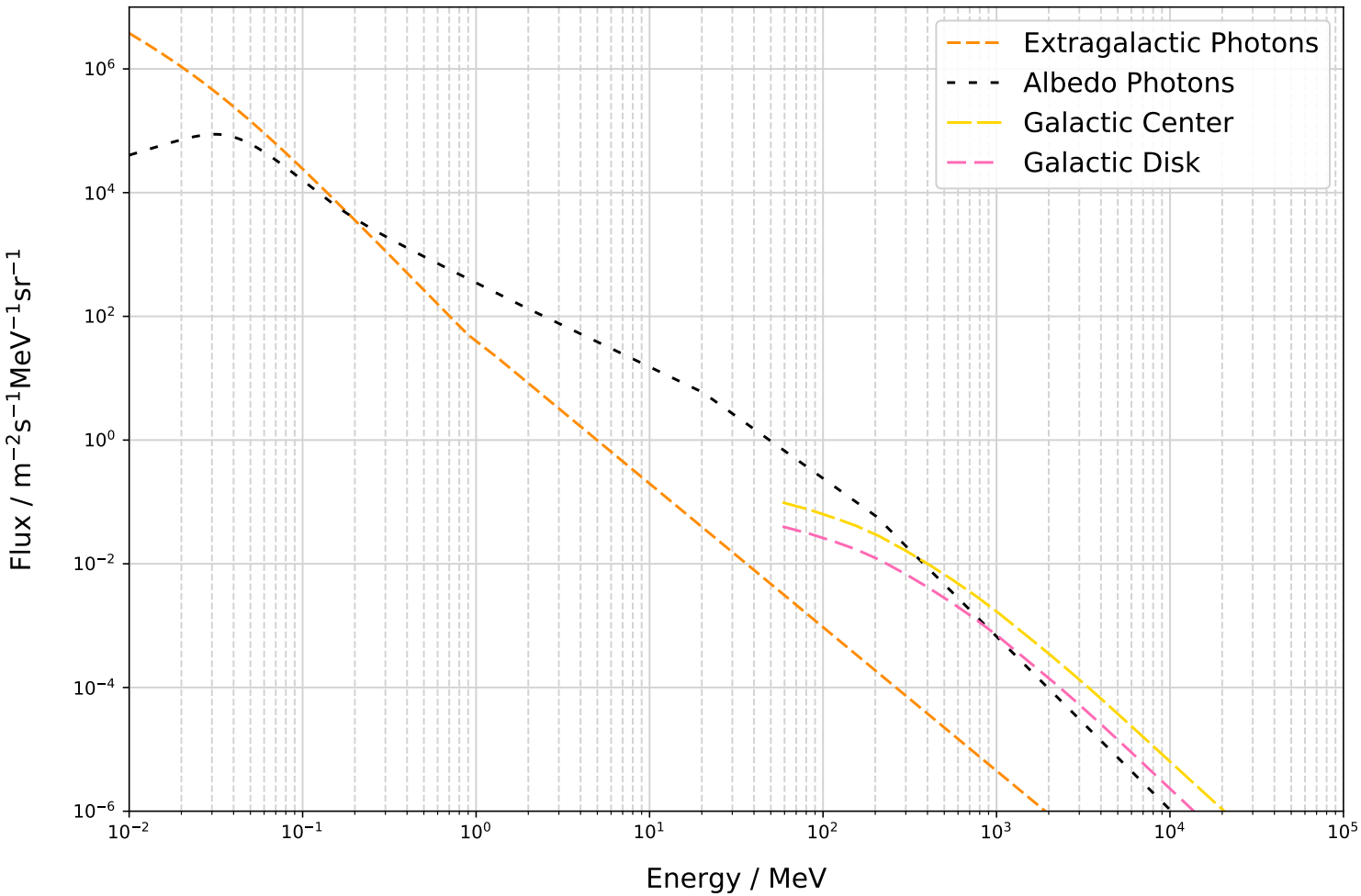
- Altitude $h = 550$ km
- Inclination $i = 0^{\circ}$
- Medium solar activity

General Background: Charged Particles and Neutrons



Dominant: $E < 6$ GeV secondaries. $E > 6$ GeV primary protons.

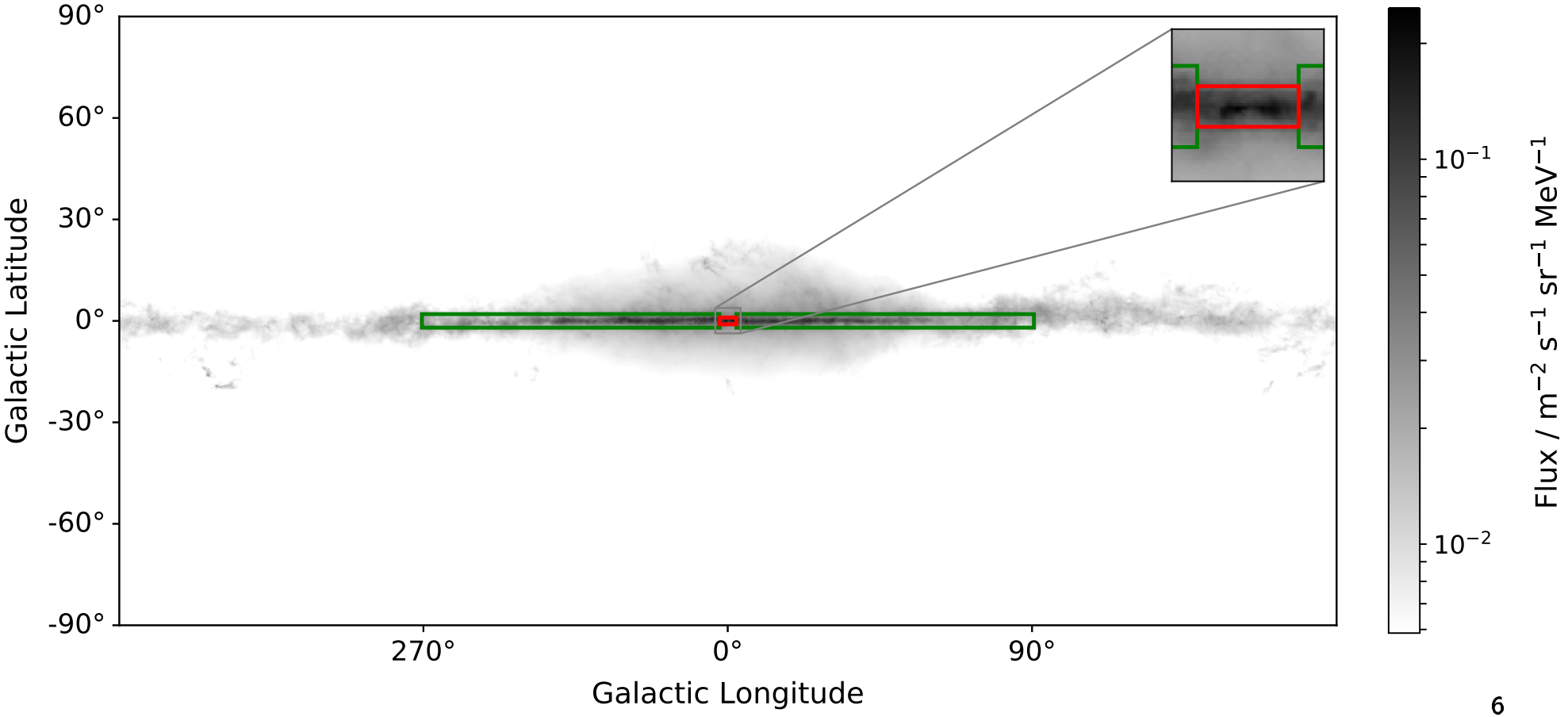
General Background: Photons



Dominant (depend on line of sight!): $E > 100$ keV extragalactic, $E > 100$ keV albedo

General Background: Photons

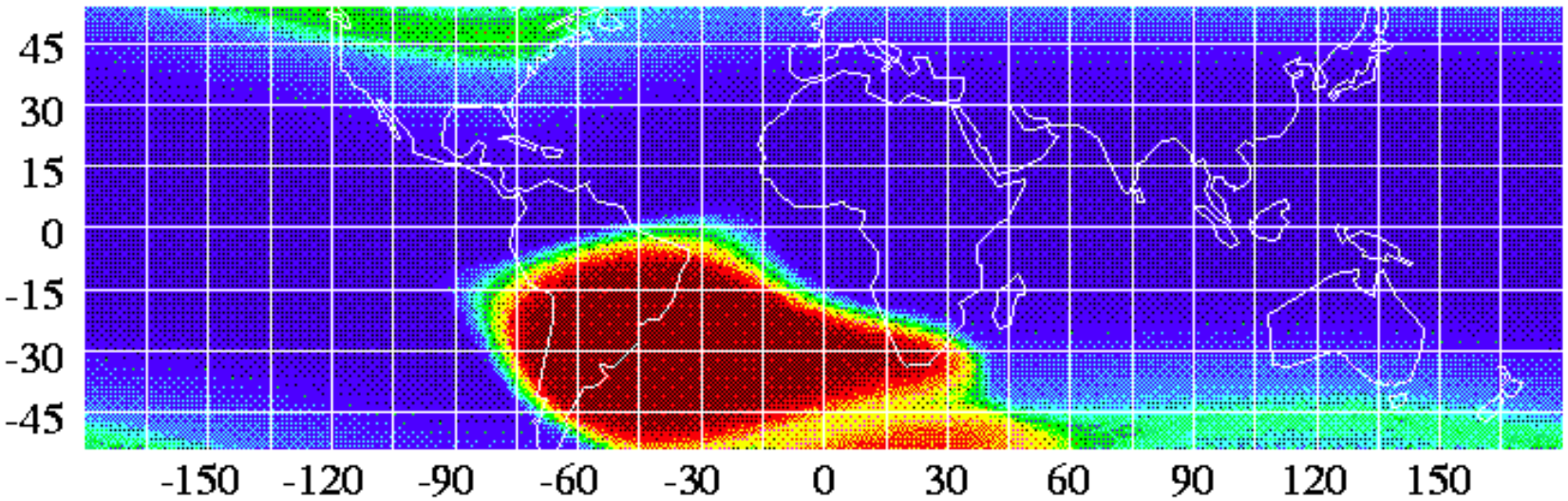
Dominant: Galactic center ($b = \pm 1^\circ$, $l = \pm 2.5^\circ$, $E > 400$ MeV) or the Galactic disk ($b = \pm 2^\circ$, $l = \pm 90^\circ$, $E > 1$ GeV)



General Background: Validity

	Orbit Parameters	Energy
Extragalactic Photons	Independent	4 keV - 820 GeV
Galactic Photons	Independent	58 MeV - $\sim$ 513 GeV
Albedo Photons	All LEOs	1 keV - 400 GeV
Primary Protons	All LEOs	10 MeV - 10 TeV
Primary Alphas	All LEOs	10 MeV - 10 TeV
Primary Electrons/Positrons	All LEOs	570 MeV - 429 GeV
Secondary Protons	$1.06 \leqslant R_{cutoff} \leqslant 12.47$	1 MeV - 10 GeV
Secondary Electrons/Positrons	$1.06 \leqslant R_{cutoff} \leqslant 12.47$	1 MeV - 20 GeV
Atmospheric Neutrons	Altitude: $\sim$ 100 km - $\sim$ 1000 km Inclination: $< 65^{\circ}$	0.01 eV - $\sim$ 30 GeV

South Atlantic Anomaly

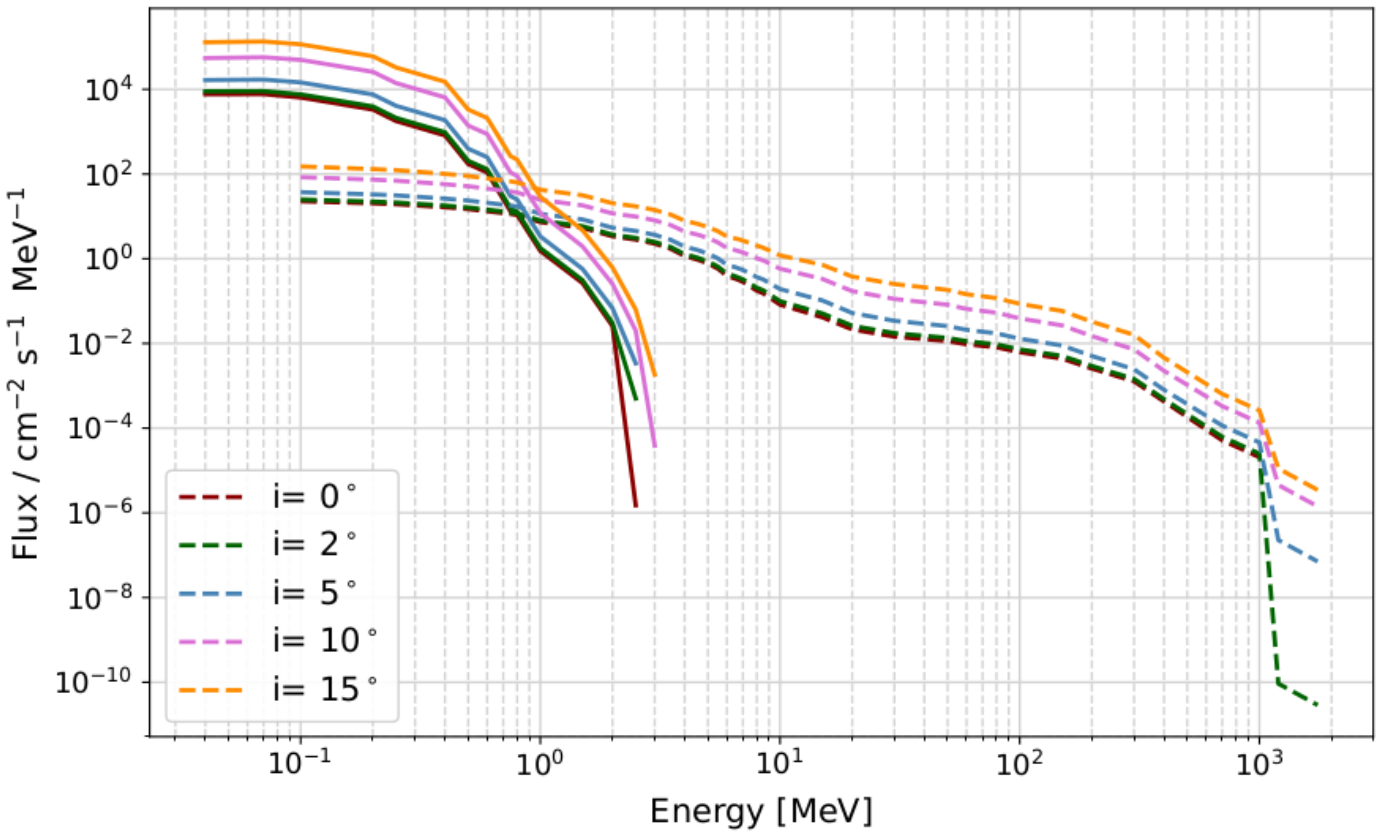


Area where the inner Van Allen radiation belt comes closest to the Earth's surface.

South Atlantic Anomaly (SAA) shape and boundaries change both with the orbit altitude and the considered energy threshold

South Atlantic Anomaly

- AE9/AP9 Model
- Average spectrum over 1 month ($\sim$ 450 orbit)
- Altitudes: 550 and 600 km
- Inclinations: 0°, 1°, 2°, 3°, 4°, 5°, 10°, 15°



Activation Simulations

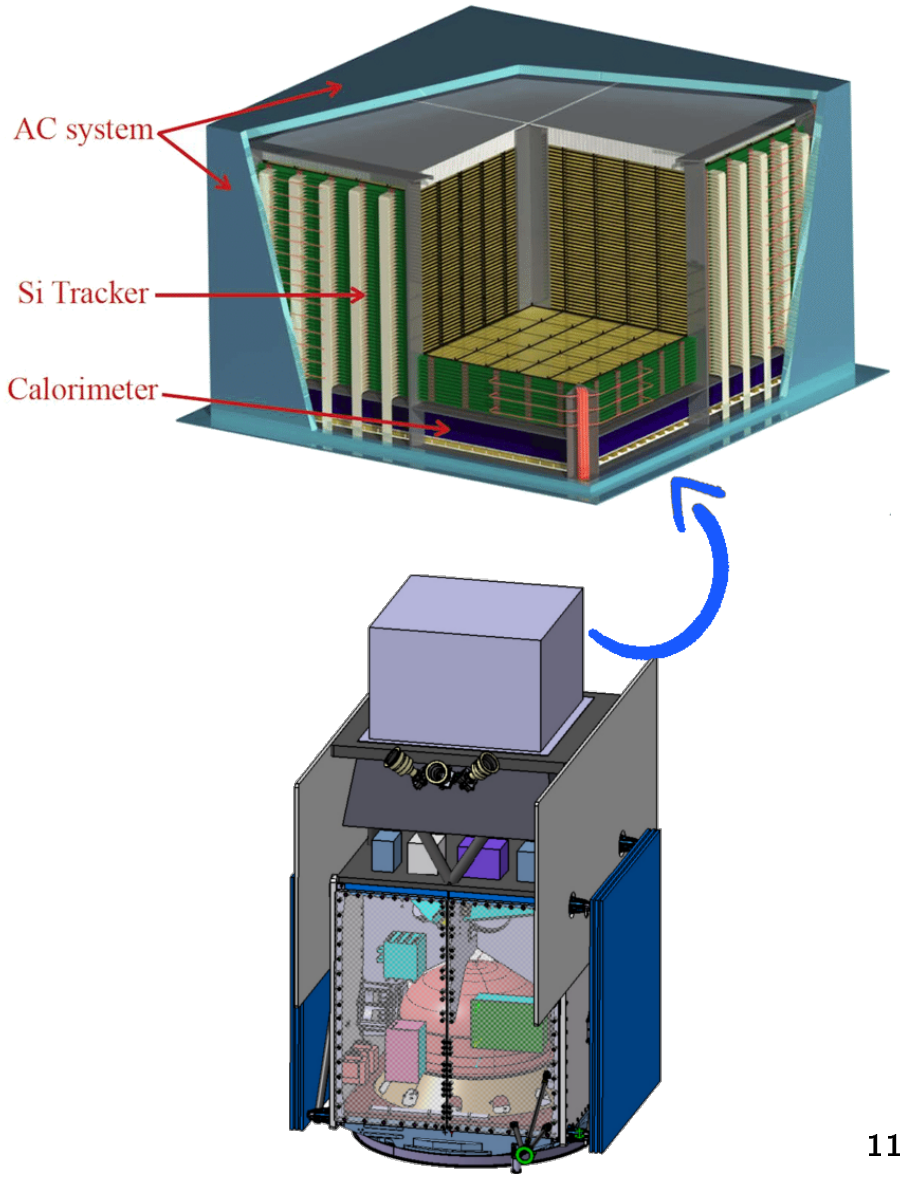
Particles passing through the detector can create unstable isotopes.

Divided in 3 steps:

- Calculation of the created isotopes
- Irradiation:
  - SAA Short term: Costant 10 min with cool-down: 0, 60, 120, 300, 600 s
  - SAA Long term: Constant 72 days (equivalent to 1 year of passages) with cool-down 45 minutes
  - General background: Constant 1 year, no cool-down
- Activation
- Reconstruction

Activation Simulations: e-ASTROGAM

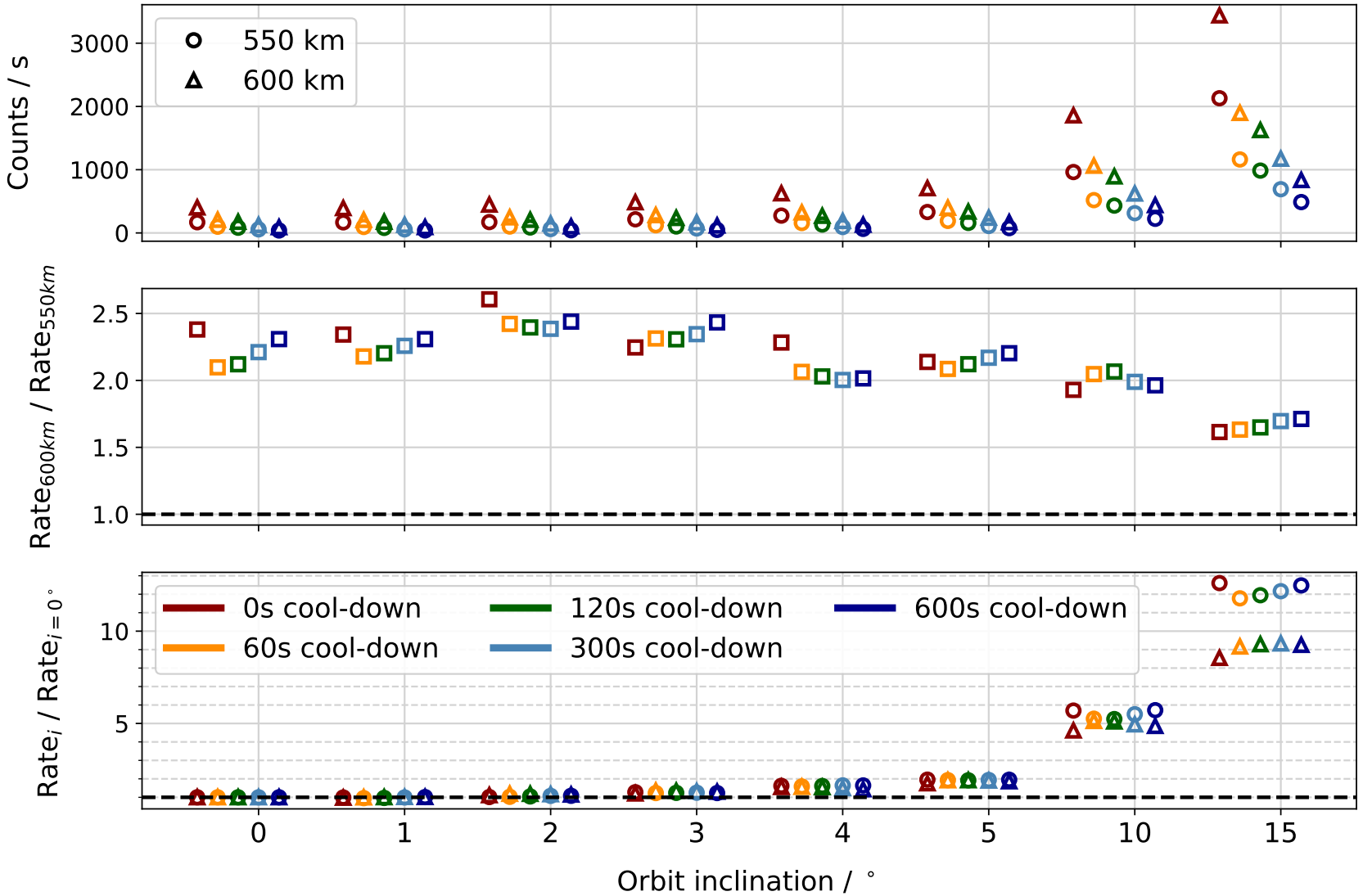
- Tracker: double sided Silicon detector
- Calorimeter: Thallium activated Cesium Iodide
- Anticoincidence: Plastic scintillator tiles coupled to SiPM
- Supports, spacecraft, electronics, passive materials, etc...



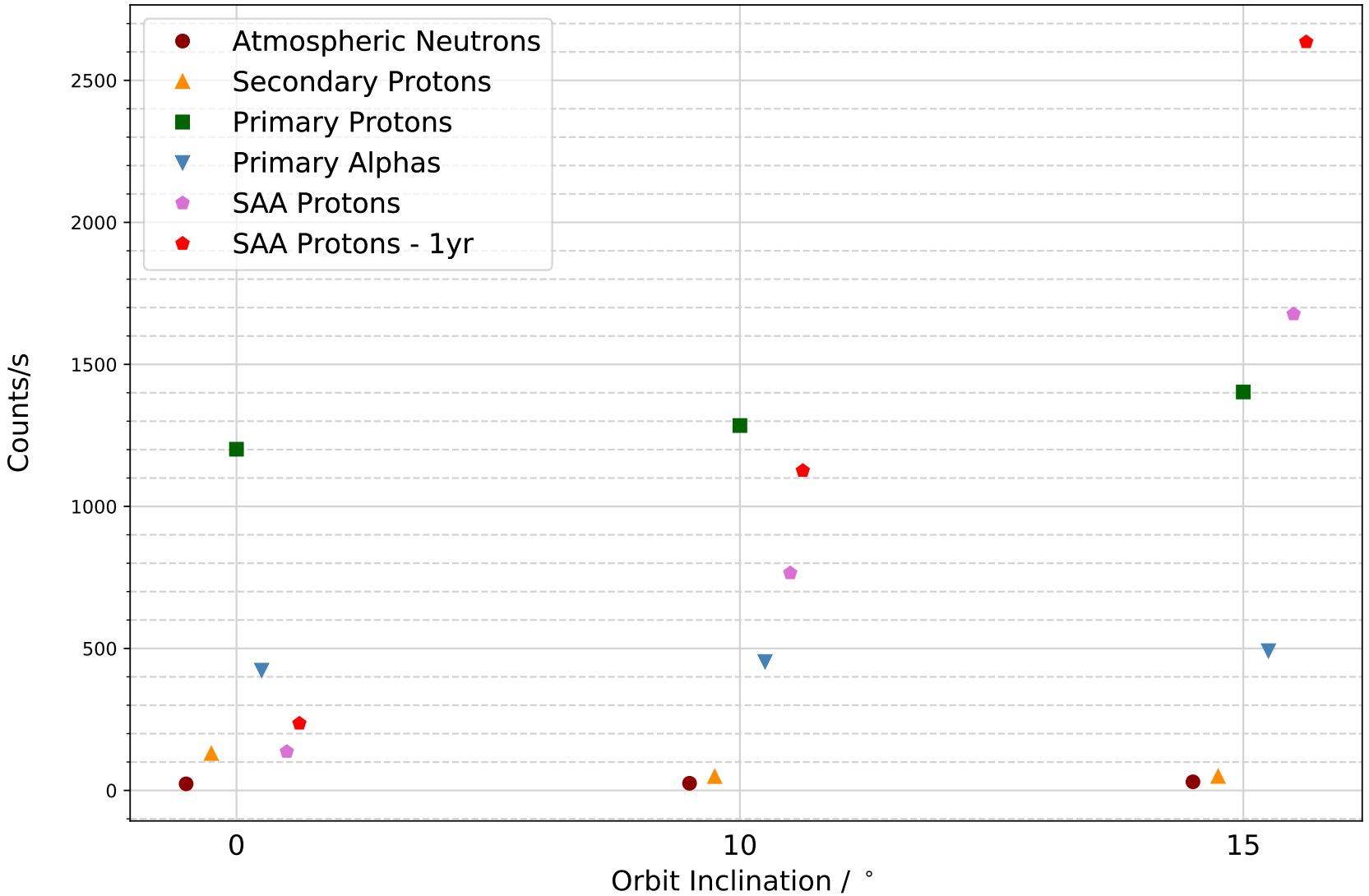
Activation Simulations

Isotope	$T_{1/2}$	Activation$_i$ / Activation$_{max}$ General Background	SAA 1 yr	SAA 1 orb.	Volumes
^{11}C	20 m	0.2 (0.6 sp)	1	0.8	Anticoincidence Supports Spacecraft Electronics
^{128}I	25 m	1	0.9	0.4	Calorimeter Crystals
^{126}I	13 d	0.3	0.7	< 0.1	
^{132}Cs	6.5 d	0.2	0.8	< 0.1	
^{134}Cs	2.1 yr	0.5	0.3	< 0.1	
^{125}I	59 d	0.2	0.5	< 0.1	
^{131}Cs	9.7 d	0.1	0.5	< 0.1	
^{123}I	13 h	0.1	0.5	< 0.1	
^{122}I	3.6 m	0.1	0.1	0.1	
^{126}Cs	1.6 m	< 0.1	< 0.1	0.1	
^{25}Al	7.2 s	< 0.1 (0.1 sp)	< 0.1	0.5	Spacecraft Electronics Tracker Wafers Calorimeter Diodes
^{28}Al	2.2 m	0.3 (0.4 n)	< 0.1	0.5	Calorimeter Diodes Electronics Tracker Wafers
^{15}O	2 m	0.1 (0.3 sp)	< 0.1	1	Anticoincidence Electronics Supports

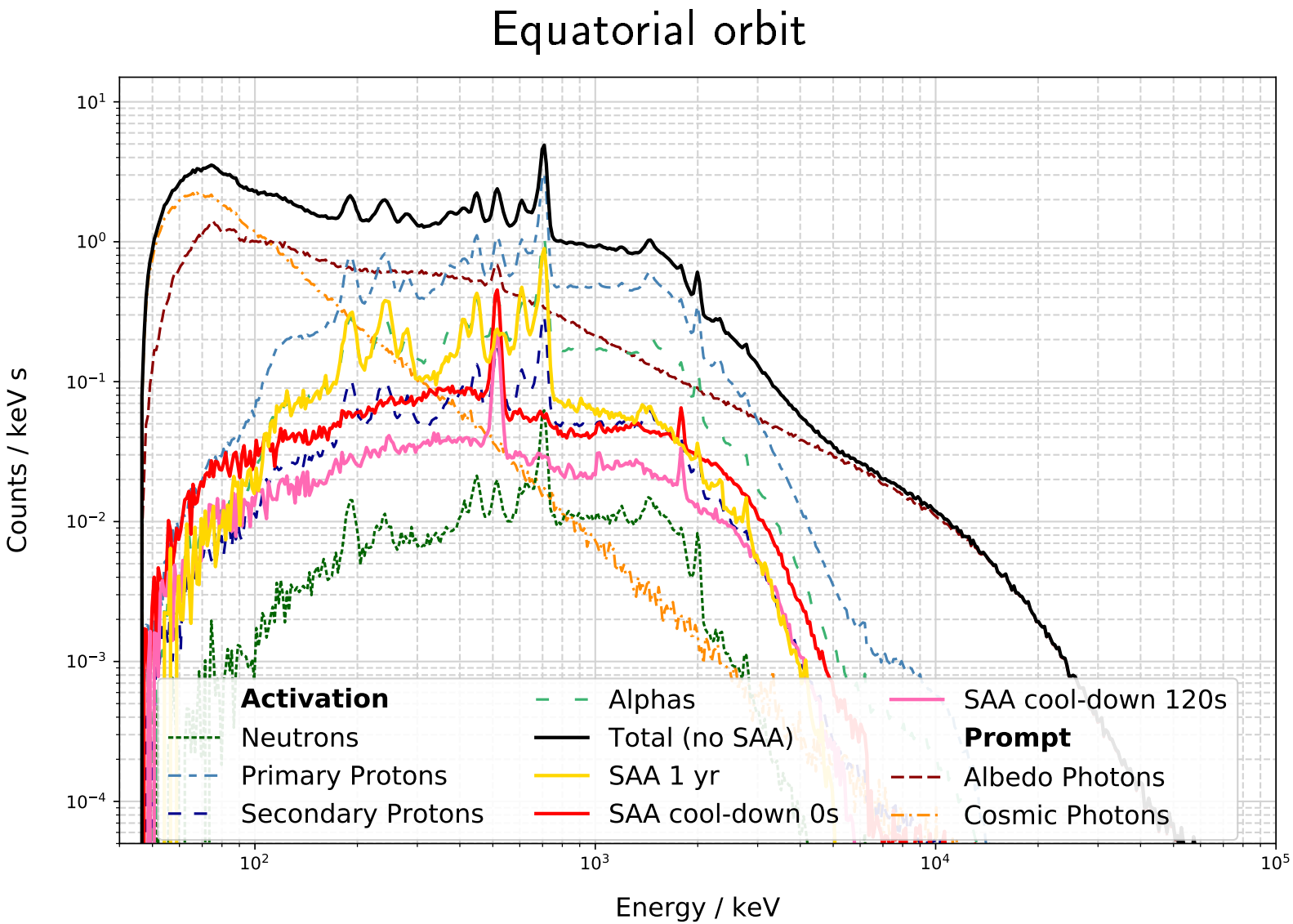
Activation Simulations: SAA



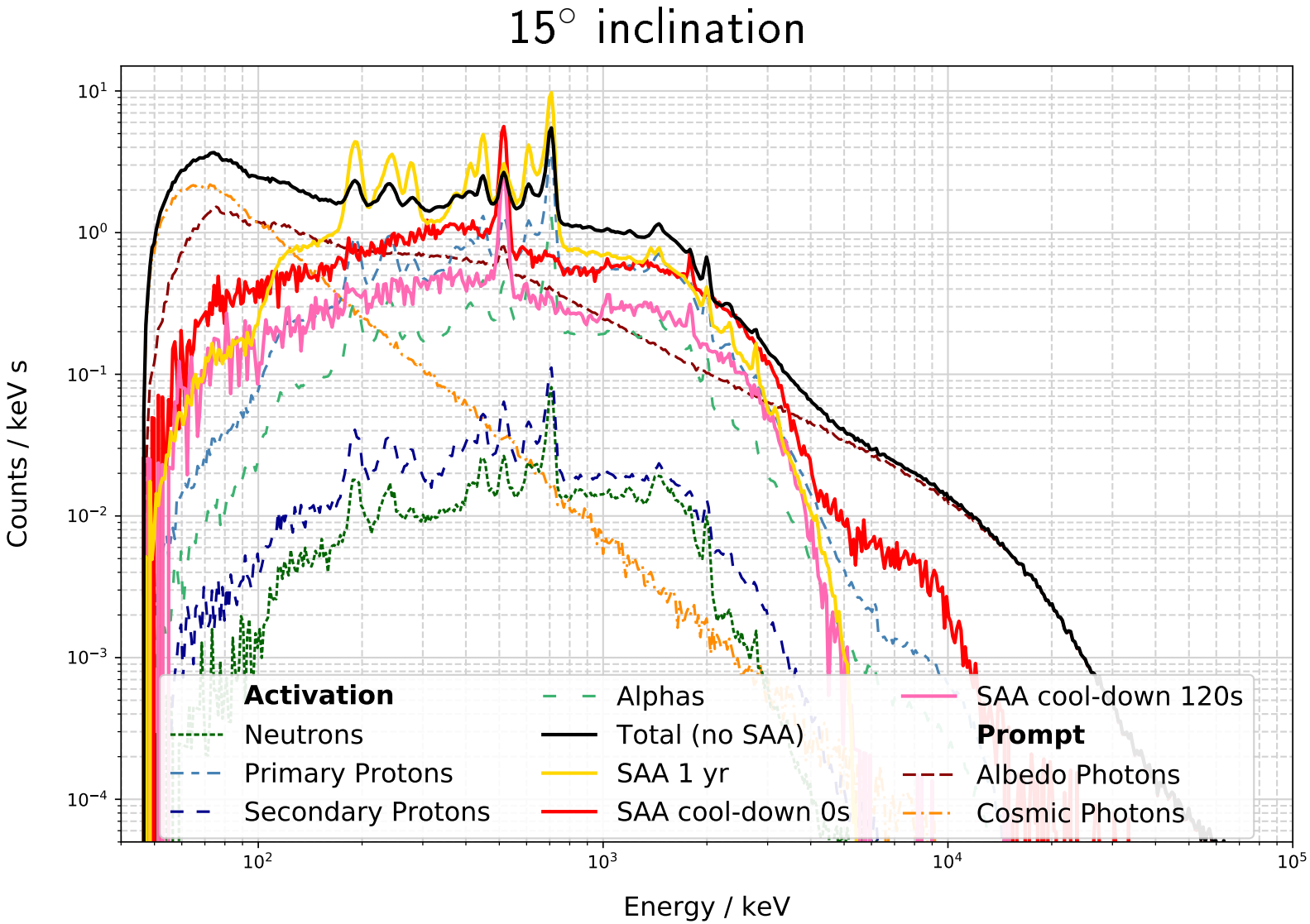
Activation Simulations: All Components



Activation Simulations Spectra



Activation Simulations Spectra



Conclusions

- A model of all the background components on a LEO was developed
- Paper has been submitted to Experimental Astronomy
- Python macros are already available on github (`https://github.com/pcumani/LEOBackground`)

Conclusions

- Primary protons are the main contributor of the activation, α a fourth of that, neutrons and secondary protons negligible
- SAA contribution to the rates gains importance when increasing the inclination: 0° negligible, 10° second contributor, 15° main contributor
- SAA long term activation spectrum higher than the sum of all the other components between 150 and 720 keV at 15°, comparable to α at 0°
- SAA short term contribution to 511 keV line always important. At 0° quickly drops, at 15° long cool down is needed

Conclusions

- SAA contribution increase by a factor of 2 from 550 to 600 km. Small changes for the general background

The orbit with the lowest background has an altitude of 550 km and a low inclination ($i < 5^{\circ}$)

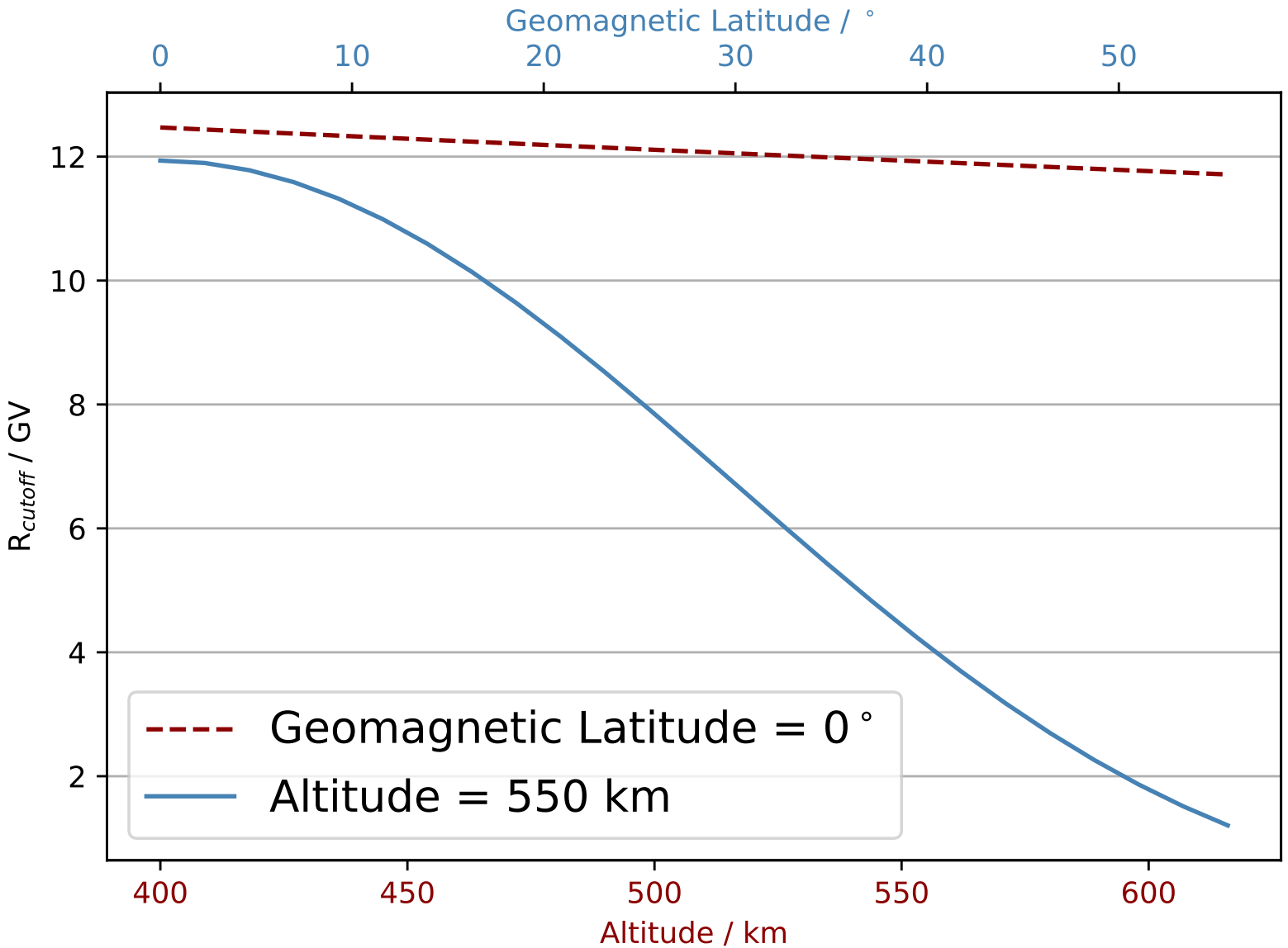
Spare slides

On-orbit Background

- Geomagnetic latitude assumed equal to the inclination
- Average geomagnetic cutoff (in GV): is calculated as in Smart and Shea (2005):

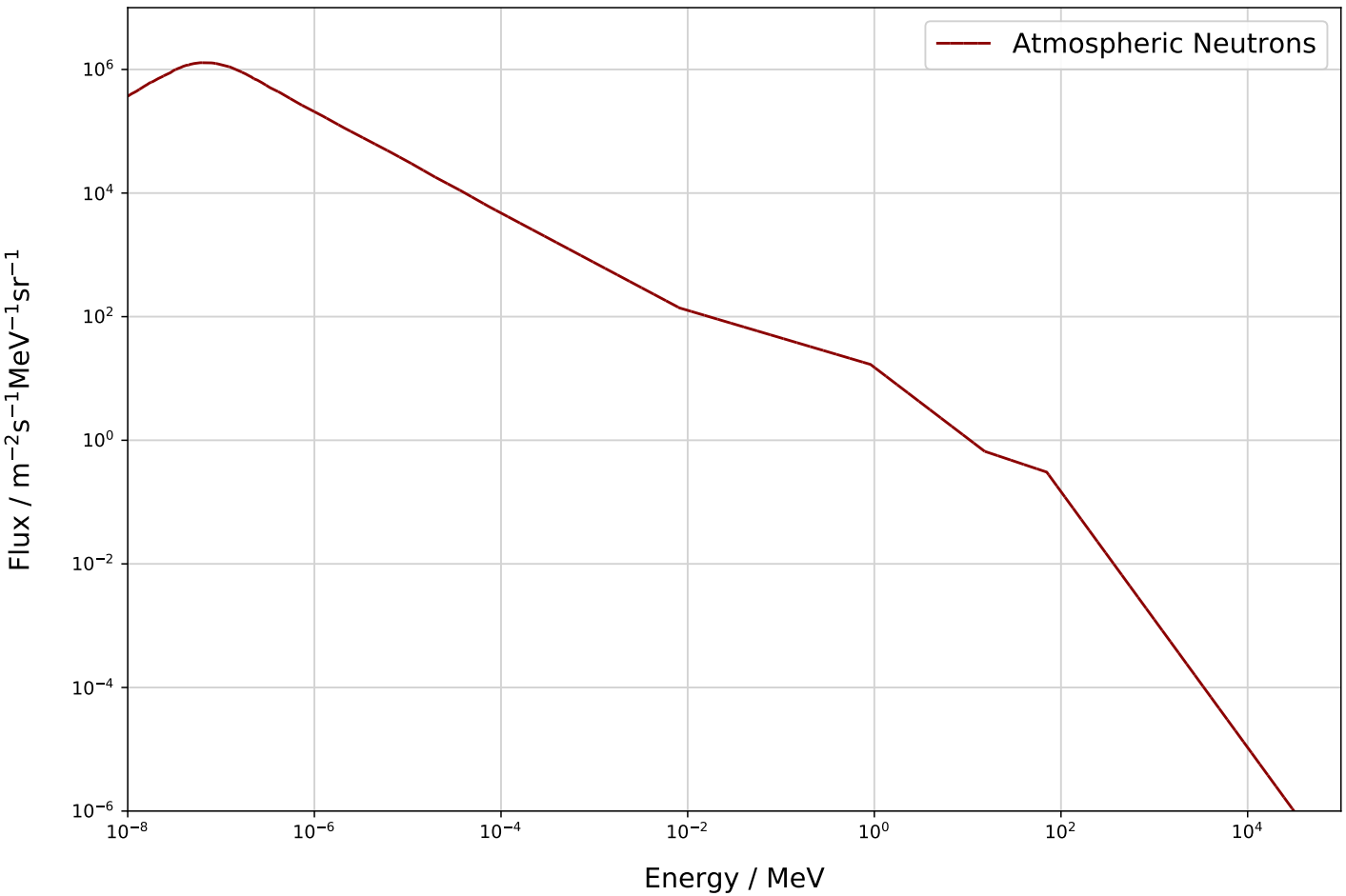
$$R_{cutoff} = \frac{g_1^0 \cdot R_\oplus}{4} \cdot \left(1 + \frac{h}{R_\oplus}\right)^{-2} \cos^4 \lambda$$
$$= 11.9 \text{ GV} \cdot \frac{g_1^0}{29442.0 \ \mu\text{T}} \cdot \left(\frac{R_\oplus + 550 \text{ km}}{R_\oplus + h}\right)^2 \cos^4 \lambda \quad (1)$$

On-orbit Background: Geomagnetic cutoff

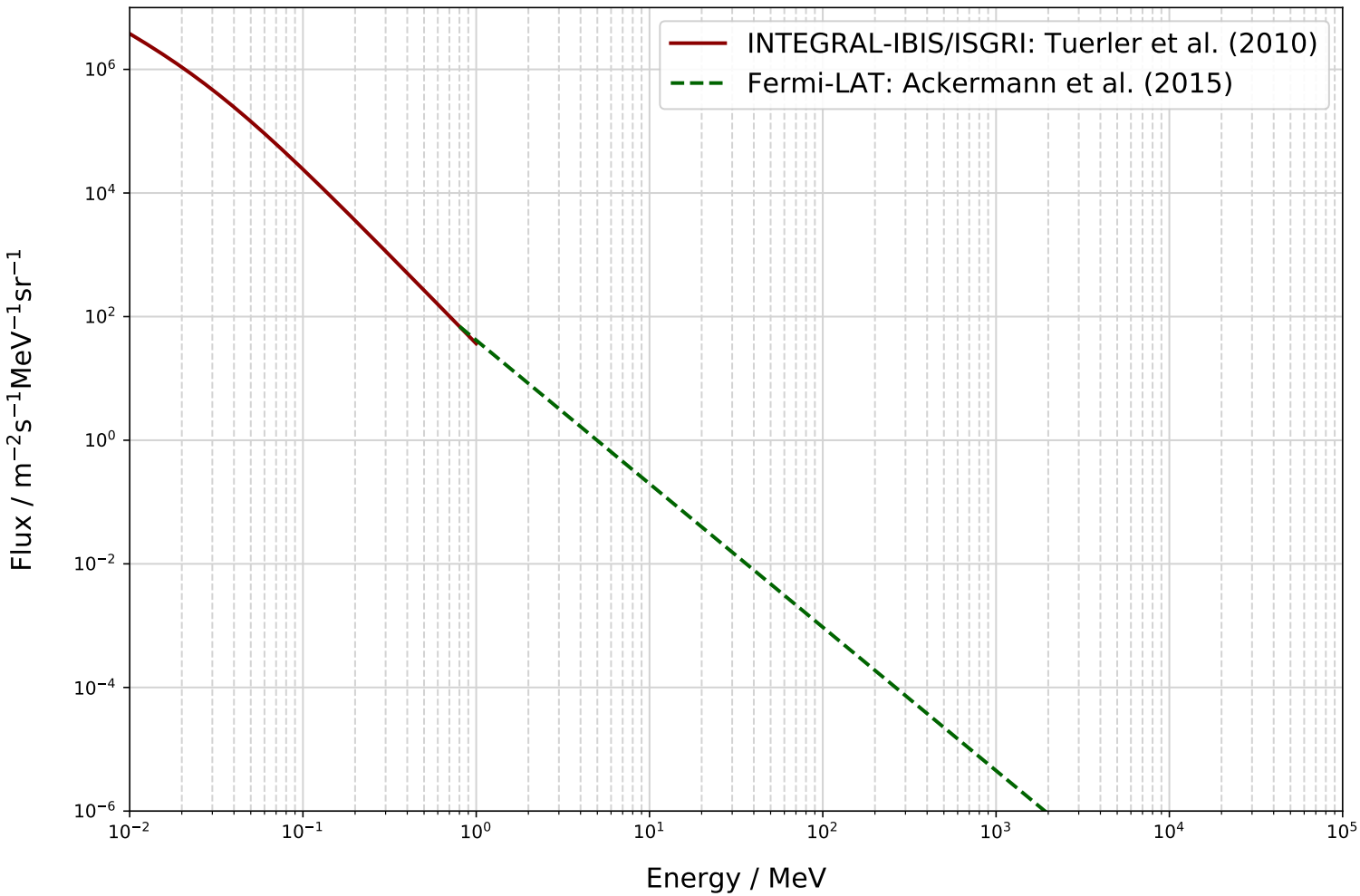


Atmospheric Neutrons

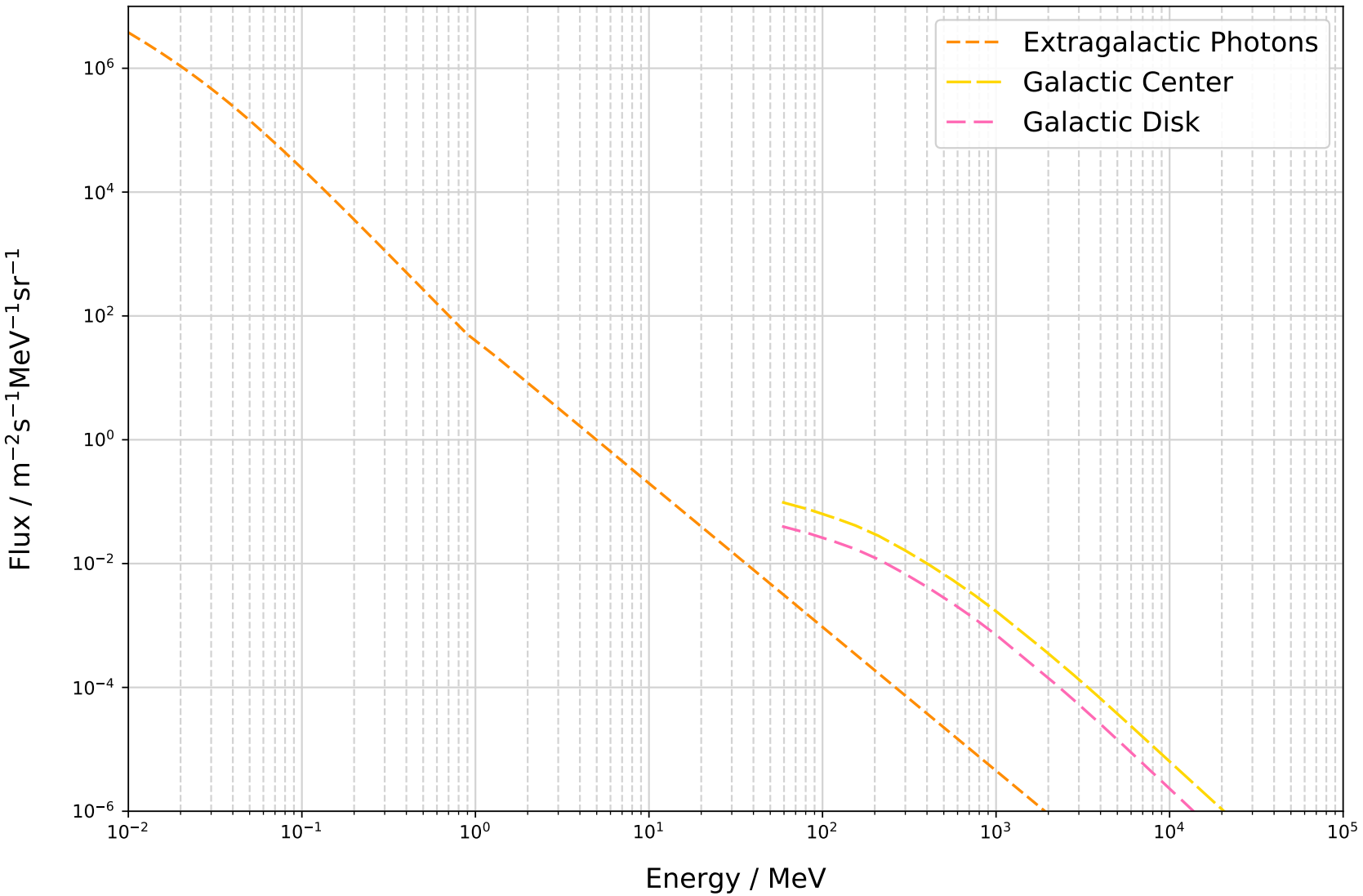
$E > 8$ keV Kole et al. (2015), $E < 8$ keV Lingenfelter (1963)



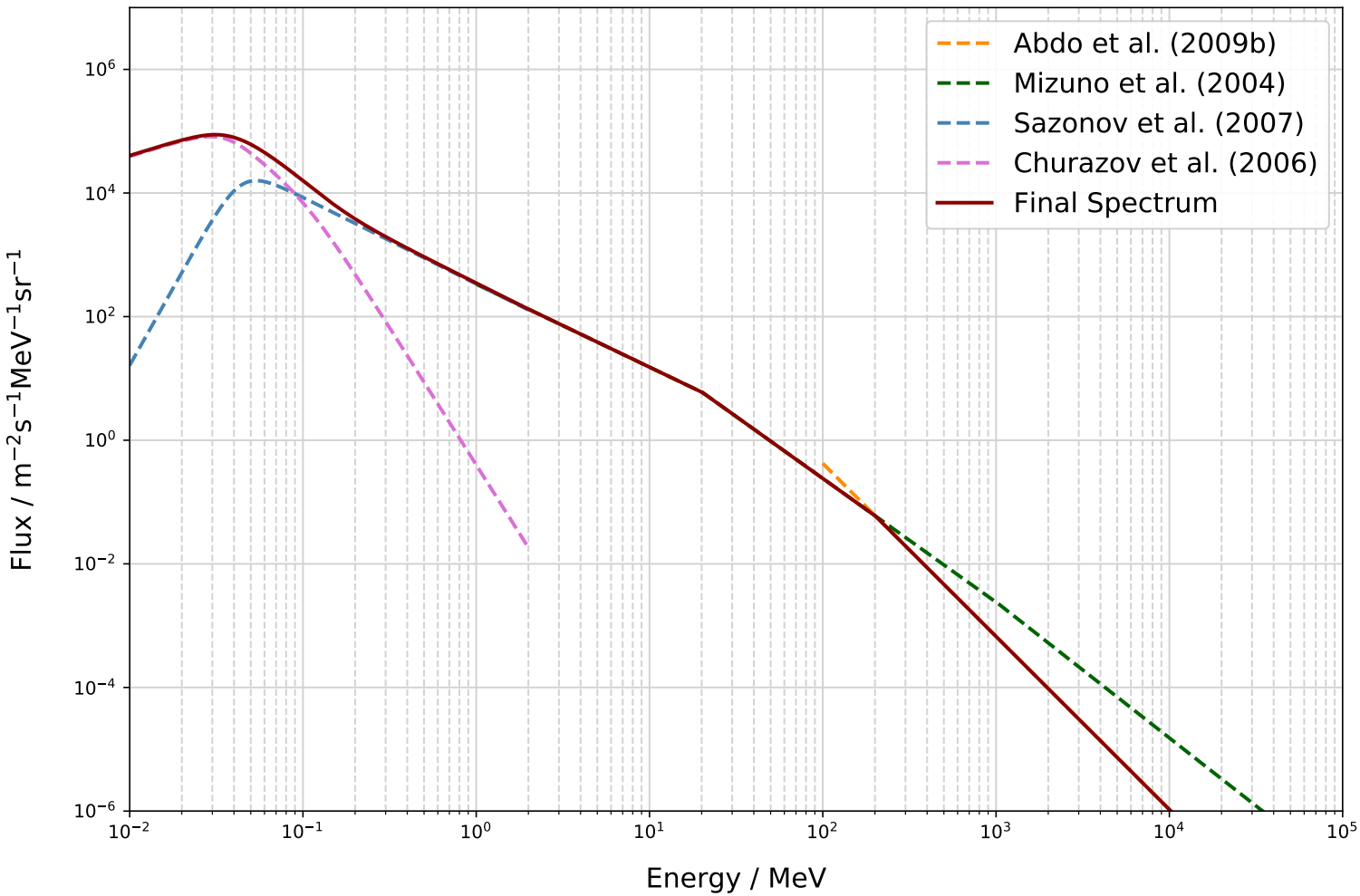
Extragalactic Photons



Photons


Extragalactic Photons
Galactic Center
Galactic Disk
Flux / m^{-2}s^{-1}MeV^{-1}sr^{-1}
Energy / MeV
10^{6}
10^{4}
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}

Albedo Photons

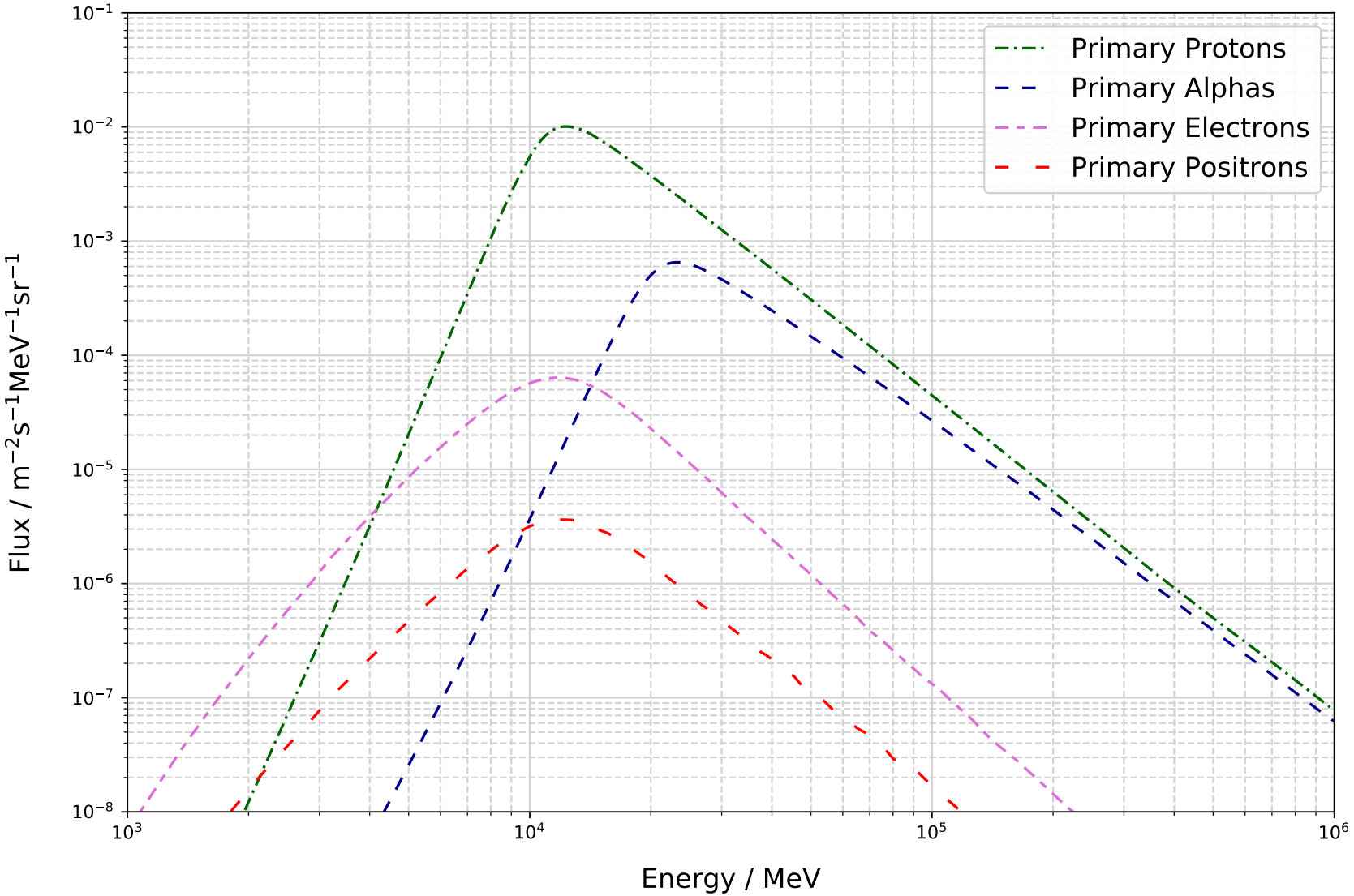


Albedo Photons

- E<1.85 MeV: The sum of:
  - Hard X-ray surface brightness of the Earth's atmosphere Sazonov et al. (2007)
  - Reflected cosmic X-ray background from Churazov et al. (2006)
- 1.85 MeV < E < 200 MeV: From Mizuno et al. (2004)
- E>200 MeV: From Abdo et al. (2009):

All the results are normalized to the Mizuno et al. (2004) ones

Primary Charged Particles



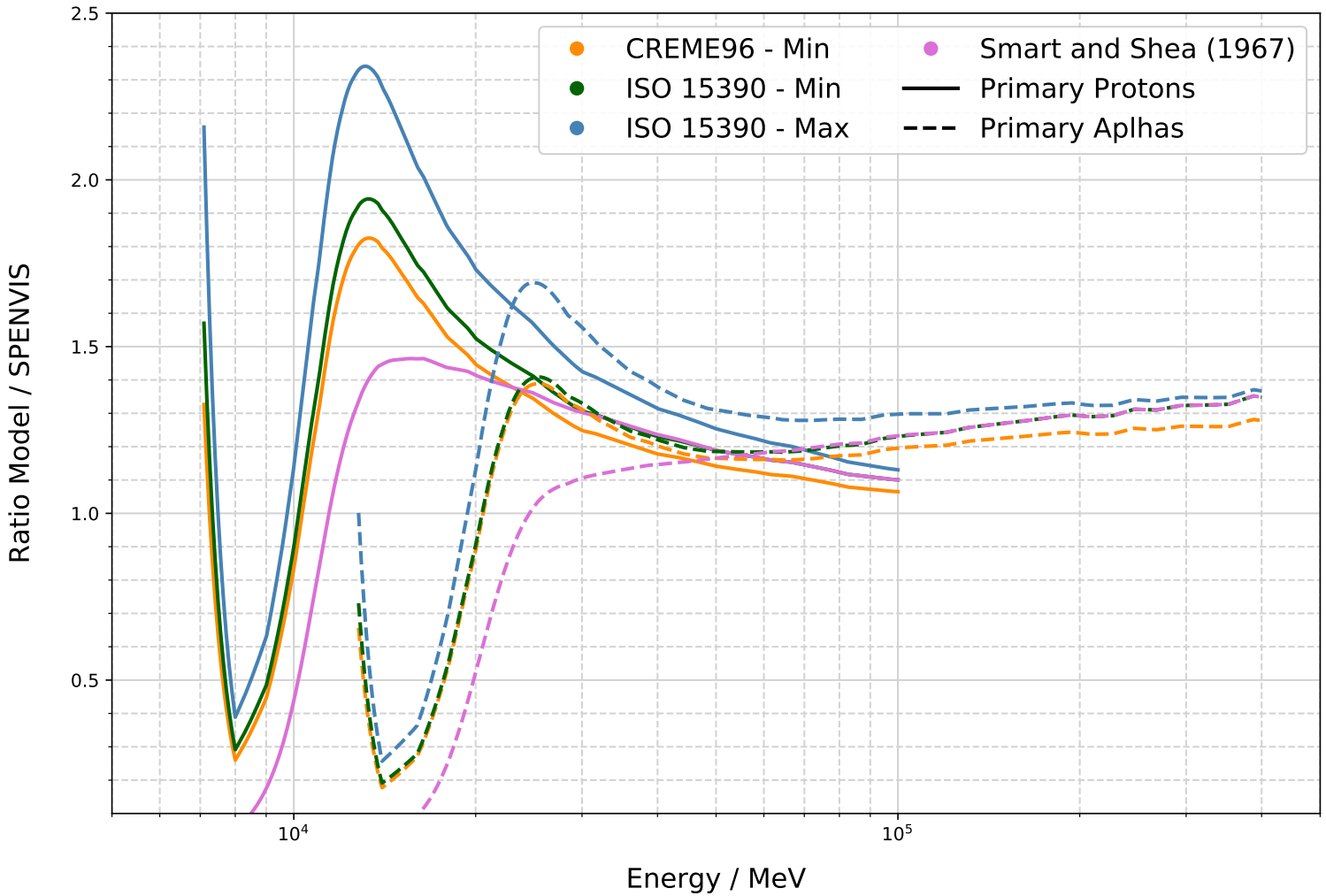
Primary Charged Particles

AMS data (Aguilar et al. (2015), Aguilar et al. (2014)) plus reduction factor from the geomagnetic cutoff.

Why not SPENVIS?

- Not rely on an external tool
- Consistency with primary electrons/positrons spectra (that can not be calculated using SPENVIS)

Primary Charged Particles



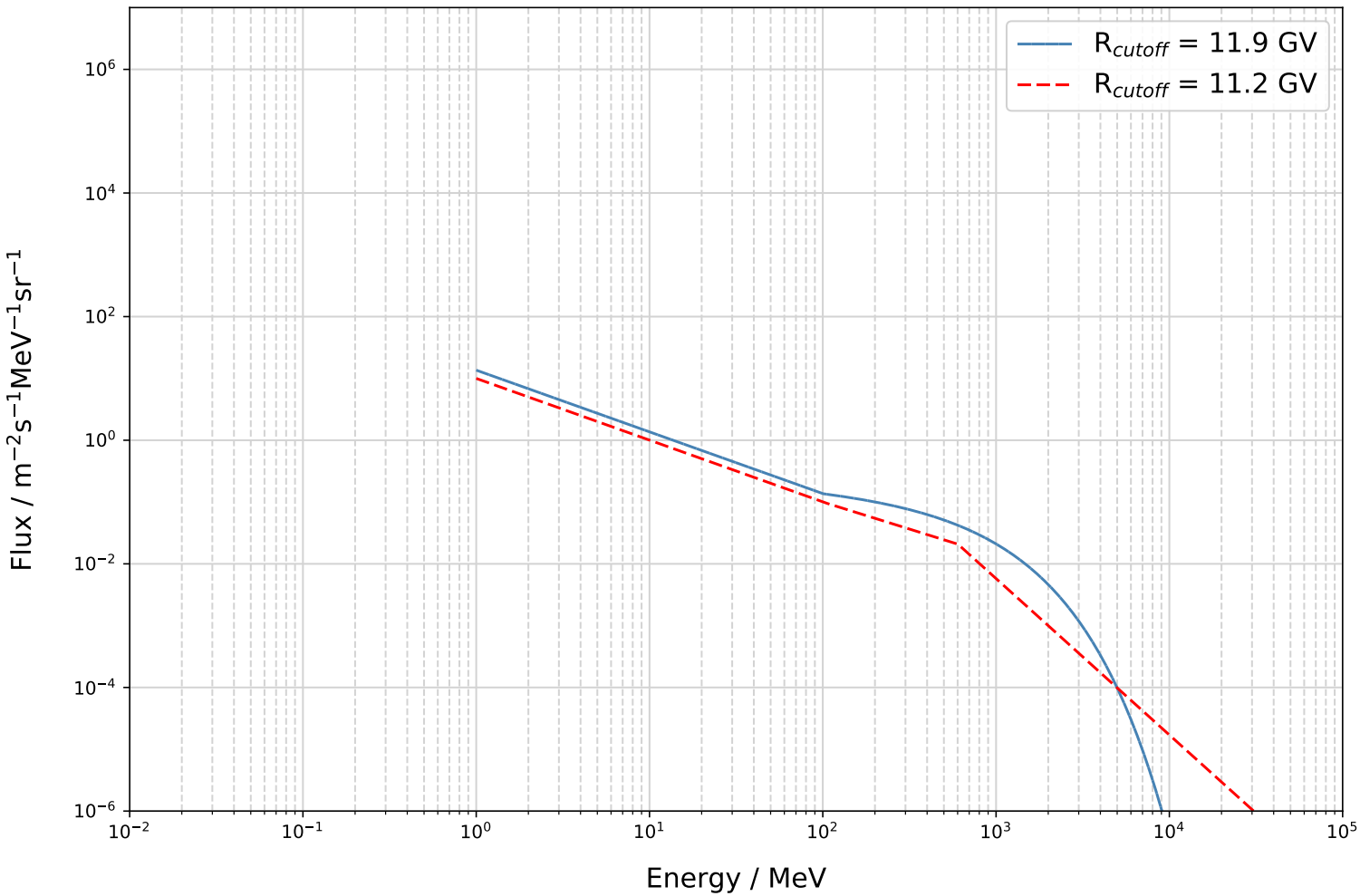
Secondary Protons

Mizuno et al. (2004) model from AMS-01:

- Altitude 380 km
- different geomagnetic latitudes λ

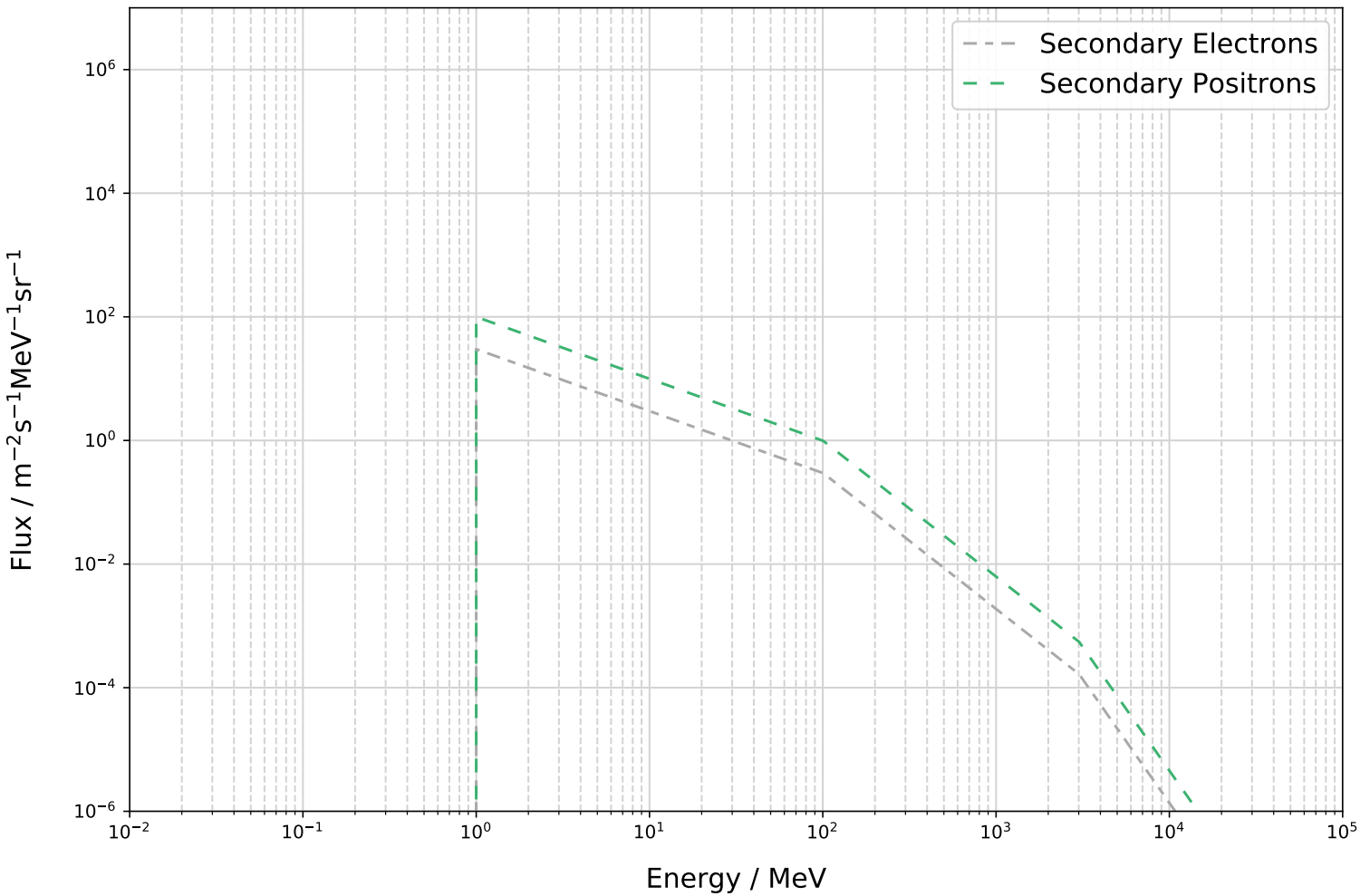
We assume that R_{cutoff} is a more relevant parameter to describe the particle flux for different altitudes and inclinations

Secondary Protons

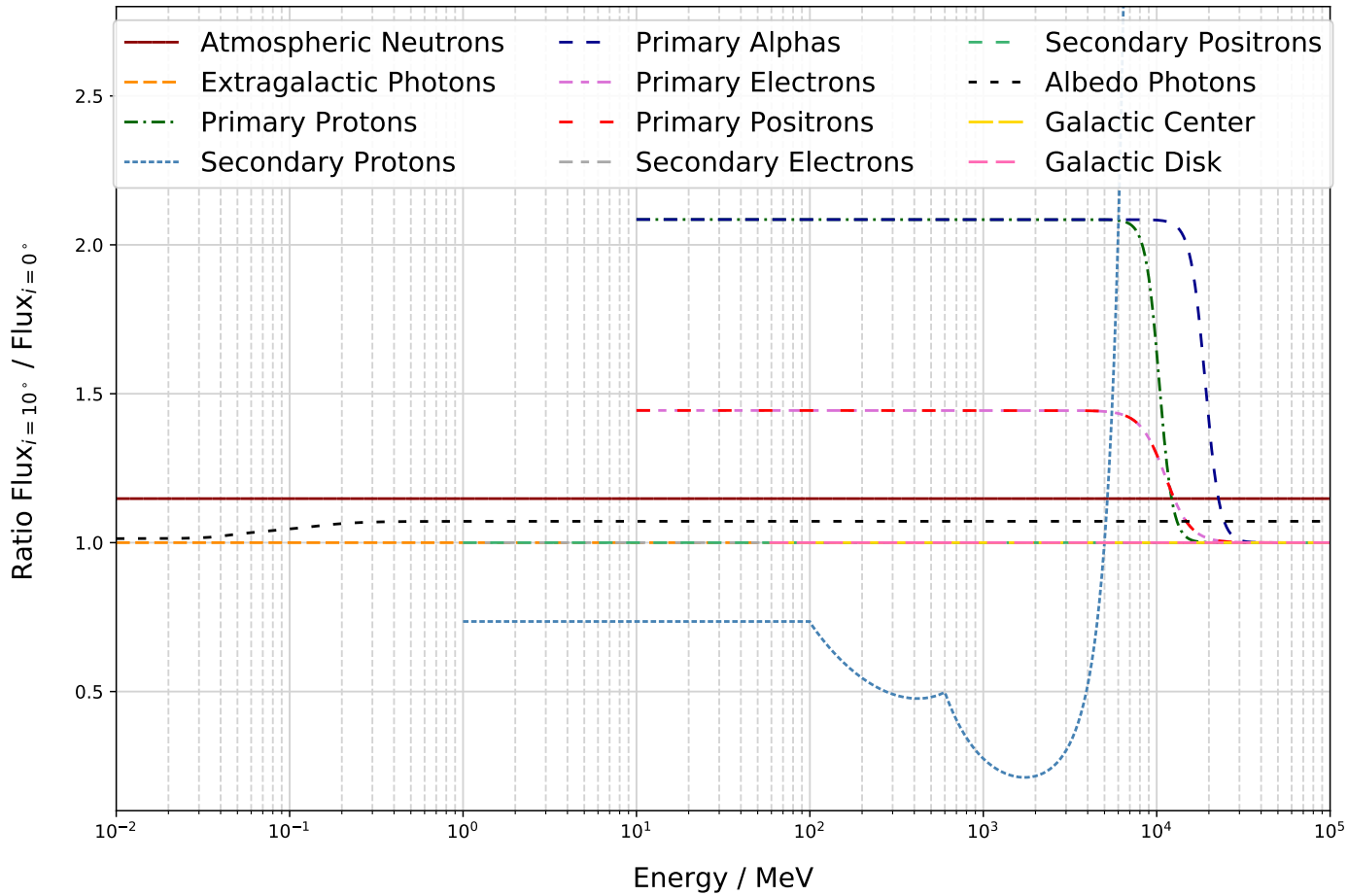


Secondary Electrons & Positrons

From Mizuno et al. (2004)



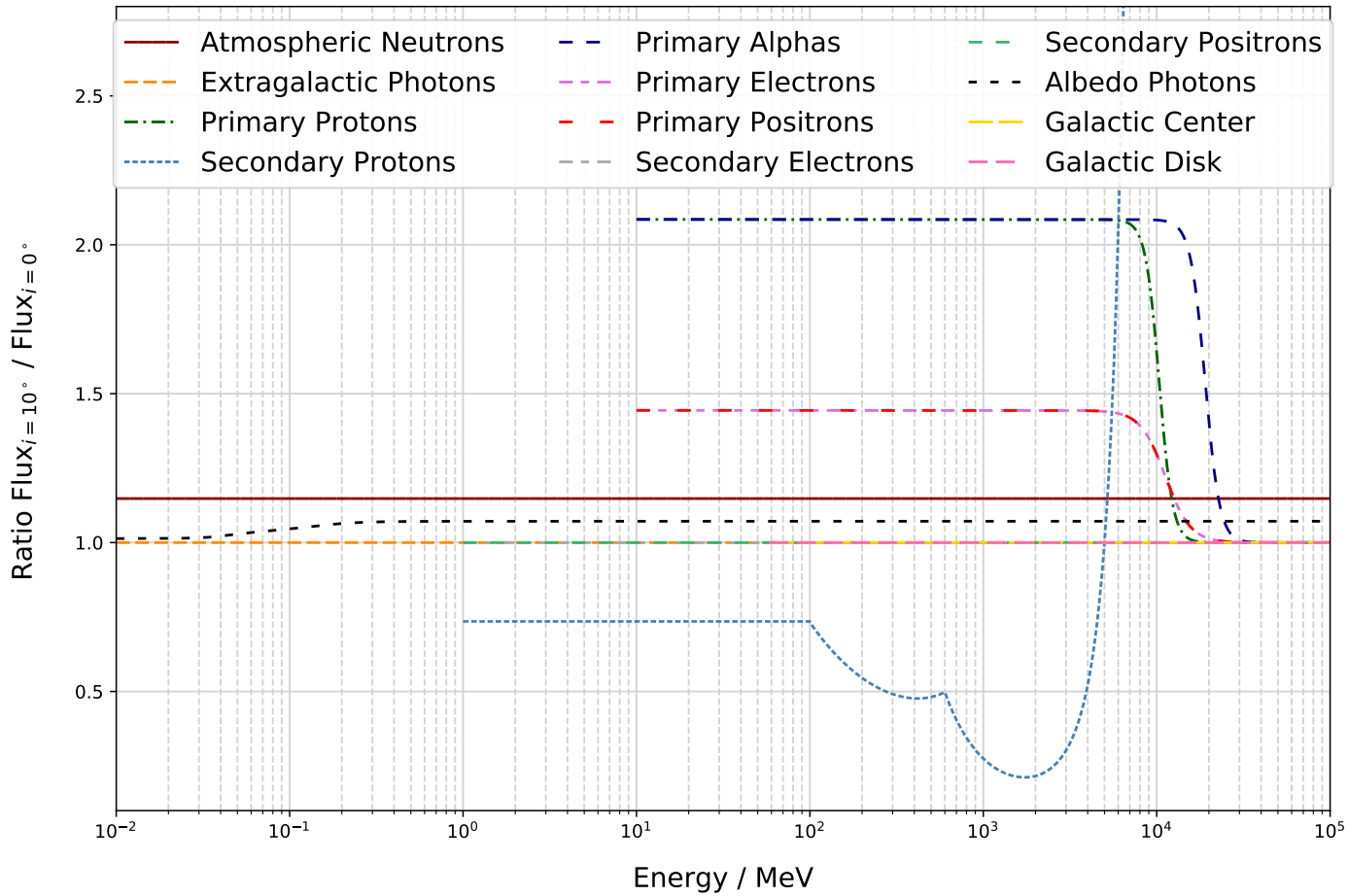
General Background: Inclination Change



Unchanged: Galactic and extra-Galactic photons background

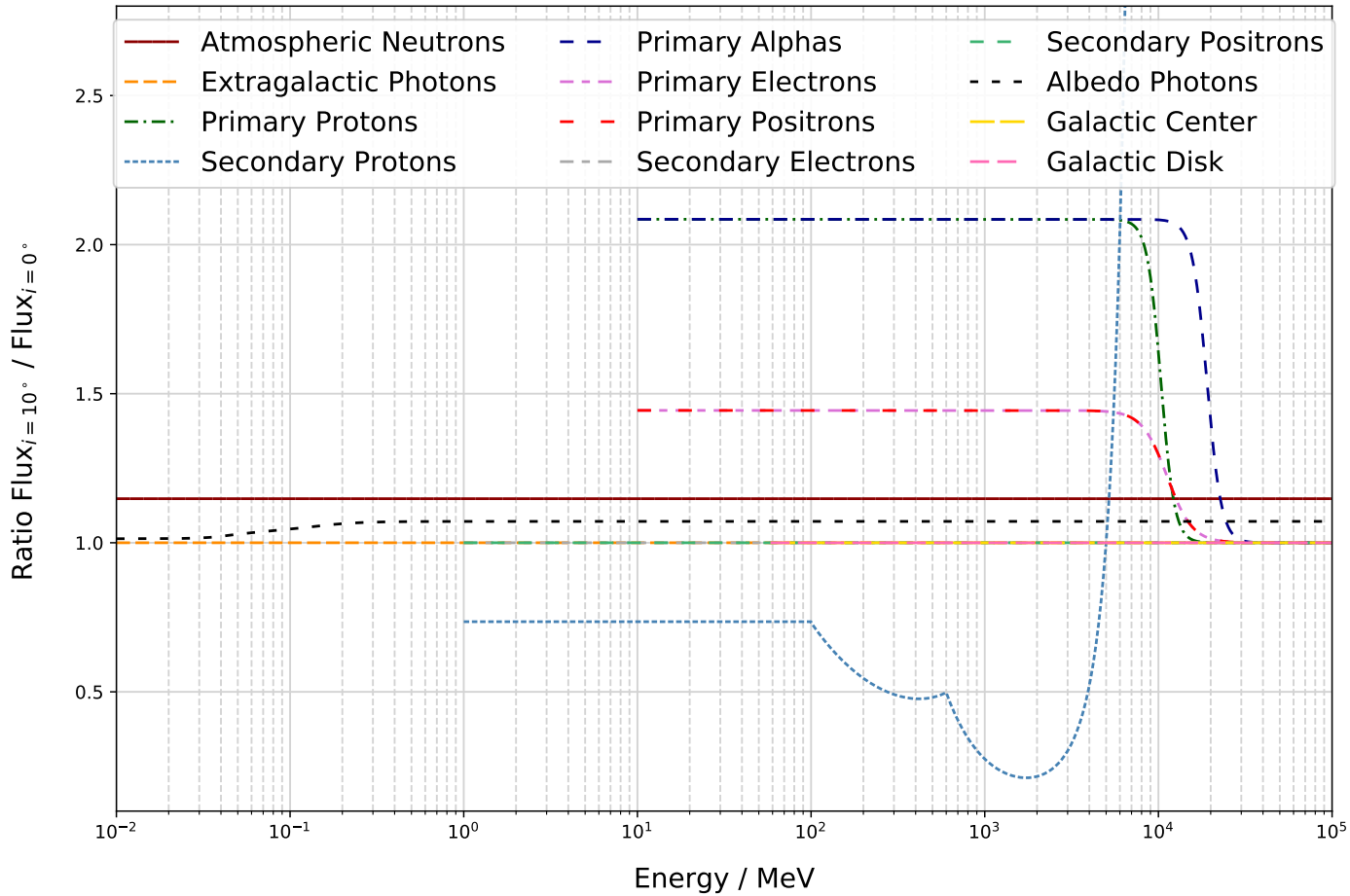
Secondary $e^{\pm}$ spectra (change shape for lower cutoff values)

General Background: Inclination Change



Secondary p (shape change with cutoff): decrease up to a factor > 2, E$\lesssim 4$ GeV rapid increase.

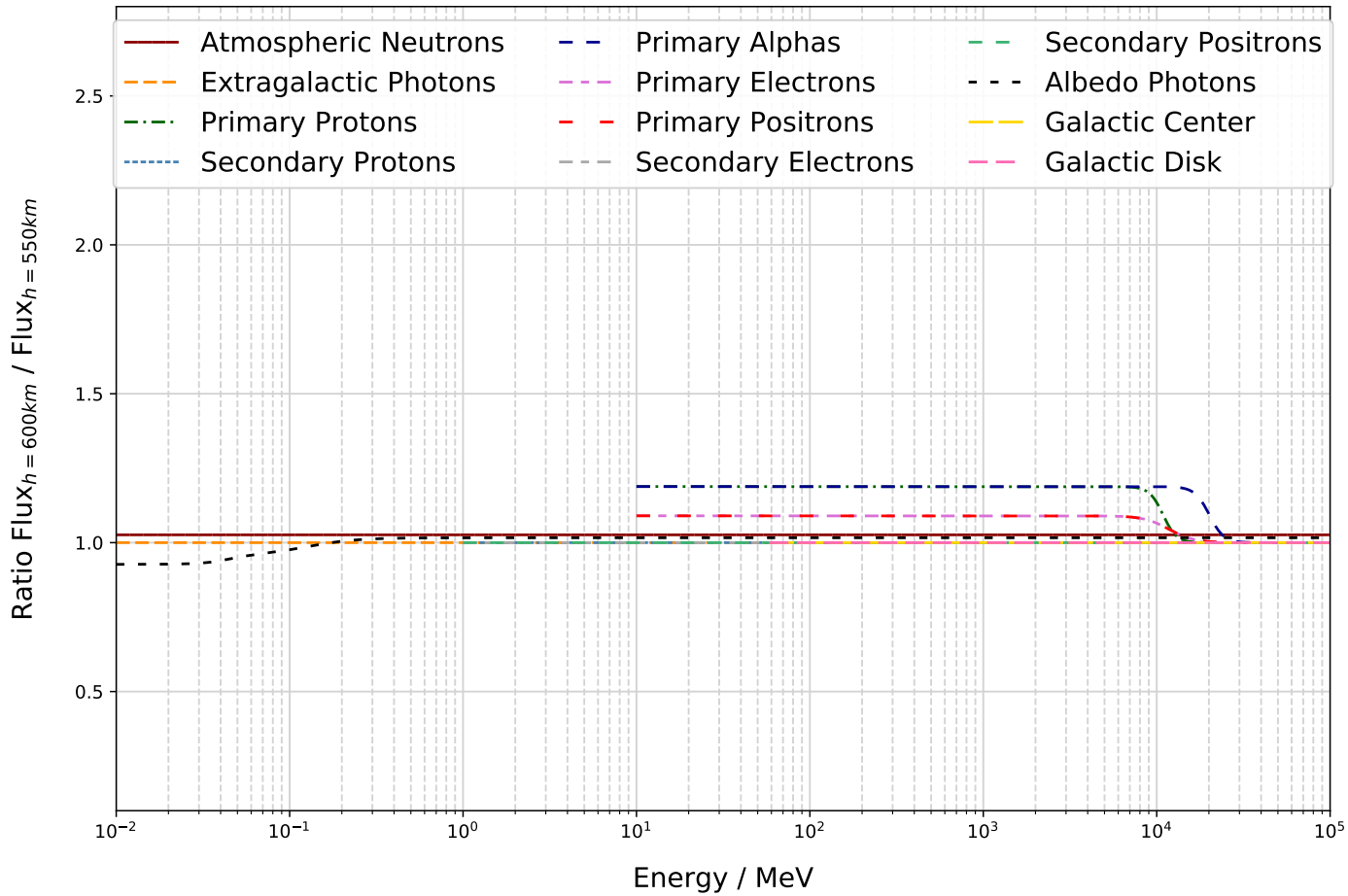
General Background: Inclination Change



Albedo γ: Change $\leqslant 10\%$. Atmospheric n: $\sim 17\%$ change.

Primary p, α ($e^{\pm}$): factor >2 (1.4) increase only for E < cutoff

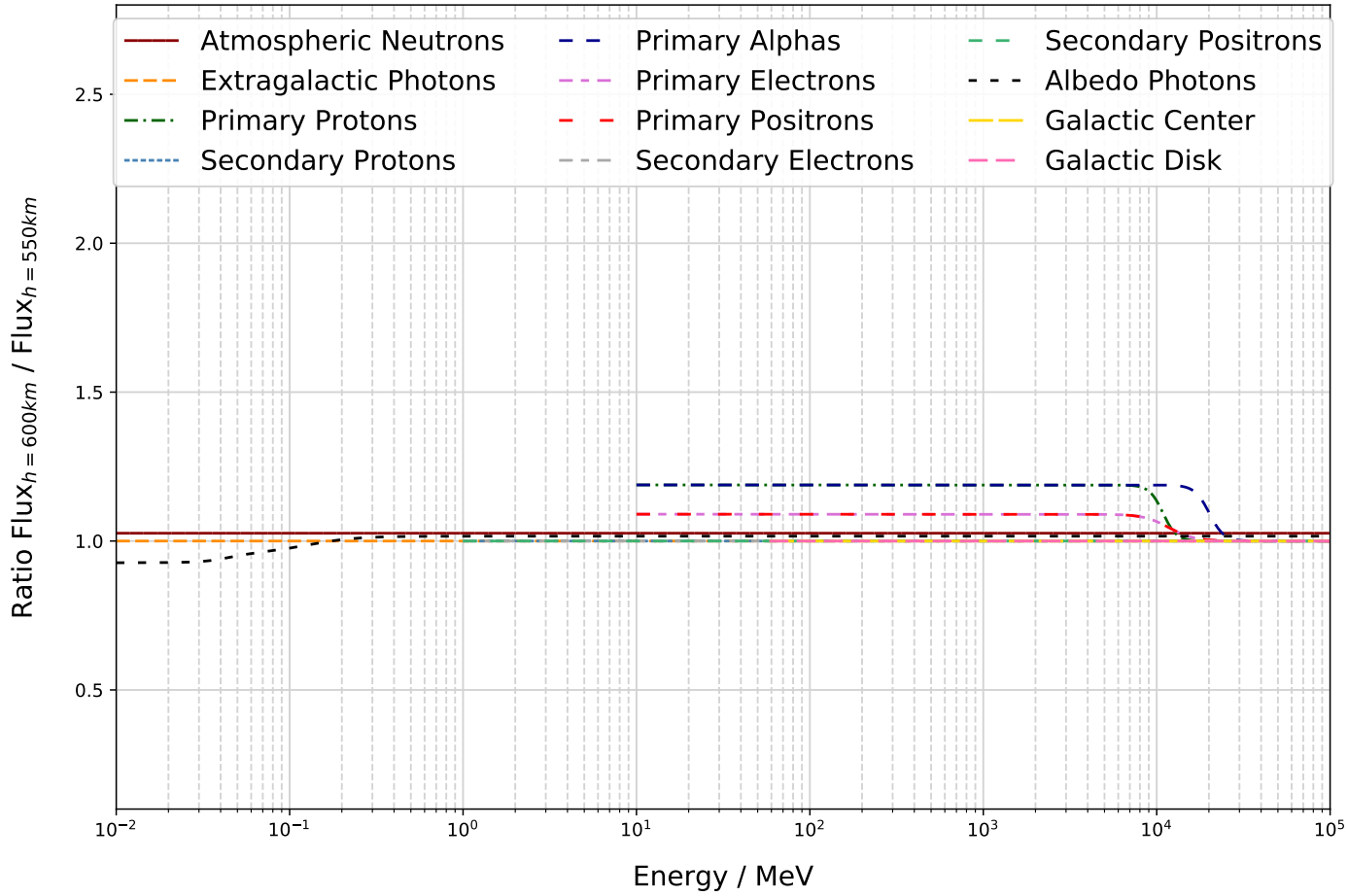
General Background: Altitude Change



Charged secondaries: shape change only for lower cutoff values

Albedo photons / Atmospheric neutrons: 10% or less change

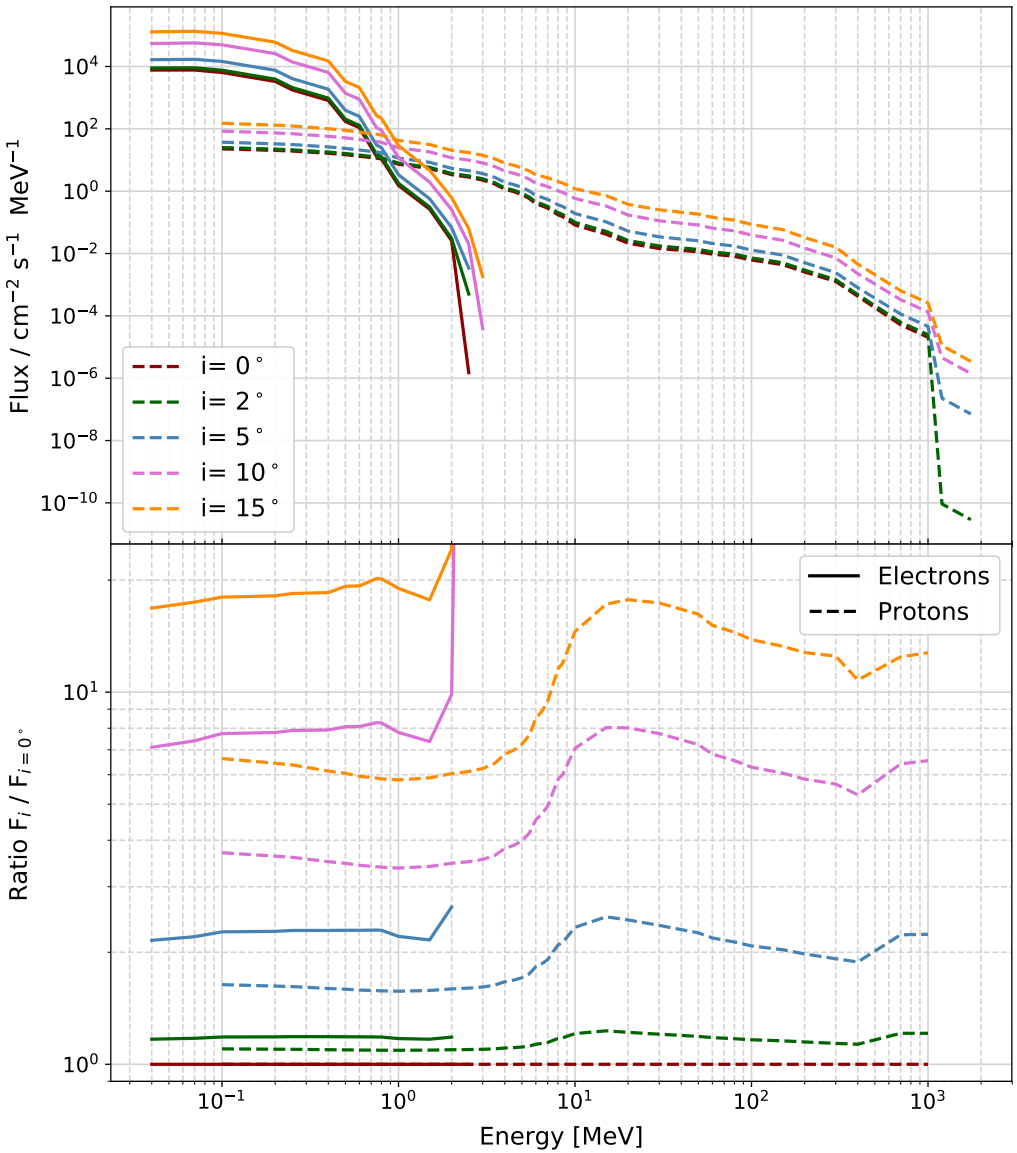
General Background: Altitude Change



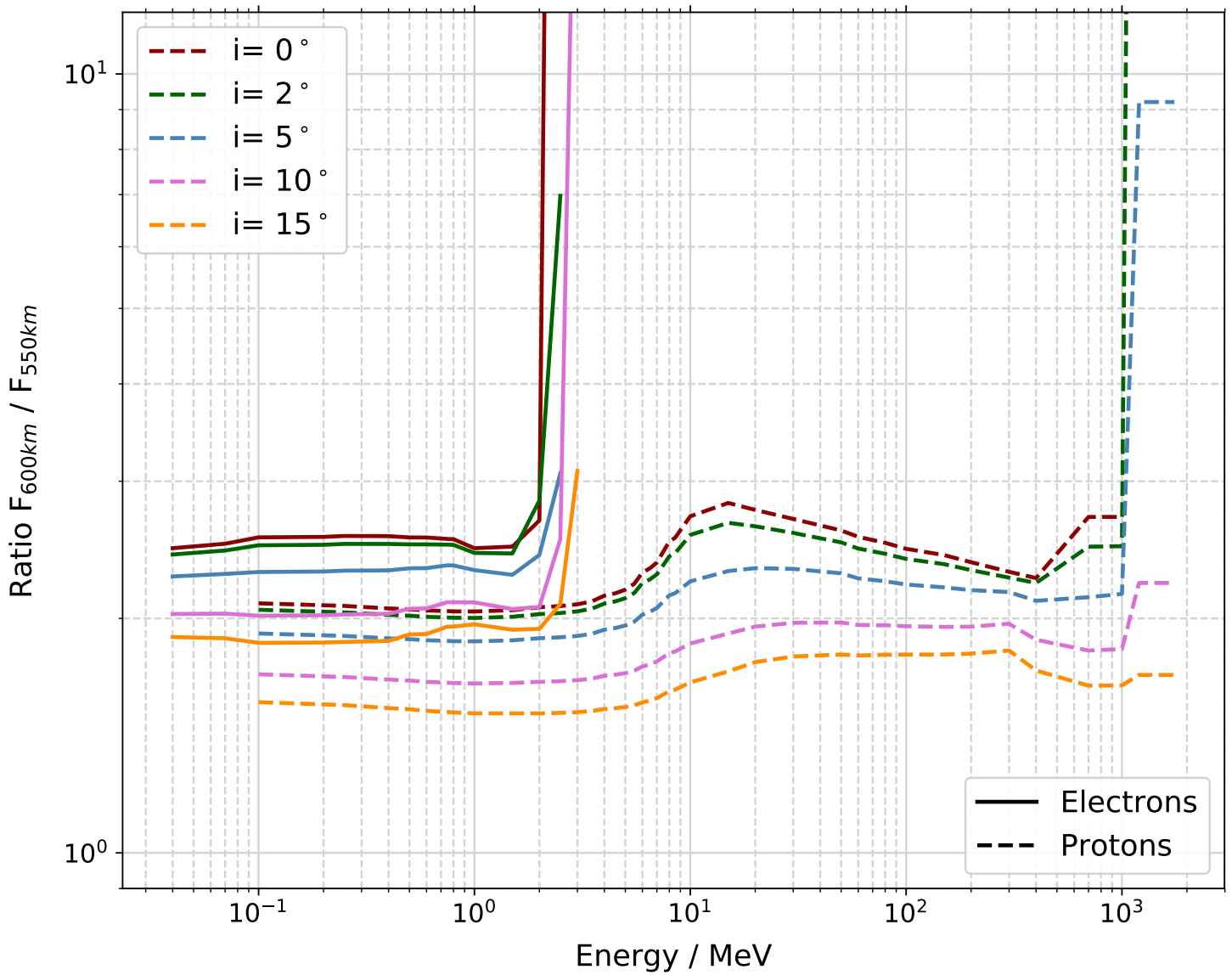
Primary charged particles: differences appear at energies lower than the cutoff, quickly disappearing afterward

South Atlantic Anomaly

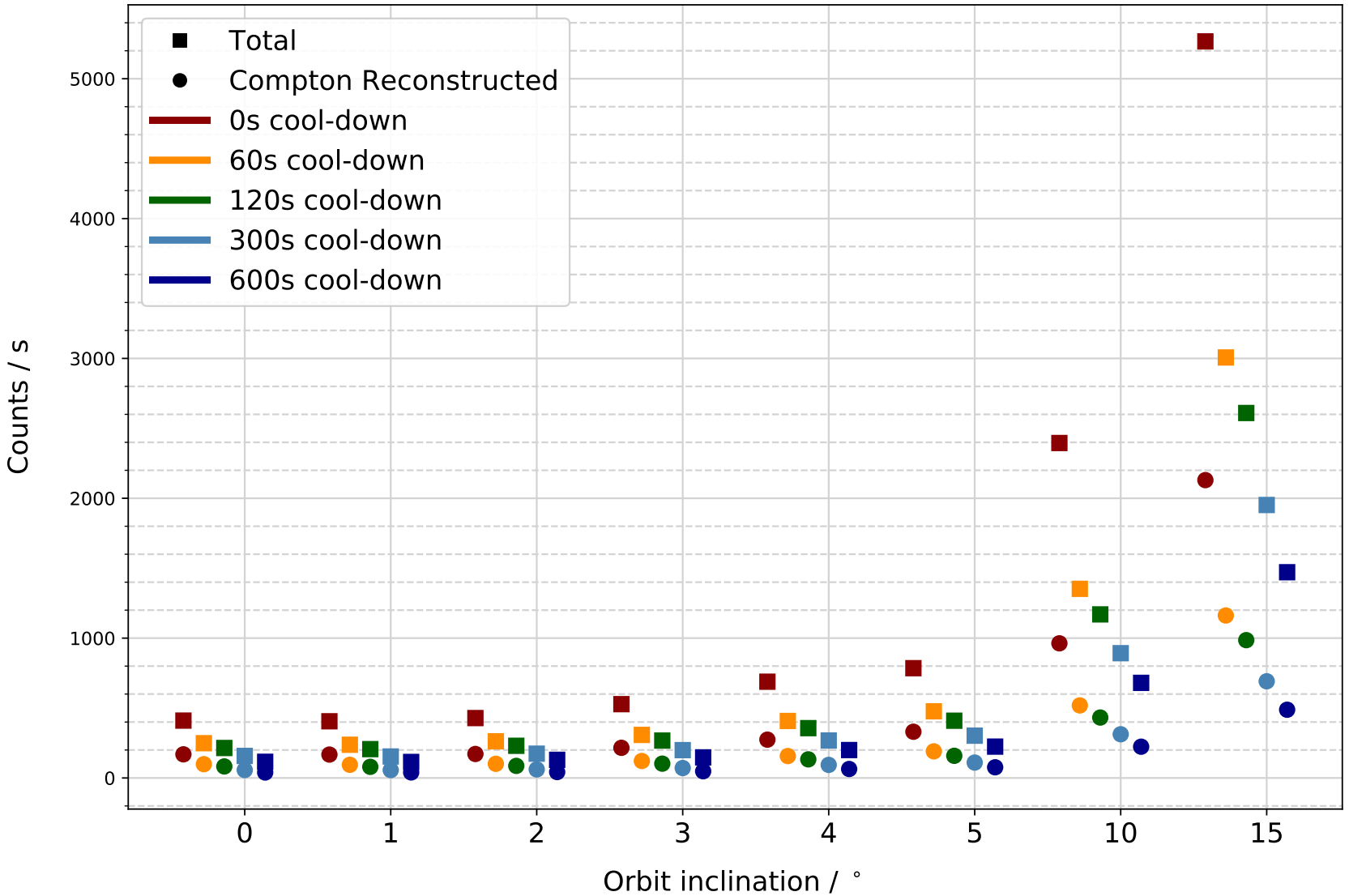
- AE9/AP9 Model
- Average spectrum over 1 month ($\sim$ 450 orbit)



South Atlantic Anomaly



Activation Simulations: SAA



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T. Mizuno et al. Cosmic-ray background flux model based on a gamma-ray large area space telescope balloon flight engineering model. *The Astrophysical Journal*, 614(2):1113, 2004. URL `http://stacks.iop.org/0004-637X/614/i=2/a=1113`.

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M. Aguilar et al. Precision measurement of the proton flux in primary cosmic rays from rigidity 1 gv to 1.8 tv with the alpha magnetic spectrometer on the international space station. *Phys. Rev. Lett.*, 114:171103, Apr 2015. doi: 10.1103/PhysRevLett.114.171103. URL `https://link.aps.org/doi/10.1103/PhysRevLett.114.171103`.

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