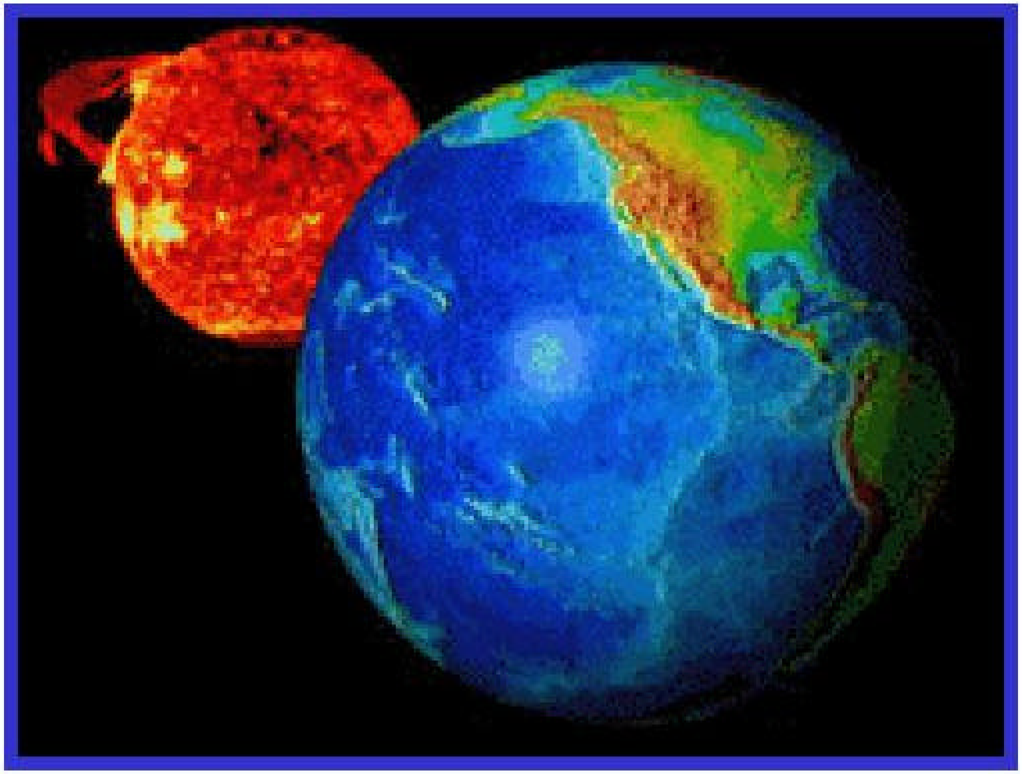
Probabilistic Model for Low Altitude Trapped Proton Fluxes*



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OUTLINE

- **Introduction**
- **Motivation**
- **Methods and Results**
  - Statistical model for variation in solar cycle activity
    - Solar 10.7 cm radio flux ($F_{10.7}$)
  - Statistical results for low altitude trapped proton levels
    - Solar cycle dependence
    - Energy spectra
    - Orbital dependence
- **Conclusions**

INTRODUCTION

- **AP8 Trapped Proton Model**
  - De facto standard for assessing trapped proton flux for all orbits
  - Static maps of long-term average proton fluxes
  - 2 versions: 1 for solar maximum and 1 for solar minimum conditions
  - Based on selected satellite data from 1960s and 70s
- **This work deals with low altitude (< 1000 km) trapped proton fluxes, where significant discrepancies with AP8 have been observed.**
- **Notable prior work includes:**
  - AFRL - CRRES, APEX satellite data
  - BIRA and Aerospace – SAMPEX satellite data
  - Boeing Low Altitude Trapped Proton Model – NOAA/TIROS satellite data (1978-1995).
    - Calculates proton fluxes as a continuous function of time
    - Incorporates true solar cycle dependence and secular variation of geomagnetic field

INTRODUCTION (continued)

- Trapped Proton Model-1 (TPM-1) – adds CRRES satellite data (1990-1991) to Boeing model to expand the spatial extent and proton energy range of the model.

- **In this paper, we further expand the utility of TPM-1**
  - combine TPM-1 solar cycle dependence with a new statistical model of solar cycle activity to assess variations of low altitude trapped proton fluxes due to atmospheric effects.

MOTIVATION

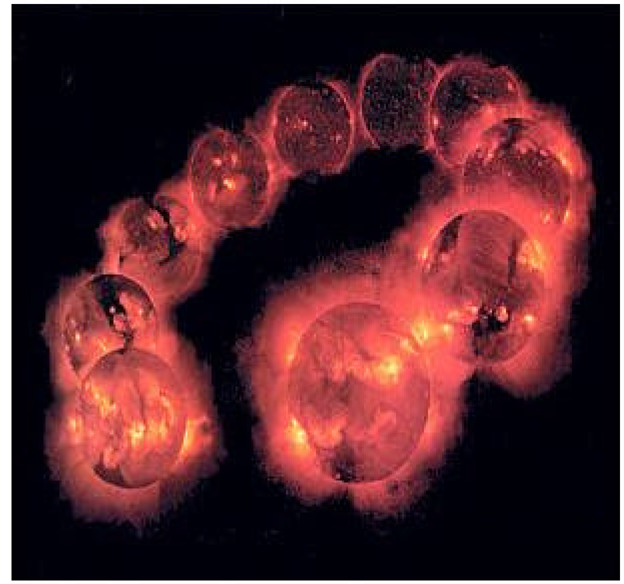
- **Low altitude trapped proton fluxes depend on solar cycle activity.**
  - High solar activity levels heat and expand the upper atmosphere, which increases the removal rate of trapped protons through collisions in the upper atmosphere.
  - The effect is to decrease trapped proton flux levels during solar maximum.
- **The solar cycle activity level can not be accurately predicted for long-term mission planning.**
- **A probabilistic model would allow trapped fluxes to be determined as a function of confidence level.**
  - Gives cost vs. risk information to the spacecraft systems designer
  - Allows assessment of how large variations can be from expected fluxes
  - Especially useful for COTS microelectronics due to its vulnerability to radiation

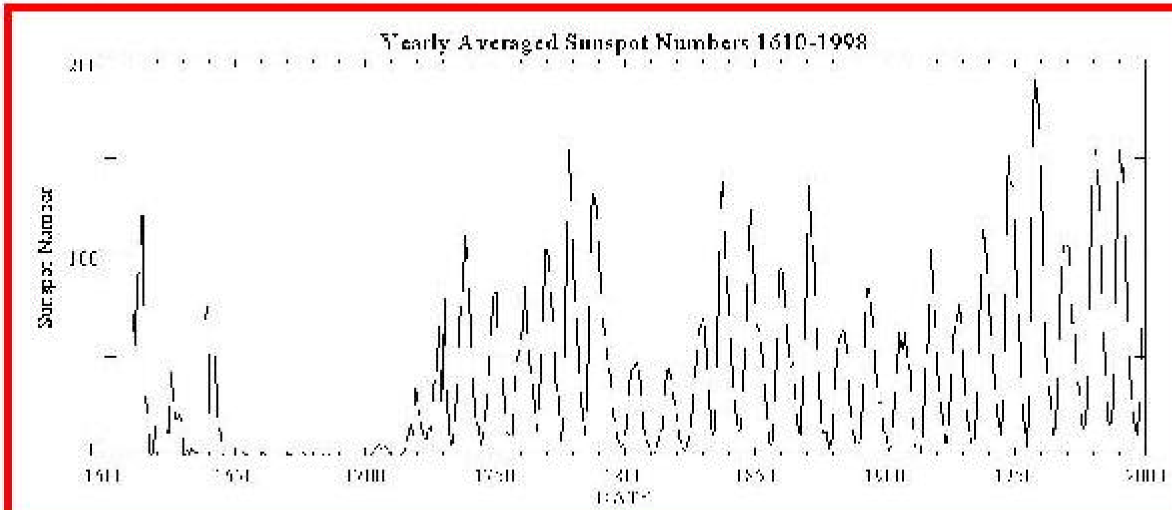
THE SOLAR ACTIVITY CYCLE

- Solar cycle length has varied between 9 and 13 years.
- A typical 11 year cycle consists of 7 years "solar maximum" and 4 years "solar minimum".
- Common indicators of solar activity:

  - sunspot numbers

  - 10.7 cm radio flux ($F_{10.7}$)

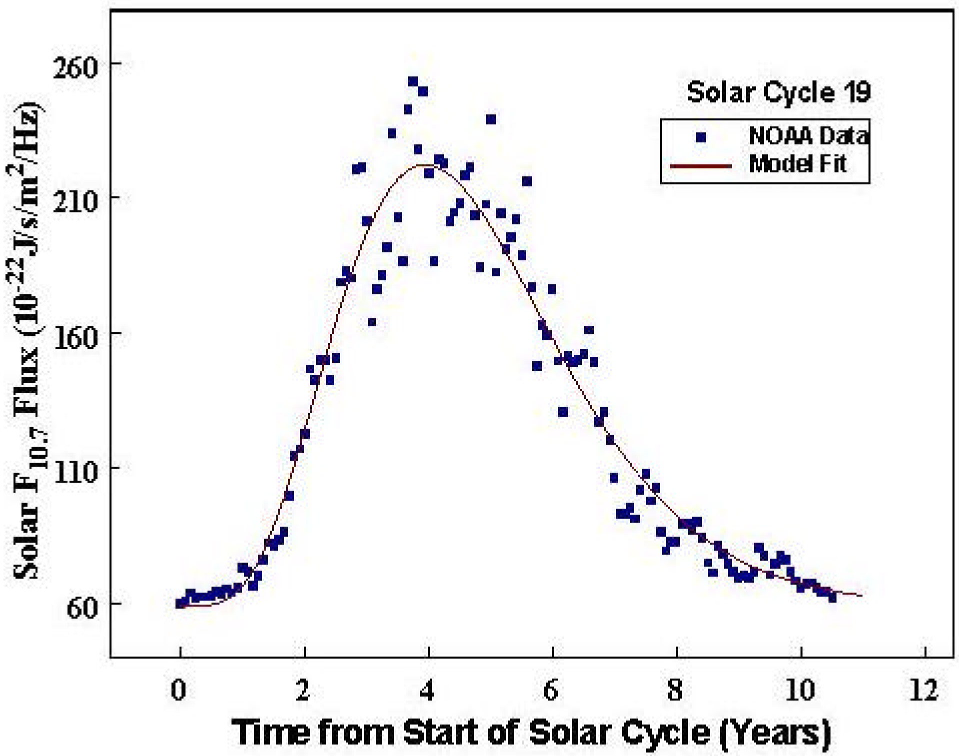




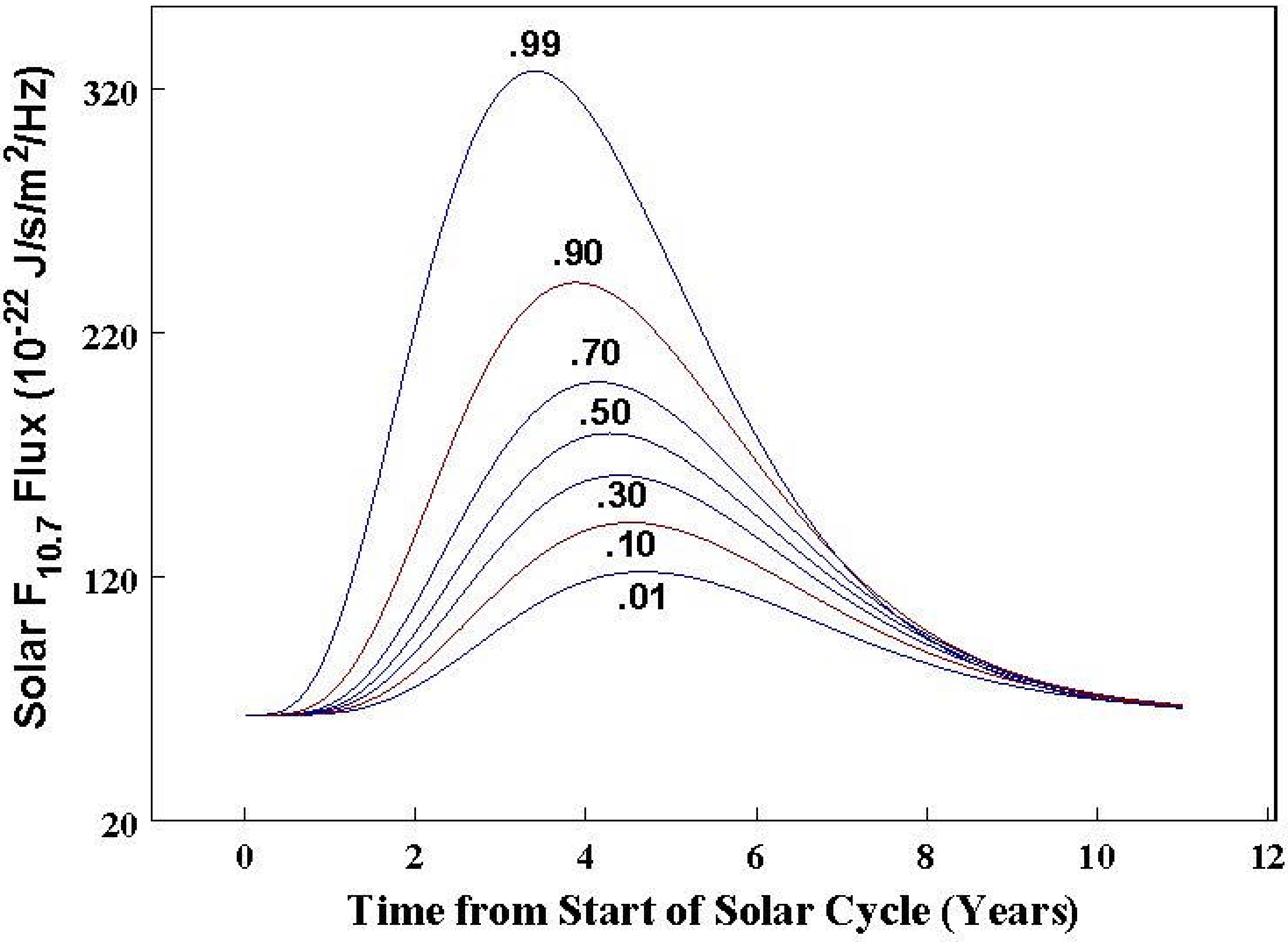
SOLAR CYCLE ACTIVITY

- **TPM-1 uses $F_{10.7}$, a measure of solar activity, as a proxy for atmospheric heating.**
- **Distribution of $F_{10.7}$ can be fitted to gamma density function superimposed on a low level, constant background.**
- **All available $F_{10.7}$ data, obtained from NOAA, are used in the analysis**
  - Last 5 solar cycles
  - Data corrected by NOAA for various effects (antenna gain, atmospheric absorption, etc.)
- **Fitted distributions used to develop probabilistic model of $F_{10.7}$.**

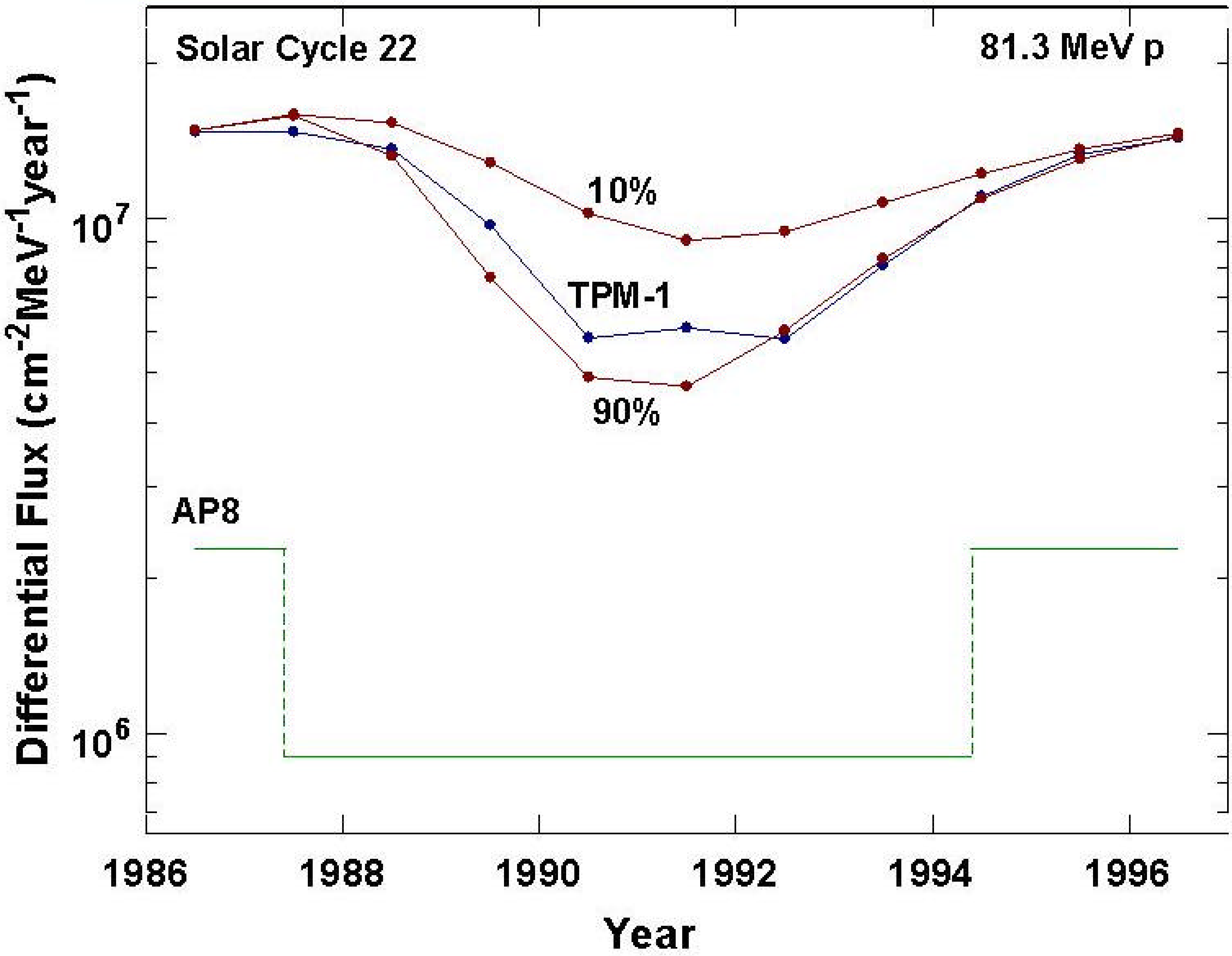
Fitted Distribution of $F_{10.7}$



STATISTICAL MODEL OF $F_{10.7}$

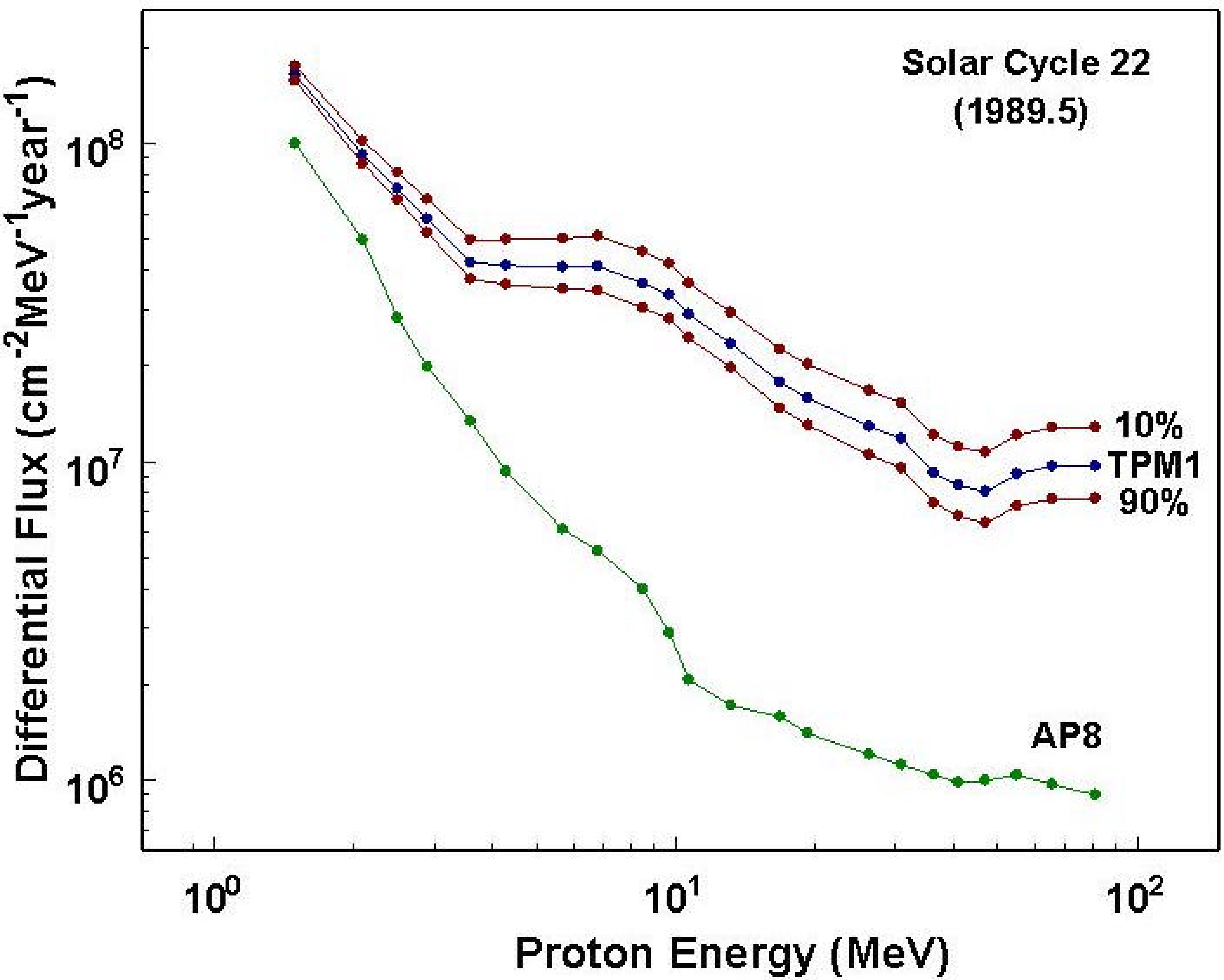


SOLAR CYCLE DEPENDENCE:
ISS Orbit – 437x361 km, 51.6º Inclination

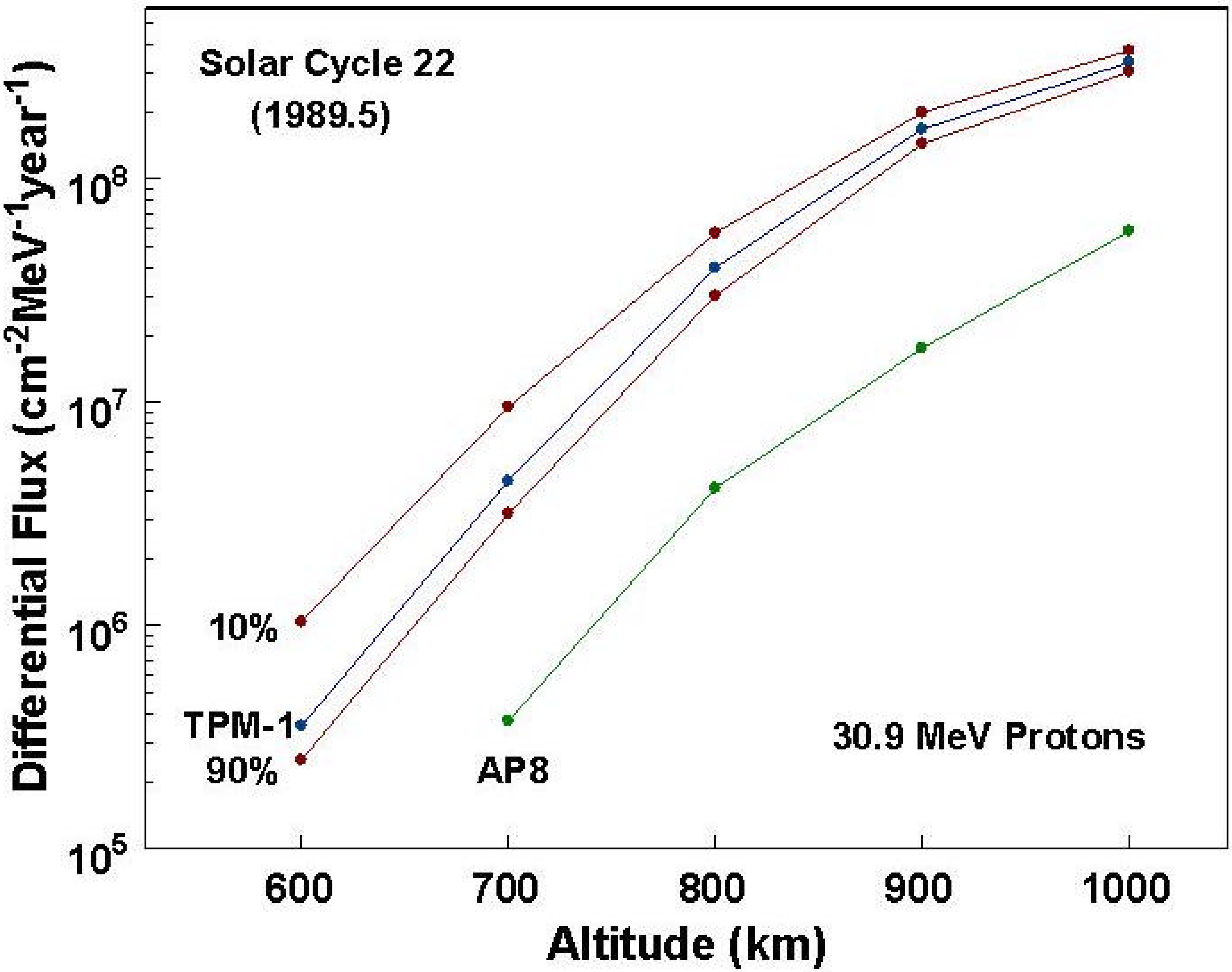


ENERGY SPECTRUM:

ISS Orbit – 437x361 km, 51.6º Inclination



ALTITUDE DEPENDENCE
Equatorial Orbit



CONCLUSIONS

- **TPM-1 is a significant improvement over AP8 for low earth orbits.**
  - Trapped proton fluxes are notably higher, especially for high energies.
  - Fluxes vary continuously with time, allowing more accurate predictions, especially for missions a few years or less in duration.
- **Proton fluxes in low earth orbit can also vary substantially from one solar maximum time period to the next. This is due to atmospheric heating and cooling effects resulting from varying solar activity levels.**
- **Variations are most significant:**
  - At low orbital altitudes
  - At low angles of orbital inclination
  - For high energy protons
- **This work suggests that an improved procedure for assessing trapped proton radiation effects for future low altitude (< 1000 km) missions is to evaluate fluxes as a function of confidence level.**
  - Provides spacecraft designers a tool by which they can trade off cost vs. risk for a given orbit and time period.
- **Further expands the utility of TPM-1.**