# AE9/AP9/SPM: New Models for Radiation Belt and Space Plasma Specification

**05 May 2014**

**Presented by:**
**Judy A. Fennelly, PhD**
**Chief Engineer**
**Battlespace Environment Division**
**Air Force Research Laboratory**

*Integrity ★ Service ★ Excellence*

# Authors

- Bob Johnston — Air Force Research Lab (Principal Investigator)
- Paul O'Brien — Aerospace Corp. (Principal Investigator)
- Gregory Ginet — MIT Lincoln Lab (Principal Investigator)
- Stuart Huston — Atmospheric & Environment Research Inc.
- Timothy Guild — Atmospheric & Environment Research Inc.
- Judy Fennelly — Air Force Research Lab

# Outline

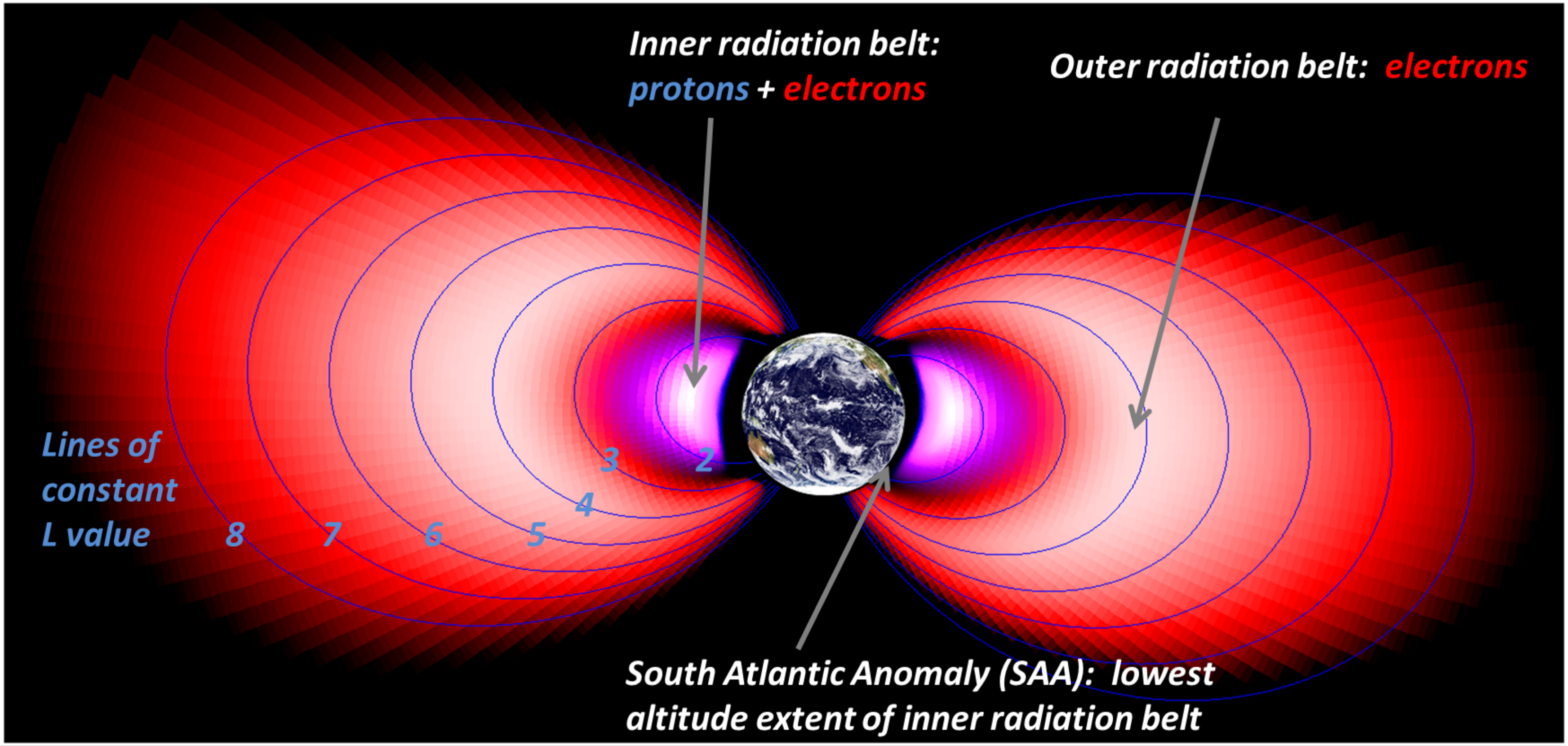
- Introduction
- Overview of AE9/AP9/SPM
- Model Application
- Validation and Comparisons
- Current & Future Releases
- Summary

# Introduction to AE9/AP9/SPM

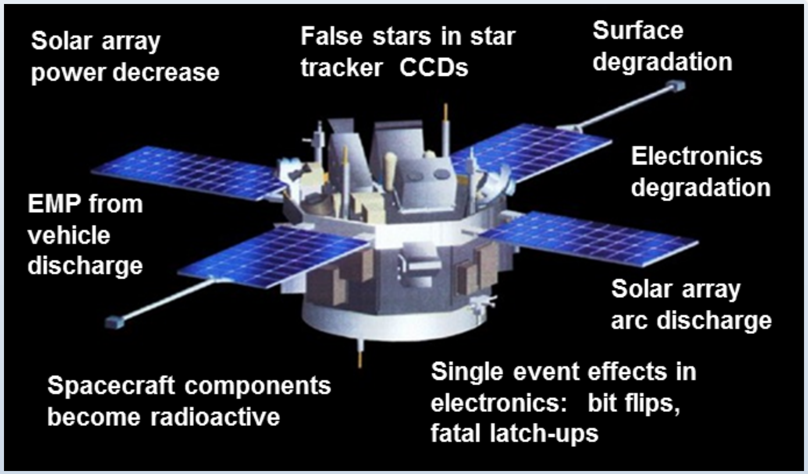
**AE9/AP9/SPM is a suite of empirical models describing the trapped electron, proton, and plasma in the near earth space environment**

- **AE9/AP9/SPM meets the satellite and space instrumentation design community's need for radiation environment specification model**
  - **Responsive tool with expanded range of features not available with legacy models**
  - **Uses the most up-to-date data available**
  - **Introduces quantitative statistics for use in design efforts**

# Near-Earth Radiation Environment

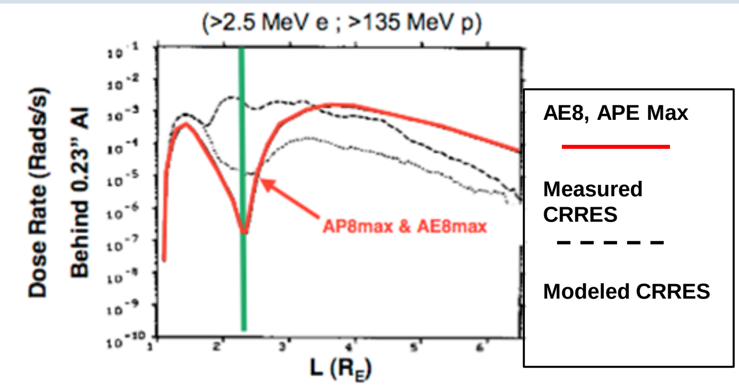


# Need for Accurate Near-Earth Radiation Environment Estimations




**Energetic protons, electrons and plasma pose a wide range of hazards to spacecraft and components**

**These hazards are dynamic and sometimes not accurately captured in legacy models**




For MEO orbit (L=2.2), #years to reach 100 kRad:

- Quiet conditions (NASA AP8, AE8) : 88 yrs
- Active conditions (CRRES active) : 1.1 yrs

AE8 & AP8 under estimate the dose for 0.23" shielding

# Legacy Space Environmental Electron and Proton Models

## AE8 & AP8 electron and proton empirical models are the most widely used of the various legacy models

- These are capable models, but do not meet emerging needs of the design community

- AE8/AP8 lacked the ability to trade actual environmental risks like other system risks
  - AE8/AP8 could never answer questions such as “how much risk can be avoided by doubling the shielding mass?”
- Inaccuracies and lack of indications of uncertainty
  - Creates the necessity of excessive margin in designs
- No plasma specification
  - Unknown surface dose effects
- No natural dynamics
  - Not present are environments for internal charging or worst case proton effects, such as single event effects (SEEs)

# AE9/AP9/SPM Empirical Radiation Belt and Space Plasma Model Suite

**AE9/AE9/SPM suite provides advanced capabilities for estimating the natural trapped radiation environment in near-Earth Space for satellite design**

- Unprecedented coverage in energies and particle types addressing major space environmental hazards
- Includes uncertainties and dynamics that have never been available for use in design
  - Data-based statistics quantifying uncertainties from both measurements and space weather variability
  - Estimate design margins (95th percentile rather than arbitrary factors)
- Dynamic scenarios allow users to create worst cases for internal charging, single event effects, and impacts on mission life

# AE9/AP9/SPM Suite Coverage

| MODEL | AE9 | AP9 | SPM |
|---|---|---|---|
| Species | $e^-$ | $H^+$ | $e^-$, $H^+$, $He^+$, $O^+$ |
| L Range | $0.98 < L^* < 12.4$ | $0.98 < L^* < 12.4$ | $2 < L_m < 10$ |
| Energy Range | 40 keV – 10 MeV | 100 keV – 400MeV (V1.0-V1.05)<br>100keV – 2 GeV (V1.20) | $e^-$ : 1 -40 keV<br>$H^+$, $He^+$, $O^+$: 1.15 – 164 keV |

- **AE9/AP9 covers trapped radiation over full range of orbit regimes**
- **SPM introduces coverage of plasma energies and species**
- **AP9 V1.20 will extend energy range up to 2 GeV, based on Van Allen Probe observations**

# Range of Near-Earth Particle Hazards

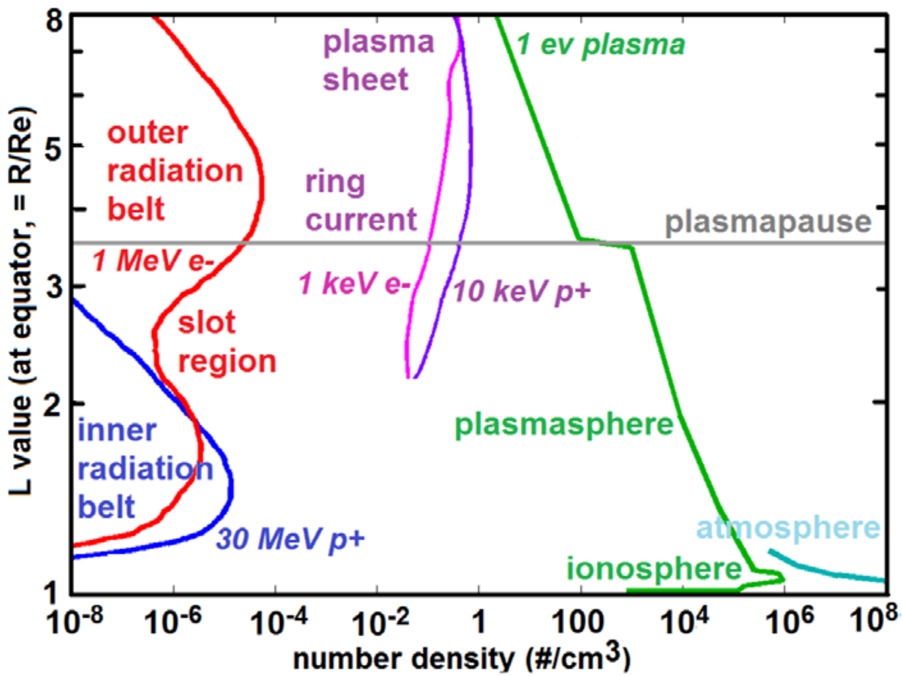
**PARTICLE ENERGIES :** 1 eV 10 eV 100 eV 1 keV 10 keV 100 keV 1 MeV 10 MeV 100 MeV 1 GeV

Plasmasphere

Ring Current & Auroral Precipitation

Radiation Belt Particles

**AE9/AP9/SPM Suite Energy Range Coverage (trapped particles only)**



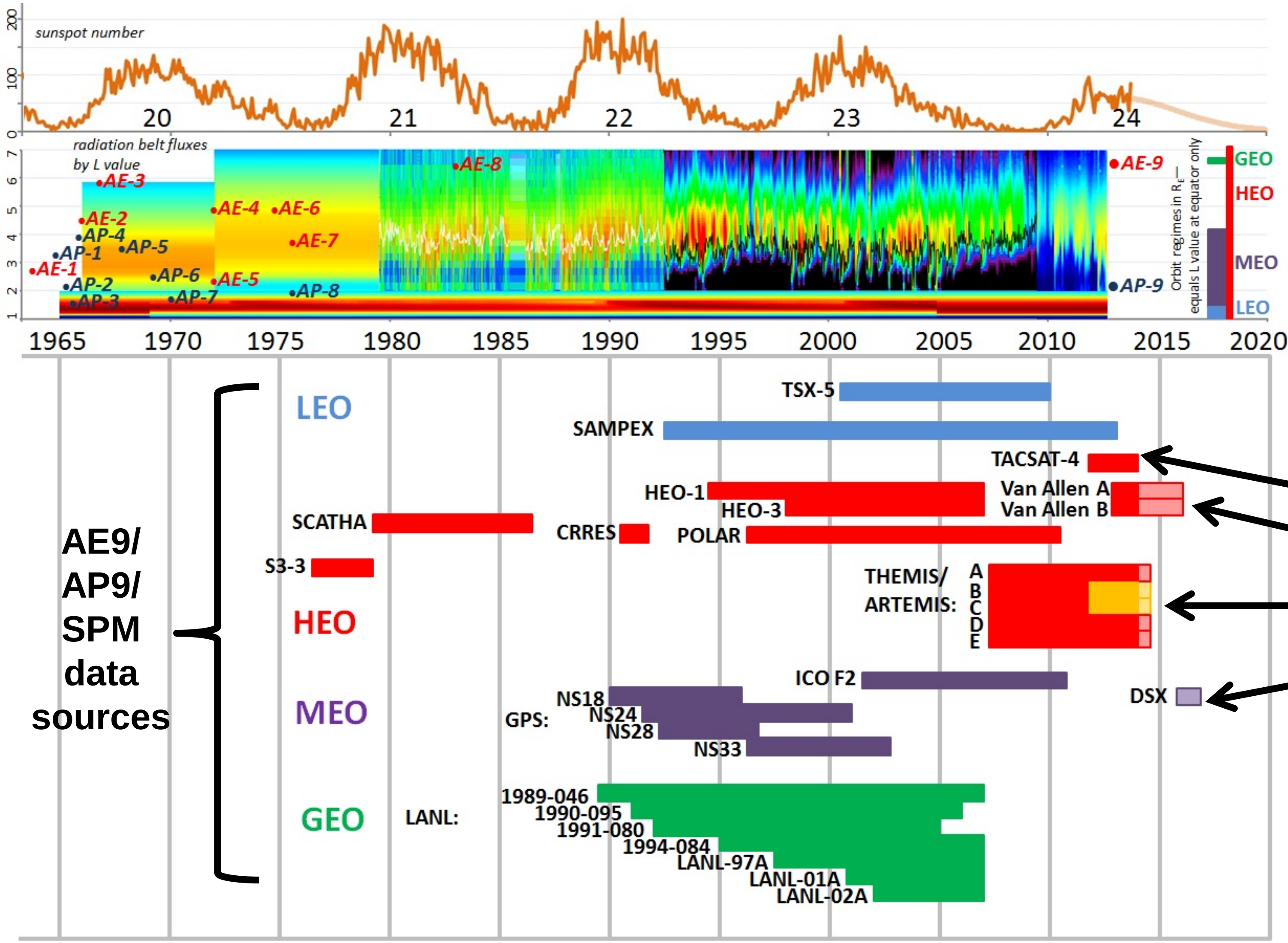
# AE9/AP9/SPM Incorporates High-Quality Data Sets

The AE9/AP9/SPM suite is based on data sets mostly acquired after development of AE8 and AP8 and covers greater spatial and energy ranges than the prior models

- Maps of the particle fluxes are created from these data sets
- Estimates of uncertainties include both measurements uncertainties and space weather variability

- AE9/AP9/SPM incorporates 33 data sets measured by space-based sensors
- Data sets were selected for accuracy in inner magnetosphere
- Data during solar proton events were eliminated
  - resulting maps describe trapped radiation only
- Cross-calibration was done to a single standard sensor, both eliminating relative biases and providing estimates of measurement uncertainty

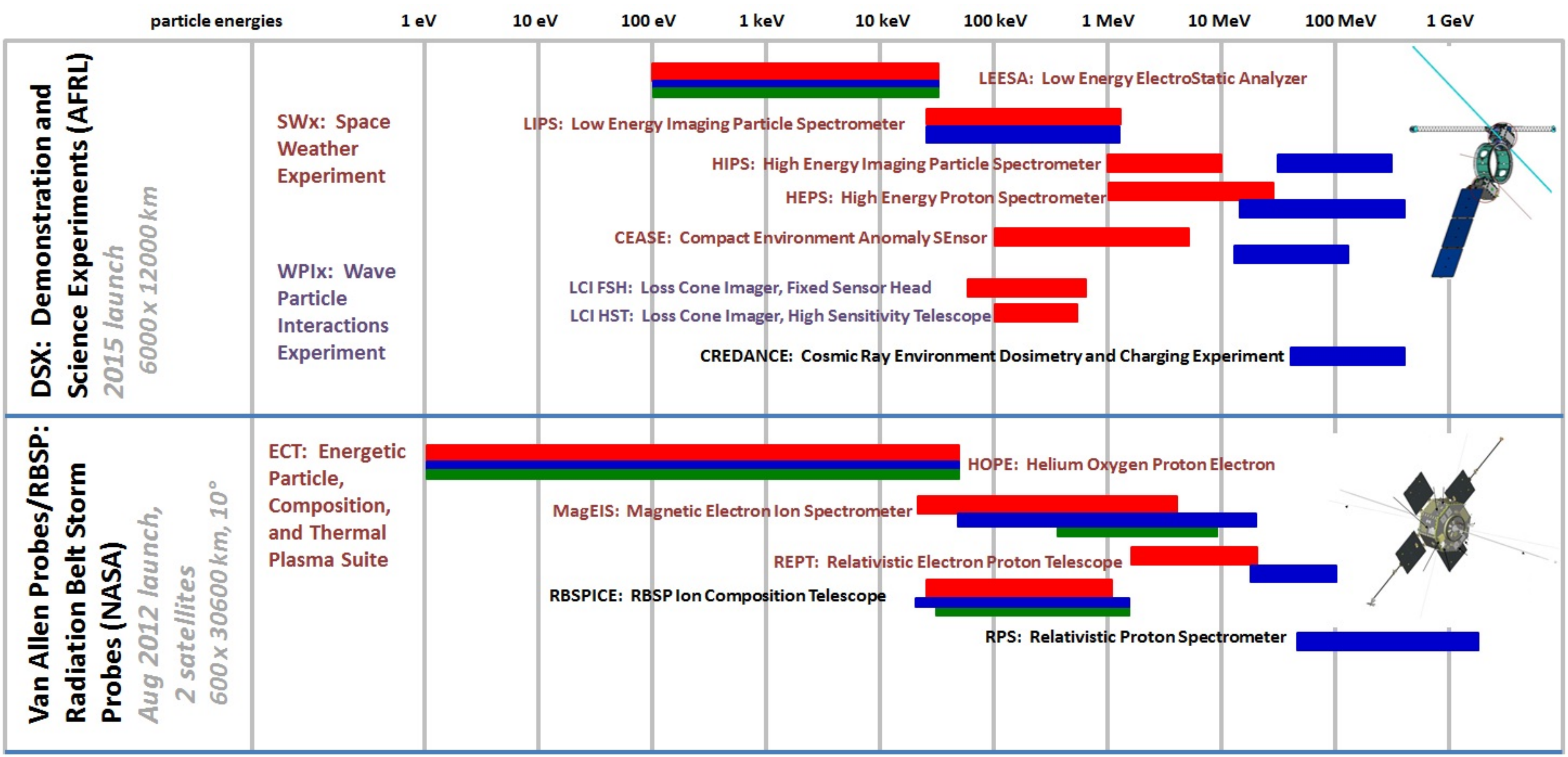
# Data Sets
# Used for AE9/AP9/SPM




**Most data sets used cover min+max solar cycle conditions**

**Will be used in future versions**

# Examples of Future AE9/AP9/SPM Data Sets

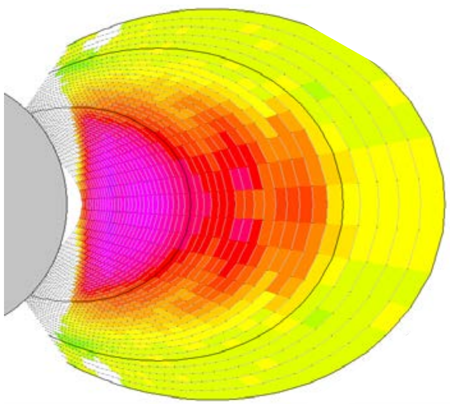



**Key:**

Electron Energies
Proton Energies
Ion Energies

# AE9/AP9/SPM Architecture Overview

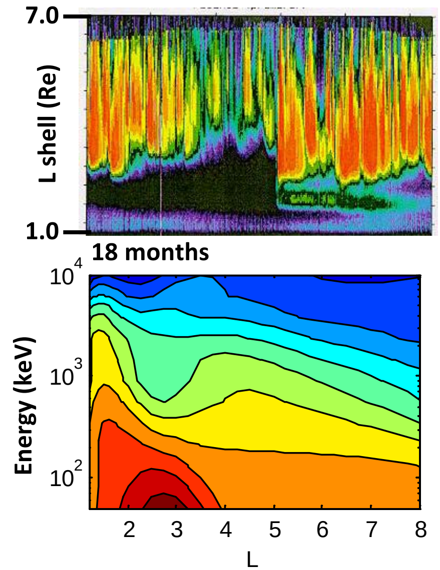
## AE9/AP9/SPM Creates Flux Maps based on Satellite Data



- Creates maps for median and $95^{th}$ percentile of distribution function
  - Maps characterizes both nominal and extreme environments
- Includes error maps with instrument uncertainty

+

## Satellite data & theory

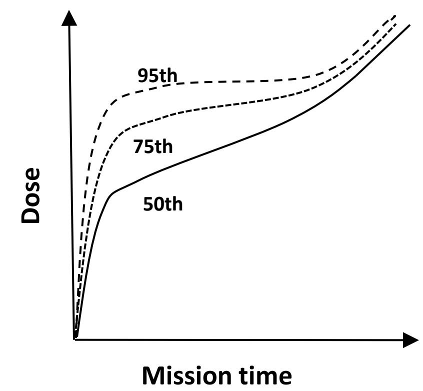



### Statistical Monte-Carlo Model

- Compute spatial and temporal correlation as spatiotemporal covariance matrices
- Set up $N^{th}$-order auto-regressive system to evolve perturbed maps in time

=

## User's orbit




### User application

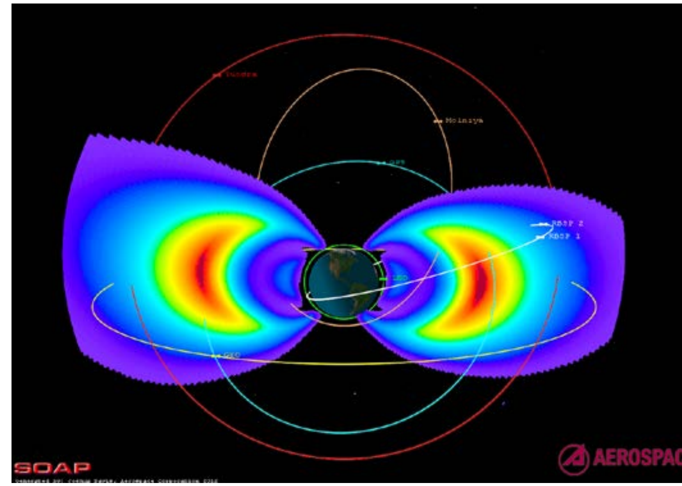
- Runs statistical model N times with different random seeds to get N flux profiles
- Computes dose rate, dose or other desired quantity derivable from flux for each scenario
- Aggregates N scenarios to get median, $75^{th}$ and $90^{th}$ confidence levels on computed quantities

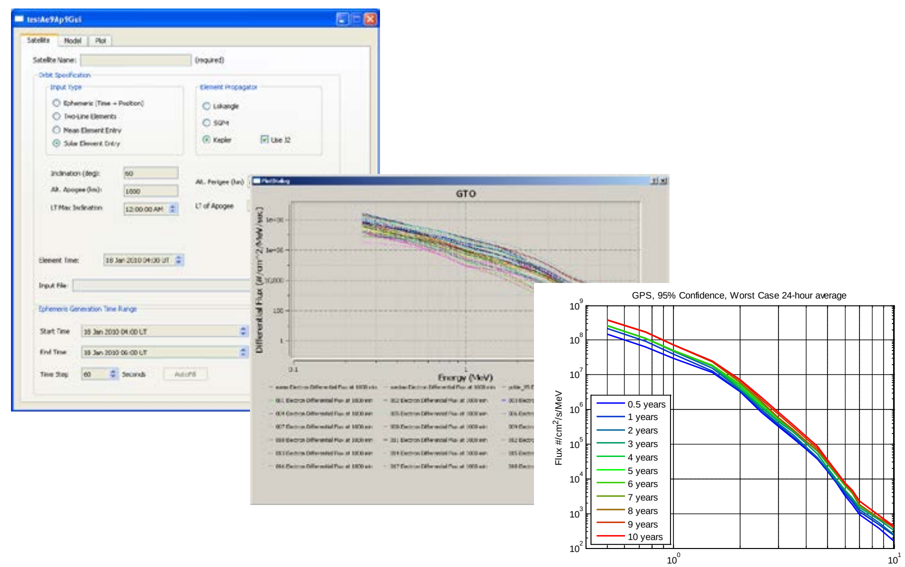


AFRL

# How to Use AE9/AP9

- **Model provided with GUI and CmdLine access**
- **Specify input and options:**
    - **orbital elements or ephemeris**
    - **coordinate system**
    - **model(s) to use—AE9/AP9/SPM, legacy models**
    - **mode—e.g. mean or Monte Carlo scenarios**
- **Model provides requested quantities**
    - **fluxes, fluences, doses**
- **Results for appropriate modes include statistics (e.g. median and 95th percentile) for risk assessment**

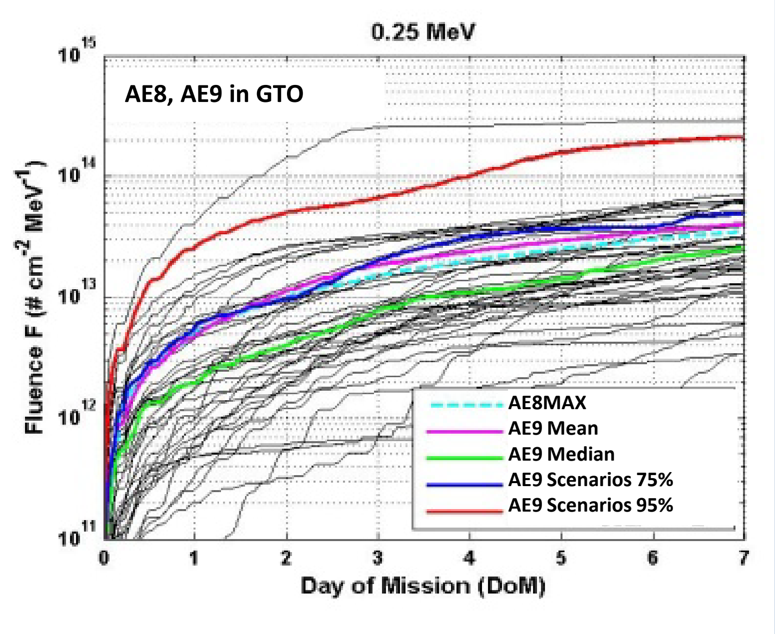


# Model Comparison and Validation

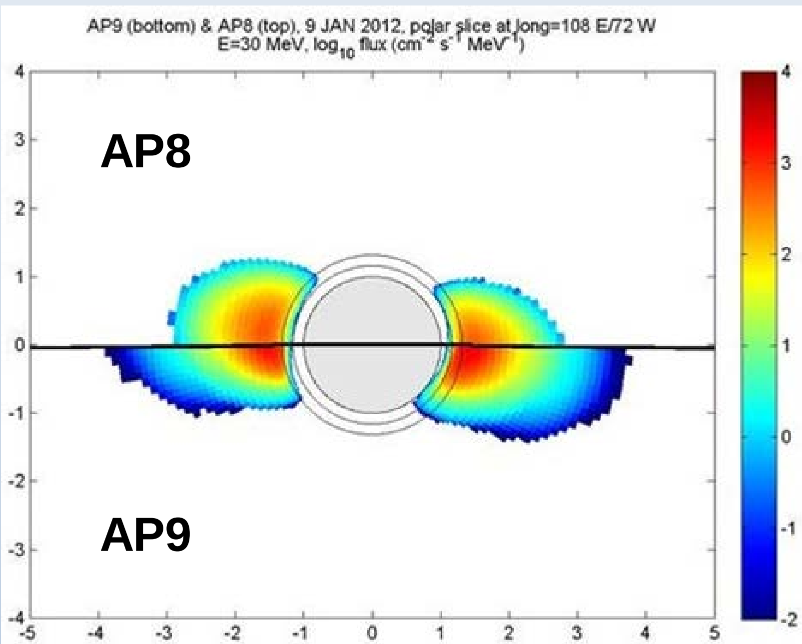
**Model comparisons and validations conducted:**

- **AE9/AP9/SPM results compared to legacy models including AE8/AP8**
- **AE9/AP9 results validated against independent LEO, HEO, GEO data sets**
- **Implementations of AE8/AP8 and SHIELDOSE within AE9/AP9 tool validated against results from SPENVIS and IRBEM**

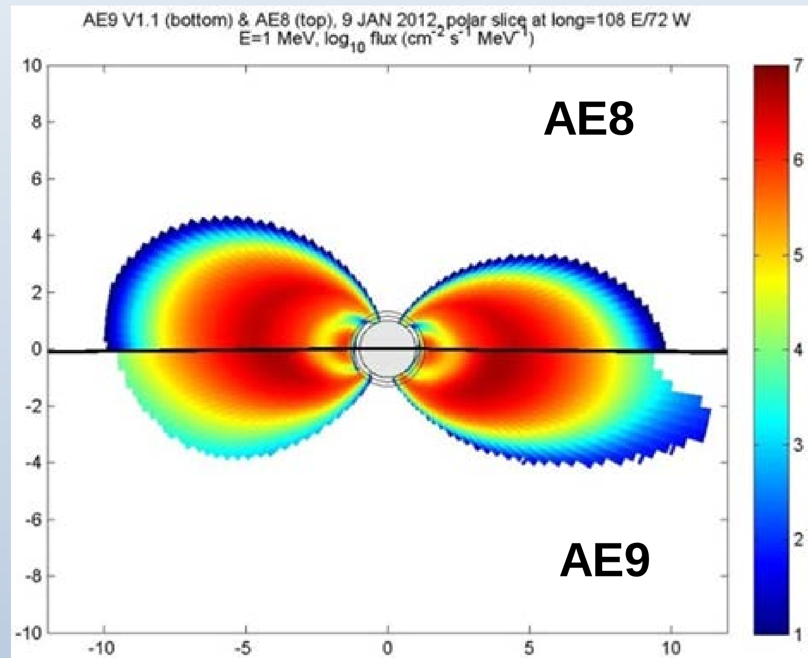


# AE9/AP9 Compared to AE8/AP8

## protons (30 MeV)

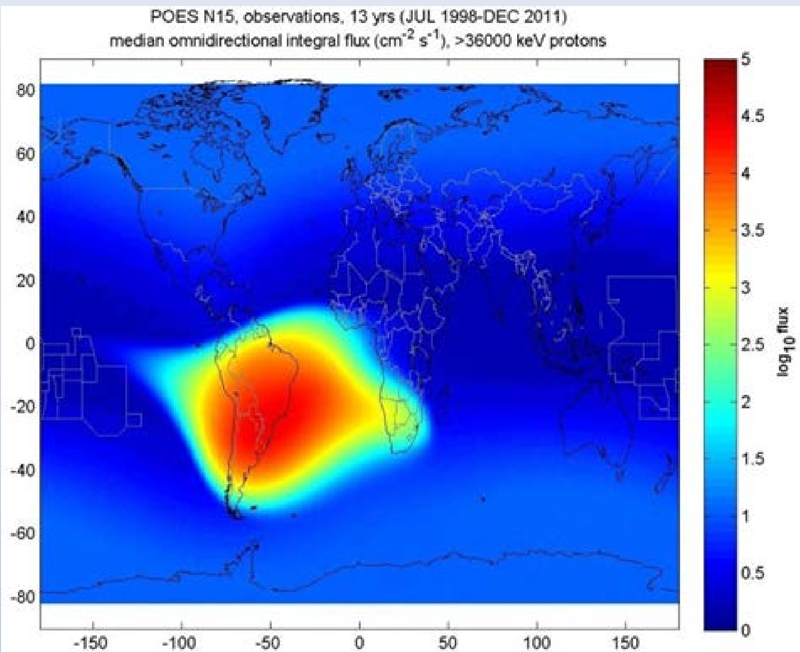



## electrons (2 MeV)

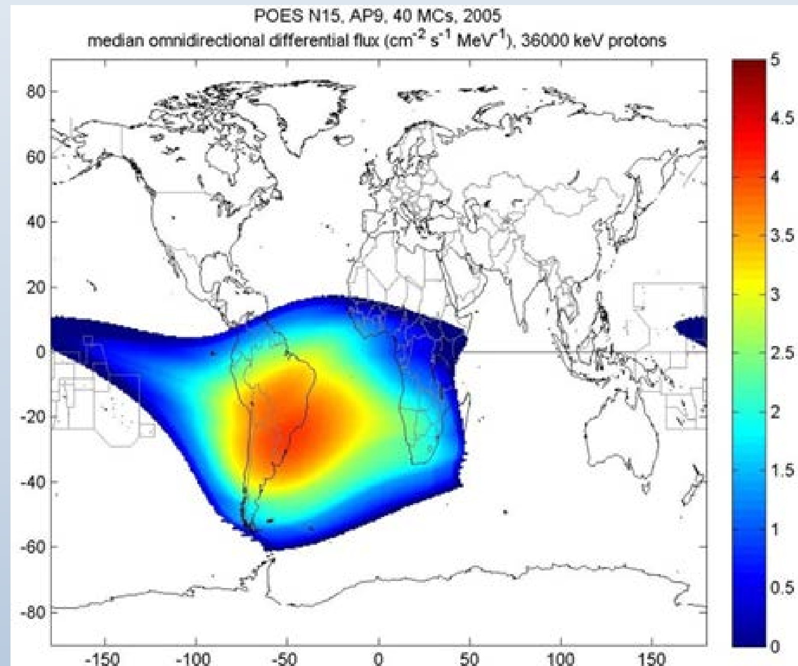


# AP9 Validation—POES 15 (LEO)

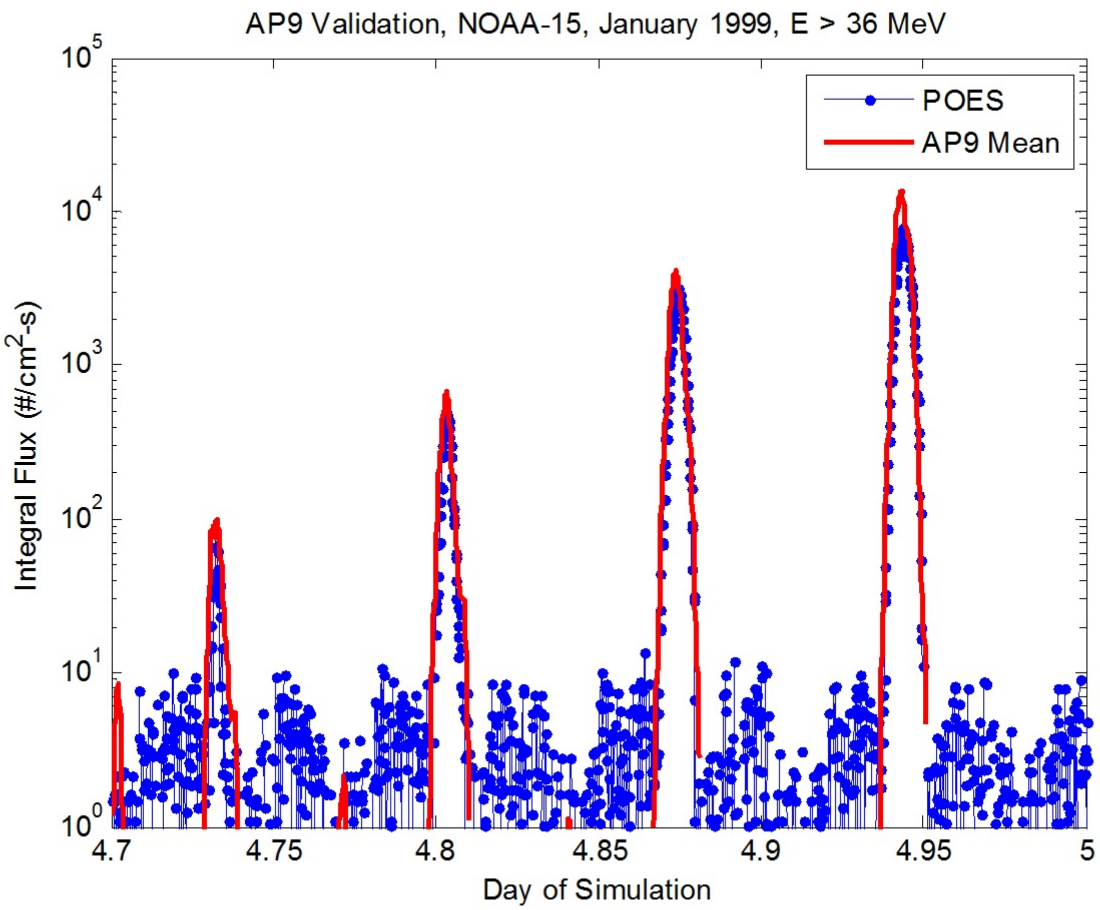
**POES 15 observations, >36 MeV protons**



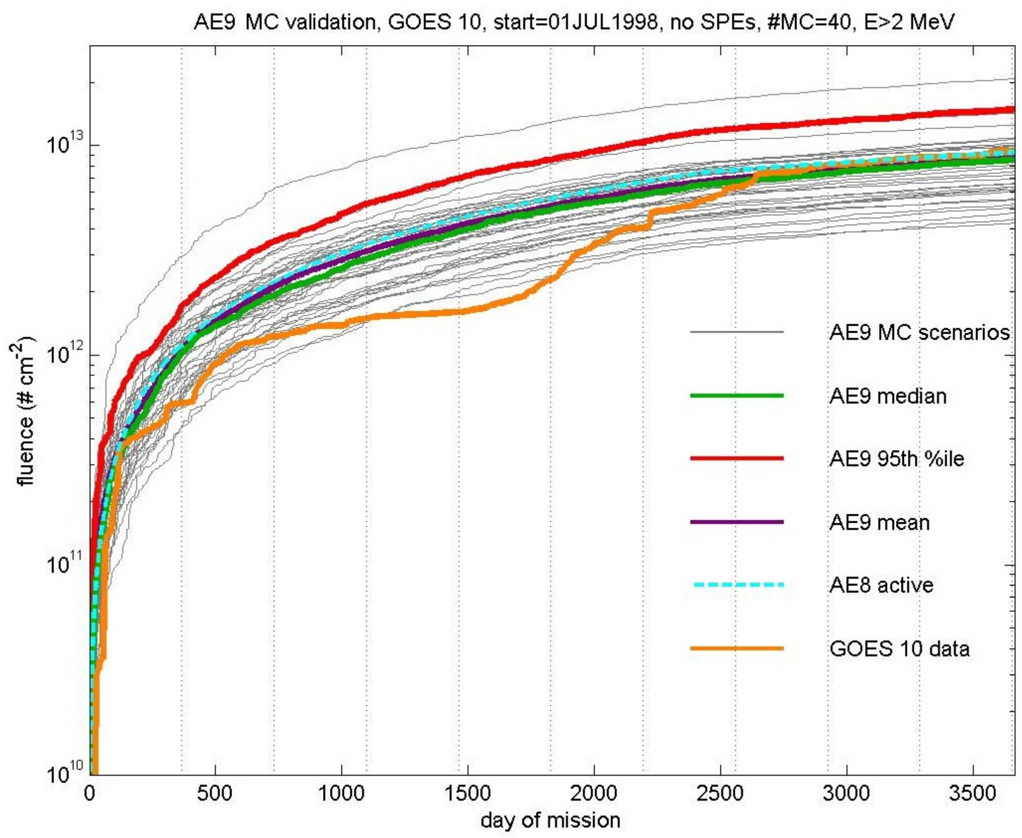

**AP9 median results, >36 MeV protons**



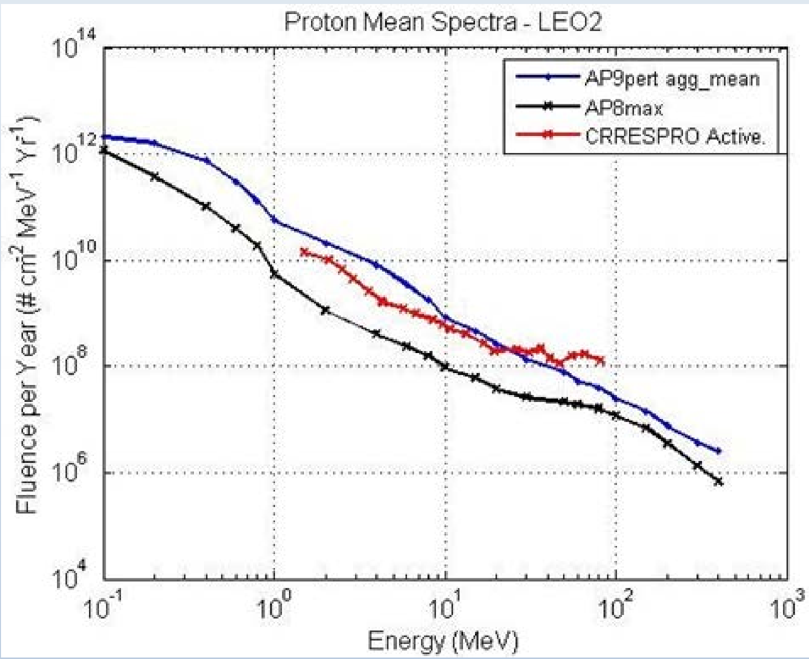
# AP9 Validation—POES 15 (LEO)

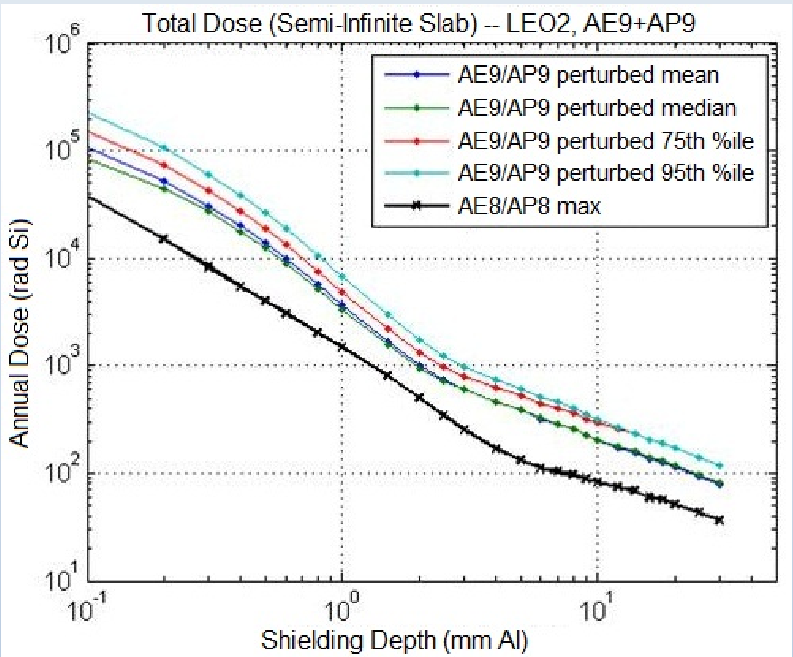


# AE9 Validation—GOES 10 (GEO)

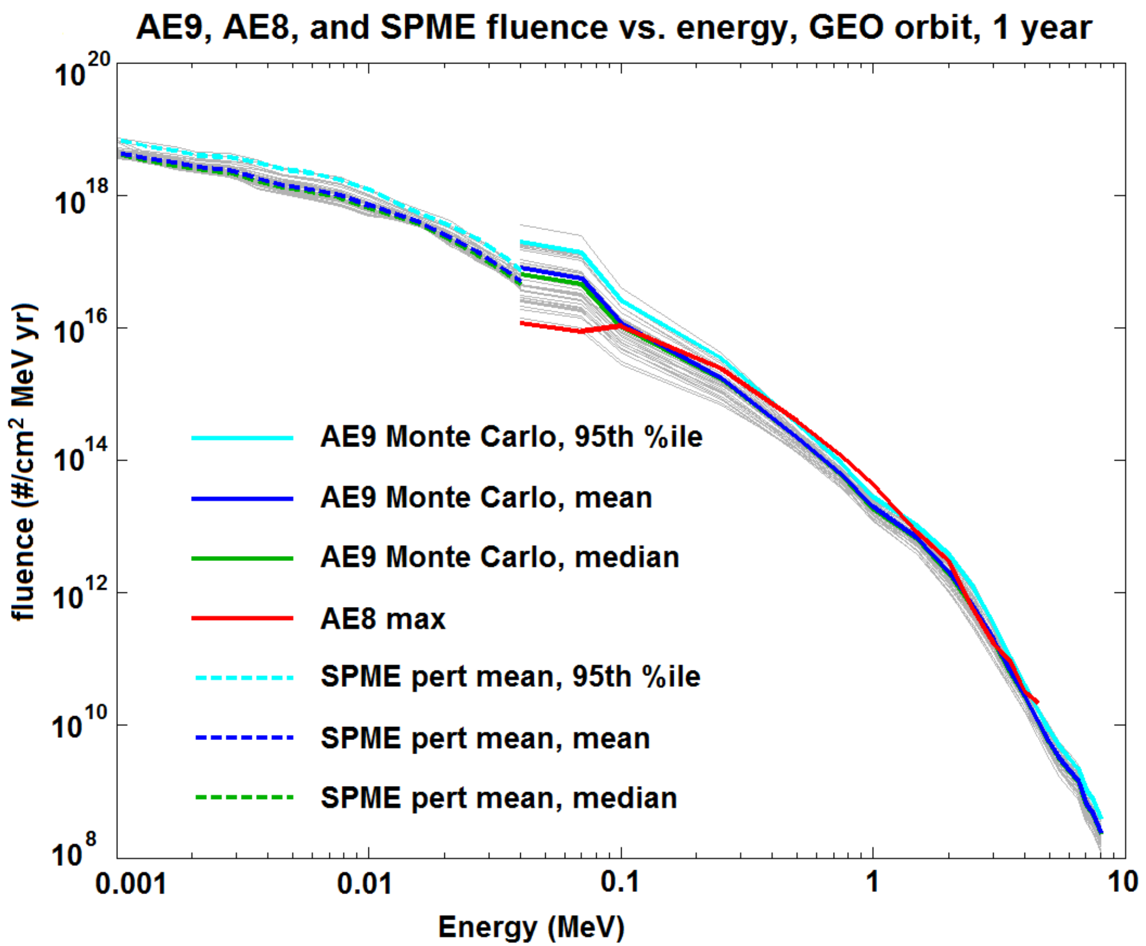


# AE9/AP9 Fluence and Dose Estimates, LEO (800 km)

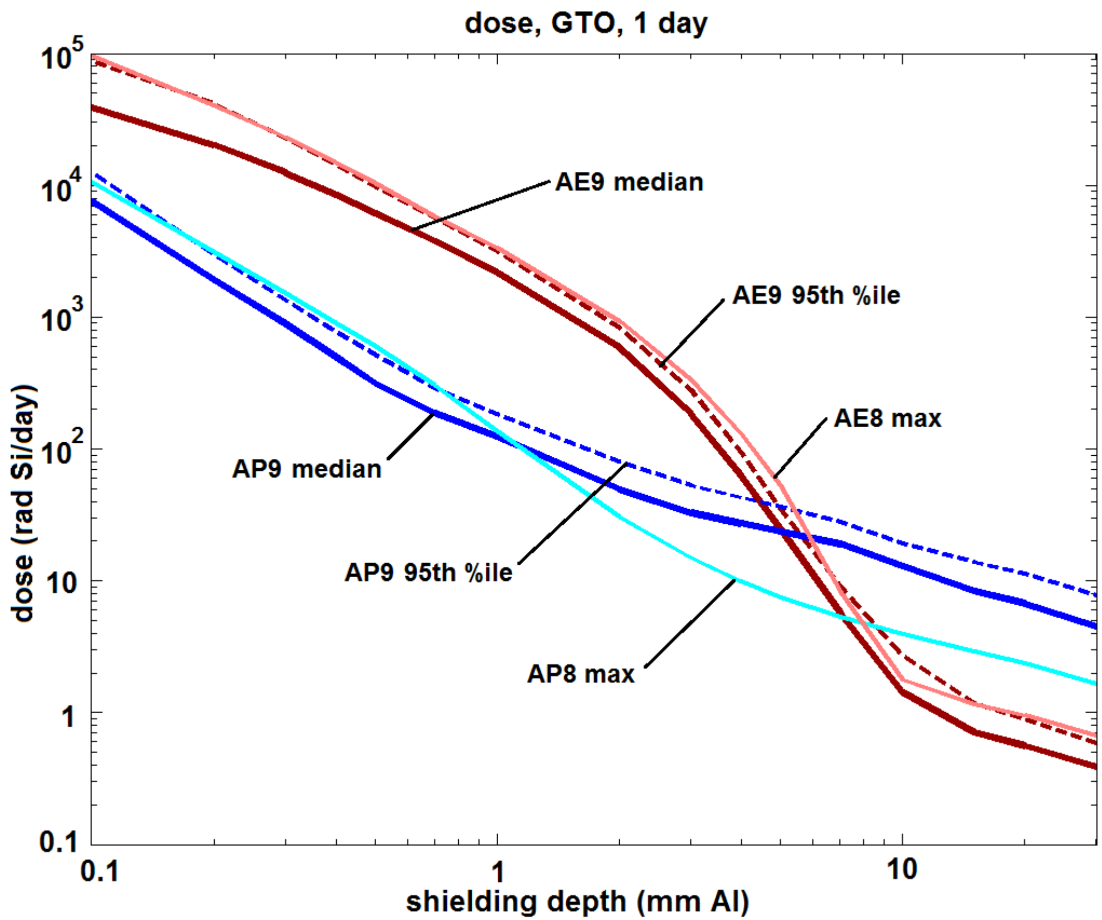


# AE9/AP9/SPM Fluence Estimates, GEO



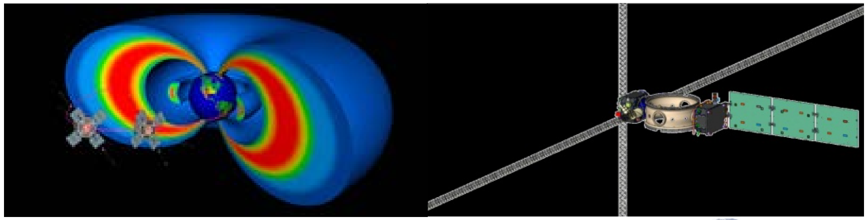
# AE9/AP9 Dose Estimates, GTO



# AE9/AP9/SPM
# Current Version and Future Plans

- V1.0 released in 2012, current version V1.05 released in 2013
- AE9/AP9 proposed as an ISO standard trapped radiation model
- V1.2 features
  - New data: TacSat-4 protons, THEMIS plasma
  - New features: more orbit element/coordinate options, pitch angle tool
- V1.5 features
  - Parallelization capability for runs on clusters—needed to speed up long runs
  - New kernel-based effects calculation
  - New data: Van Allen Probe & Azur protons, Van Allen Probe & DEMETER electrons, SCATHA & AMPTE plasma
  - International collaborators on board and new model name:

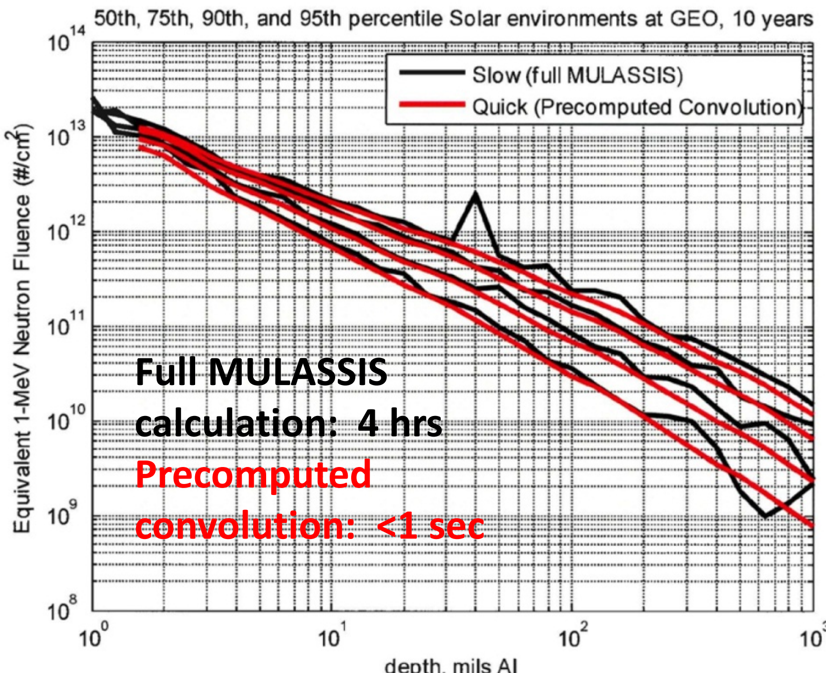
    IRENE — International Radiation Environment Near Earth
- V2.0 and later features
  - Sample solar cycle flythrough option
  - New modules
  - New data: PAMELA, DSX/SWx, ERG



# Kernel-Based Effects Calculation

- **V1.5 will include AE9/AP9 capability to use independently-calculated radiation effects for faster effects results in the AE9/AP9 environment:**
  - **User precomputes desired effect vs. depth/particle/energy for a particular material/geometry/component, using independent particle simulation code**
  - **Results are formatted as a "kernel" for import into AE9/AP9/SPM**
  - **AE9/AP9/SPM environment plus effects kernel yields rapid calculations of specific effects**

- **Sample kernel for single event effects is in development**
- **Provides ability to rapidly obtain AE9/AP9 environment effects for specific components**




from O'Brien and Kwan, 2013, Aerospace Report TOR-2013-00529

# Summary

- **AE9/AP9/SPM meets the design community's need for state-of-the-art radiation environment specification**
  - More coverage in energy and location
  - Introduces statistics describing uncertainties and environment variability
- **Plans are in place for future updates in both data and features**
  - Architecture supports updates with new data
  - Future features will expanded capabilities, addressing additional hazards and more options for applying model results to design

# Contact Information

- Comments, questions, etc. are welcome and encouraged!
- Please send feedback to (copy all):
  - Bob Johnston, Air Force Research Laboratory, AFRL.RVBXR.AE9.AP9.Org.Mbx@kirtland.af.mil
  - Paul O'Brien, Aerospace Corporation, paul.obrien@aero.org
  - Gregory Ginet, MIT Lincoln Laboratory, gregory.ginet@ll.mit.edu
- Information and discussion forum available on NASA SET website:
  - http://lws-set.gsfc.nasa.gov/radiation_model_user_forum.html
- The model will eventually be available for web download
  - In the meantime contact Gregory Ginet, MIT Lincoln Laboratory, gregory.ginet@ll.mit.edu