Stochastic Orbital Lifetime Analysis

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Outline

- Need for Stochastic Analysis
- Orbital Lifetime Monte Carlo Tool
- Key Parameters
- Sensitivities
- Conclusions

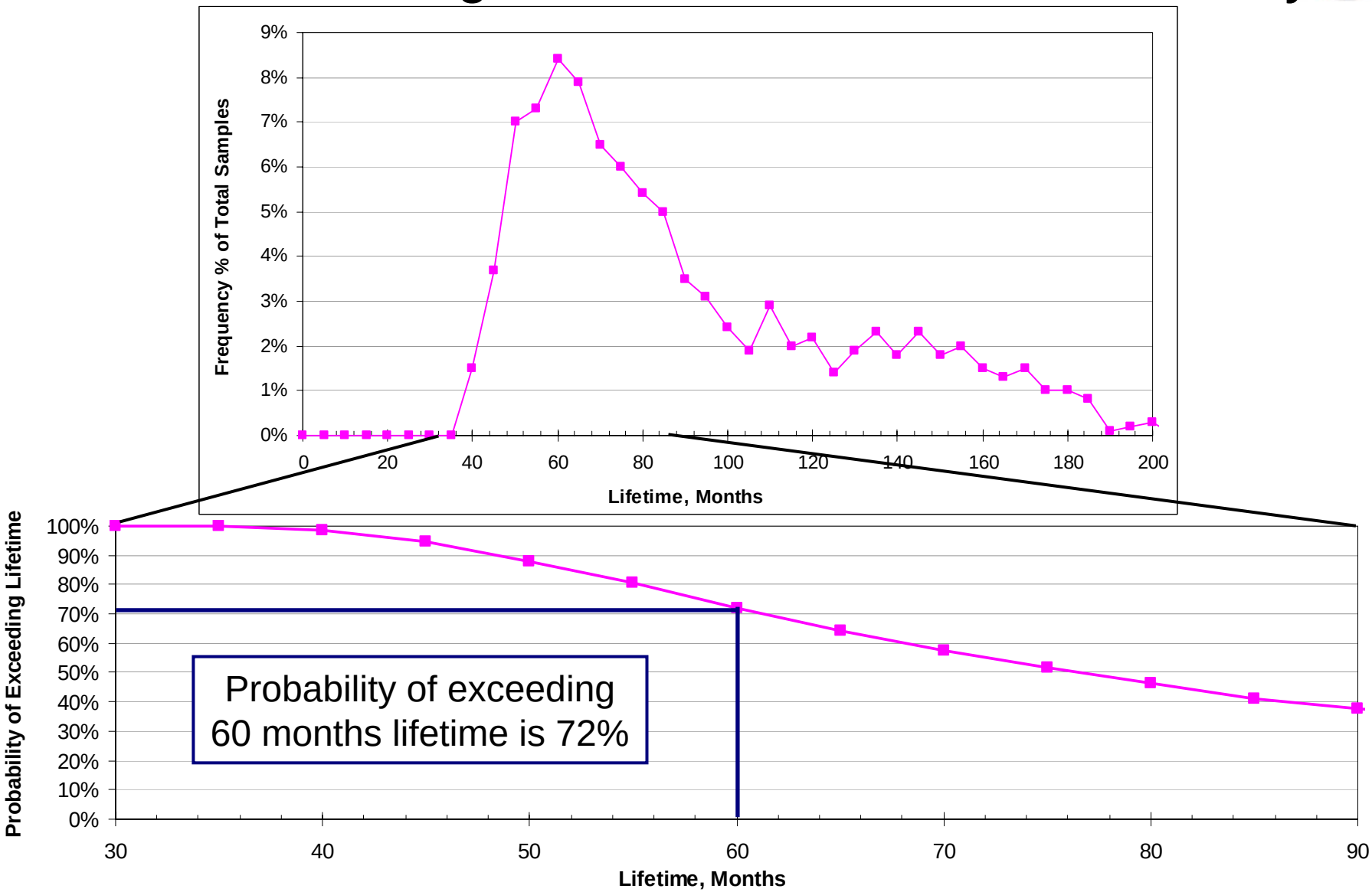
Need for Stochastic Analysis

- Determine the orbital lifetime of a spacecraft
  - Minimum mission goals based on science and/or operational requirements
  - Maximum goals generally defined by spacecraft governing agency
- Point design analyses
  - Difficult to select appropriate assumptions
  - Ignores probability of occurrence of events
- Stochastic analyses
  - Simultaneously vary multiple parameters based on probability of occurrence
  - Provides clear, visual representation of probability of meeting a given lifetime

OLMC – Orbital Lifetime Monte Carlo

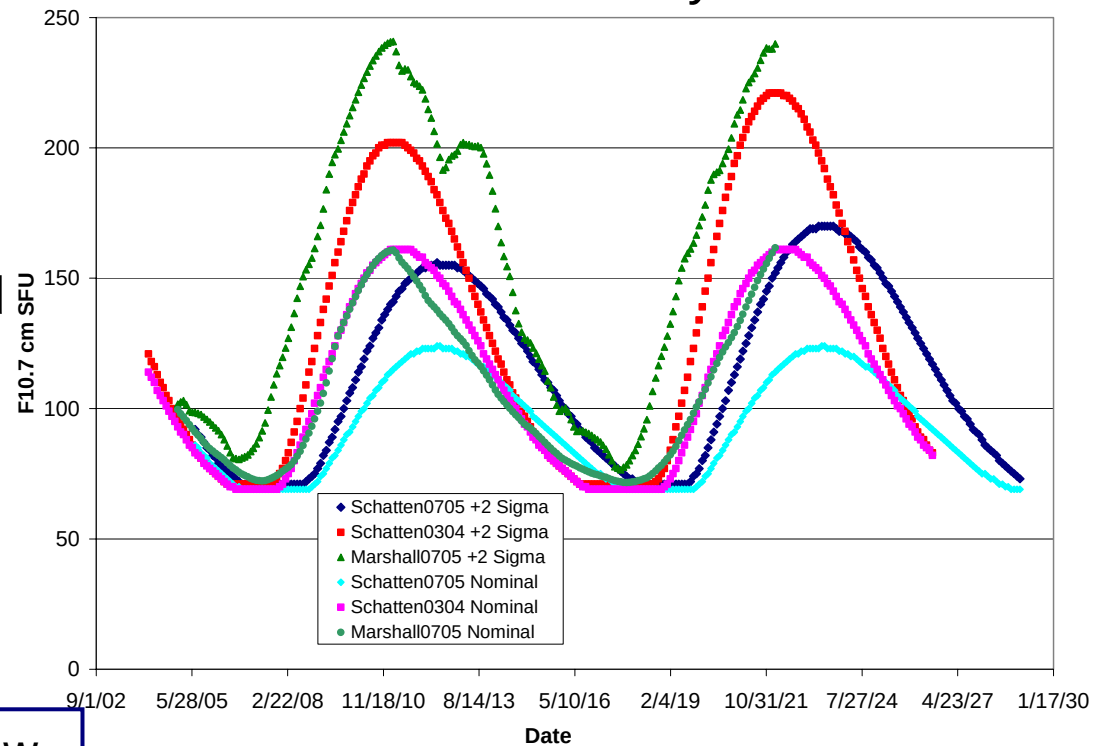
- OL – Orbital Lifetime
  - Validated heritage Fortran code
  - Long term variations of orbital parameters
  - Limited to altitudes less than 2,500 km
  - Perturbations
    - Atmospheric drag
    - Solar radiation pressure
    - Gravitational effects due to the Earth's oblateness, the Sun, and the Moon
- MC – Monte Carlo
  - New Fortran code
  - Up to 10,000 cases
  - Sets up the key parameter sigma values established for each run

Products – Histogram and Exceedance Probability



Key Parameters

- F10.7 cm solar flux predictions
  - Difficult to predict resulting in significant uncertainty
  - Nominal 11-year cycle but has varied between 9-17 years
  - OLMC factors
    - Solar activity magnitude
    - Timing of the peak
  - OLMC factors modeled as normal distributions
  - Prediction sets
    - NASA MSFC
    - Dr. Kenneth Schatten
    - Custom profiles can be utilized



Comparison of prediction sets show difficulty in correctly predicting solar flux magnitude and timing of the peak

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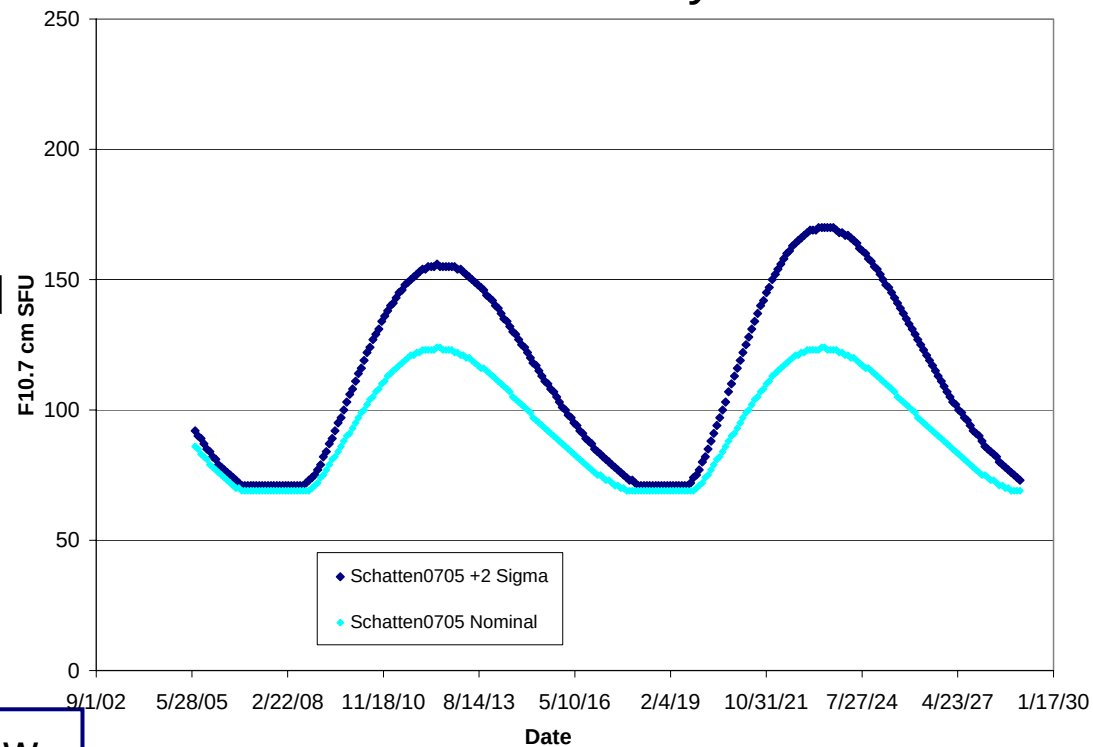

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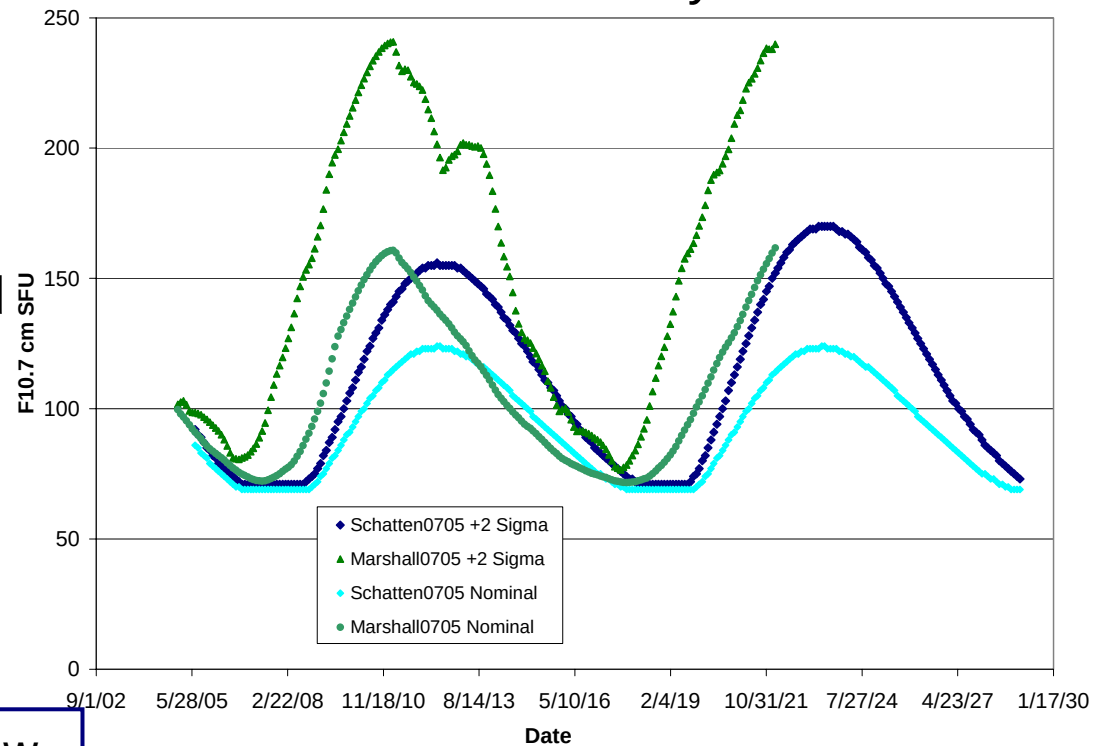

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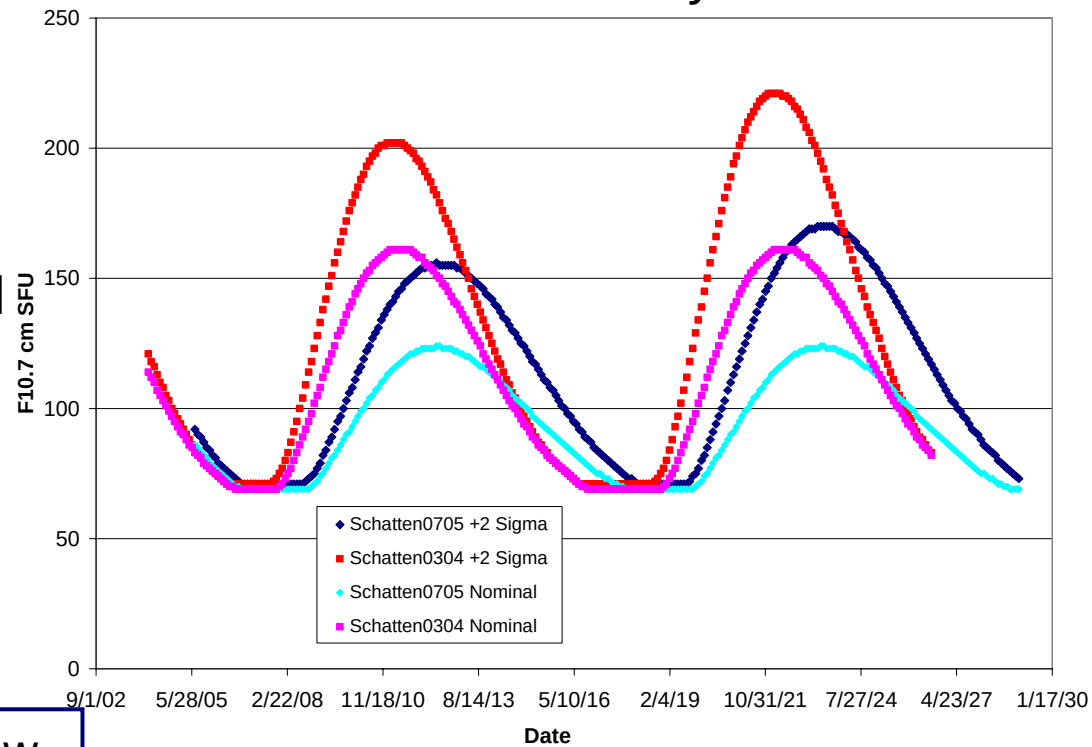

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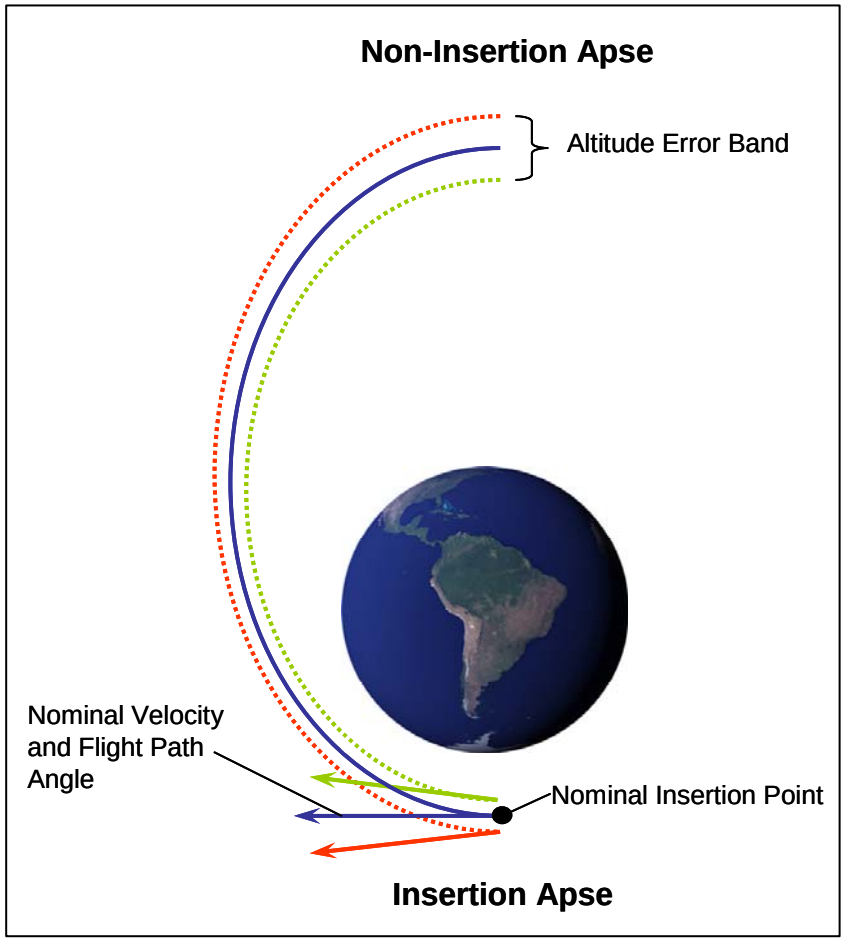
Key Parameters - Continued

- Launch vehicle dispersions
  - Accuracy with which the launch vehicle is capable of placing a spacecraft into its target orbit
  - Dispersions in OLMC
    - Injection apse
    - Velocity
    - Flight path angle
  - Modeled as normal distributions

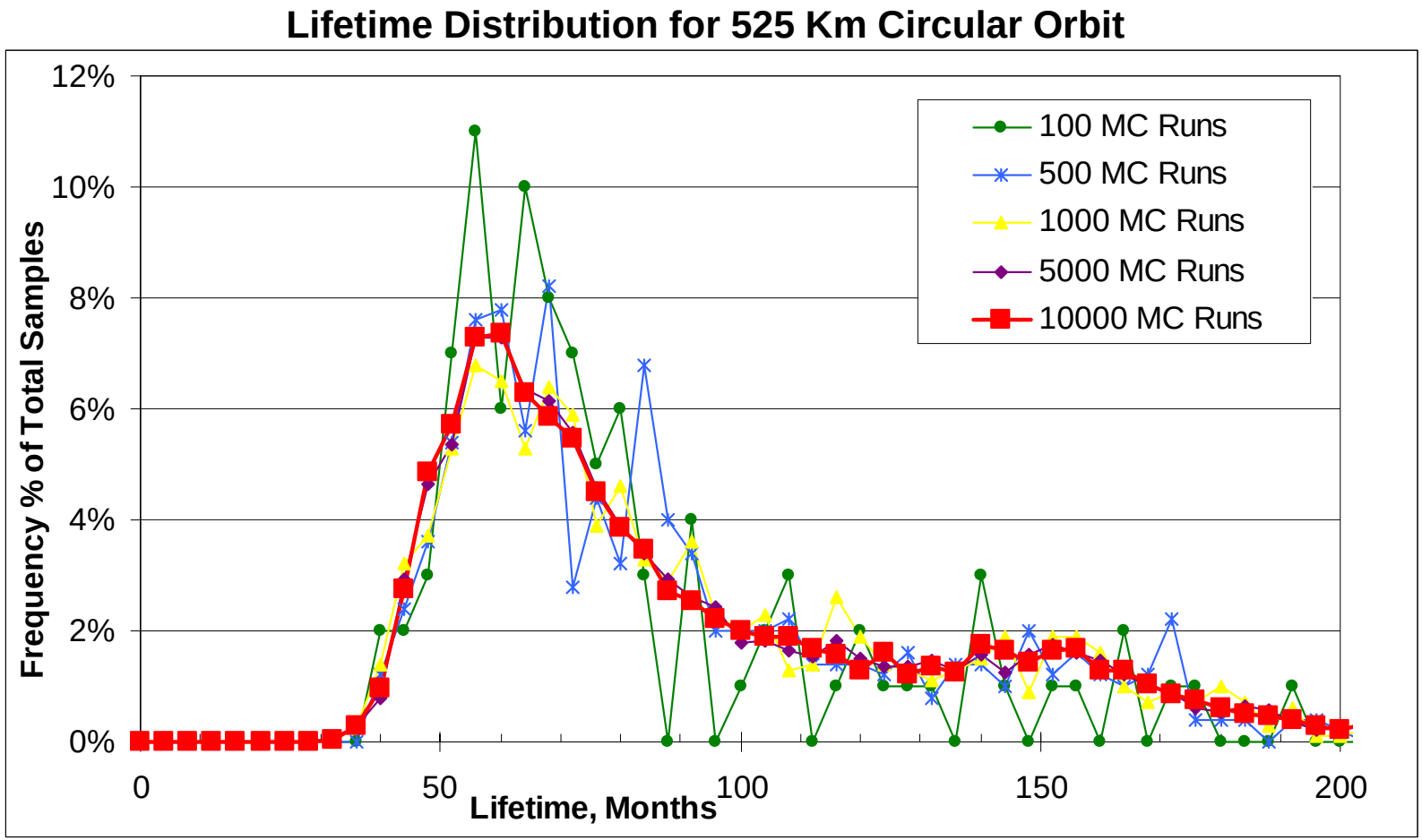


Launch vehicle manufacturers typically provide injection and non-injection apse errors, the latter being directly related to velocity and flight path angle

Key Parameters - Continued

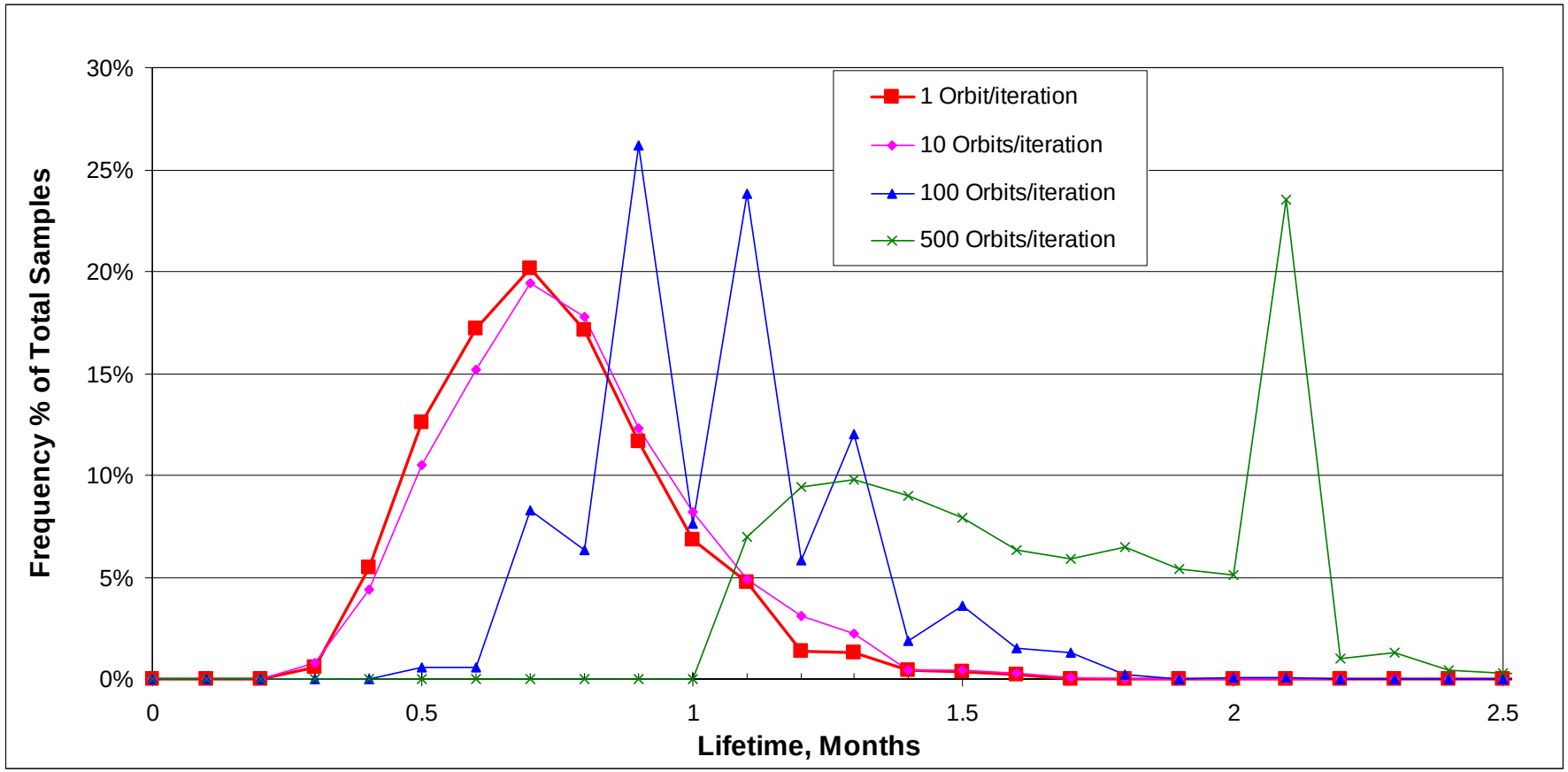
- Launch delays
  - Based on historical data, if available
    - Modeled as a Weibull distribution
  - Fixed launch delays, if no data available
    - Vary launch date (normal distribution)
- Ballistic coefficient
  - Defined as: $m/(C_D A)$
  - Uncertainties associated with projected area, drag coefficient, and mass
  - Modeled as a normal distribution

Sensitivity to Number of MC Runs



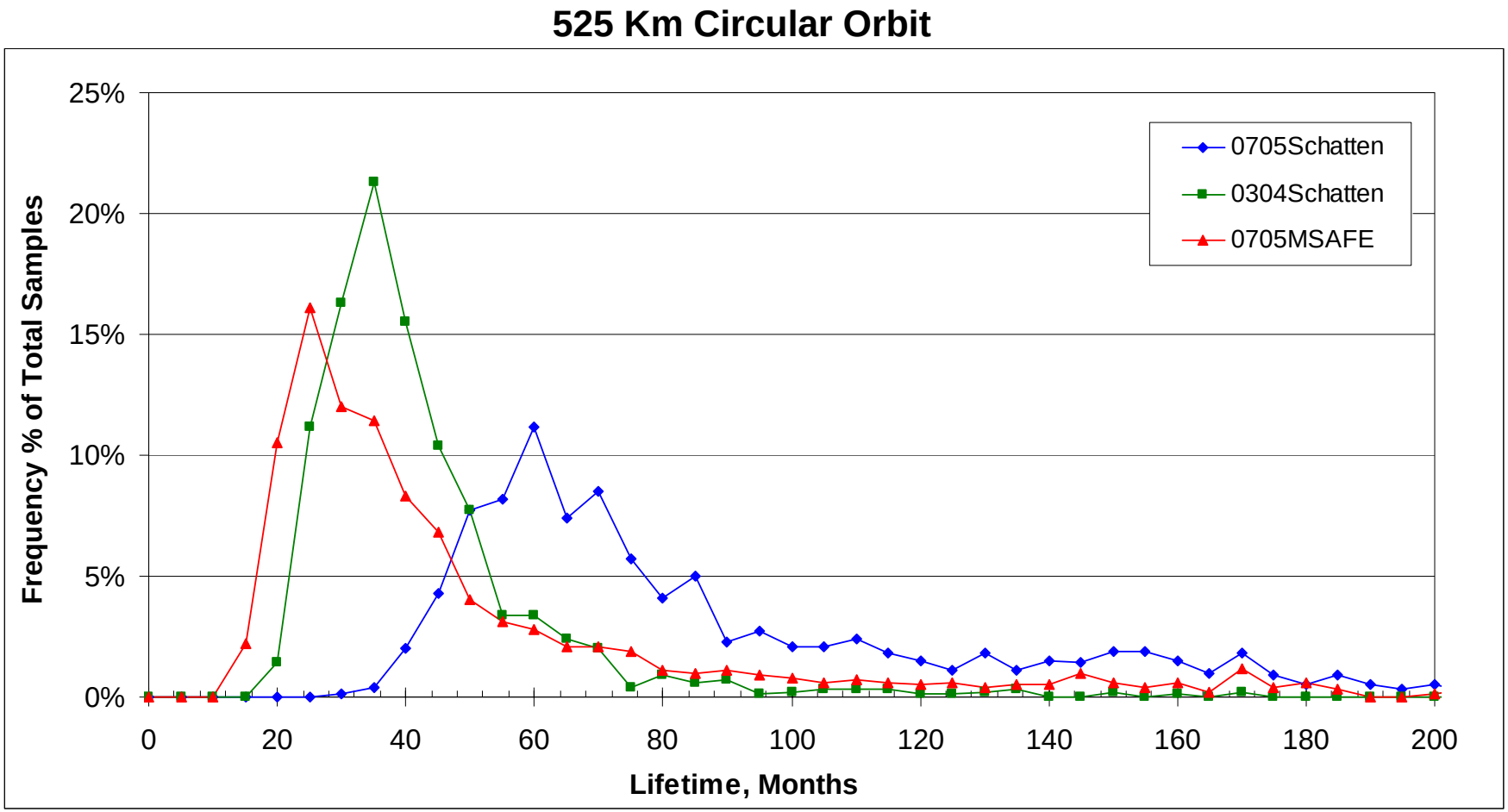
Visual inspection of histograms is recommended to determine the acceptable number of Monte Carlo runs

Sensitivity to Number of Orbits per Iteration



Lower altitude orbits show a high sensitivity to the number of orbits per iteration

Sensitivity to Solar Flux Profile



Multiple profiles should be utilized, given the high sensitivity of lifetime to the solar flux prediction and the intrinsic variability of available predictions

Conclusions

- Normal distributions are appropriate for launch vehicle dispersions represented by injection altitude, velocity, and flight path angle
- Uncertainty distribution for launch delays should be determined based on data available
  - Weibull was appropriate based on data obtained by the authors
- For any scenario, visual inspection of the lifetime histogram and computation of mean and median variation should be done at multiple settings for orbits per iteration and number of Monte Carlo runs to determine acceptable settings for desired ‘reasonable’ distribution and repeatability
- Solar flux predictions are the primary driver for variations in lifetime, therefore caution needs to be exercised when basing analyses on a single prediction

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