On FAME's Eclipses, Occultations and Stray-Light Events

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ABSTRACT

I present statistics for the occurrence of eclipses and occultations during FAME's mission. An eclipse is defined as an event during which the center of the Sun and the center of the Earth are separated by less than the radius of the Earth, as seen from the spacecraft. Likewise, I define an occultation to occur when (part of) the Earth blocks a view of the heavens by one of FAME's viewports. None of the calculations presented include any stray light.

Eclipse seasons last about 31 days, and are separated by about 153 days. The maximum duration of an eclipse is about 67 minutes. Eclipses happen during roughly 17% of the mission days. Astrometric data should be taken during eclipses, and any eclipse-induced disturbances need be as smooth as possible.

Occultations happen much more frequently than eclipses: on average once every three rotations, and cost 1.1% of the total observing time. Most occultations last roughly 115 seconds. The histogram of separations between occultations has several peaks: at 0.225 rotations (the basic angle), one at it's complement (one minus the basic angle) and four peaks at 16.26, 16.5, 17.28 and 17.5 orbits (10.8, 11, 11.5 and 11.7 hours). The torque due to absorbed Earthshine during an occultation sequence is expected to move the S/C by an additional 0.9 pixel in the in-scan direction. If stray Earthshine enters the focal plane from twice the Earth's angular radius, "stray-light events" last twice longer than actual occultations, but corrupt four times as much observing time.

1. Simulation Parameters

I simulated a FAME mission of 2.5 yrs with the aim of determining the eclipse and occultation frequencies employing the same set of IDL programs inherited used to calculate the star transit rates. FAME is assumed to be in geosynchronous orbit at $42,162$ km from Earth's center, and is inclined by 28.7 degrees with respect to the ecliptic. From this vantage point, the Earth subtends an angle of $\arctan 2 \times 6,371/42,162 \sim 17.2$ degrees. The sun-angle

equals 45° , the precession period equals 20 days, and the scan-rate 540 arcseconds/second. FAME's field of view is approximately 1 degree ($FOV_{FAME} = 1°$), and the basic angle is set to 81°.5. For completeness, I also include eclipses and occultations due to the Moon. However, these events are very rare indeed.

2. Occultations

An occultation happens when Earth passes through one of FAME's viewports. At the standard scan rate, it takes the field of view $(17.2 + 2 \times FOV_{FAME}) \times 3600/540 = 128$ seconds to cross the full extent of the disk of the Earth. As seen in the top panel of figure 1, Earth shines in one of the viewports one out of six rotations. This figure also shows that occultations happen frequently during several consecutive rotations, followed by an interval between 10.8 and 11.7 hours without occultations. The duration of the occultation sequence is set by the time the S/C travels $(17.2 + 2 \times FOV_{FAME})$ in its orbit (19.2/360*24 hr). During the average occultation sequence of 76.8 minutes (1.92 rotations) of two occultations per rotation, the Earth shines 3.84 times in a viewport.

2.1. Occultations & Spin Dynamics

During such occasions, the additional torque due to absorbed Earthshine is maximal and results in a position change of about 88% of a pixel. Here we assume that 15 Watt Earthshine is absorbed 1 meter from the spin axis, and that 10%[1] of the torque acts to spin-up the spacecraft. We then have $\tau = I \times \frac{d\Omega}{dt} = 0.510^{-8}$Nm, and with $I = 350$ kg m^{-2} we get $\frac{d\Omega}{dt} = 1.4310^{-11}$ rad s^{-2}. Thus, during Earthshine falling in a port we have an acceleration of about 2.9 μas s^{-2}, leading to a total change in spin-rate of $128 \times \frac{d\Omega}{dt} \sim 0.38$ mas/sec, or about 0.7 parts per million. Each time Earthshine is absorbed in the viewport, the in-scan position change follows from integrating the acceleration incurred, or 2.9μas $s^{-2} \times 128^2 = 0.047$ arcsec, or 23% of a pixel, leading to a 0.88 pixel per occultation sequence (Murison & Olling, 2000, private communications).

These occultation events act like mini thruster burns in the sense that small "discontinuities" in the attitude will be introduced. However, it is expected that these events complicate but do not inhibit the data reduction process, mainly due to the fact that occultations in-

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[1]This fraction depends on the relative location of the center-of-mass of the S/C and the entrance of the viewport.

troduce just attitude changes, but not any S/C vibrations.

2.2. Stray Light

When Earth is just outside the field of view, Earthshine will still enter the instrument and some fraction will scatter onto the CCD array. This effect will both lengthen the time interval that no astrometric and photometric data can be taken (too much/irregular background) and the interval that the Earthshine torque acts to spin-up the rotation. Obviously, we need an as large rejection of stray light entering the focal plane as possible. No information as to the degree of data corruption as a function of earth distance exists at this time. The average duration (τ) of a "stray-light event" (SLE) and the fraction of rotations in which SLEs happens ($F_{rot,SLE}$) is linearly proportional to the "stray-light radius" of the Earth ($R_{SLE,\oplus}$). However, the fraction of the sky in which stray-light events happen is proportional to the *square* of Earth's stray-light radius (see figures 3 and 4). To summarize:

- $< \tau_{SLE} > \sim 115 \left(\frac{R_{SLE,\oplus}}{R_\oplus} \right)$ seconds $\sim 4.8 \left(\frac{R_{SLE,\oplus}}{R_\oplus} \right)$ percent of a rotation

- $F_{rot,SLE} \sim 16 \left(\frac{R_{SLE,\oplus}}{R_\oplus} \right)$ percent

- $\frac{\tau_{SLE}}{\tau_{mission}} \sim \frac{2 \times \pi R_{SLE}^2}{Area_{sky}} \sim 1 \left(\frac{R_{SLE}}{8°6} \right)^2 \sim 1 \left(\frac{R_{SLE,\oplus}}{R_\oplus} \right)^2$ percent

For example, if the effectife stray-light radius of the Earth equals twice it's physical radius $[\left(\frac{R_{SLE,\oplus}}{R_\oplus} \right)=2]$, stray-light events occur in approximately 32% of all spacecraft rotations, last about 2 minutes and render 9.6% ($\sim 35°$) of such stray-light rotations useless. If the stray-light radius is as large as 30° , more than half of the rotations will contain a stray-light event that would take out an arc of more than 60 degrees.

The minimization of stray-light may also be important for astrometric observations near bright giant planets (Jupiter, Saturn, etc.) that might be used for test of general relativity (Kaplan, 2000, private communications).

3. Eclipses

Twice per year, one of the nodes of the orbit of the spacecraft points towards the Sun so that the Earth covers the sun once per day. The timescale for the duration of the eclipse season is set by the Earth's orbital motion: eclipse season starts when one limb of the Earth

just touches the Sun, and it ends when the other side has crossed the Sun completely. To first approximation, the eclipse duration equals two times the diameter of the Earth divided by the circumference of a circle times the length of the year, or 35 days, which is close to the duration measured from the model time lines, of 31 days.

3.1.   Eclipses & Spin Dynamics

During eclipses, the dominant torque due to solar radiation drops to zero. This allows for other disturbing torques to manifest themselves more strongly, so that they can be more easily recognized in the data reduction process[2]. Eclipses also provide an excellent opportunity to check the validity of the models that handle Solar radiation torques. In order to do so, it is important to continue to take data during eclipses, and that any changes must be as adiabatic as possible.

Because eclipses happen during about 17% of the mission days, it is important that the data taken during these eclipse days can be utilized to its fullest possible extent. This means that eclipse-induced disturbances in the S/C rotation, nutation and vibration spectra (e.g., due to flapping solar cell arrays, etc.) must be damped out on the shortest possible time-scale (10 minutes?). Likewise, any distortions in the behavior of the optics need be minimized, during and after an eclipse.

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[2]For example, it was found the HIPPARCOS' magnetic moment changed dramatically during eclipses, presumably due to battery operation.
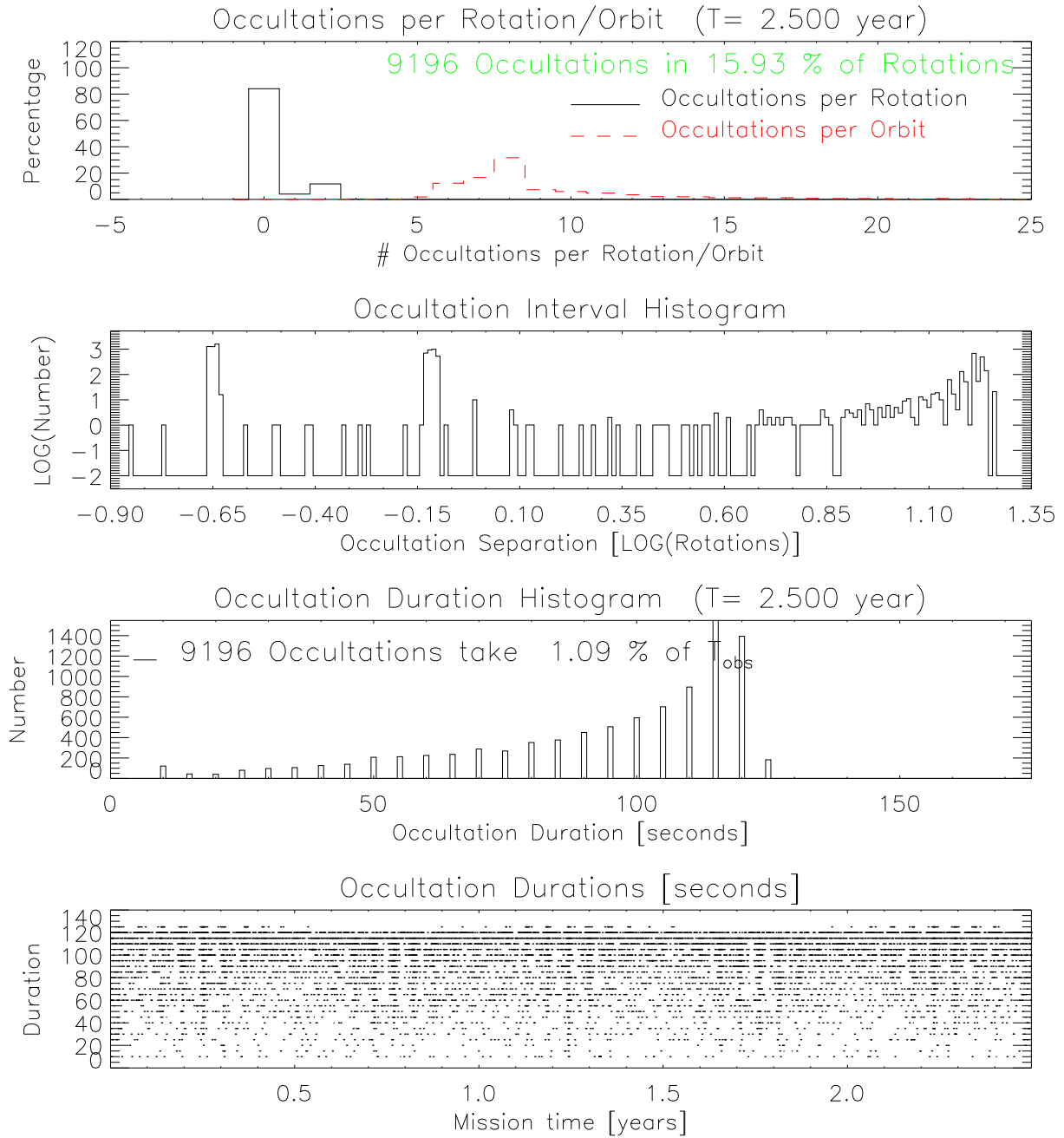
Occultations per Rotation/Orbit (T= 2.500 year)

9196 Occultations in 15.93 % of Rotations

Occultations per Rotation
Occultations per Orbit

Percentage

Occultations per Rotation/Orbit

Occultation Interval Histogram

LOG(Number)

Occultation Separation [LOG(Rotations)]

Occultation Duration Histogram (T= 2.500 year)

9196 Occultations take 1.09 % of T_{obs}

Number

Occultation Duration [seconds]

Occultation Durations [seconds]

Duration

Mission time [years]

Fig. 1.— Occultation statistics. From bottom to top, the panels plot: 1) occultation duration versus mission time, 2) occultation duration frequency distribution, 3) time between occultations, and 4) the number of occultations per rotation (full black histogram) and day (dashed red histogram).
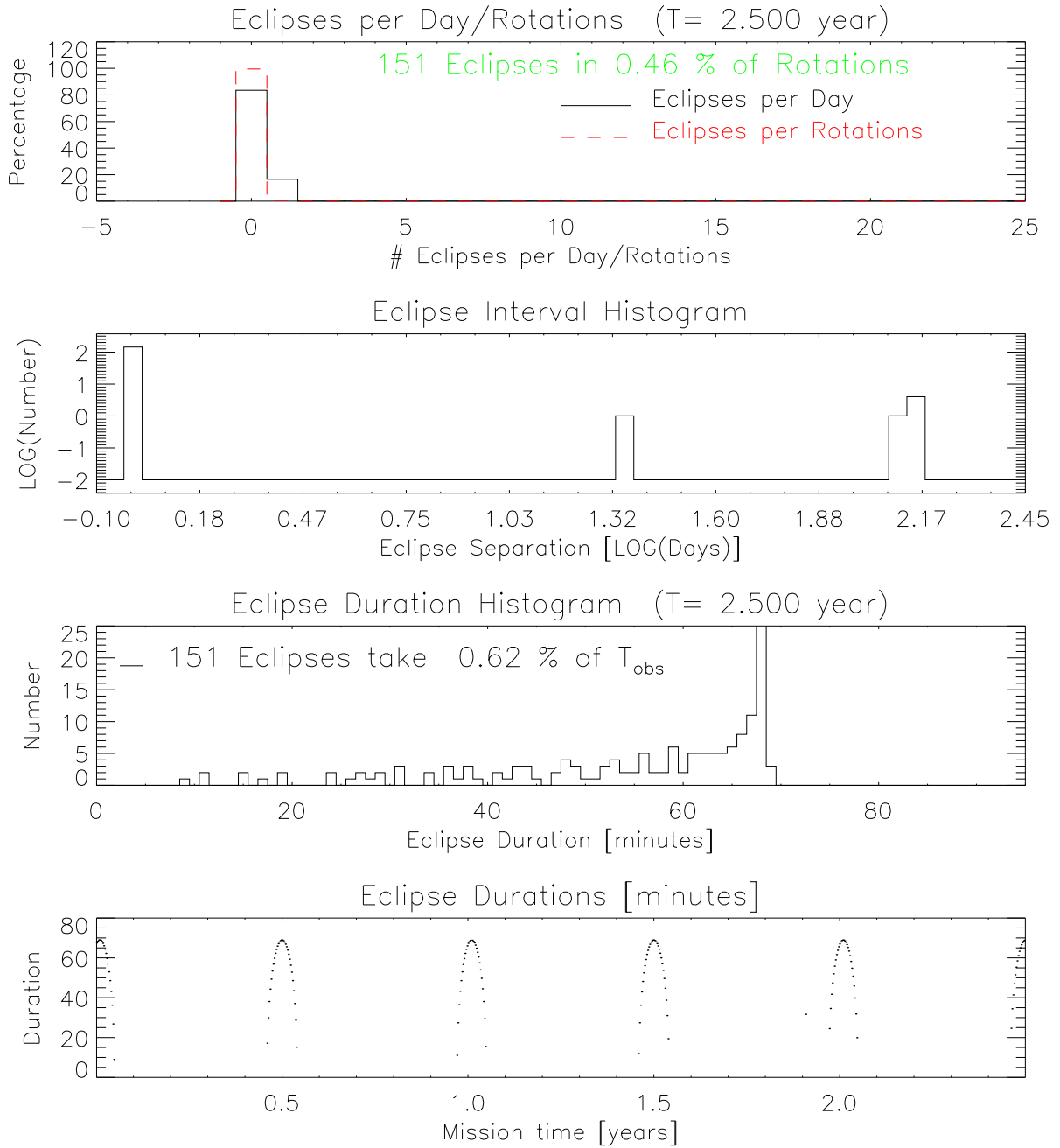
Fig. 2.— Eclipse statistics. From bottom to top, the panels plot: 1) eclipse duration versus mission time. Each eclipse season spans about 31 days (full width at zero duration), while they are separated by ∼ 153 days. 2) eclipse duration frequency distribution, 3) time between eclipses, and 4) the number of eclipses per day (full black histogram) and rotation (dashed red histogram).
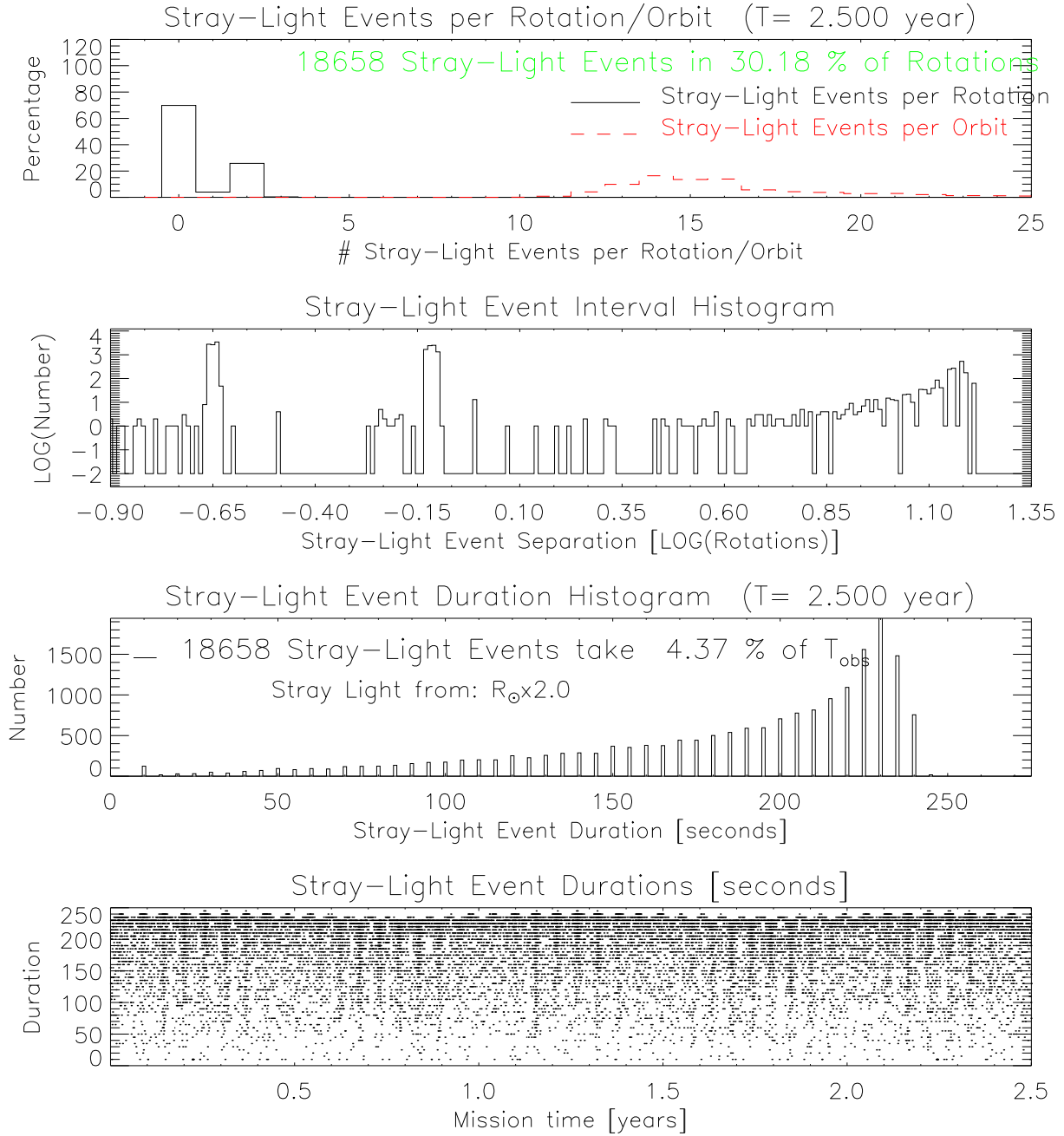
Fig. 3.— "Occultation," or "stray-light event" statistics resulting from a stray-light *radius* of 17.2 degrees. For explanation of the individual panels, see figure 1.
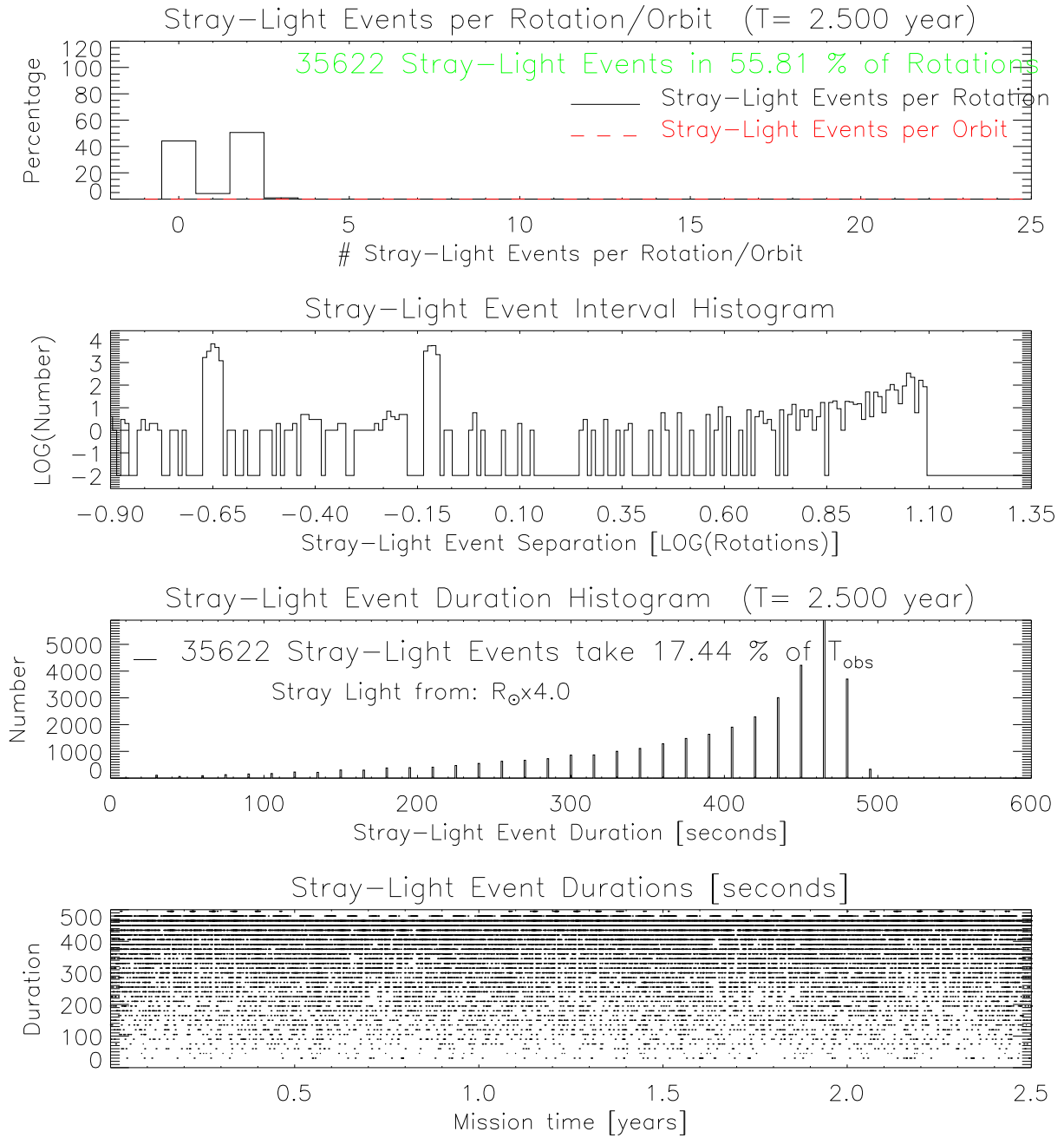
Fig. 4.— "Occultation," or "stray-light event" statistics resulting from a a stray-light *radius* of 34.4 degrees. For explanation of the individual panels, see figure 1.