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MEMORANDUM

SUBJECT: TRAPPED-RADIATION ENVIRONMENT

PROJECT: CHANDRA X-RAY OBSERVATORY

DATE: 2006.01.31

SUMMARY

Pursuant to a request from the ACIS team, Project Science computed the long-term external fluence of trapped protons in the evolving orbit of the Chandra X-ray Observatory. These data help characterize the vulnerability of the ACIS front-illuminated CCDs to damage (CTI increase) during unprotected radiation-belt passes, as the orbit evolves. Of course, the *Chandra* team will not intentionally leave the ACIS exposed during perigee passes.

DISCUSSION

Project Science obtained a long-term ephemeris (see *ORBITAL EPHEMERIS*) for *Chandra*'s orbit from the Flight Operations Team. Using the supplied orbital elements, we used ESA's SPENVIS (SPace ENVironment Information System) tool to propagate the orbit in the standard AP8 environment (see *SPENVIS COMPUTATIONS*). From the SPENVIS runs, we tabulated and plotted the orbit-averaged trapped-proton spectral intensity and intensity for each year of the supplied ephemeris (see *RESULTS*). Four attached files document the results (see *DATA PRODUCTS*).

ORBITAL EPHEMERIS

NGST/ Eric Martin provided the *Chandra* orbital elements in two files. The first provides the daily orbital elements for the first 15 years of the mission (1999.08–2014.08); the second, monthly elements for nearly 20 years starting 2006.02. Upon merging the two data sets, we obtained a 27-y (1999.08–2026.12) monthly ephemeris. The attached file `orb-eph_27y.txt` provides the tab-delimited data describing the orbit, at approximately monthly intervals. Chart 1 of the attached file `orb-rad_27y.pdf` plots the orbit's inclination, apogee, and perigee.

SPENVIS COMPUTATIONS

We performed a 20-orbit SPENVIS simulation starting in mid-August of each year of the ephemeris — 1999.08–2026.08 at 1-year intervals. For *Chandra*'s 63.5-h period, each run then spans 52.9 days. For the radiation environment, we used the standard AP8 model for trapped protons — AP8-Max for 1999–2003, 2010–2014, and 2021–2025; AP8-Min for other periods.

For each SPENVIS run, we recorded SPENVIS computed the trapped-proton differential flux $F_E(E;t)$ [#/(cm^2 s MeV)] at energy E [MeV] and integral flux $F(>E;t)$ [#/(cm^2 s)] for proton energy > E [MeV], averaged over the 20-orbit run. For convenience, we converted these values to orbital spectral intensity $I_E(E;t)$ [#/(cm^2 sr MeV orbit)] and orbital intensity $I(E;t)$ [#/(cm^2 sr orbit)], tabulated in the attached files `orb-dif_27y.txt` and `orb-int_27y.txt`, respectively.

RESULTS

Charts 2–9 of the attached file `orb-rad_27y.pdf` (from data files `orb-dif_27y.txt` and `orb-int_27y.txt`) show the evolution of the trapped-proton orbital fluence. At the lower proton energies — responsible for most of the CTI increase of the front-illuminated CCDs — the trapped-proton fluence is highest at the start of the mission and evolves quasi-periodically throughout the mission, due primarily to evolution of the orbit's eccentricity. For these low-energy protons, orbital-fluence minima occur around 2006 and around 2017. Near these minima, the 0.1–0.5-MeV trapped-proton fluence is lower than its initial value by about 2 orders and 1 order of magnitude, respectively. However, between these minima, the low-energy-proton fluence is comparable to (but somewhat less than) its initial value.

DATA PRODUCTS

The four (4) attached files comprise the data products from this study:

1. `orb-eph_27y.txt` is a tab-delimited ASCII listing describing *Chandra*'s orbit, from 1999.08 to 2026.12, in monthly intervals. The first 7 columns — (1) date, (2) semi-major axis, (3) eccentricity, (4) inclination, (5) right ascension of ascending node, (6) argument of perigee, and (7) true anomaly — specify the orbit. The remaining columns give (8) mean anomaly, (9) apocenter, (10) pericenter, (11) apogee, and (12) perigee. Distances are in kilometers (km); angles, in degrees.
2. `orb-dif_27y.txt` is a tab-delimited ASCII listing of the average orbital trapped-proton differential fluence, from 1999.08 to 2026.08, in yearly intervals. Column 1 gives the year; the remaining columns, the spectral intensity $I_E(E)$ in #/(cm^2 sr MeV orbit) at energy E. The second record specifies proton energies E in MeV.
3. `orb-dif_27y.txt` is a tab-delimited ASCII listing of the average orbital trapped-proton integral fluence, from 1999.08 to 2026.08, in yearly intervals. Column 1 gives the year; the remaining columns, the intensity I(E) in #/(cm^2 sr orbit) for energy > E. The second record specifies proton energies E in MeV.
4. `orb-rad_27y.pdf` presents 9 plots illustrating the evolution of *Chandra*'s orbit and trapped-proton orbital fluence over 27 years. The charts show (1) the orbit's inclination, perigee, and apogee; (2) spectral-intensity spectrum $I_E(E;t)$ for years 1999–2012; (3) the same, for 2013–2026; (4) spectral-intensity time dependence $I_E(t;E)$ at 7 energies; (5) spectral-intensity time dependence at 17 energies, scaled to the initial (1999.08) value for each. Charts 6–9 display plots for the intensity I, analogous to charts 2–5 for the spectral intensity I_E.