Geocoronal Lyman Alpha Observations with COS

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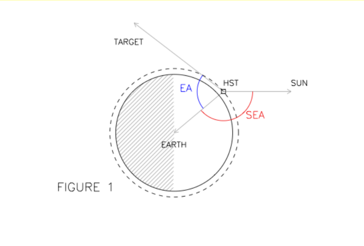
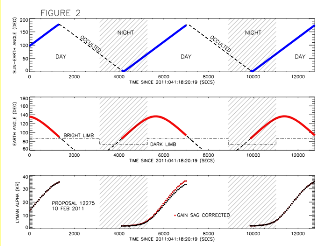
The time-tagged mode of the Cosmic Origins Spectrograph (COS) provides a convenient method of studying the orbital variation of geocoronal Lyman-alpha emission at the altitude of HST. We have analyzed G130M blank sky exposures from scheduled STIS parallels and observations for which the target acquisition failed. We supplement these with observations of WD standard stars from flat field and sensitivity monitoring programs where the stellar Lyα profile can be modeled and its contribution to the geocoronal emission removed. Data were corrected for time-dependent sensitivity changes and gain sag. The measurements have been fit by an analytical model based on the orbital position of HST and the angle between the target and the Earth as seen from HST. The Lyα emission varies from less than 2 kR for a target observed at orbit midnight to 37 kR for one observed at the bright Earth limb at orbit noon. A long-term trend of increasing flux is evident, consistent with solar Lyα measurements by SOLSTICE on SORCE as the next solar maximum is approached. We expect the irradiance at solar maximum to be at least 50-55 kR. This level still should not trigger local count rate violations for the FUV detector, but will accelerate gain sag of the microchannel plates in the regions where Lyα falls.





Introduction and Data Reduction

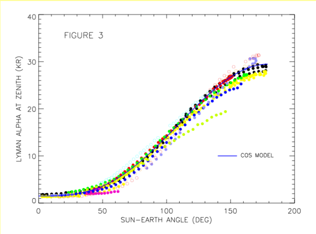
- Geocoronal Lyα is caused by resonance scattering of solar Lyα photons in the Earth's exosphere, with a small background contribution from the interplanetary medium. The intensity varies strongly with illumination angle of the Sun as seen by HST (the Sun-Earth angle, SEA) and the look-angle through the terrestrial atmosphere to the target (the Earth Angle, EA). It is greatest at HST orbit noon (maximum SEA) with the target near the Earth limb (minimum EA). See Figure 1.
- We are interested in determining an analytical model to predict the Lyα intensity and its effects on the COS FUV detector. G130M observations from the COS Airglow web site were analyzed, supplemented with COS flat field programs utilizing WDs where the stellar Lyα absorption profile can be modeled and removed. Data from each corrtag file were summed into 10-second bins from 1214.4 –1217 Å with an extraction height large enough to cover the filled aperture. Count rates were converted to kilo-Rayleighs by a calibration derived from the corresponding X1D file, which removes the time-dependence of instrument sensitivity. Corrections for localized gain sag were determined and applied. Figure 2 shows the time-series for a 3-orbit observation.

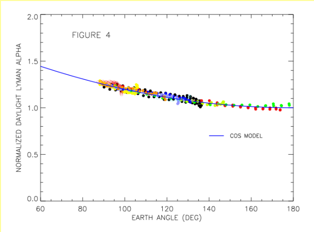
Model Development

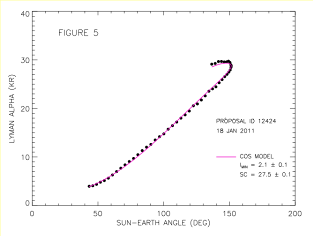
- Based on OSO-4 and OGO-4 observations, F. Walter of the GHRS team parameterized geocoronal Lyα variation as

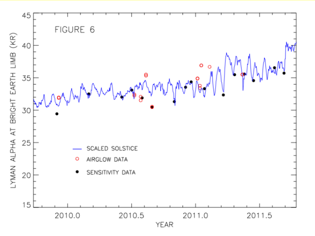
$$I = I_{min} + SC \times [\cos^2((180\text{-}SEA)/2)] \times [1+((180\text{-}EA)/90)^2]$$

with angles measured in degrees. The cosine term for SEA models the solar illumination as seen by HST, and the parabolic term for EA approximates optical depth dependence. I_{min} is the intensity seen at orbit midnight, and SC is the amplitude of diurnal variation. During GHRS Science Verification, he found I_{min}=4 and SC=37 kR (Heap et al, PASP, 107, 871, 1995).
- Using this function as a guide, we investigated the dependence of intensity as measured by COS on SEA and EA. In Figure 3, the time-series of each observation is shown as a different color. The data are normalized to the local zenith using the EA correction below. We find the SEA dependence is modeled better by a $\cos^3((180\text{-}SEA)/2)$ term.
- The dependence on orbital position (SEA) is much stronger than that for the look-angle (EA). We find it is highly variable between observations as well. For the EA parameterization, we use data taken during daylight normalized to orbit noon from the SEA dependence above. Figure 4 shows that a better fit to look-angle is $[1+((180\text{-}EA)/180)^2]$.









Model Fits and Results

- Data from each COS observation were fit with a model of

$$I = I_{min} + SC \times [\cos^3((180\text{-}SEA)/2)] \times [1+((180\text{-}EA)/180)^2]$$

Figure 5 shows an example of such a fit. The mean 1-sigma error for all observations was 0.5 kR. Much of the uncertainty in I_{min} and SC occurs from the mixture of multiple grating settings and lack of full-orbit coverage. I_{min} was found to range from 0.75 - 2.90 kR, and SC from 22.6 - 27.5 kR.
- Since the geocoronal emission arises from scattered solar Lyα photons, we can compare the COS measurements with contemporaneous solar Lyα values measured by SOLSTICE on the SORCE satellite, available at the LASP Interactive Solar Irradiance Data Center (ISIRD, *http://lasp.colorado.edu/lisird/lya*). The mean ratio of geocoronal to solar Lyα irradiance was found to be 0.11.
- In Figure 6 we show the temporal variation of the COS data compared to the scaled SOLSTICE values. To increase the cadence of observations, we also analyzed all G130M sensitivity monitoring data taken of WD0947+857 in the same way as the flat field observations.
- Evident in the COS data is the long-term increase in Lyα flux as the next solar maximum is approached and the 27-day variation due to solar rotation.

Approaching the Next Solar Maximum

- COS was installed in HST in May 2009, during the last minimum of the solar cycle. Although it is difficult to predict with any real precision the time and level of activity of the next solar maximum, we use the data from Cycle 23 to gauge the increase that may occur in the geocoronal Lyα emission during Cycle 24 and assess the effects on the detector.
- Figure 7 shows the scaled Cycle 23 data from the composite Lyα values from LISIRD shifted to match the current cycle SOLSTICE data observed so far. We anticipate that COS will see 50-55 kR at the bright Earth limb at solar maximum.
- In Figure 8, we find that the corresponding peak count rate will be about 1 count/sec/pixel. The local count rate limit for COS is 1.67 c/s/pix. While geocoronal Lyα is not expected to cause a detector shutdown, care may be needed for observing objects with high fluxes in the Lyα region.