SWCX Key Project Summary

June 12, 2018

1 Summary

The goal of the key project is to characterize the SWCX properties and build a semi-empirical model to make available through a web interface. At first order, the intensities of O VII and O VIII depend linearly on solar wind conditions. In particular, the intensity I is the integral over the line of sight ds of the product of the ion density n_{ION}, the neutral density (n_H and n_{He}), and the interaction cross-section α:

$$I_{OVII} = \int n_{O7+}(\alpha_{O7+,H} n_H + \alpha_{O7+,He} n_{He}) < g > ds, \tag{1}$$

and

$$I_{OVIII} = \int n_{O8+}(\alpha_{O8+,H} n_H + \alpha_{O8+,He} n_{He}) < g > ds, \tag{2}$$

where $< g >$ is the average solar wind speed (bulk and thermal), and the cross-sections α are velocity dependent.

At first order, for a simplified model where, instead of the integral, we use a simple linear dependence on density of neutrals and of $O7+$, we can find the OVII intensity as:

$$I_{OVII} = \alpha_{O7+} \times (\frac{\alpha_H}{\alpha_{He}} n_H + n_{He}) \times \int n_{O7+} < g > ds, \tag{3}$$

which can be written as:

$$I_{OVII} = \alpha_{O7+} \times (\frac{\alpha_H}{\alpha_{He}} n_H + n_{He}) \times f_{O7+}. \tag{4}$$

Step 1: correlation between n_{O7+} and n_p. Most of the time, n_{O7+} is not available from OMNI, therefore we want to be able to use n_p instead. To do that, we looked at archival data to verify the dependence of n_{O7+} vs. n_p, and we found that, on average, it is not linear, but cubic as shown in Fig. 1, which shows the scatter plot of f_{O7+} vs. f_p from ACE data. We fit the distribution with a power law, the best fit parameter has a power index = 3.

Step 2: find the average f_p. The proton flux has high variability on a time scale of single day. The SWCX intensity, however, depends on the interactions along a line of sight of a few A.U. To account for the full line of sight we need to average the fp. The basic idea is that the proton flux measured during the days before the SWCX observation tells us the distance from Earth of the interacting ions. We used several strategies to average the proton flux:

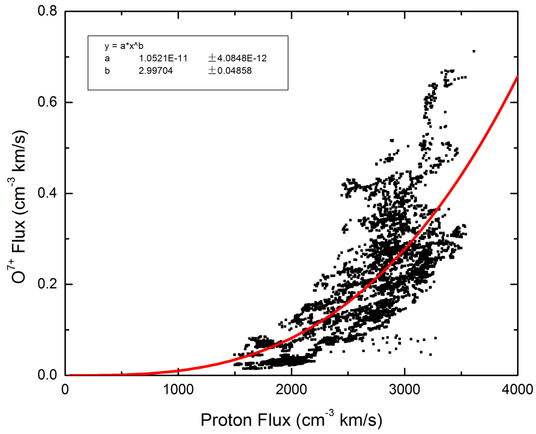

Figure 1: $O7+$ vs. proton flux (from ACE data).

- Boxcar average over the 90 days before the observation (approximately 18 A.U. assuming SW speed of 350 km/s). It gives a very smooth average in time. But the last and first days have the same weight, we might expect that the distant signal is weaker. What if we include additional days?
- Weighted average over 90 days. The weight is $1/r$, where r is the distance from Earth computed using the solar wind speed. It accounts naturally for the choice of 90 days (beyond that there is only a minor contribution). But the average is rather spiky.
- Geometry and time dependent integrals (computed by D.K.) based on the observation start time, mid time, and end time. More "realistic", but difficult to compute.

Finally we decide to use boxcar average over 90 days.

Step 3: Test the simplified model. The SWCX OVII intensity depends on the density of neutrals. The neutral density changes from target to target and from observation to observation (with seasons). We normalized the OVII flux of each observation by the corresponding neutrals density and plotted as a function of f_p, i.e., $I_{OVII}/(\frac{\alpha_H}{\alpha_{He}}n_H + n_{He}) \propto f_{O7+} \propto f_p^3$. (Fig. 2). The distribution matches very well the expected 3rd power (in Fig. 2 the H:He ratio is 2). Of the three points that do not follow the distribution, they all show evidence of Geocoronal SWCX.

Test on H:He cross section ratio: we remove the three data points with possible Geocoronal SWCX contamination, fit the renormalized OVII by neutral integral with the proton flux, and compare the power-law fitting results for different values for the ratios (1, 2, 3, 4, 8). We found that the index goes higher with increased ratios (the fit is getting worse with increasing ratios). The index is close to 3 for ratio of 1 and 2.

Step 4: Procedures for the web interface to caluclate the predicted SWCX (OVII only now)

- Get the input parameters, Date, Coordinate, H:He ratio

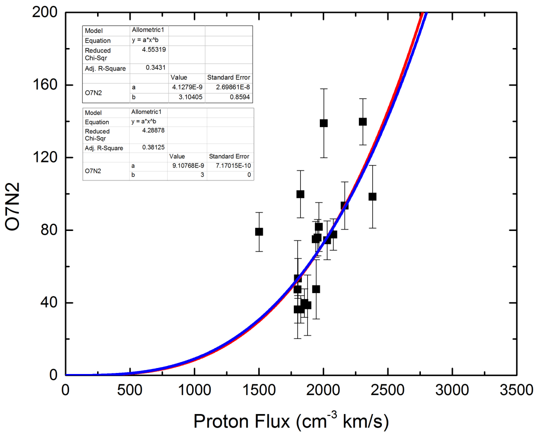

Figure 2: Normalized OVII vs. average proton flux (ACE). The two lines represent a power-law fit with index fixed at 3 and free index (best value close to 3).

- Calculate the averaged proton flux f_p based on the date
- Calculate the neutral integral based on Koutroumpa's code (the Earth's position, line of sight direction)
- Calculate the predicted SWCX intensity based on the results from step 2 and 3 using the fitting results from the Key Project (power-law normalization and index).

We tested the SWCX empirical model based on the neutral distribution data of year 2000. We only have the neutral distribution data from 1996-2005 from Dimitra.

2 Issue: The predicted SWCX value is too high!

The range of proton flux from Key Project is relatively narrow, covering from 1500 to 2500 cm^{-3} km/s. If the proton flux is high (e.g., $>$ 3000 cm^{-3} km/s) for a given date, the calculated SWCX will be very high due to the power-law relation.

We included the results from the Chandra Deep Fields South (CDFS) and MBM 12 (both observed by XMM) since they cover both the solar minimum and maximum in Fig. 3. It is clear that the proton flux of the key project (close to the Solar Maximum, from 2012-2015) are smaller than the values of CDFS at solar maximum (2001 and 2002, red points at the right side of the figure).

The proton flux is calcualted based on ACE data. We compared the differences between the data from ACE and WIND in Fig. 4. The proton flux from WIND is about 20-30% larger than that from ACE after 2009.

We include He Cone data, which were observed by both Suzaku (in year 2005, 2006, and 2009) and XMM (in year 2001 and 2003). In Fig. 5 we show the OVII intensity as a function of neutral density times the

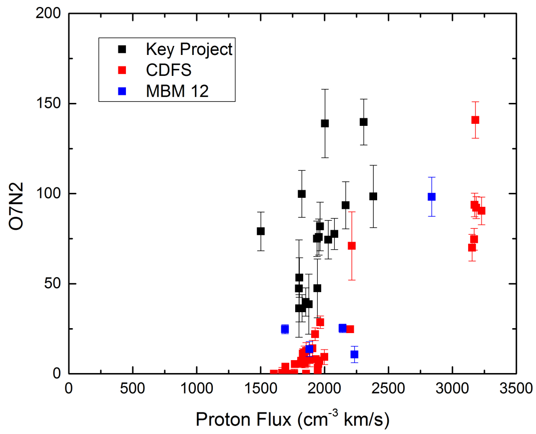

Figure 3: Normalized OVII vs. average proton flux (ACE) for Key project, CDFS, and MBM 12

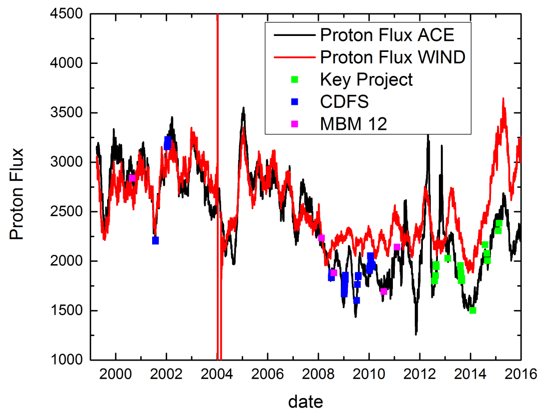

Figure 4: Averaged proton flux from ACE and Wind.

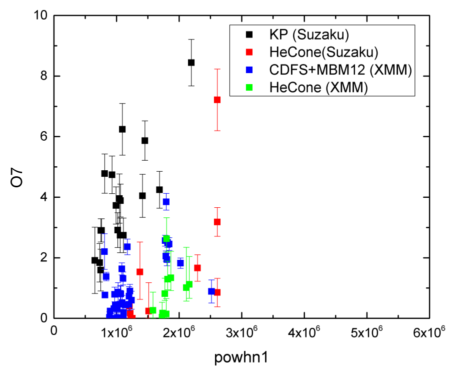

Figure 5: Averaged proton flux from ACE and Wind.

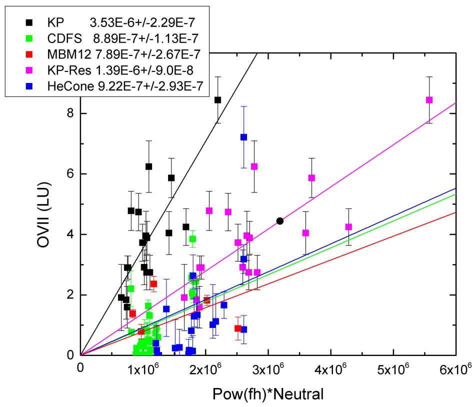

Figure 6: Averaged proton flux from ACE and Wind.

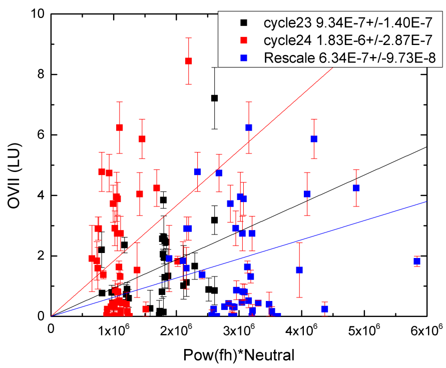

Figure 7: Averaged proton flux from ACE and Wind.

power-law of proton flux. The data from Suzaku are more scatter than from XMM.

We fitted the OVII internsity as a function of neutral density times the power-law of proton flux for Key project, CDFS, MBM12 and He Cone data separately. As shown in Fig. 6, the OVII intensity from Key project are higher than those from others.

Is it due to different solar cycle? The key project were observed in solar cycle 24, near solar maximum (in year 2012-2015). As seen from the sunspot plot, the maximum of sunspot in solar cycle 24 is relatively smaller than in solar cycle 23. In Fig. 7 we show the fitting in two different solar cycles. We also show the fitting for cycle 24 after we rescale the proton flux based on the ratio of maximum sunplot number in two solar cycles, which shows less discrepancy between two cycles.