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Response of the interplanetary hydrogen population to global changes of solar activity: a quantitative analysis based on SOHO/SWAN and SOHO/LASCO-C2 data comparison

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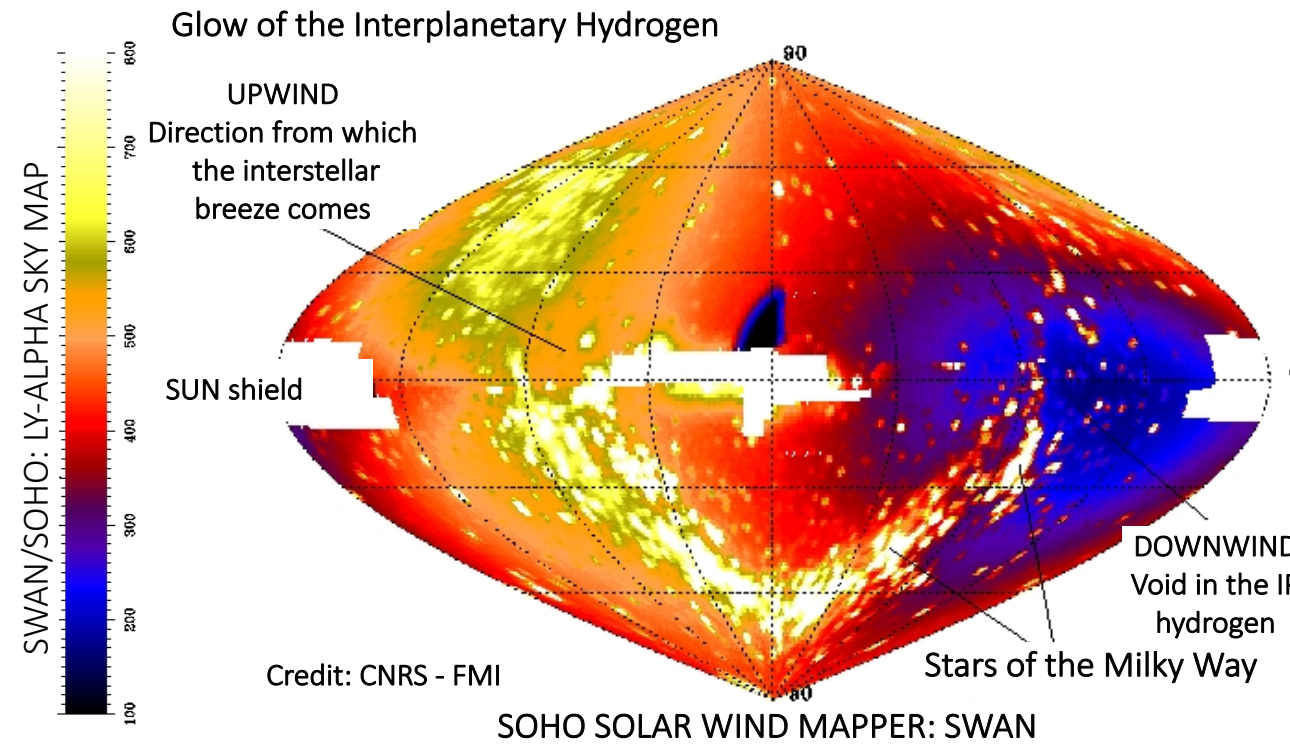
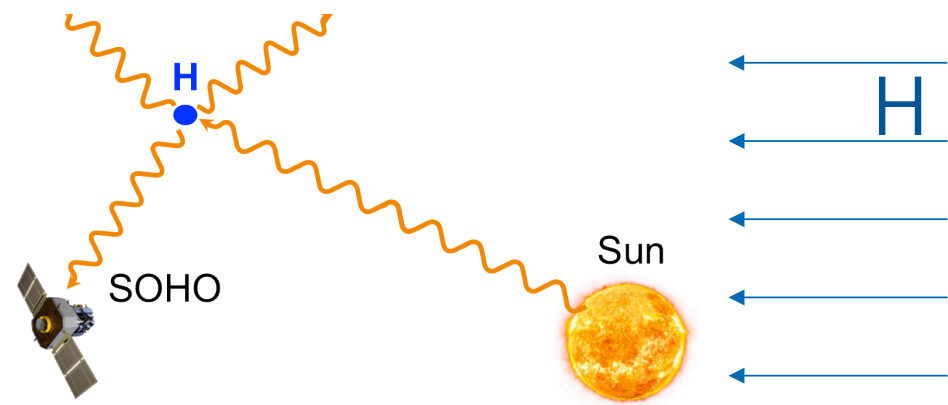
Abstract

For more than two decades the SOHO/SWAN instrument has been monitoring the full-sky hydrogen backscattered Lyman- α emission, and the derived three-dimensional solar wind proton flux. We present a comparison of the time series of the latitude-integrated hydrogen ionization rates (β) derived from the inversion of the SWAN full-sky maps with the integrated coronal electron density derived from the inversion of SOHO/LASCO-C2 white light images. The analysis shows a variable time lag of the SWAN β of a few Carrington rotations, correlated with the solar cycle phase (larger delay during solar maxima compared to minima). This is a direct consequence of the variation of the size of the hydrogen ionization cavity and the time it takes for hydrogen atoms to propagate in the inner heliosphere. This effect should be taken into account in studies of the interstellar neutral populations in interplanetary space.

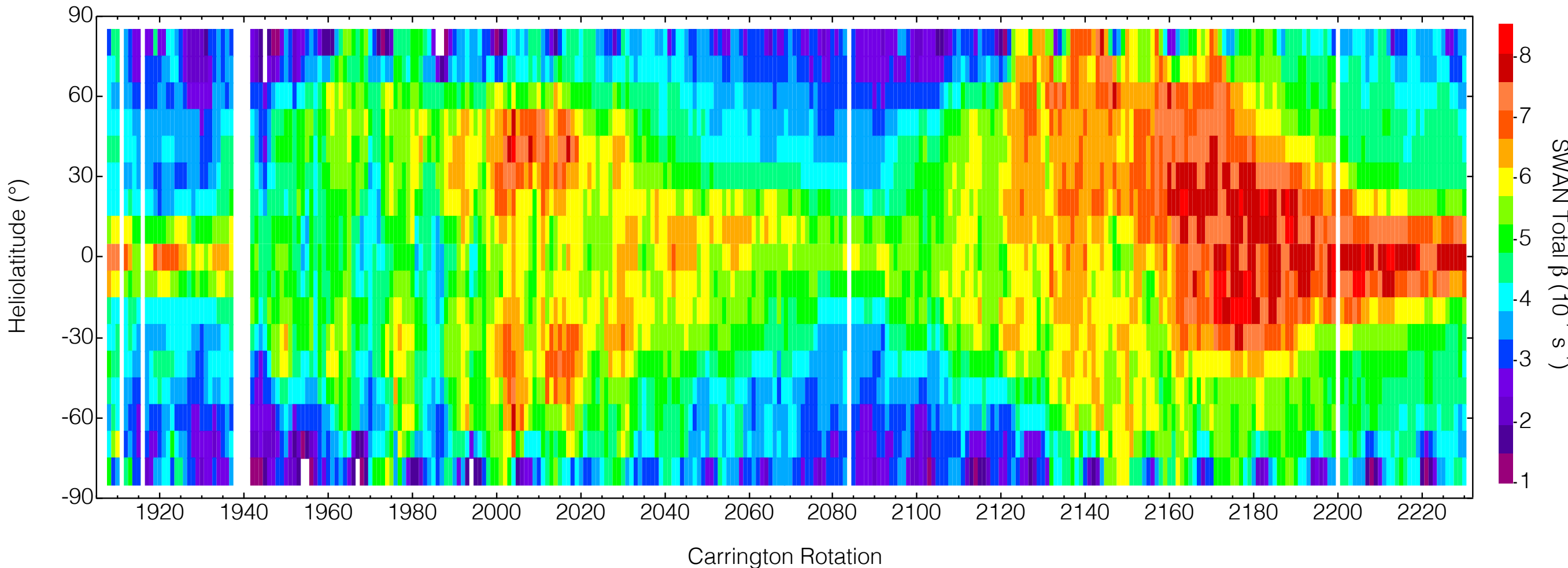


SOHO/SWAN heliolatitude maps of total Ionization Rates β

H atoms in interplanetary space backscatter solar Lyman- α radiation. SOHO/SWAN records full-sky maps of the backscattered Lyman- α .



The maps reflect the radiation pressure and ionization effects (proton charge exchange - CX, photoionization) on the interplanetary H distribution, allowing to monitor the solar wind flux at all heliographic latitudes.



An inversion model calculates the **Total Ionization Rate (β)** for H at all heliolatitudes for every SWAN map (> 5000 maps).

Details on the method in [Quémerais et al. JGR, 111, A09114 \(2006\)](#); [Koutroumpa et al. GeoRL, 46, 4114 \(2019\)](#).

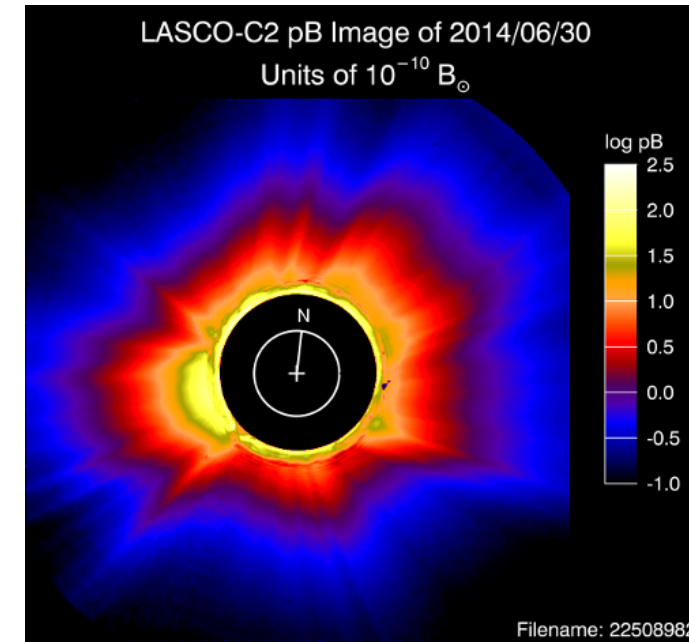


SOHO/LASCO heliolatitude maps of electron density

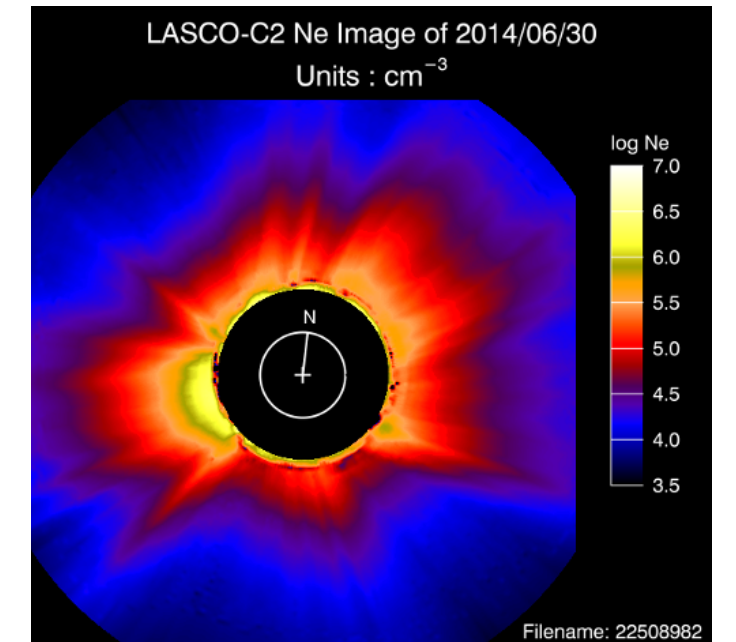
From the SOHO/LASCO white light polarized images we calculate the electron density in the corona at different radial distances.

LASCO-C2 data archive & processing details:
<http://idoc-lasco-c2-archive.ias.u-psud.fr>

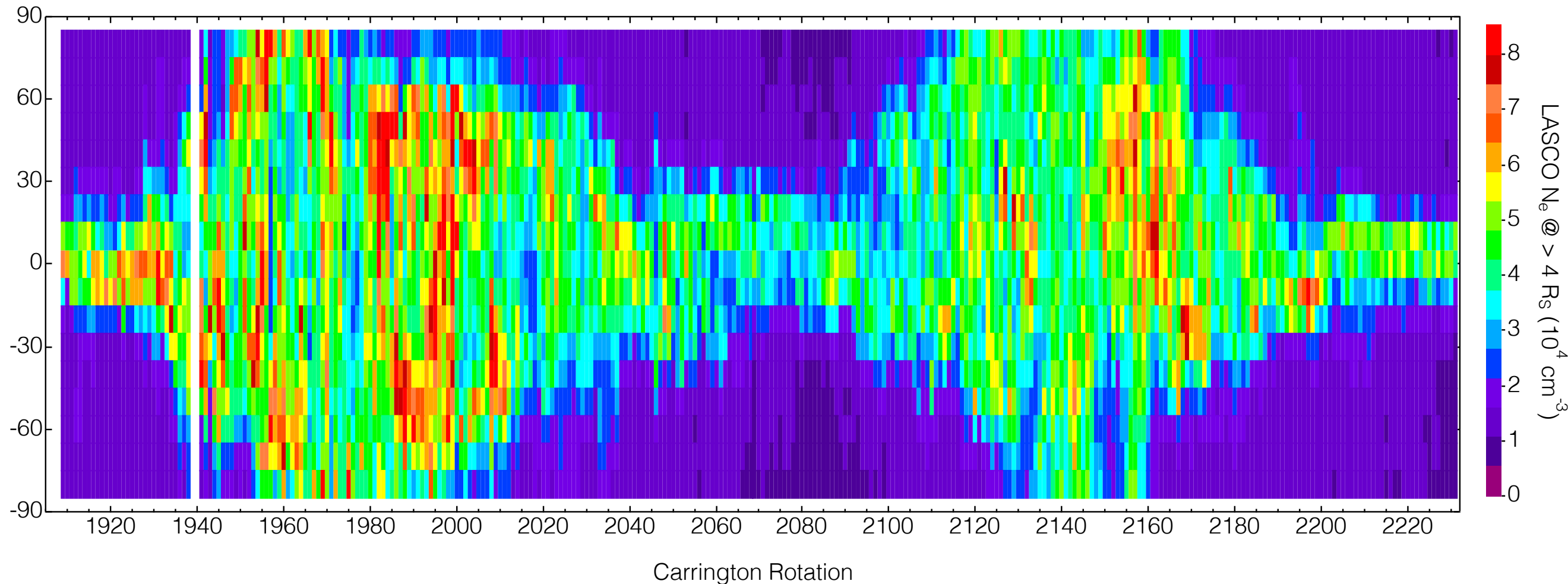
Details on the inversion method:
Quémerais & Lamy, A&A 393, 295 (2002);
Lamy et al. Solar Phys. 295, 89 (2020)



Polarized radiance “pB” images, corrected for all instrumental effects and calibrated in units of $10^{-10} B_{\odot}$.



N_e images in cm^{-3} , assuming local spherical symmetry of the corona.

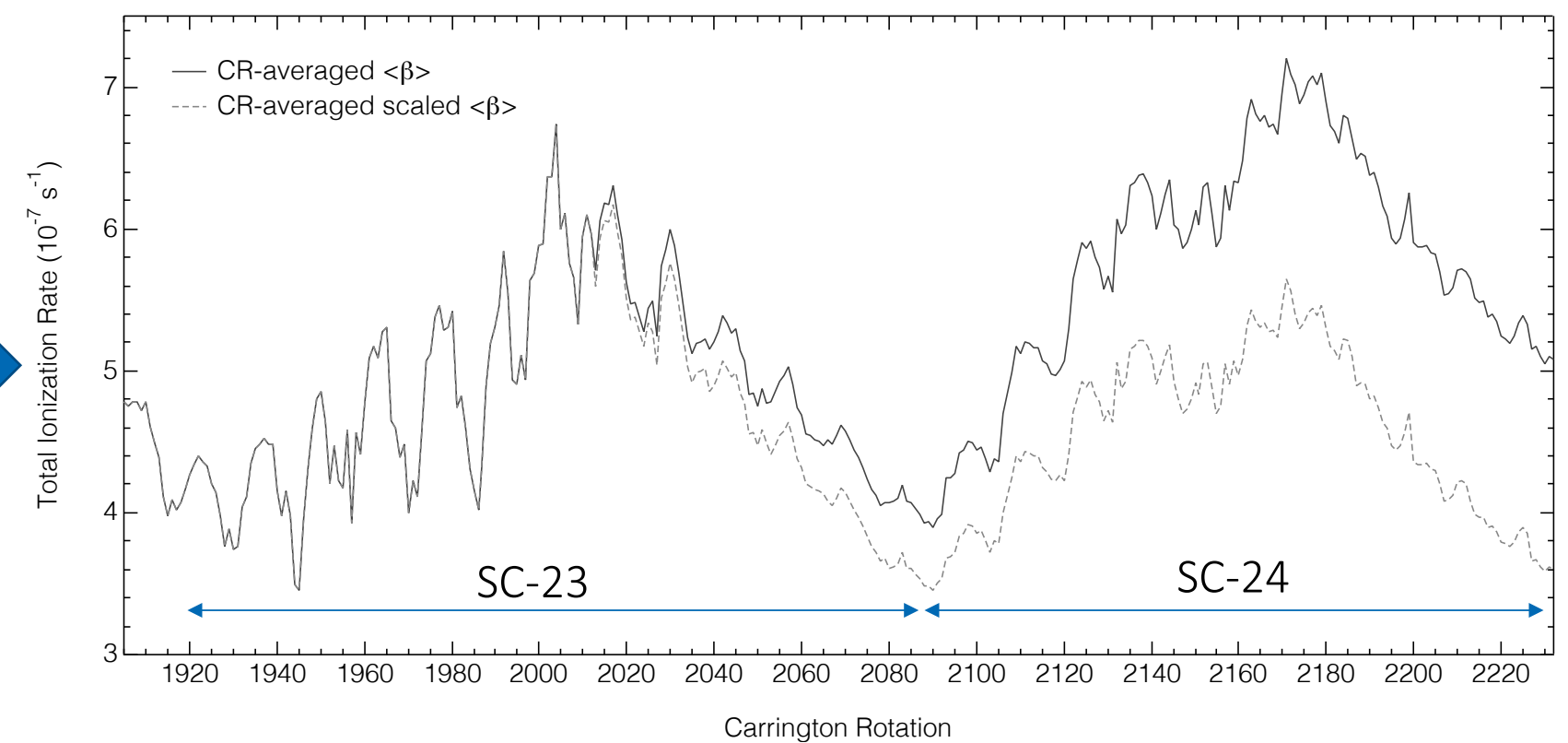
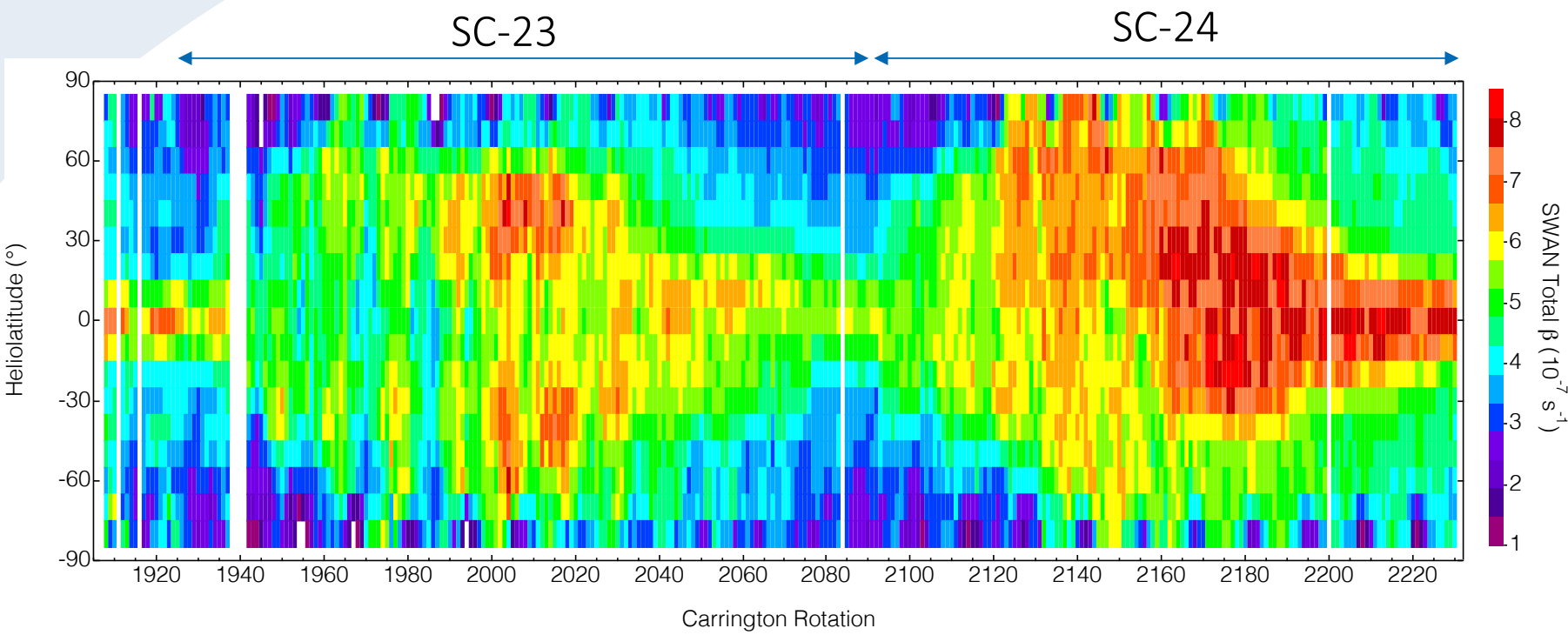


Multi-annual synoptic maps are then produced as a function of heliolatitude.
For this analysis we use synoptic maps averaged for distances $R = [4 - 5.5] R_S$.



SOHO/SWAN disk-averaged integrals of β

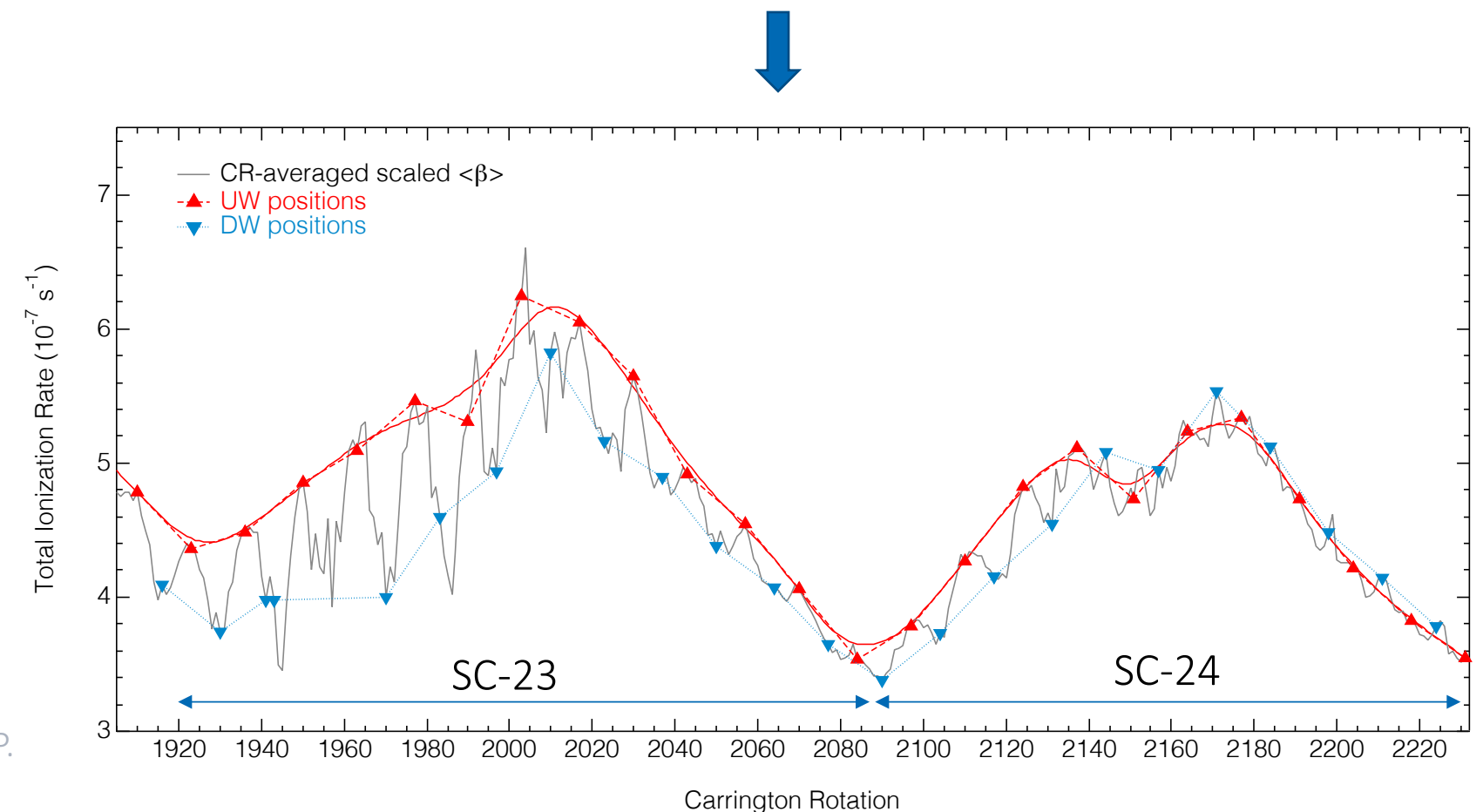
$$\langle \beta \rangle = \int_{-\pi/2}^{\pi/2} \beta(\theta) \frac{\cos(\theta)}{2} d\theta$$



- We empirically correct for SWAN's loss of sensitivity, evaluated at $\sim 2\%$ per year after 2003 (Baliukin et al., 2019 and personal communication).

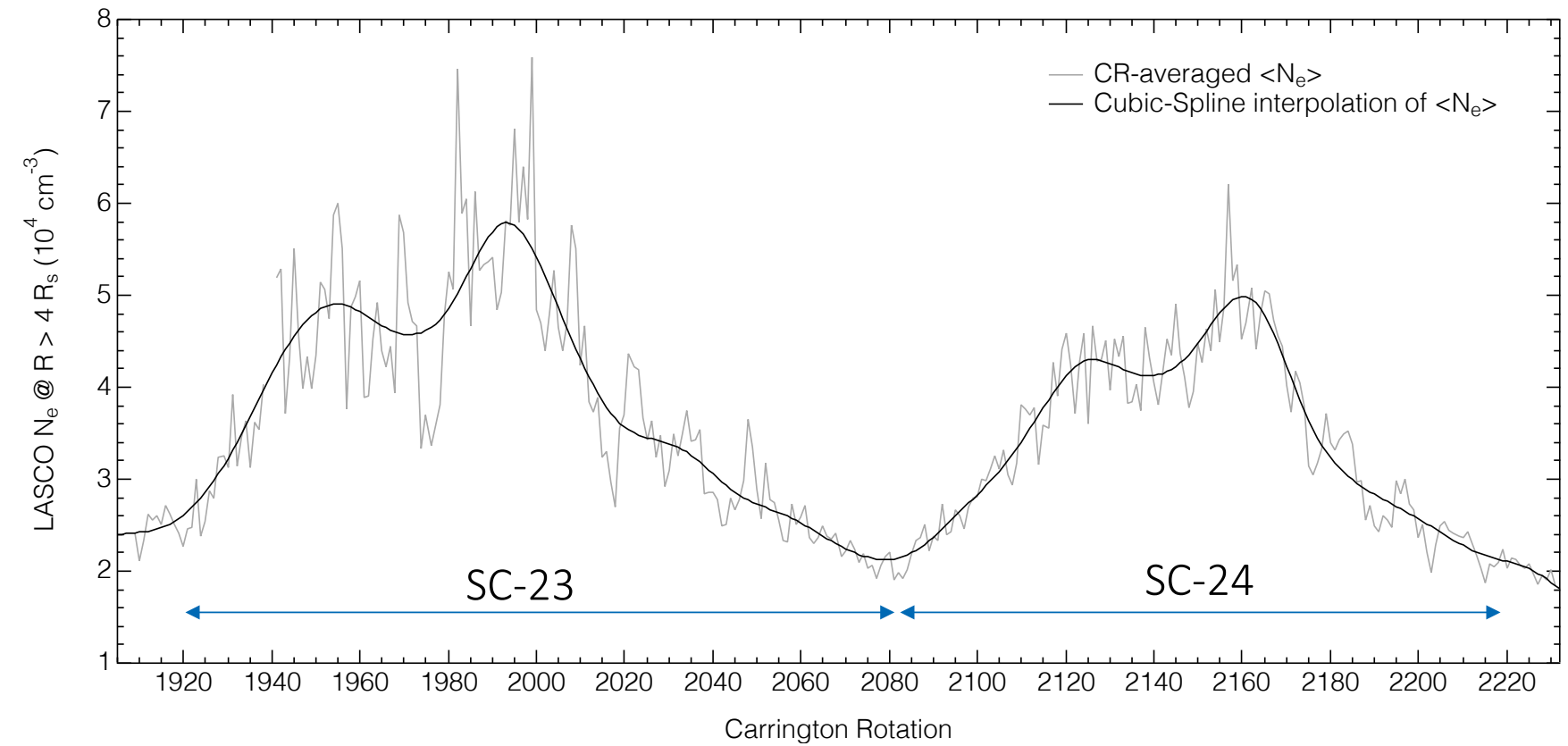
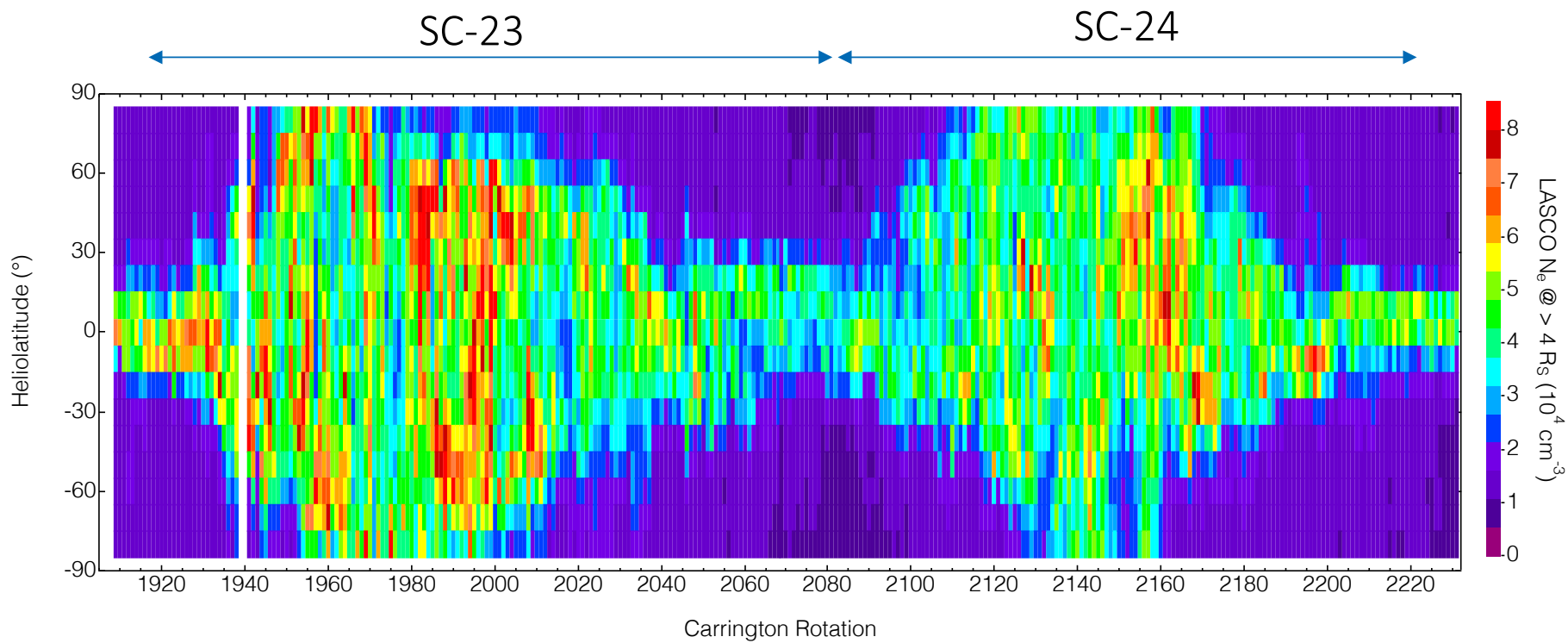
- The annual modulation is an artefact of the SWAN analysis, that underestimates the I.R. for down-wind (DW) positions of SOHO. *Work is in progress to quantify this bias.*

- For the correlation analysis we consider only $\langle \beta \rangle$ values within **27 days of the up-wind (UW) positions** of SOHO and perform a cubic-spline interpolation in between.



SOHO/LASCO Disk-averaged Ne integrals

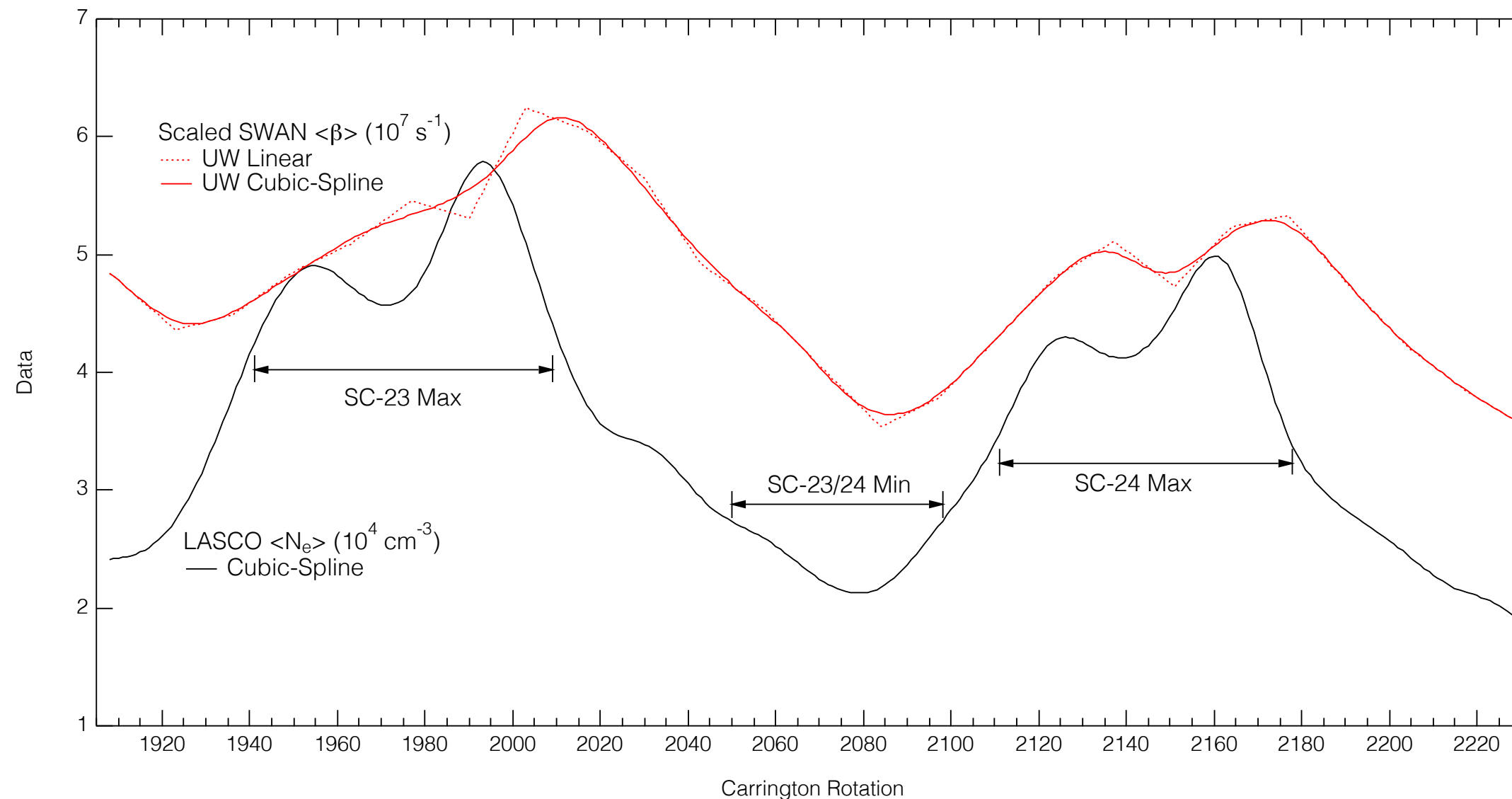
$$\langle N_e \rangle = \int_{-\pi/2}^{\pi/2} N_e(\theta) \frac{\cos(\theta)}{2} d\theta$$



We smooth the short-term modulations by a cubic-spline interpolation.



SWAN – LASCO correlation study



-We select three sections, encompassing the SC-23 solar maximum, the solar minimum (SC-23/24 Min) and the SC-24 solar maximum.

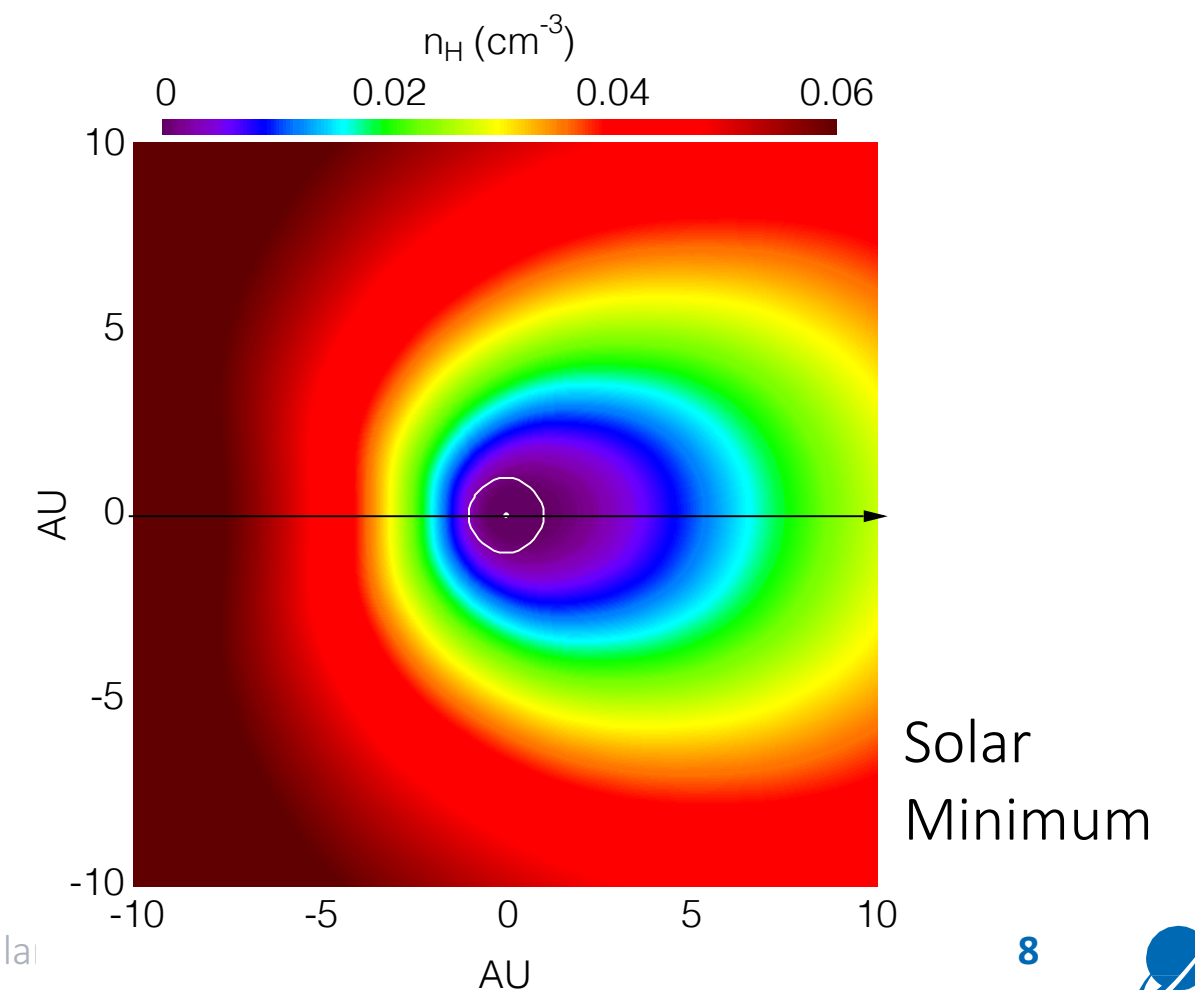
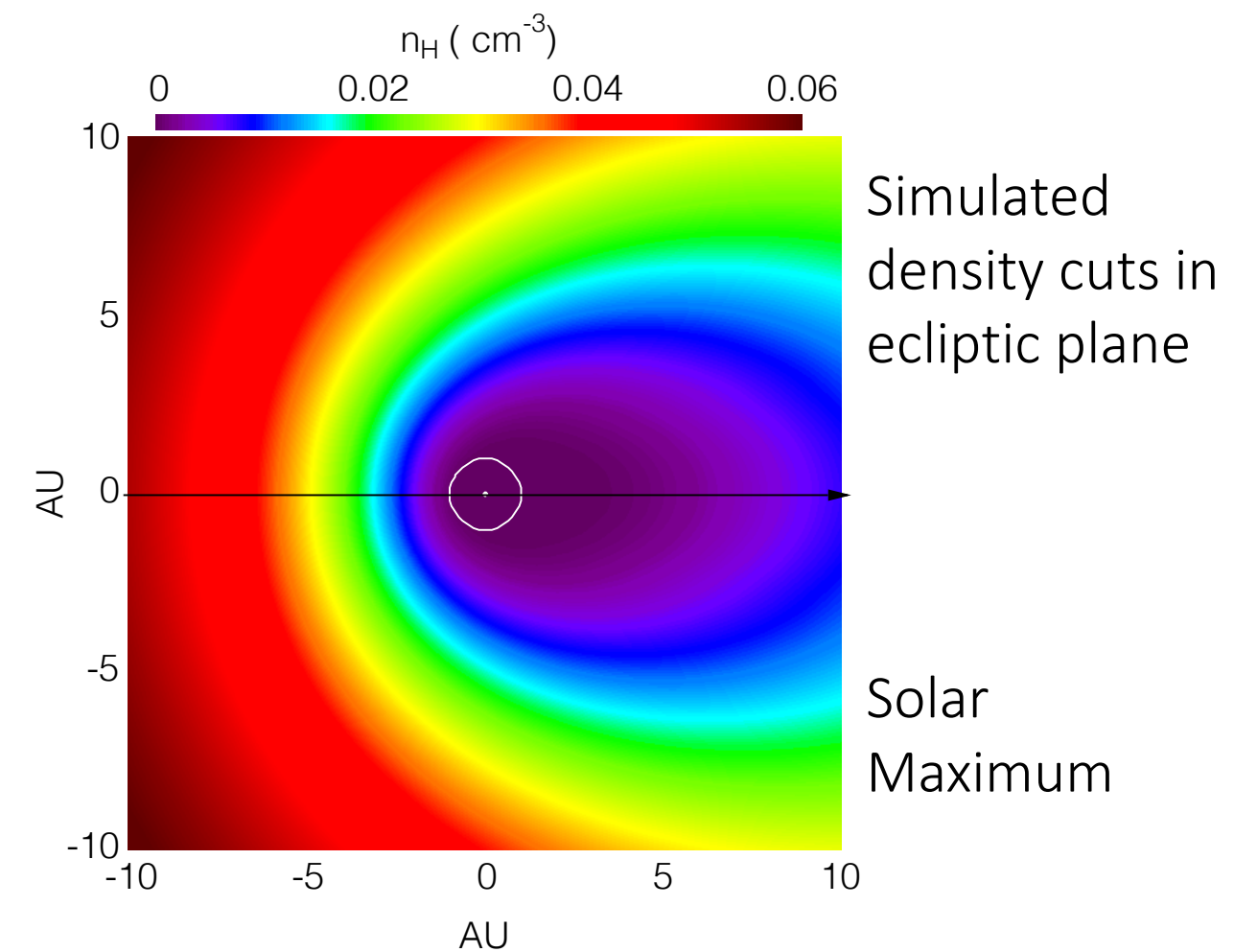
-We estimate the time lag of the scaled SWAN $\langle\beta\rangle$ for the three periods by shifting the SWAN data curve in order to maximize the Pearson's correlation coefficient.

-We find a time lag of **18.3 ± 0.4 CR for SC-23 Max, 8.6 ± 0.8 CR for Solar Min, and 12.8 ± 0.4 CR for SC-24 Max.**



Summary & Conclusions

- A correlation study was performed between the latitude-integrated time series of the SOHO/SWAN H ionization rates ($\langle\beta\rangle$), and the SOHO/LASCO coronal electron density N_e averaged for distances $R = [4 - 5.5] R_s$.
- The study showed a time lag of the SWAN $\langle\beta\rangle$ that is correlated with the solar cycle.
 - For the SC-23 Max (2001) the time lag is of 18.3 ± 0.4 CR
 - For the SC-23/24 Min (2008-2009) the time lag is of 8.6 ± 0.8 CR
 - For the SC-24 Max (2014) the time lag is of 12.8 ± 0.4 CR
- We interpret the time delay and its variations as a consequence of the effects of solar activity on the size of the ionization cavity and the time it takes for H atoms to propagate to the inner heliosphere.
- During solar minimum, the ionization cavity is smaller, H atoms are closer to the Sun and the observer, so the time delay between the outer corona (seen by LASCO) and the inner H distribution (seen by SWAN) is small.
- It is worth noticing that the time lag of the SC-24 Max is smaller than the previous SC-23 Max, for the same reasons, since SC-24 was in general weaker than SC-23.
- Work is in progress to improve the analysis by correcting for the SWAN loss of sensitivity and inversion method bias.



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