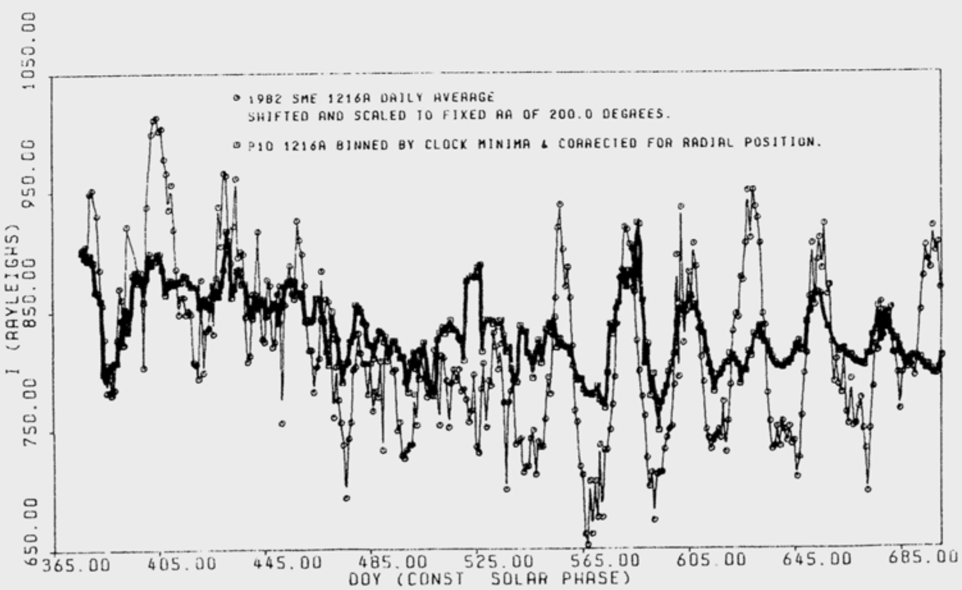
Goal: Start an all-heliosphere Lyman-alpha campaign to study 27-day variations

Why? Heliospheric Lyman-alpha is multiply scattered *around* the Sun; so observed heliospheric 27-day variations should be increasingly damped with increasing radial distance

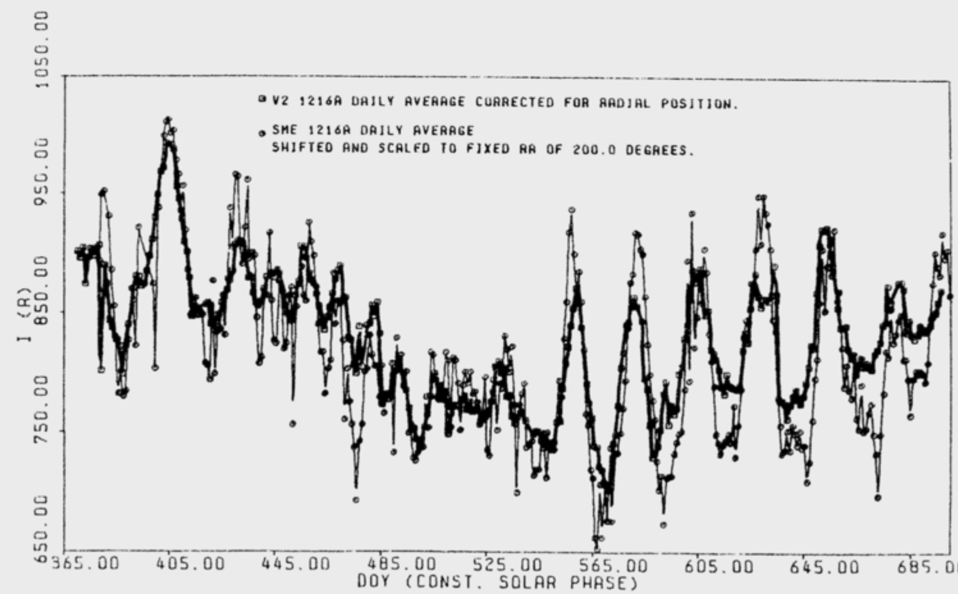
The damping can determine the **heliospheric hydrogen density**, independent of UV calibrations.

Shemansky, Judge and Jessen 1984 found strong damping in Pioneer 10 (at 30 AU) and less damping in Voyager 2 (at 10 AU) Lyman-alpha data from 1982…

Pioneer 10 (thick) compared to SME (thin)



Voyager 2 (thick) compared to SME (thin)



THE ASTROPHYSICAL JOURNAL, 463:349–358, 1996 May 20

26 DAY MODULATION OF THE SKY BACKGROUND Lyα BRIGHTNESS: ESTIMATING THE INTERPLANETARY HYDROGEN DENSITY

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Received 1995 January 23; accepted 1995 March 10

ABSTRACT

We present here a series of sky background observations, all having a fixed pointing direction for at least one solar rotation, made with both *Voyager* UVS instruments between 1981 and 1993. These data show modulations with a 26 day period, which we have used to estimate the interplanetary hydrogen density. A comparison of these data with multiple scattering computations of the damping of the solar Lyα flux modulation yields an interplanetary hydrogen density of 0.15 ± 0.10 cm^{-3}. This result is independent of instrument calibration, but its accuracy is limited by the difficulty of estimating the solar Lyα line flux in every direction at the time of observations. To estimate the solar H Lyα line flux, we have used the *Solar Mesosphere Explorer* H Lyα flux measurements between 1981 and 1988 and the He I 1083 nm equivalent width data after 1988.

We find also that a linear relation between the integrated H Lyα line and the line center does not apply near the solar maximum. *Voyager 2* data obtained in 1989 are in better agreement with an empirical nonlinear relation derived by Vidal-Madjar. Finally, for the present position of the *Voyager* spacecraft, we estimate that the factor by which the modulation is damped is at least 0.4, which means that the antisolar sky background modulations have an amplitude less than 40% of the amplitude of the subspacecraft solar flux at line center.

Subject headings: diffuse radiation — interplanetary medium — ultraviolet: solar system

Quemerais et al.: 27-day wave damping with distance illustrated for a hydrogen density of 0.15 cm^{-3}

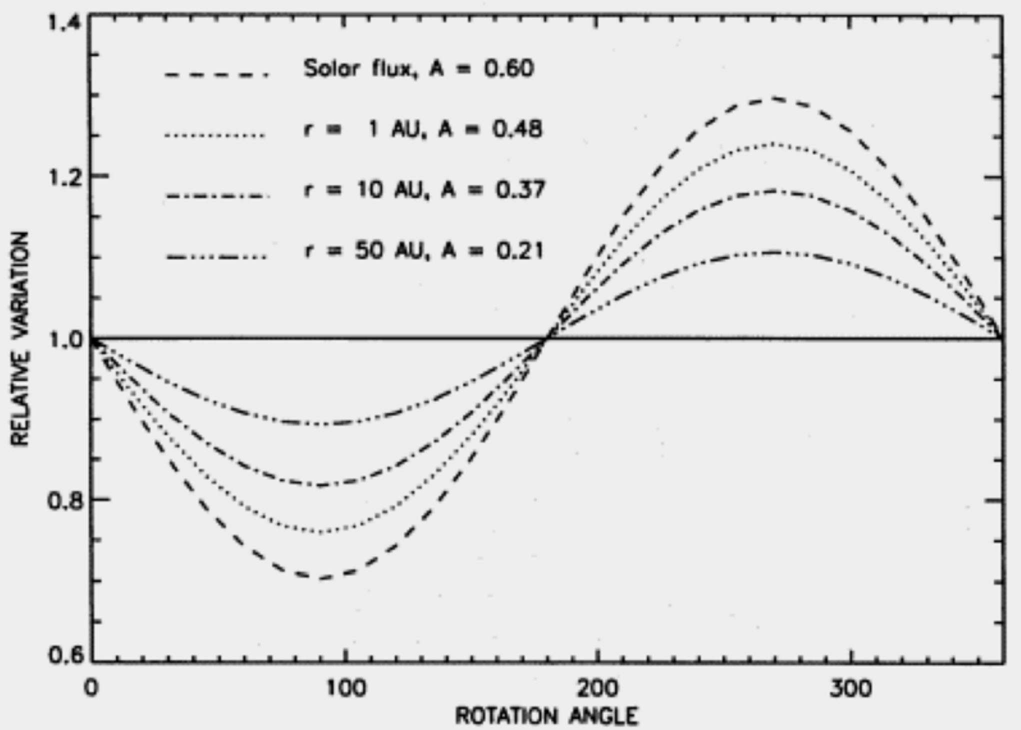

FIG. 5.—Relative variation of the Lyα intensity during one solar rotation. The assumed illuminating solar flux is shown by the dashed line with an amplitude of 0.6. The other three curves show the antisolar intensity for a spacecraft at a distance *r* from the Sun in the upwind direction. Corresponding distributions on the Sun of the secondary photons are shown in Figs. 1–3. The resulting amplitudes are 0.48, 0.37, and 0.21 for *r* equal to 1, 10, and 50 AU, respectively. Amplitudes of the *secondary* intensities are 0.32, 0.29, and 0.20, respectively. So, the difference between the case at 1 AU and the one at 10 AU is mainly due to the strong decrease of the fraction of the emission arising from primary photons, from 60% to 25%.

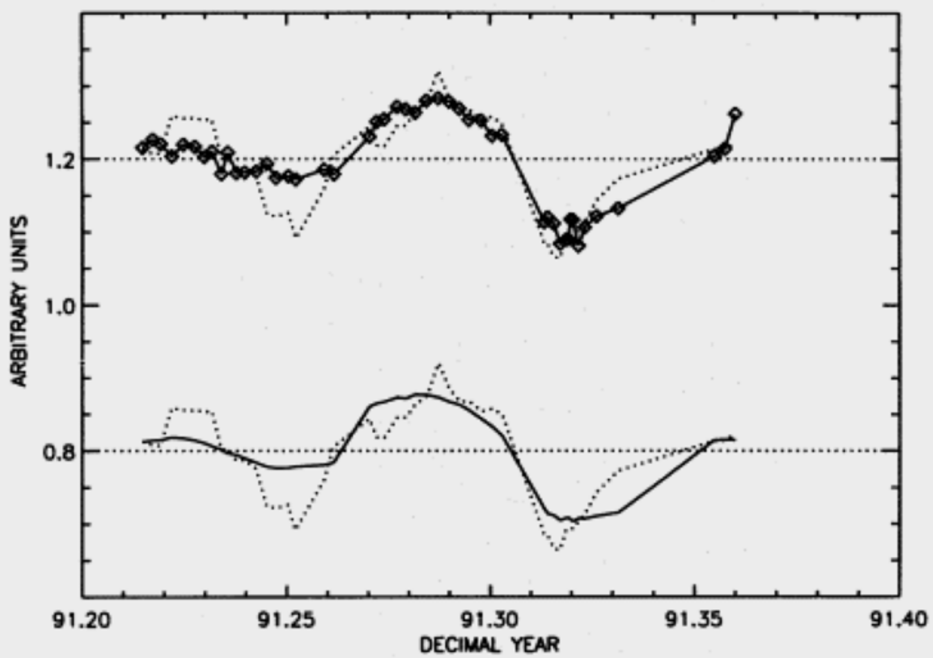

FIG. 12.—Comparison of *Voyager 1* UVS data modulation with a model computation with $N_H = 0.10$ cm^{-3}. The solar Lyα flux (*dotted line*) has been obtained from He 1083 nm equivalent width data. Variables have been normalized to the average value for a constant line of sight. Upper curves have then been shifted by 0.2, and lower curves have been shifted by −0.2. Upper solid line shows the data, and lower solid line shows the model result corresponding to the best fit in Table 2.

Quemerais et al. next applied their damping model to 1991 Voyager data, here using a hydrogen density N_H =0.10 cm^{-3}.

The amplitude of 27-day Lyman-alpha waves was damped by **0.4** at ~44 AU (New Horizons recently hit 50 AU)

Paper concluded N_H=0.15+/-0.10 cm $^{-3}$

Generous error bars reflect somewhat noisy Voyager data.

(New Horizons potentially provides higher signal-to-noise data)

A&A 491, 21–28 (2008)
DOI: 10.1051/0004-6361:20078862

Astronomy & Astrophysics
Special feature

Diagnostics of interstellar hydrogen in the heliosphere

Radiation transport of heliospheric Lyman-α from combined Cassini and Voyager data sets

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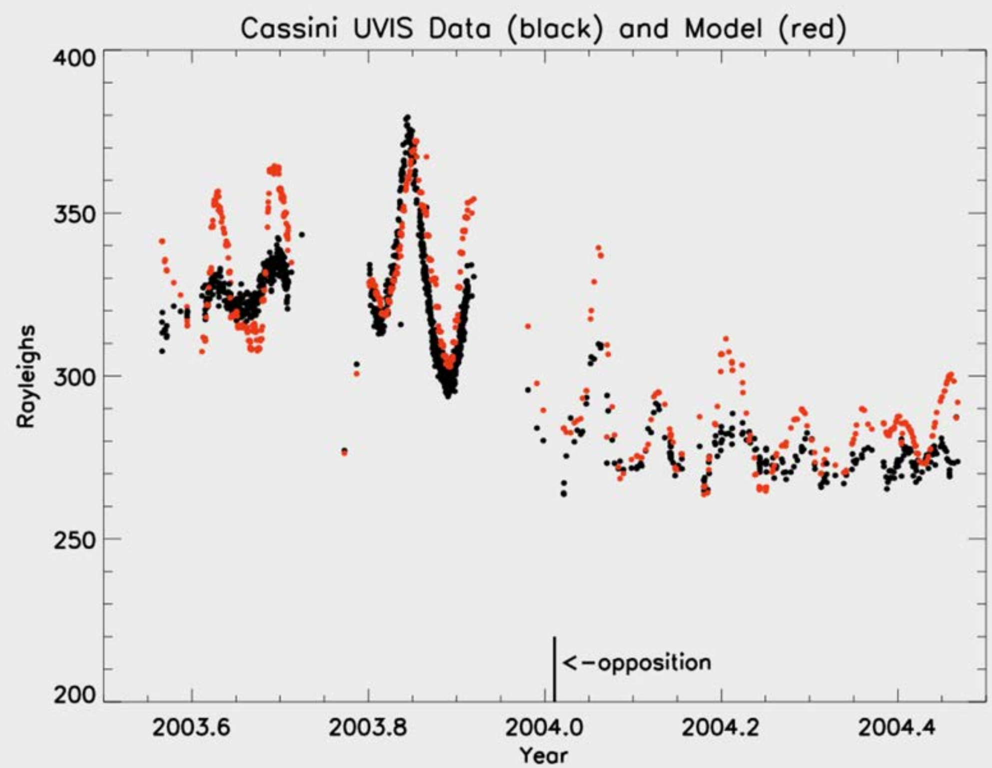

Fig. 5. UVIS data modulations observed in the upwind hemisphere from downwind on Saturn approach in the period 2003.5–2004.5 are generally in good agreement with the optically thin model using $A = 0.8$, with solar rotations near Cassini opposition in early 2004 modeled better than the others.

Cassini Data from 2003-2004 (10 AU out from the Sun).

A single-scattering model matched some rotations of the data.

Damping from multiple scattering is not yet obvious at 10 AU

Voyager 1 data from 2003-2004

- Solar modulations at 88-92 AU

were very damped, by a factor of ~0.21 compared to the optically thin model

We next compared this damping to expectations from Pradip Gangopadhyay's two-shock outer heliosphere model

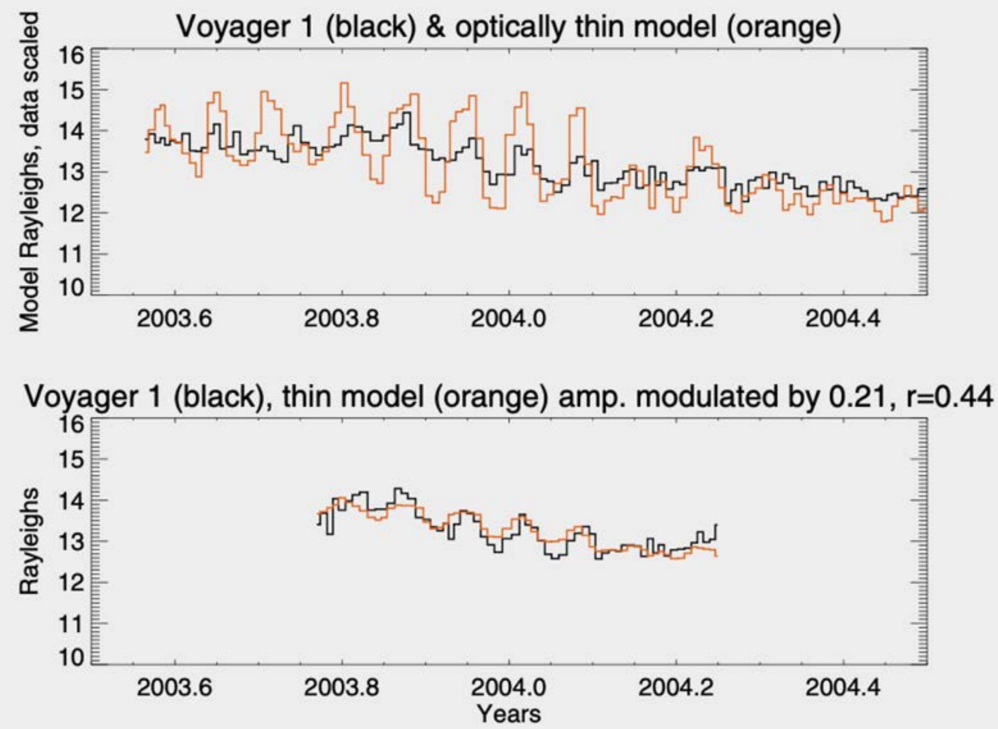

Fig. 7. *Top panel*: comparing the Voyager 1 data from this period to the optically thin model shows many of the same features are present in both time-series, but with greatly reduced amplitude in the data. This indicates that multiple scattering is important at this large distance from the Sun. *Bottom panel*: improved agreement between the model and the Voyager 1 data from late 2003 to early 2004 is obtained in this case by reducing the amplitude of the 27-day waves in the optically thin model by a damping factor of 0.21. The interval plotted is shorter to avoid edge effects from the 81-day smoothing used to detrend the data.

Table 2. Estimates of neutral H density (near termination shock TS) from Lyman-α wave damping with distance.

Reference	Data source	Observation Year	Distance to Sun (AU)	H density at TS (cm^{-3})
Shemansky et al. (1984)	Pioneer 10	1982	30	0.11–0.12
Shemansky et al. (1984)	Voyager 2	1982	12	0.16–0.17
Quemerais et al. (1996)	Voyager 1, 2	1981–1993	up to 56, 44	0.15 ± 0.10
This paper Pryor et al. (2008)	Cassini UVIS, Voyager	2003–2004	10, 90	~0.085–0.095

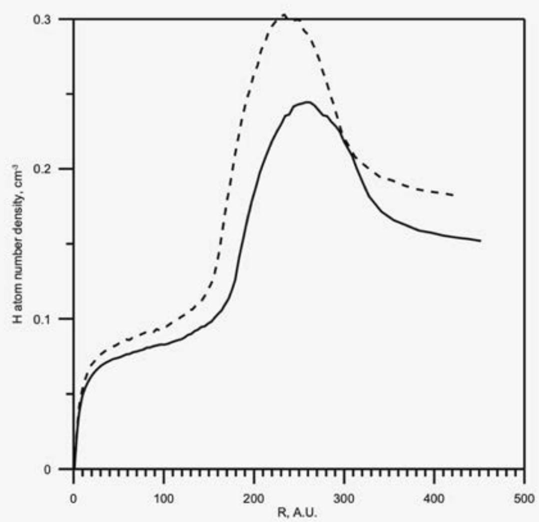

Fig. 8. The radial hydrogen density profile in the upwind direction is shown for the two models described in Table 1. Model 1 is the upper curve and has a termination shock distance of 97 AU and Model 2 is the lower curve with a termination shock distance of 106 AU. A hydrogen wall is present (local maximum) between 200 and 300 AU in both models. The Voyager data modeled here involve upwind lines-of-sight that sample a region of increasing density with distance.

H Densities are ~ constant outside the ionization cavity near the Sun, until heliospheric boundaries are approached. Pradip's models used in Pryor et al. 2008 included a **hydrogen wall** (left) H density tabulated is the value near the termination shock, after filtration by outer heliospheric boundaries.

Lyman-alpha damping estimates for the hydrogen density so far are compatible with New Horizons SWAP based estimates from pick-up protons…
(N_H=0.127+/-0.015 cm^{-3} at Termination Shock)

THE ASTROPHYSICAL JOURNAL, 903:48 (11pp), 2020 November 1 https://doi.org/10.3847/1538-4357/abb80a

CrossMark

Density of Neutral Hydrogen in the Sun's Interstellar Neighborhood

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Received 2020 June 9; revised 2020 September 2; accepted 2020 September 11; published 2020 October 30

Abstract

Interstellar neutral atoms, unlike charged particles, freely penetrate the heliosphere, allowing us to sample the physical state of the interstellar matter directly. Most interstellar hydrogen atoms are ionized before reaching the inner heliosphere and become energetic protons picked up by the solar wind and transported away from the Sun. Consequently, observations of interstellar hydrogen atoms by missions operating within a few astronomical units from the Sun are subject to significant systematic uncertainties. We analyze observations from the Solar Wind Around Pluto instrument on New Horizons, the first experiment to provide extensive measurements of the picked-up protons far from the Sun. Analyzing the density of these protons, we find an interstellar neutral hydrogen density at the termination shock of $0.127 \pm 0.015\ cm^{-3}$, i.e., ~40% higher than previously thought. We show that the Voyager observations of the slowdown of the solar wind further support this value. This result resolves a problem of why energetic neutral atom fluxes, created from pickup ions by charge exchange with hydrogen atoms, are roughly twice that expected from numerical models. Our result also implies higher charge exchange rates at the heliospheric boundaries and, consequently, a less asymmetric shape of the heliosphere. Based on a previous study of the atom filtration in the heliospheric boundaries, we estimate the neutral hydrogen density in the unperturbed local interstellar medium of $0.195 \pm 0.033\ cm^{-3}$. This value agrees with astrophysical observations of the interstellar clouds in the Sun proximity.

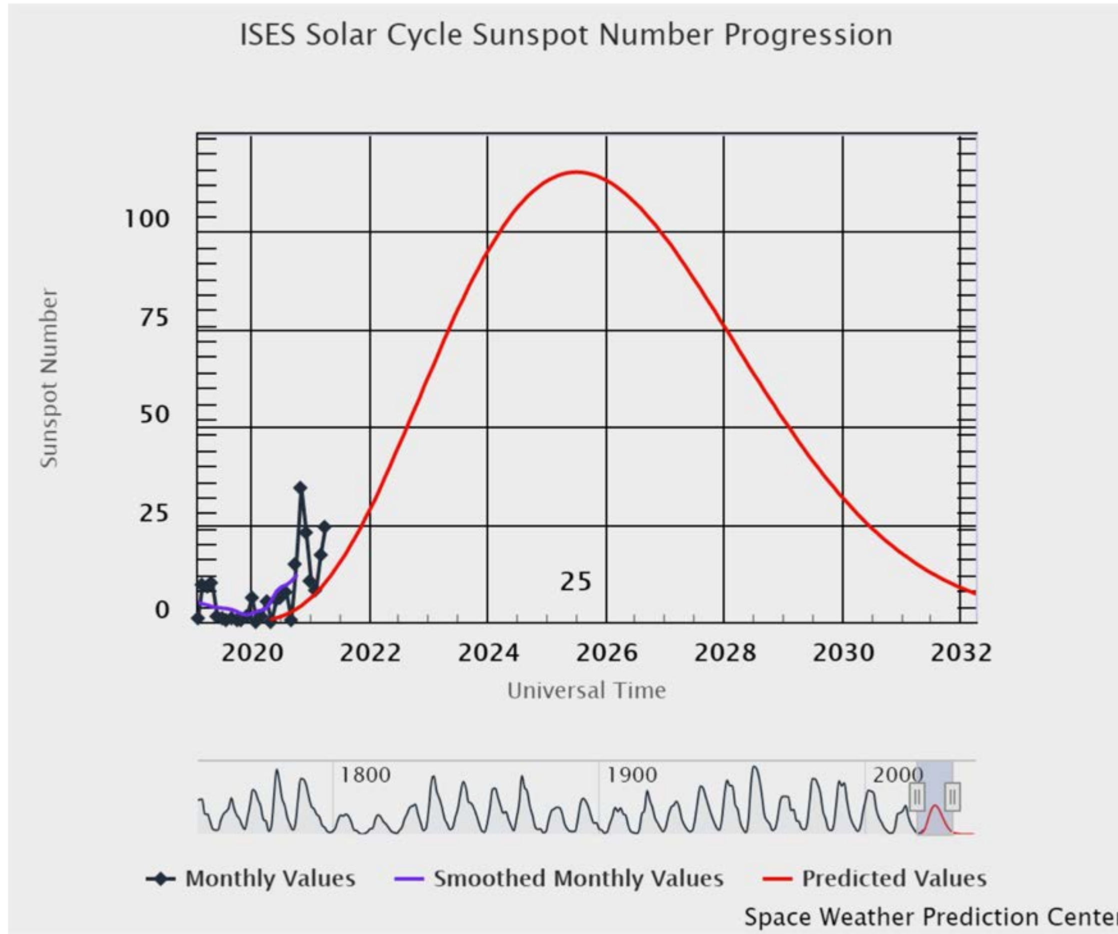
Unified Astronomy Thesaurus concepts: Pickup ions (1239); Solar wind (1534); Heliosphere (711); Interstellar atomic gas (833); Interstellar medium (847); Interstellar clouds (834); Space plasmas (1544)

New complications:

- Galactic Lyman-alpha signal may be significant in the outer heliosphere
- Katushkina et al., 2017 found possible galactic signal ~25 R
- Gladstone et al., 2021 found isotropic galactic signal 43+/-3.4R
- This needs to be worked into future damping calculations
- Pradip’s code is no longer available
- Others here may have suitable codes?

When should we have a campaign?

- At solar minimum, 27-day modulation is usually small (no sunspots)
- Should be done during current rising phase in solar activity at a time when the Sun has a significant active region..
- Based on previous work, expect New Horizons to see significantly damped (factor of ~0.4?) 27-day waves at its current location.
- Best results will be obtained when Earth and New Horizons are near opposition: seeing same Sun!



Summary:

-New Horizons Ultraviolet Spectrometer could improve on these earlier hydrogen density determinations

-New Horizons has not yet studied 27-day variations at Lyman-alpha.

-Maybe we can arrange for a campaign involving multiple spacecraft in coming years?