Solar cycle variations in geocoronal H\textalpha column emission intensities

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Fabry-Perot interferometers are being used to investigate the influence of the solar cycle variation on the Earth’s upper atmosphere. Understanding this influence is important for determining the basic state of the region, as well as for distinguishing between natural variability and possible longer term climatic trends. Observations of thermospheric + exospheric H\textalpha column emissions by the Wisconsin H\textalpha Mapper (WHAM) Fabry-Perot (Kitt Peak, Arizona) during solar cycle 23 show a statistically significant solar cyclical variation, with higher emissions observed during solar maximum conditions. These data add to the Wisconsin long term midlatitude H\textalpha emission data base containing observations spanning 1977 to the present. The high signal-to-noise WHAM observations corroborate suggestions of a solar cycle trend seen in Wisconsin H\textalpha emission observations over the previous solar cycle (cycle 22).

1. Introduction

Geocoronal hydrogen is the byproduct of middle and upper atmospheric chemical, photolysis, and charge exchange reactions involving its hydrogenous source species below such as methane, water vapor, and molecular hydrogen [see, e.g. Brasseur and Solomon, 1986]. Atomic hydrogen spans the thermosphere and exosphere, becoming increasingly dominant with altitude. Due to its long orbital trajectories, upper atmospheric hydrogen is more globally mixed compared with its hydrogenous source species below.

Ground-based remote sensing of the very faint fluorescence emissions from atomic hydrogen [H\textalpha (6563 Angstroms, \sim 1-10 Rayleighs), and, more recently, H\beta (4861 Angstroms, \sim 0.25 – 1 Rayleigh)] is one of the primary diagnostics for studying the neutral upper atmosphere. The Fabry-Perot spectrometer is particularly advantageous for making observations of faint, diffuse sources such as the geocorona due to the instrument’s simultaneous high spectral resolution and high throughput.

The thermospheric + exospheric H\textalpha emission is primarily excited by the line center portion of the solar Lyman-\beta (1026 Angstrom) flux. The H\textalpha column emission intensity observed by the Fabry-Perot is a measurement of the integrated volume emission rate along the observational line-of-sight, with the peak in the emission rate arising from just above the Earth’s shadow.

2. Observations

Long term comparisons of thermospheric + exospheric H\textalpha emissions require cross-calibrated and well-understood instrumentation, a stable calibration source, reproducible observing conditions, separation of the terrestrial from the galactic emission line, and consistent data analysis, accounting for differences in viewing geometry.

Like other Wisconsin-based instruments, WHAM is a ground-based, 15 cm double-etalon Fabry-Perot. WHAM is remotely operated, semi-automated, and has optics especially designed for using the CCD-based (charge coupled device camera)
annular summing technique [Coakley et al., 1996]. WHAM’s resolving power [~25,000] is sufficient for separation of the terrestrial emission from the Doppler-shifted galactic line and for retrieval of the Hα column emission intensity.

WHAM is used primarily for making astronomical observations of interstellar medium emissions [Reynolds, 1997; Haffner et al., 2003]. The terrestrial spectra present in these observations also provide a rich resource for studying geocoronal atomic hydrogen Hα emissions.

As for all of the other Wisconsin-based atmospheric, planetary, and astronomical hydrogen Hα observations, WHAM is calibrated using nebular calibration. The absolute intensity of the thermospheric + exospheric Hα column emission is calibrated through comparisons with specific patches of standard astronomical nebular sources, all of which have been tied to a 1° patch (centered at right ascension 20h 57m 59s and declination +44d 34′ 50″′) of the North American Nebula (NAN) [Haffner et al., 2003; Nossal et al., 2004]. Corrections are made for differences in atmospheric extinction between the calibration and observational look directions. There is about a 5% uncertainty in the relative calibration due to night to night variability in the transmittance of the atmosphere and a 10% uncertainty in the absolute calibration.

For consistency, the data for this solar cycle study were limited to WHAM observations taken during winter solstice conditions and in observing directions pointed toward low galactic emission [less than ~0.25 Rayleigh at Hα] regions of the sky. Such observations minimize uncertainty due to blending between the galactic and terrestrial Hα emission lines. The winter solstice typically offers the best sky conditions for observations, as well as longer nights. To insure consistent observing conditions, we only use observations taken during dark moon and clear sky conditions.

The annular Fabry-Perot interference pattern was converted to a spectral profile via image processing, ring summing, and normalization with a white light flat field [Coakley et al., 1996; Haffner et al., 2003; Nossal et al., 2004]. A two Gaussian atomic physics model representing the two dominant fine structure transitions contributing to the geocoronal Hα emission was convolved with the instrumental profile and adjusted to find a best fit to the geocoronal Hα column emission observation [Nossal et al., 2004].

Figure 1 shows a sample geocoronal Hα emission spectrum from an observation made on March 13, 1997 pointed toward a low galactic emission region of the sky. The exposure time was 30 seconds and the emission line intensity was 4.1 Rayleighs. Spectral displacements are expressed in velocity units with the “zero” velocity point placed at an arbitrary location. In addition to the two component fit to the geocoronal emission, the fit also includes the galactic emission (0.20 R) shown here at 105 km/sec (in relation to the arbitrary “zero” velocity point) and a faint atmospheric emission (0.13 R) at 57.5 km/sec [Hausen et al., 2002; Nossal et al., 2004].

For this case of near maximum overlap between the geocoronal and galactic emission illustrated in Figure 1, the retrieved geocoronal Hα column emission differs by less than 4% from that retrieved when the galactic emission is not fit. This result provides an assessment of the upper limit of the uncertainty due to the presence of the galactic emission in these low galactic emission region observations. The retrieved geocoronal intensities also include the cascade excitation which is estimated to be 5 ± 3% of the total intensity based upon recent observations by Mierkiewicz [2002] and revised estimates by R.R. Meier [1995; personal communication, 2004]. Neither the galactic emission, the geocoronal cascade excited emission, nor the presence of other low intensity atmospheric lines would account for the solar cyclic intensity difference shown in Figure 2 [Nossal et al., 2004].
Figure 2 displays thermospheric + exospheric H\(\alpha\) column emission intensities as a function of shadow altitude for changing solar conditions. The shadow altitude is determined by the optical depth of solar Lyman-\(\beta\) radiation (102 km) and the observational look direction. The shadow altitude is the viewing geometry parameter with the greatest influence on the geocoronal H\(\alpha\) column emission intensity. Small changes in intensity related to observational zenith angle and azimuth variations for a constant shadow height can also be detected [Nossal et al., 2001].

The 1997 observations (diamond symbol) displayed in Figure 2 were taken during solar minimum conditions, the 2004 observations during solar medium conditions ("o") and the 2000-2001 observations ("+" and "x") during near solar maximum conditions. The data included on this plot came from 23 nights of observations between December and the spring equinox. The solar minimum data (F10.7 69-76) are from 10 nights of observations, the solar medium data (F10.7 100-122) are from 5 nights of observations, and the near solar maximum data (F10.7 134-163) are from 8 nights of observations. We observe higher column emission intensities during solar maximum periods with the increase dependent upon viewing geometry. For example, at the mid range shadow altitude of 3000 km, WHAM geocoronal H\(\alpha\) column intensities are about 45% higher during solar maximum conditions than during near solar minimum conditions. The column emission intensities of the solar medium observations fall between those of the solar minimum and near solar maximum observations.

In the troposphere, Balmer-alpha photons from outside the line of sight scatter into the line of sight and enhance the retrieved column intensity. When corrections are made to the data of Figure 2 using the tropospheric scattering code of Leen [1979; Shih et al., 1985], the intensities are lowered by 14-26%, depending upon the viewing geometry. The solar cyclic difference persists because the corrections are applied to both solar minimum and maximum conditions [Nossal et al., 2004]. We have chosen to display the uncorrected primary measurements in Figure 2 because we recognize the need for an improved tropospheric scattering correction code.

3. Discussion

Detailed modeling is needed to retrieve hydrogen column abundance information from the H\(\alpha\) column emission observations [Bishop, 1999]. Case studies indicate that the hydrogen column abundance can be retrieved via forward modeling analysis [Bishop et al., 2001] with studies currently in progress to assess the sensitivity of retrievals to radiative transport forward modeling parameters [Bishop et al., 2004].

A careful examination of correction factors indicates that their magnitude is small compared with the observed solar cycle variation in the thermospheric + exospheric H\(\alpha\) column emission intensity. The higher signal-to-noise WHAM observations corroborate suggestions of a solar cycle trend in the H\(\alpha\) emissions seen in Wisconsin observations taken over the previous solar cycle (cycle 22) [Nossal et al., 1993]. The Wisconsin-based observations over solar cycle 22 also measured higher geocoronal H\(\alpha\) intensities during solar maximum periods; however past data were deemed to be of insufficient precision to make the variation statistically significant. The high signal-to-noise, and consistent calibration of the WHAM geocoronal H\(\alpha\) emission observations facilitate their use as benchmark data for comparisons with past and future data sets.
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5. References


6. Figures

Figure 1. Sample WHAM H-alpha spectrum in a region of low galactic emission (30 second exposure). Spectral displacement is expressed in velocity units. Zero velocity is placed at an arbitrary location. In relation to the arbitrary zero point, the centroid of the two component fit to the geocoronal line is located at 96.8 km/sec in this figure and its intensity is 4.1 Rayleighs. The fit in Figure 1 also includes the galactic emission (.20 R) at 105 km/sec and a faint atmospheric emission (0.13 R) at 57.5 km/sec [Nossal et al., 2004; Hausen et al., 2002].
Figure 2. Solar Cycle 23 WHAM thermospheric + exospheric H-alpha column emission intensity observations taken between December and the Spring equinox and in observing directions pointed toward low galactic emission [less than ~0.25 R at H-alpha] regions of the sky. The solar minimum (F10.7 69-76) data are from 10 nights of observations, the solar medium data (F10.7 100-122) are from 5 nights of observations and the near solar maximum data (F10.7 134-163) are from 8 nights of observations.