Hydrogen Lyman-alpha and Lyman-beta spectral radiance profiles in the quiet Sun

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In collaboration with
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Outline

• Observation of the Hydrogen Lyman line profiles
  • Ly-\(\alpha\) profiles in the quiet Sun and the center-to-limb variation
  • Comparison of Ly-\(\alpha\) and Ly-\(\beta\) profiles in the quiet Sun
  • Lyman line profiles in sunspots
• Summary
H Lyman series

• Rydberg formula

\[ \frac{1}{\lambda} = R \left( \frac{1}{(n')^2} - \frac{1}{n^2} \right) \quad \left( R = 10.972 \times 10^6 \text{m}^{-1} \right) \]

• \( n' = 1, \quad n = 2, 3, 4, \ldots \)
Lyman-alpha

- Energy loss
- Atomic hydrogen excited by central spectral irradiance
- Diagnose properties of solar structures

Wilhelm et al., ESA SP-404, 17, 1997
SUMER observation of higher Lyman line profiles

1. Average profiles:
   self-reversed & flat-topped

2. Red-horn asymmetry in network

3. Weak limb brightening

Past observations of Ly- $\alpha$ profiles

UVSP/SMM: suffer from geocoronal absorption

SUMER observation of Ly-$\alpha$ profiles

1. off-limb prominence bare

2. scattered light profile of full-sun irradiance

3. limb prominence attenuator
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The June 2008 observation

- A new method to observe Ly-\(\alpha\) with SUMER
  - Determine the value of the photon flux reduction
  - Partially close the aperture door
  - Narrow slit
Scanned regions on the Sun

- blue:
  - 24th
  - 25th
- green:
  - 26th
Intensity maps and Doppergrams

Lyα countrate

Si III Line Shift (km/s)
Ly- $\alpha$ profiles in the quiet Sun

- Blue-horn asymmetry
- Brightness-to-asymmetry relationship
- More enhanced in the blue horn if larger downflows are present
- Positions of the three peaks are offset towards longer wavelengths with increasing downflow velocities.
Log-normal distribution of the radiance

\[ f(x) = \frac{a_0}{x - a_3} \cdot \exp \left( \frac{-(\ln(x - a_3) - a_1)^2}{2a_2^2} \right) \]
Center-to-limb variation

- Polynomial fit to the three peaks
- No limb brightening
- Tend to be symmetrical, wider, and deeper towards the limb

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The September 2008 observation

- Two spectral settings

- Ly-α
- Ly-β
- Si III
- O VI
Intensity maps and Dopplergrams
Profiles in bins of radiance and TR velocity

Ly-\(\alpha\) log radiance bins
- 10.29
- 10.65
- 11.01
- 11.37
- 11.73
- 12.09

Ly-\(\alpha\) profiles

Ly-\(\beta\) log radiance bins
- 4.79
- 5.22
- 5.65
- 6.08
- 6.50
- 6.93

Ly-\(\beta\) profiles

Si III velocity bins
- -5.82
- -3.42
- -1.02
- 1.38
- 3.78
- 6.18

Si III velocity bins

Ly-\(\alpha\) profiles

Ly-\(\beta\) profiles
High-rate MDI magnetogram
Average profiles in bins of $|B_z|$
Images of moments

mean wavelength: $\lambda_c = \frac{\sum (l_i-B_i) \lambda_i}{\sum (l_i-B_i)}$,

standard deviation: $\sigma = \sqrt{\frac{\sum (l_i-B_i)(\lambda_i-\lambda_c)^2}{\sum (l_i-B_i)}}$,

skewness: $\frac{\sum (l_i-B_i)(\lambda_i-\lambda_c)^3}{\sigma^3 \sum (l_i-B_i)}$,

kurtosis: $\frac{\sum (l_i-B_i)(\lambda_i-\lambda_c)^4}{\sigma^4 \sum (l_i-B_i)}$,
Moments of the line profiles
Relationship between TR flows and 1st/3rd order moments of Ly-$\beta$ profiles

- **3rd**: The red horn tends to be more enhanced with increasing downflow

- **1st**: Strong correlation can be understood if assuming Ly-$\beta$ is more redshifted and more enhanced in the red horn in regions where larger downflows are present

![Graphs showing relationship between TR flows and 1st/3rd order moments of Ly-$\beta$ profiles](image)
Relationship between TR flows and 1st/3rd order moments of Ly-α profiles

- 3rd: The blue horn tends to be more enhanced with increasing downflow

- 1st: The enhanced blue horn will reduce the moment, so Ly-α should be more redshifted in regions where larger downflows are present
The redshift of Ly- $\beta$

- **Absolute wavelength calibration**
  
  - Ly- $\beta$ is optically much thinner than Ly- $\alpha$ and the motion of its emission source can be determined.

![Graph showing the redshift of Ly-β with emissions from He II and O I.]
Spatial distribution of kurtosis

C 4th order moment of Ly-α

F 4th order moment of Ly-β

A Ly-a
Bz (Gauss)

B Ly-b
Bz (Gauss)

Smaller value of kurtosis

Larger value of kurtosis
More reversed in the network
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Higher Lyman line profiles in sunspot regions

Dashed: plage; dot-dashed: penumbra; dotted: umbra; solid: plume
Ly-\(\alpha\) profile in sunspots

- UVSP/SMM: suffer from geocoronal absorption

Summary

• Ly- $\alpha$ profiles were observed on disk without geocoronal absorption for the first time.
  – Asymmetry of the average profile is different from other Lyman lines
  – More redshifted and enhanced in the blue horn if larger downflows are present
• Ly- $\beta$
  – More redshifted and more enhanced in the red horn if larger downflows are present
  – The average profile is redshifted
• Profiles are more reversed in network
• Lyman line profiles in umbrae and sunspot plumes are not reversed
• Models including the effects of opacity and flows need to be developed