Effects of the chromospheric Lyα line profile shape on the determination of the solar wind outflow velocity using the Doppler dimming technique

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Giuseppe Emanuele Capuano

(giuseppe.capuano@inaf.it)

Doppler dimming

Phenomenon concerning the **decrease of coronal line radiation** (for example: Lyα or OVI) in regions where atoms/ions flow out **in the solar wind** (i.e. see Withbroe et al. 1982; Noci et al. 1987).

We consider the specific intensity **only due the coronal resonantly scattered** Lyα radiation:

$$\mathcal{I}_{rad} = \frac{0.833\, h\, B_{12}}{4\pi\lambda_0} \int_{-\infty}^{+\infty} n_e\, R_{\mathrm{H\,I}}(T_e)\, dl \int_{\Omega} \frac{11 + 3(\mathbf{n}\cdot\mathbf{n}')^2}{12}\, F(\mathbf{n}', v_w, \theta)\, d\Omega$$

$$F(\mathbf{n}', v_w, \theta) = \int_{-\infty}^{+\infty} I(\lambda' - \lambda_0 - \delta\lambda, \mathbf{n}')\, \Phi(\lambda' - \lambda_0)\, d\lambda'$$

$$I(\lambda' - \lambda_0 - \delta\lambda, \mathbf{n}') = I(\mathbf{n}') \cdot \Psi(\lambda' - \lambda_0 - \delta\lambda)$$

$$\delta\lambda = \frac{\lambda_0}{c}\mathbf{v}\cdot\mathbf{n}' = \frac{\lambda_0}{c} v_w \cos\theta$$

Parameters for the synthesised dimmed coronal intensity (Lyα case)

- Electron density (n_e) (from pB intensity)
- Electron temperature (t_e)
- Chromospheric line intensity *(I)*
- Chromospheric line profile (ψ)
- Neutral HI temperature (t_{HI})
- θ is the angle between the flow **(n')** and the line-of-sight (**n**) direction
- Free parameter: outflow velocity (v_w)
- The outflow velocity v_w can be determined by a matching between the observed (UV radiation) and the synthesised I_{rad}.
- The effects due to I, n_e, t_e, and t_{HI} on the estimate of v_w have been studied by Dolei et al. (2018, 2019).
- Our aim is to study the effects due to ψ shape variations.

Doppler factor

In order to see the effects due to the chromopheric profile on the outflow velocity determination, we consider the **Doppler factor** ($\boldsymbol{D}$)**.**

It accounts for the **overlapping** between the **coronal absorption** profile (Φ) and the **exciting chromospheric** one (ψ) as a function of v_w.

$$D(v_w) = \frac{\int_\Omega F(\mathbf{n}', v_w, \theta) p(\Omega)\, d\Omega}{\int_\Omega F(\mathbf{n}', v_w = 0, \theta) p(\Omega)\, d\Omega}$$

$$F(\mathbf{n}', v_w, \theta) = \int_{-\infty}^{+\infty} I(\lambda' - \lambda_0 - \delta\lambda, \mathbf{n}')\, \Phi(\lambda' - \lambda_0)\, d\lambda'$$

$$I(\lambda' - \lambda_0 - \delta\lambda, \mathbf{n}') = I(\mathbf{n}') \cdot \Psi(\lambda' - \lambda_0 - \delta\lambda)$$

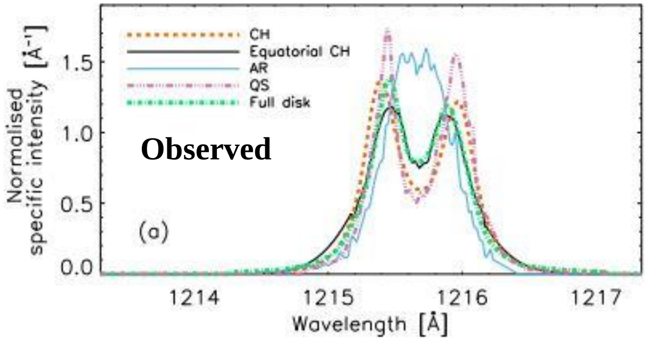
$$\delta\lambda = \frac{\lambda_0}{c} \mathbf{v} \cdot \mathbf{n}' = \frac{\lambda_0}{c} v_w \cos\theta$$

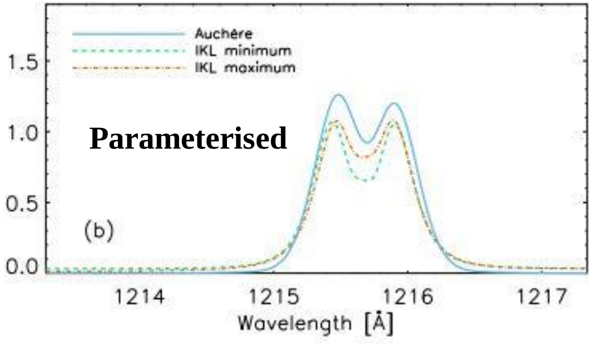
For simplicity of calculation, we **set $\boldsymbol{\theta = 0}$**.

$$D(v_w, \theta = 0) = \frac{F(\boldsymbol{n}', v_w, \theta = 0)}{F(\boldsymbol{n}', v_w = 0, \theta = 0)}$$

Bocchialini & Vial (1996)
Fontenla et al. (1988)
Lemaire et al. (2015)
Tian et al. (2009 a,b)

Auchère (2005)
Kowalska-Leszczynska et al. (2018; IKL)

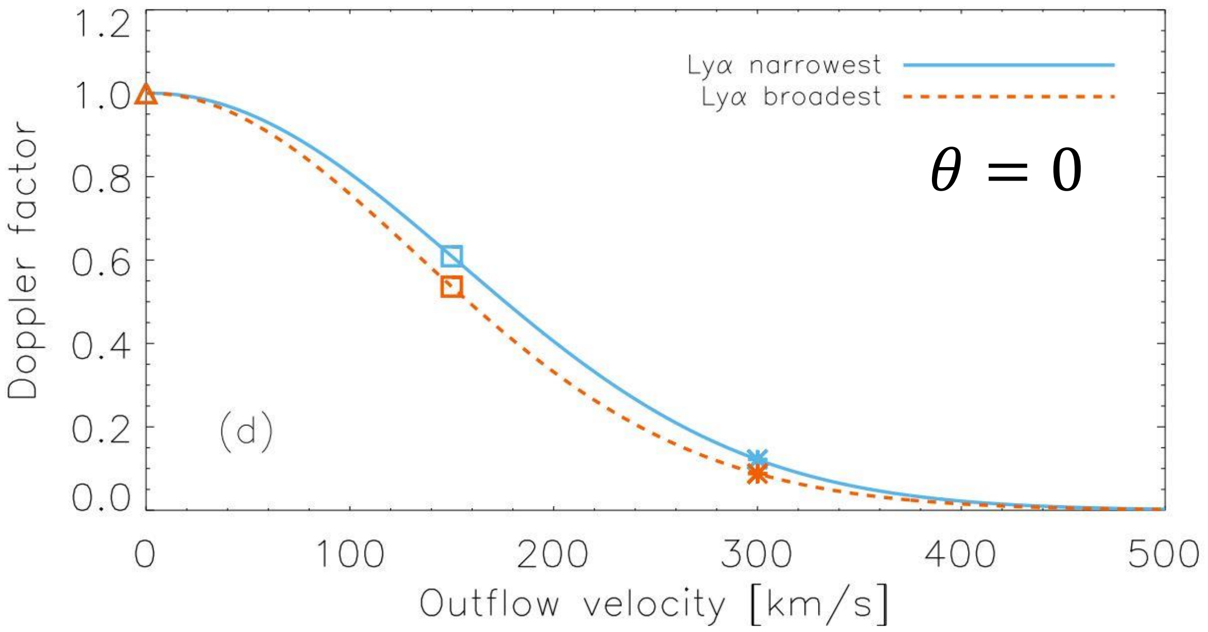


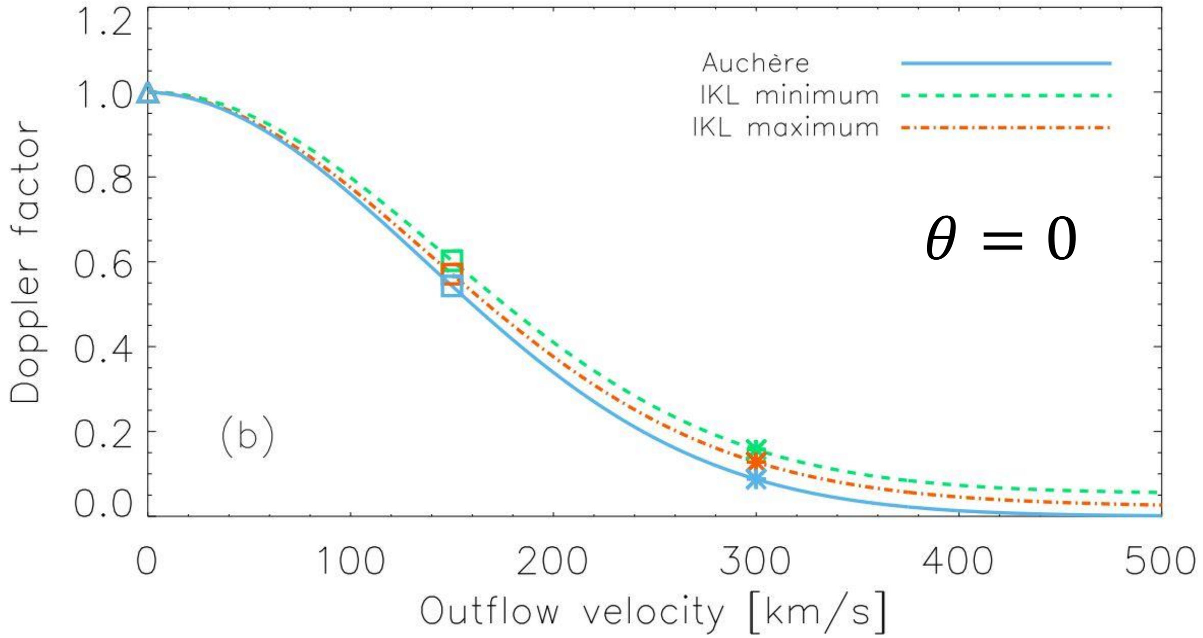


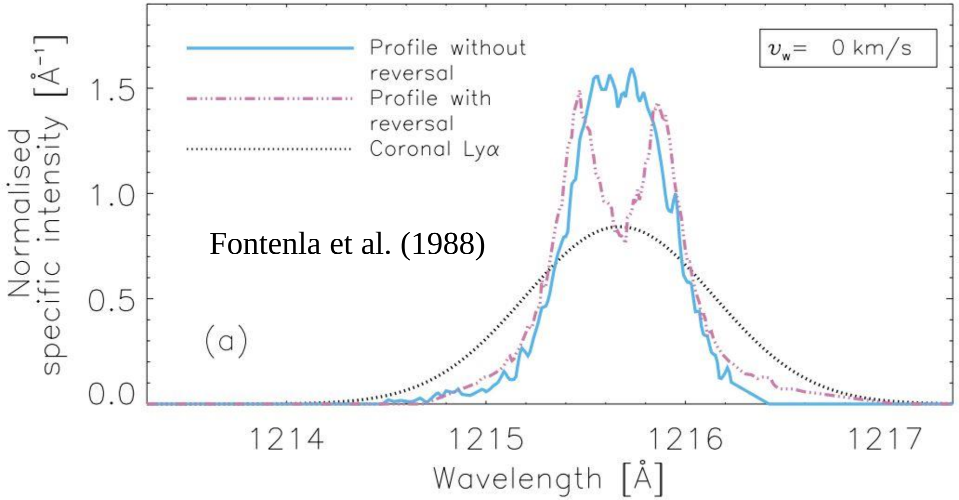
Profile parameters observed variation:

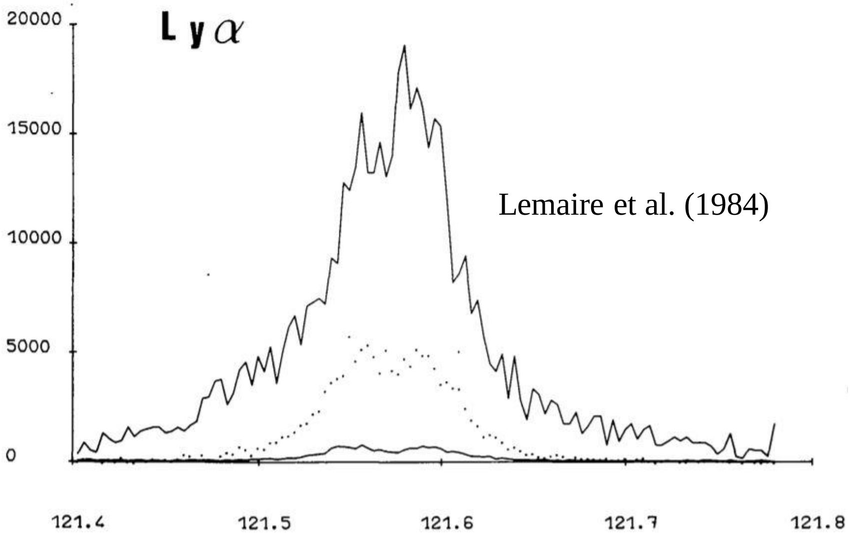
- Width (50%)
- Reversal depth (69%)
- Asymmetry (35%)
- Distance of the peaks (50%)

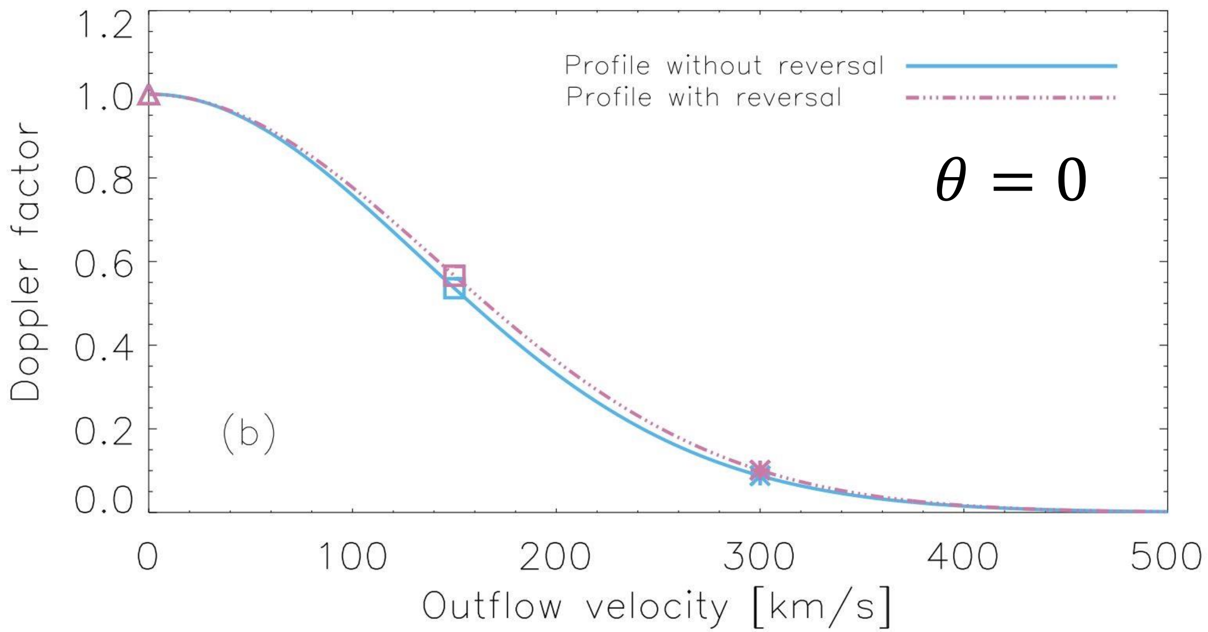
Negligible effects for what concerns all the profile parameters, both for **observed** and **parameterised** profiles.
(Capuano et al. 2021)

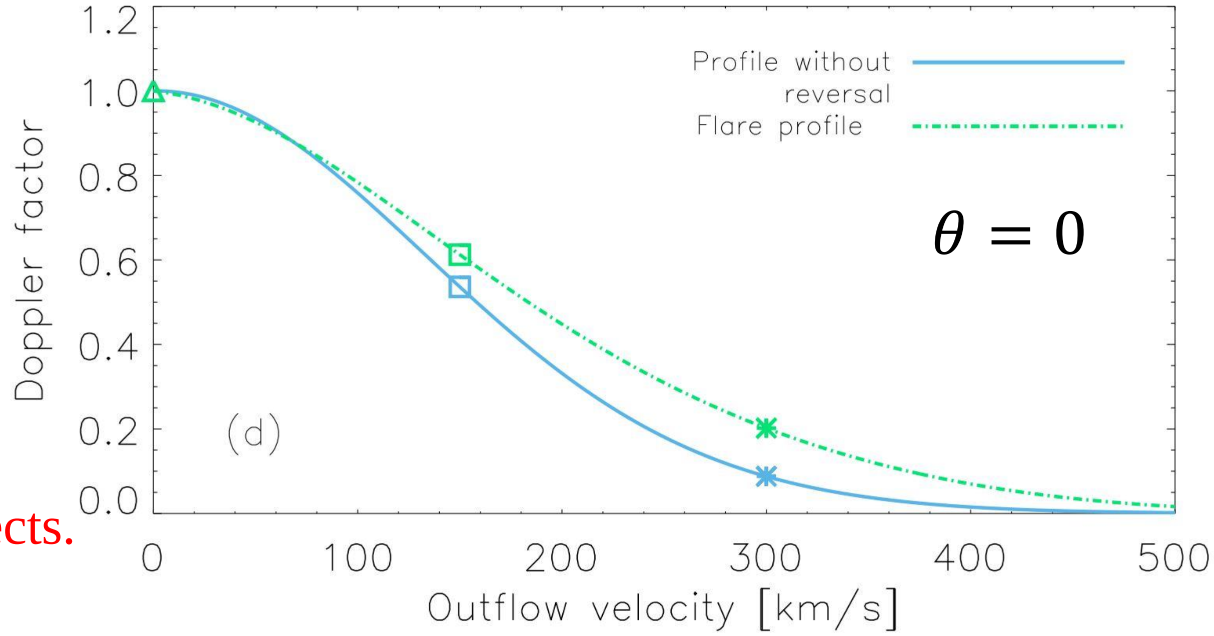












Only in the case of a **flare profile** the effects are **not negligible**.

Analysis also made with $\theta = 30°$ → not remarkable effects.

(Capuano et al. 2021)

Results and conclusions

- The variability of the pumping Lyα profile affects the estimates of the coronal HI velocity by about 9-12% (22 km s^{-1} and 30 km s^{-1}, respectively).

- Effects due to $\theta \neq 0$ below about 70 km s^{-1} (14%).

- **In the upper cases, we obtain small differences in the HI outflow velocity estimate**.

- Only when we consider a flare profile, we obtain large uncertainties values (100 km s^{-1}; 21%).

- **Therefore, a unique shape of the Lyα chromospheric profile can be adopted all over the solar disc and for different solar cycle periods.**

- Future analysis with data coming from Metis/Solar Orbiter will be performed.