More rotation and less outflows can explain Lyman-α observed line features

Maria Camila Remolina-Gutiérrez

Jaime E. Forero-Romero (Uniandes)
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Mark Dijkstra (Oslo)

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Lya lines contain a wealth of LAEs' physical information

Context

Physics undergraduate thesis at Universidad de los Andes.

Motivation

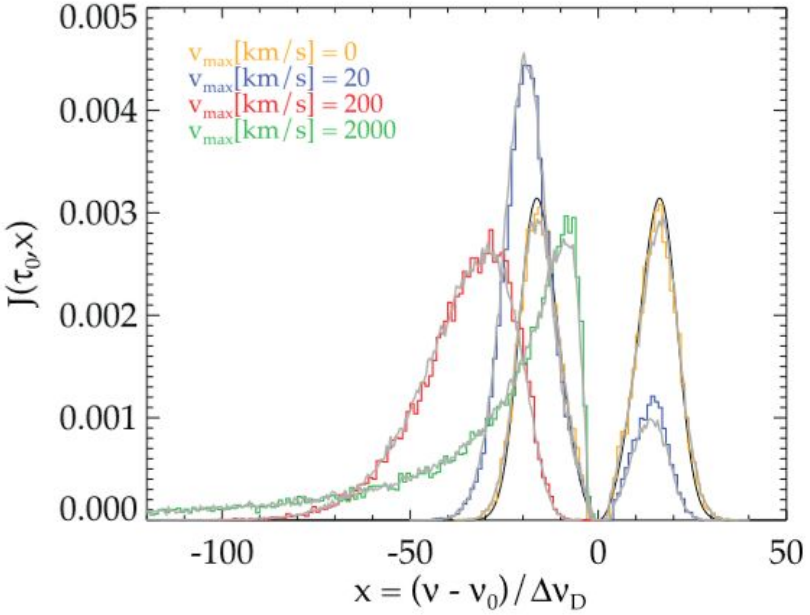
★ Previous work showed that rotation has an impact on the Lyman-alpha line morphology.

Garavito-Camargo et al. (2014)

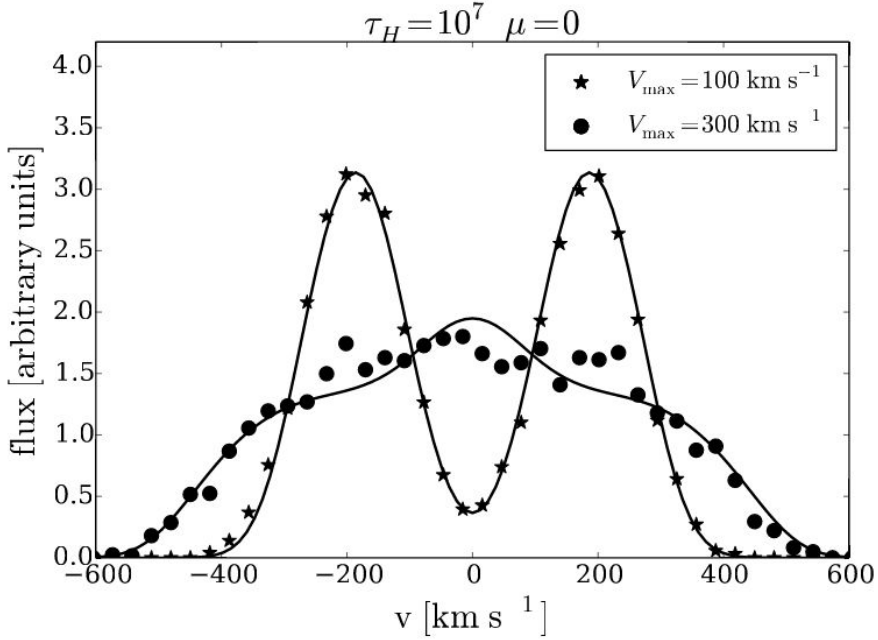
★ There is the theoretical and observational evidence for the presence of outflows in LAEs.

Verhamme et al. (2006), **Dijkstra et al.** (2006), **Laursen et al.** (2009), **Barnes et al.** (2012), **Orsi et al.** (2012), **Verhamme et al.** (2012), **Yajima et al.** (2012), **Martin et al.** (2015)

The Lyα profile depends on its outflow velocity, rotation velocity and viewing angle

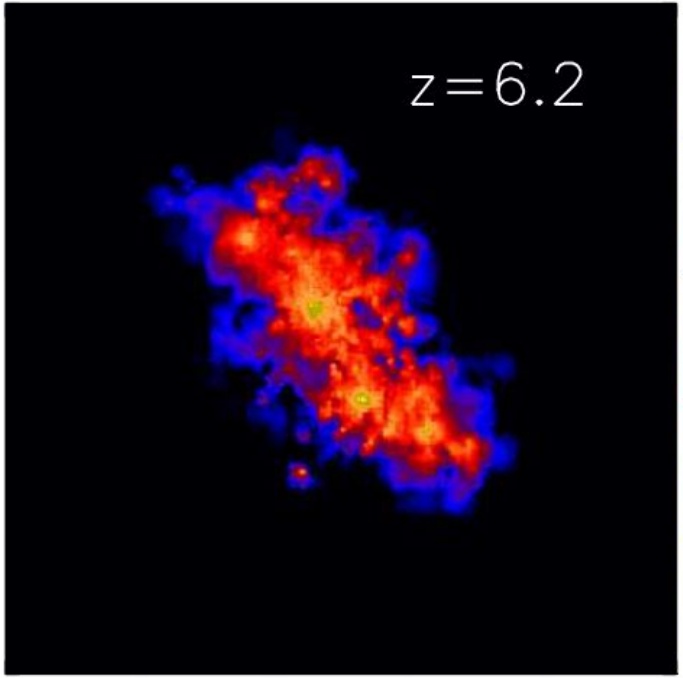


Orsi et al. (2012)

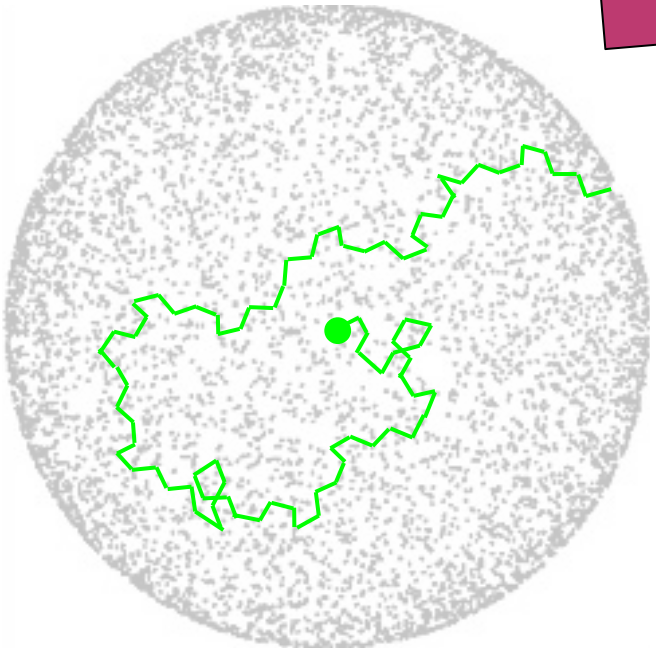


Garavito-Camargo et al. (2014)

We use simplified simulations to study this problem

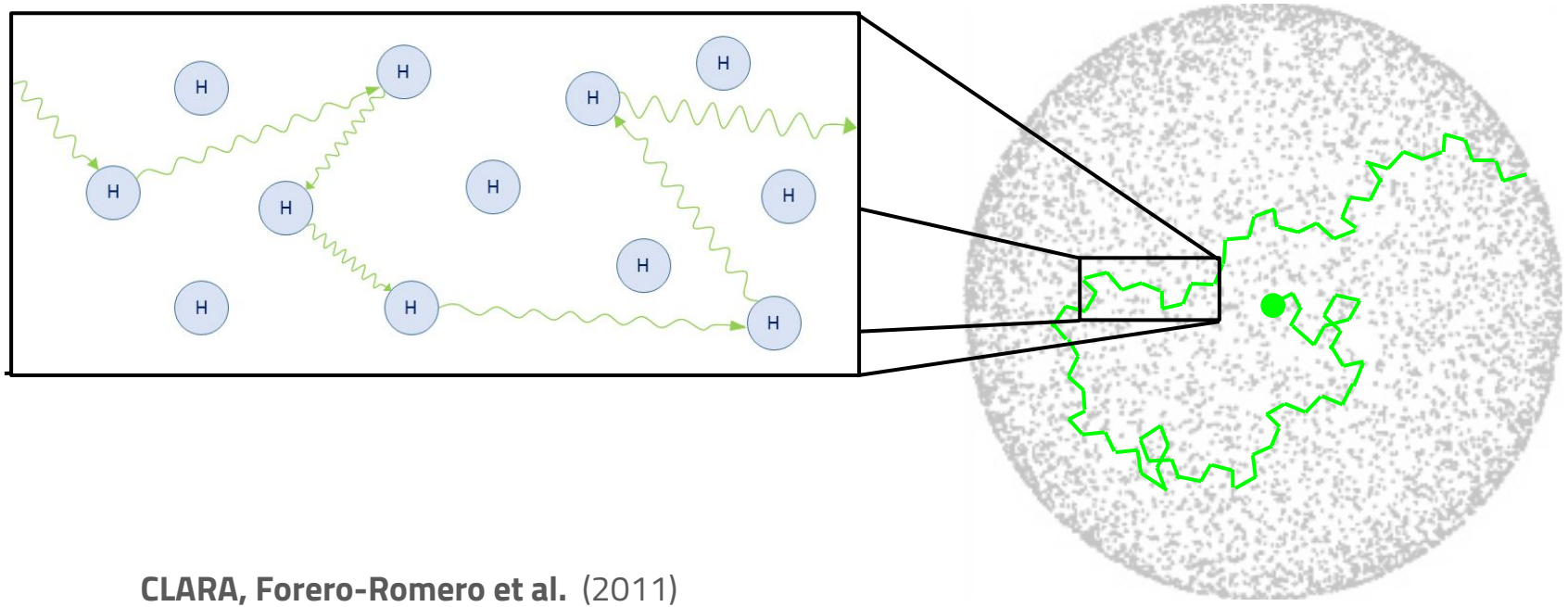


Yajima et al. (2015)



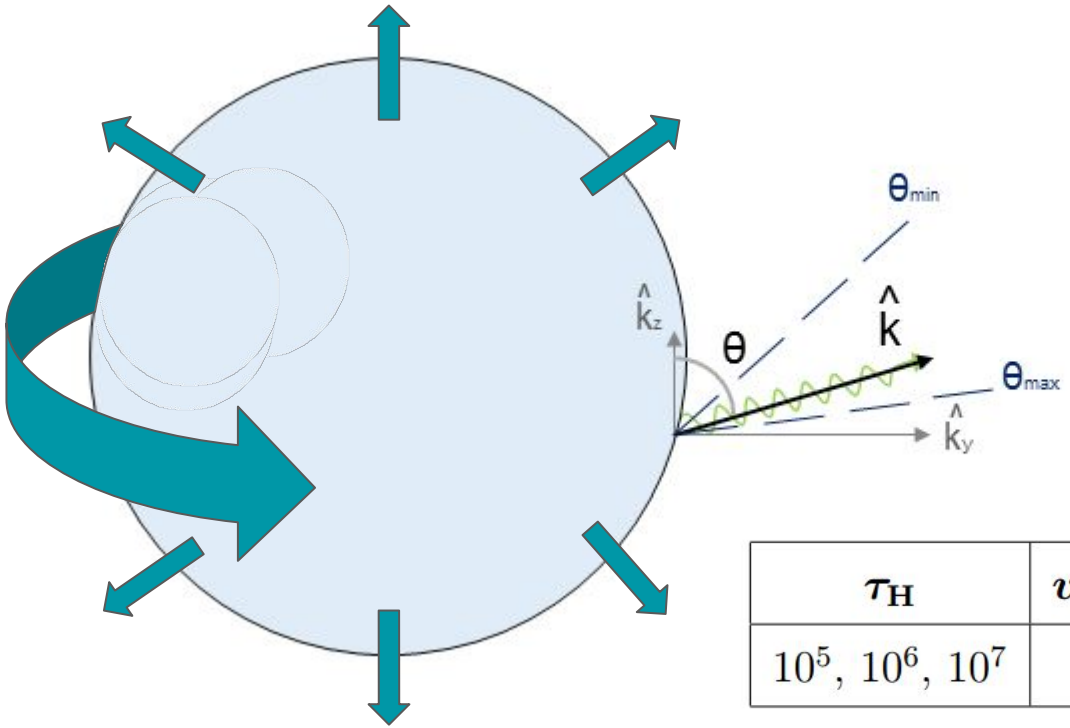
CLARA, Forero-Romero et al. (2011)

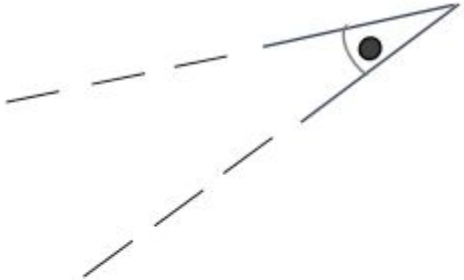
We use simplified simulations to study this problem



CLARA, Forero-Romero et al. (2011)

What if BOTH rotation and outflows are simulated?

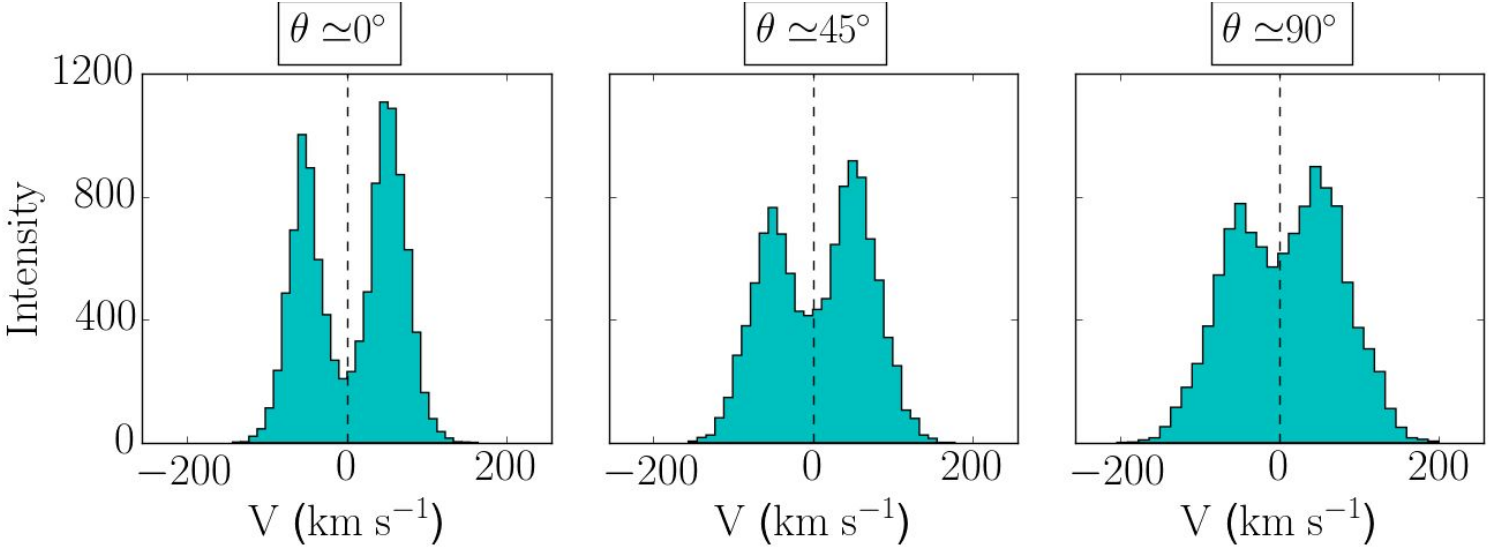


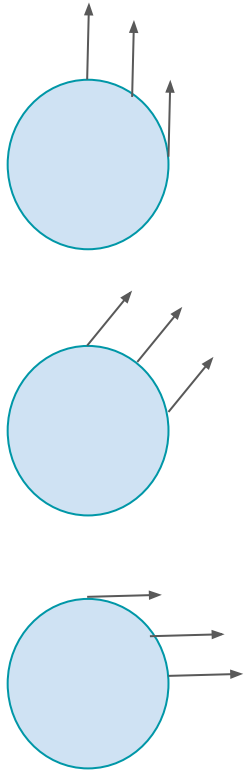


$\tau_{\mathbf{H}}$	v_{rot} (km s^{-1})	v_{out} (km s^{-1})
10^5, 10^6, 10^7	50, 100	5, 10, 15, 20, 25, 50, 75

Remolina-Gutiérrez et al. (in prep. 2016)

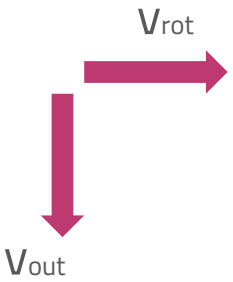
Result # 1: Rotation introduces a dependency on viewing angle



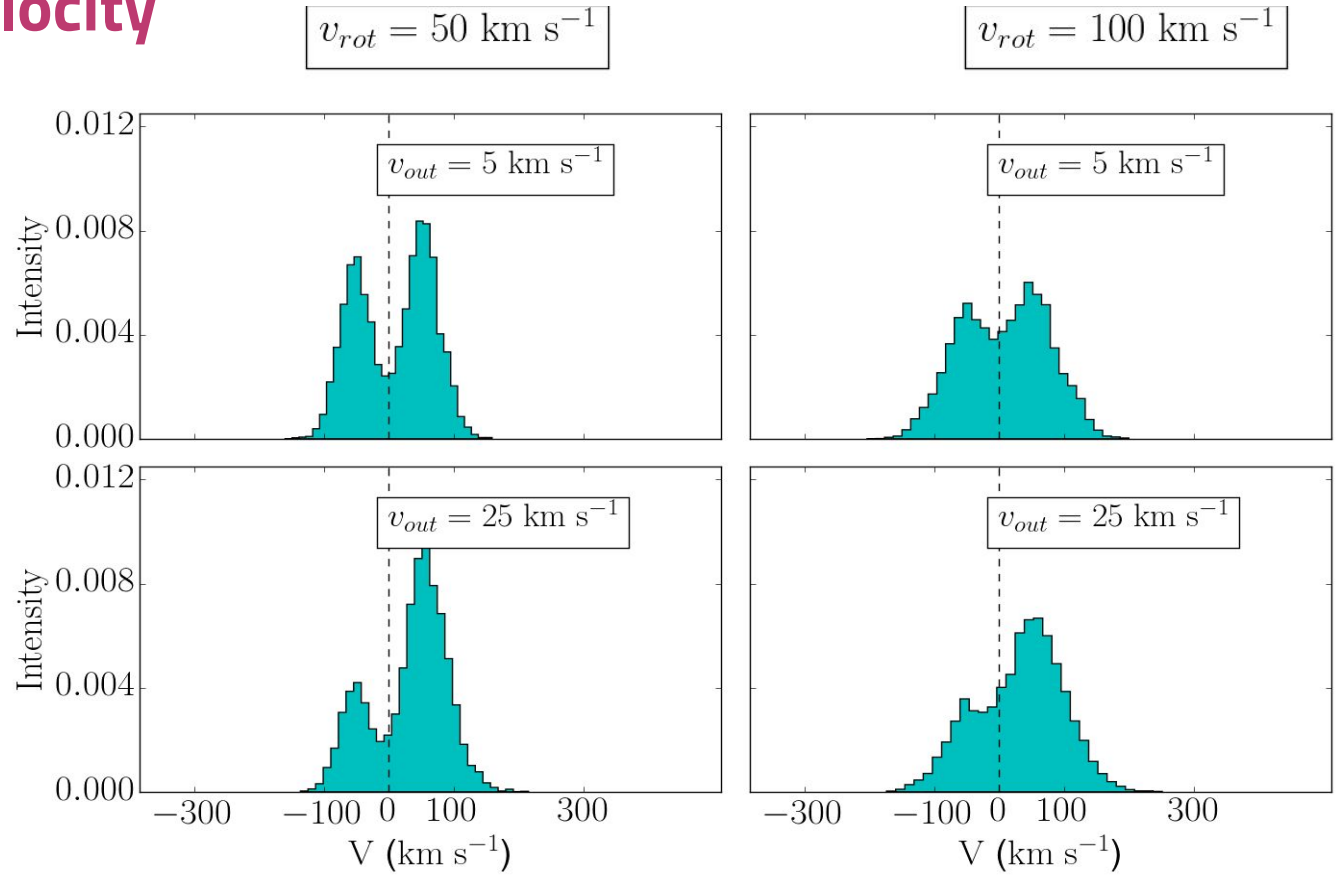


$$\tau_{\rm H} = 10^5 \; v_{\rm rot} = 50 \text{ km s}^{-1} \; v_{\rm out} = 20 \text{ km s}^{-1}$$

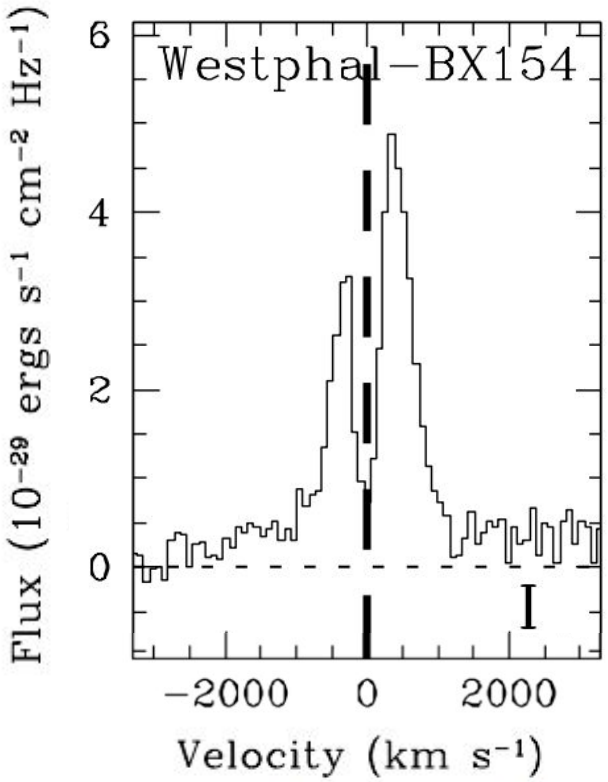
Result #2: The Lyα profile depends on its rotation and outflows velocity



$$\tau_{\rm H} = 10^5$$
$$\theta \simeq 90^\circ$$



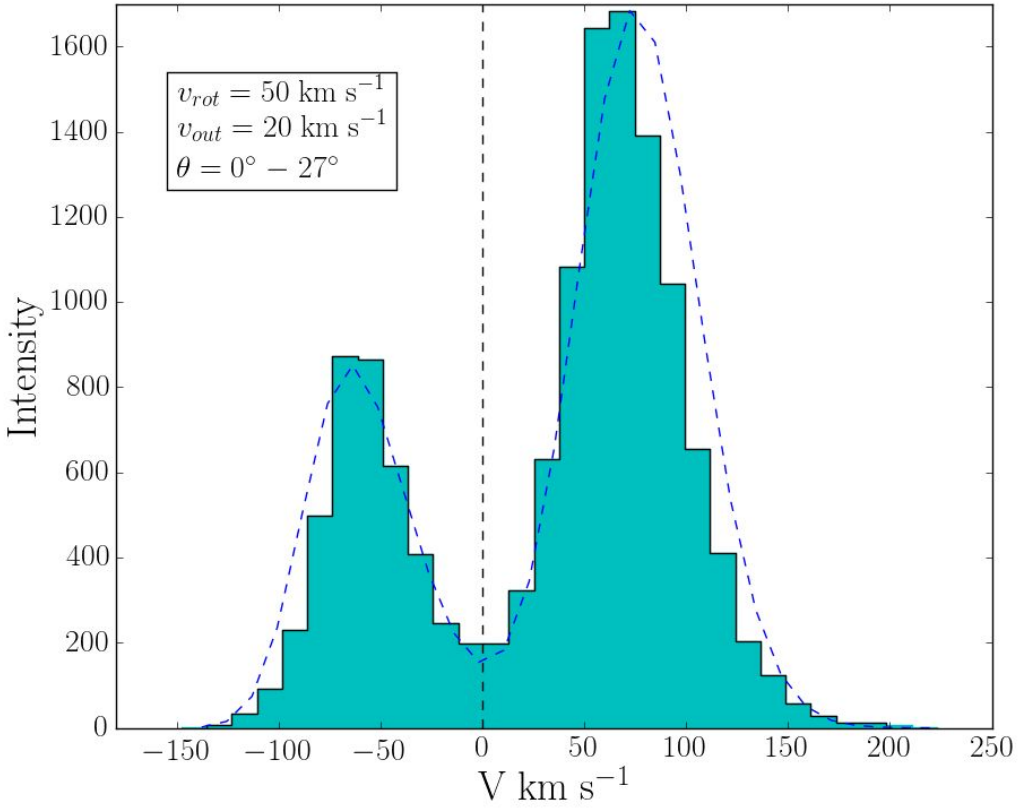
This new model ~reproduces Lya primary observed features



LAE: z=2.5954

Kulas et al. (2012)

The Lyα line can be quantified by asymmetric gaussians

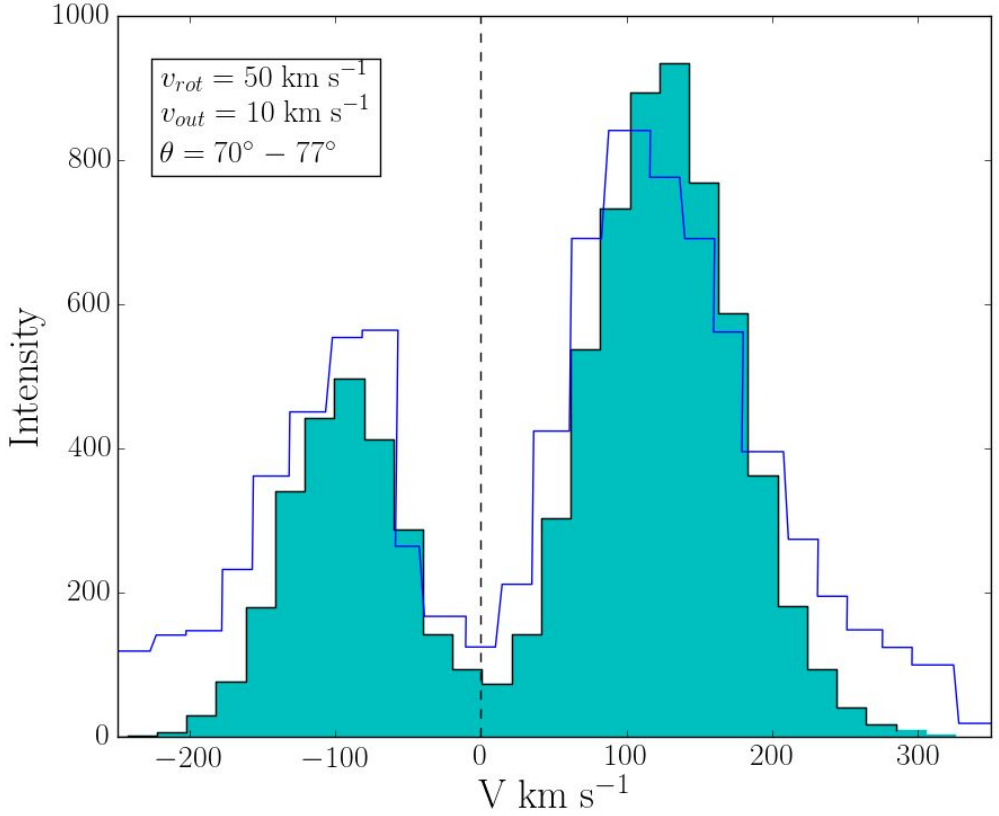


$$\tau_{\rm H} = 10^5$$

$$A_- \ \sigma_- \ c_- \ \gamma_-$$

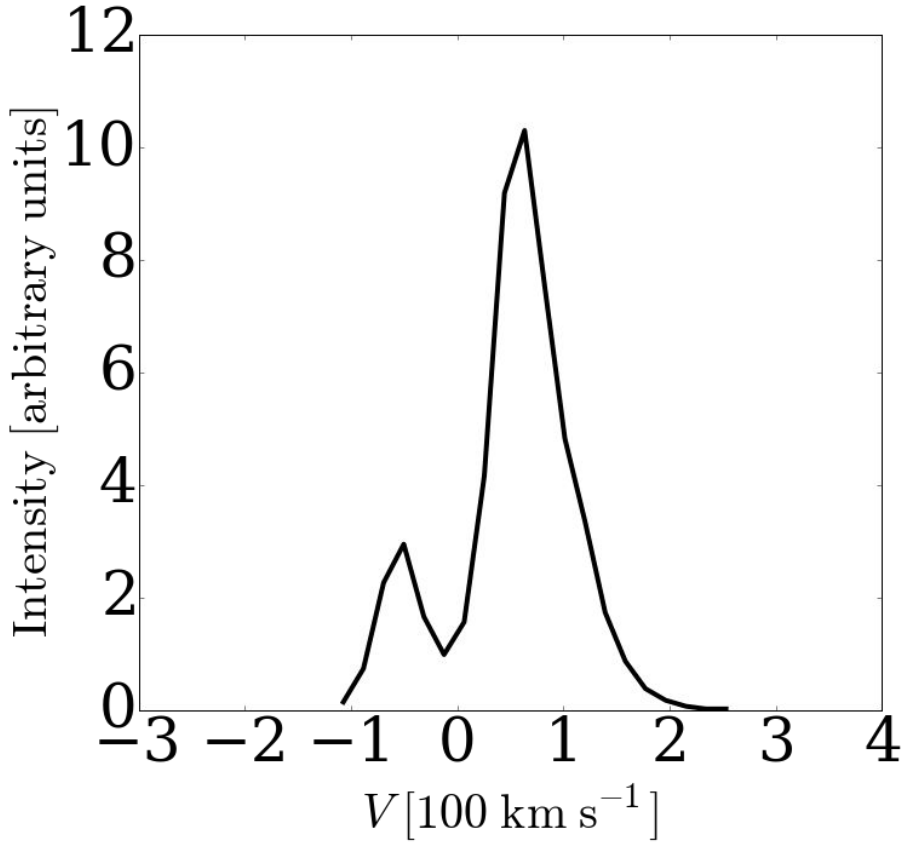
$$A_+ \ \sigma_+ \ c_+ \ \gamma_+$$

Result #3: The model can reproduce Lya main features

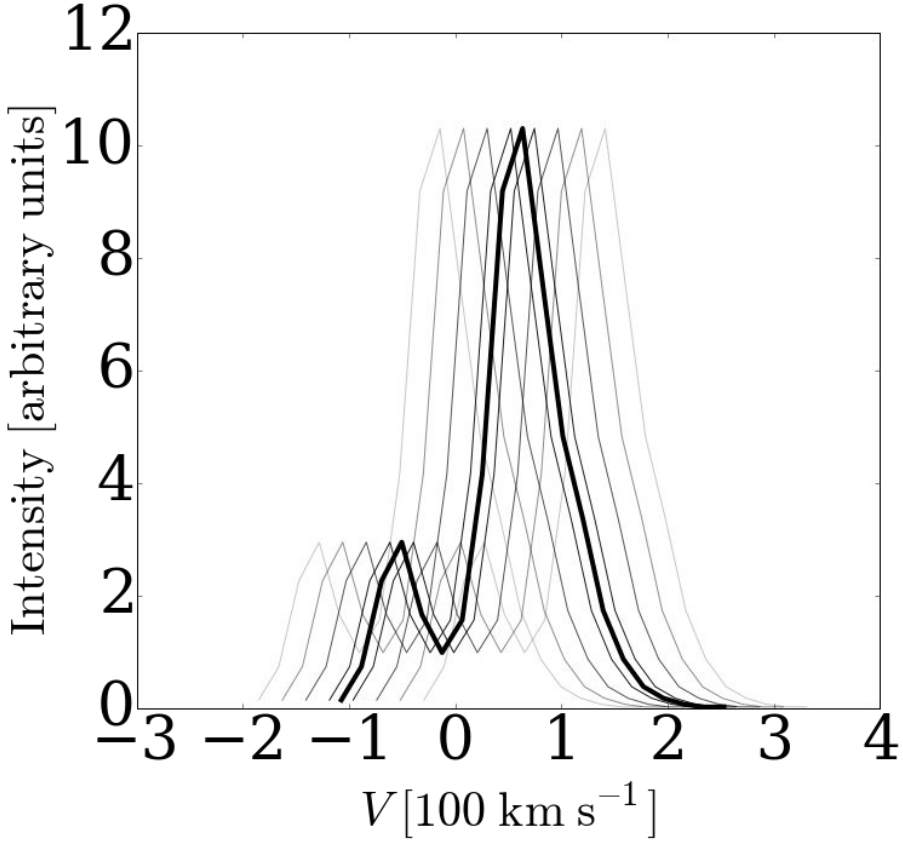


$$\tau_{\mathrm{H}} = 10^{6}$$

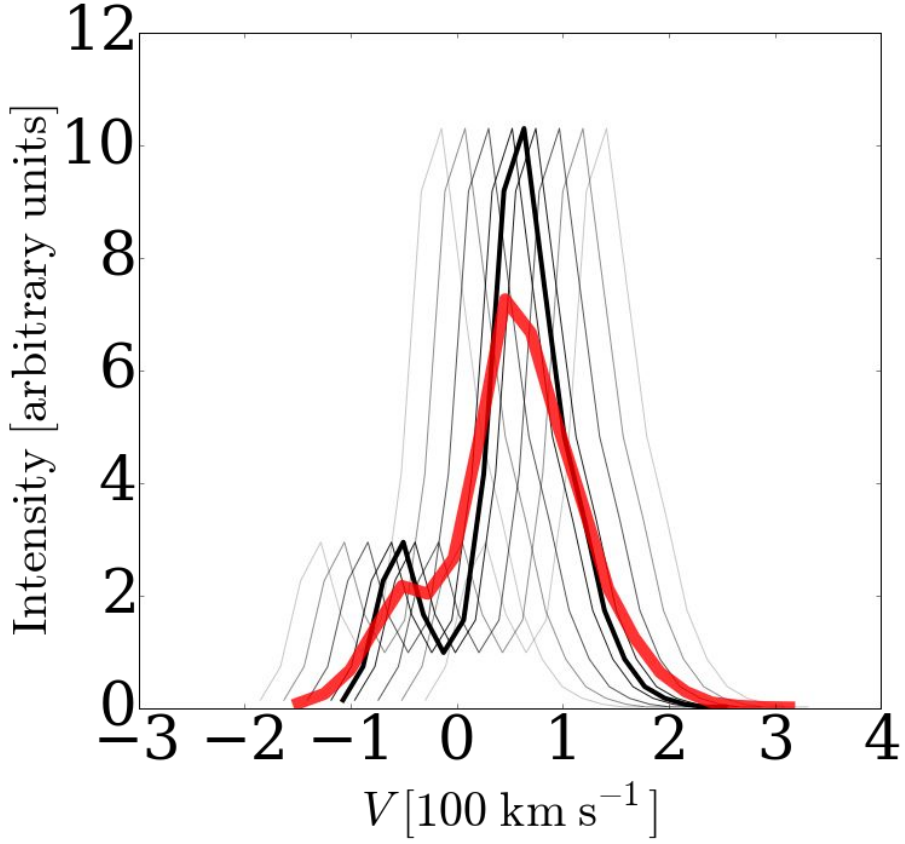
How can we understand these results?



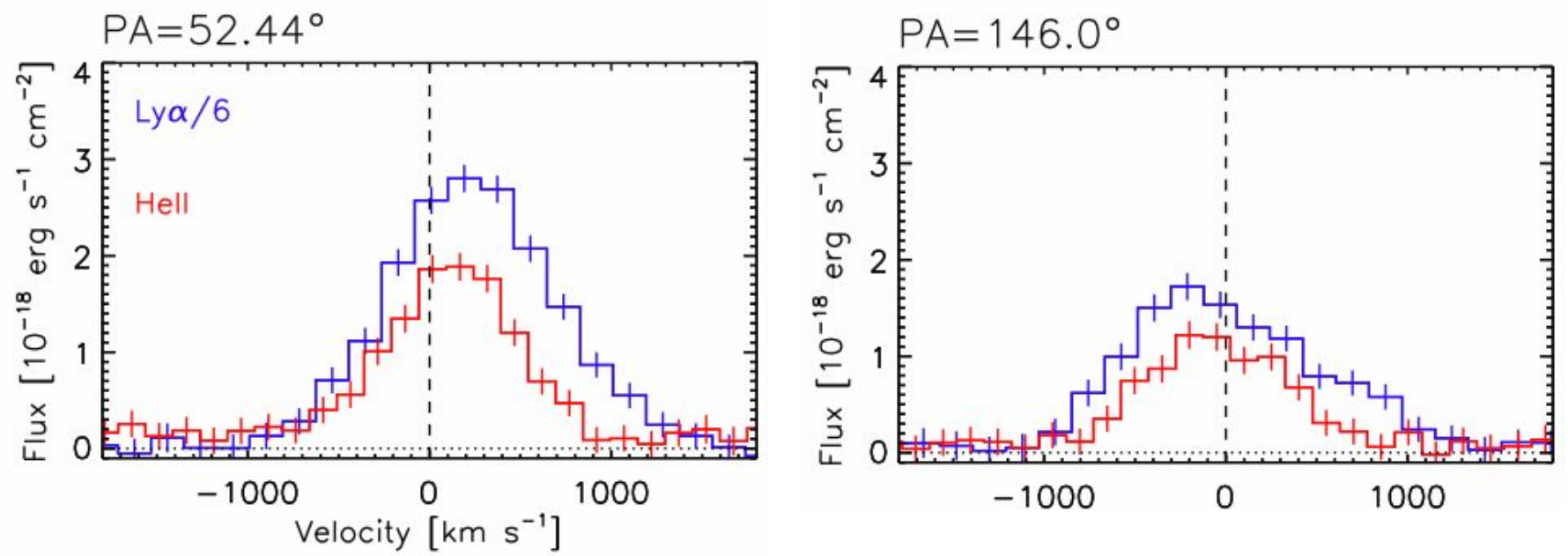
How can we understand these results?



How can we understand these results?



How can we understand these results?



Prescott et al. (2014)

Conclusions and perspectives

- ★ Rotation and outflows have a visible impact on the Lyman-alpha line and we understand the mechanism.
- ★ Rotation introduces a dependency with viewing angle.
- ★ The intensity at the line's center changes with rotational velocity.

- ★ Rotational effects should be clearly detected and characterized by MUSE.
- ★ Possible rotational velocity constraints using the Lyman-alpha line.

Gracias :)

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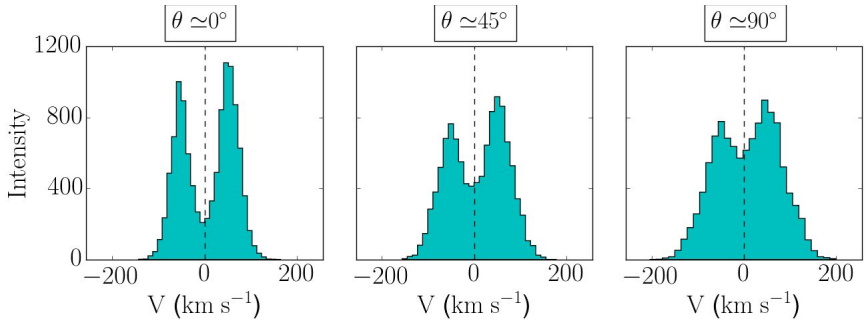
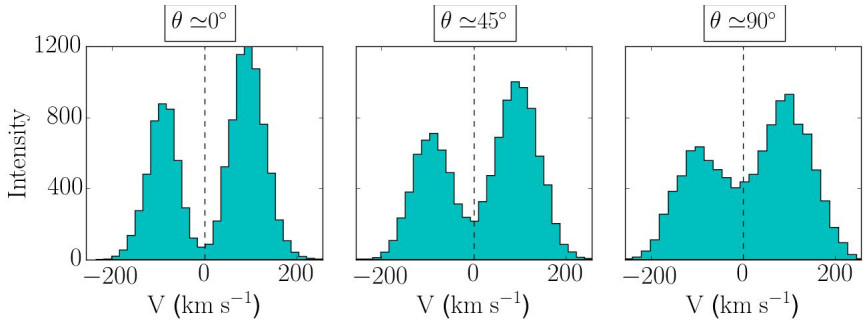
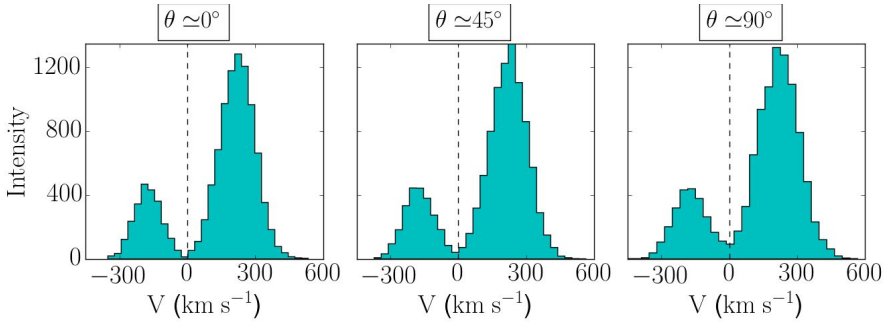
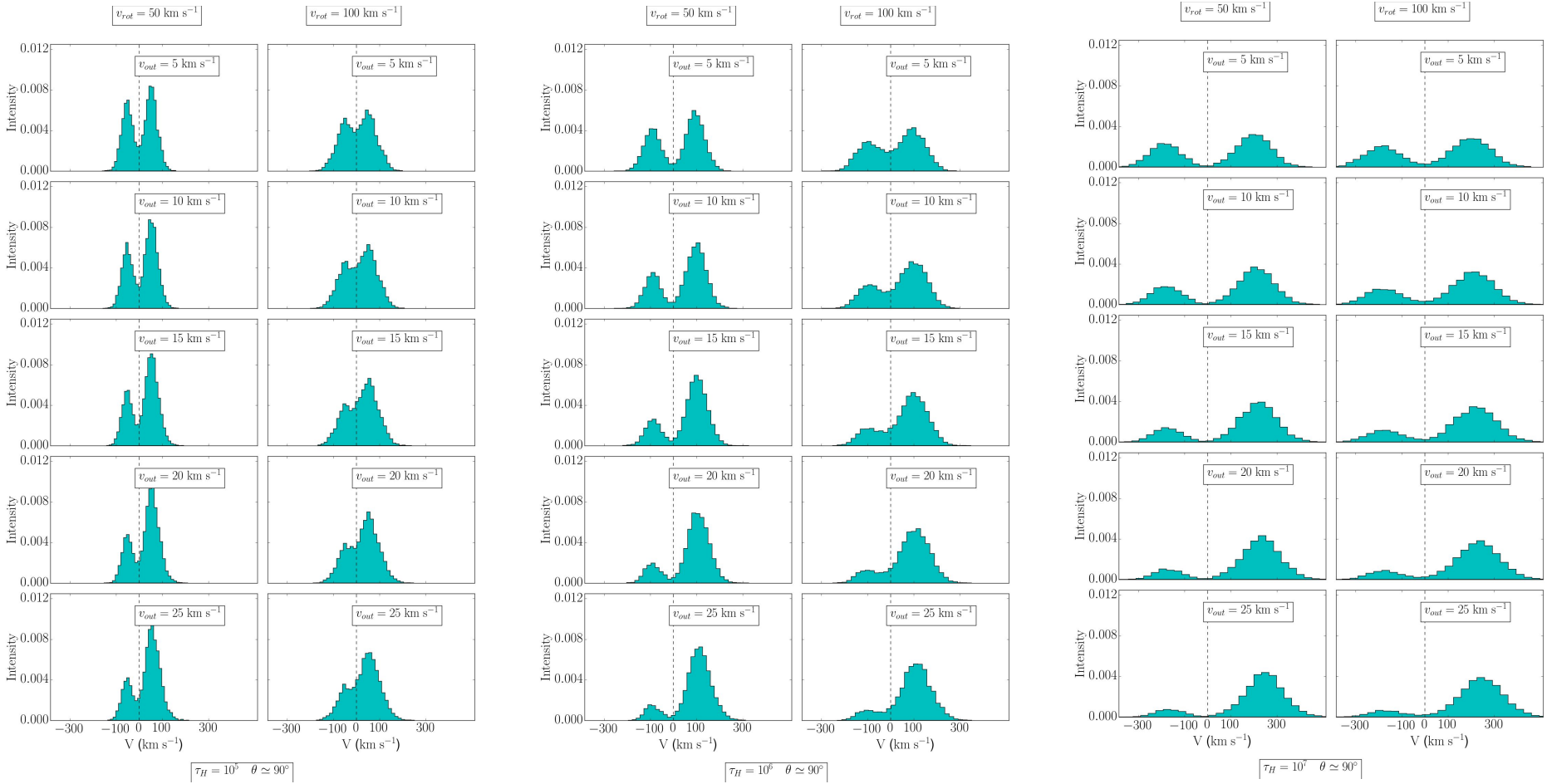
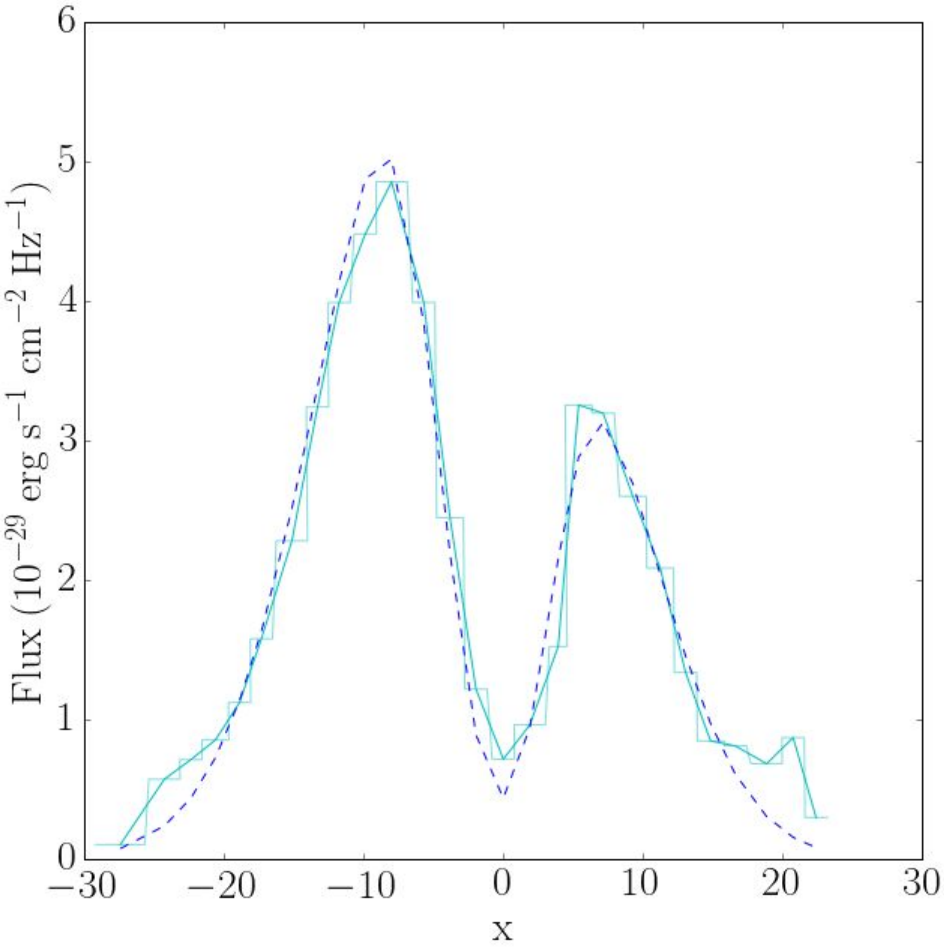
ADDITIONAL PLOTS

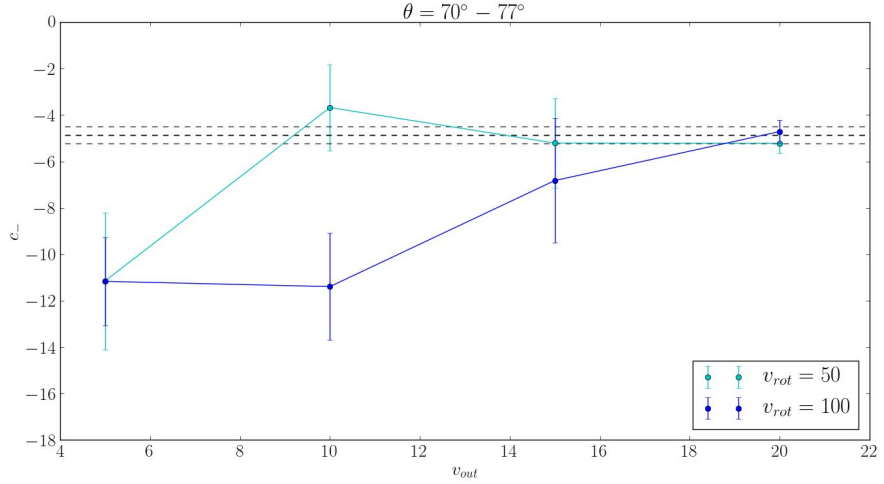

θ ≃0°
θ ≃45°
θ ≃90°
Intensity
1200
800
400
0
−200
0
200
V (km s−1)

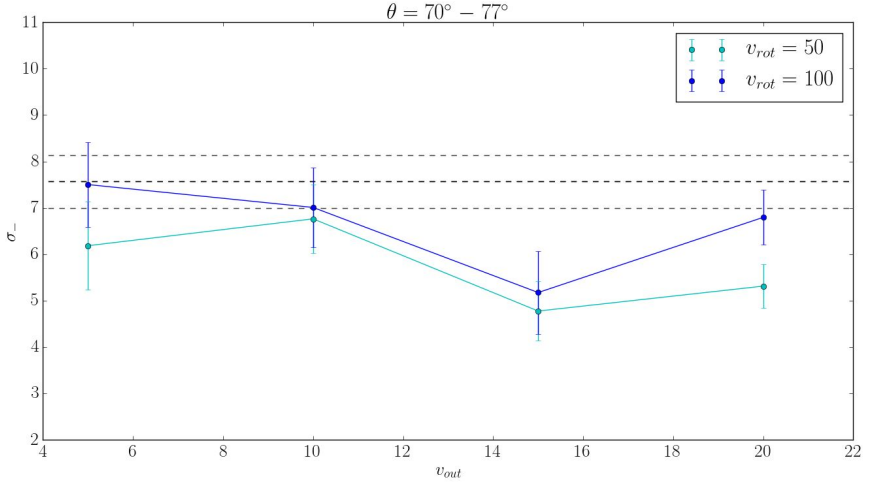

θ ≃0°
θ ≃45°
θ ≃90°
Intensity
1200
800
400
0
−200
0
200
V (km s−1)

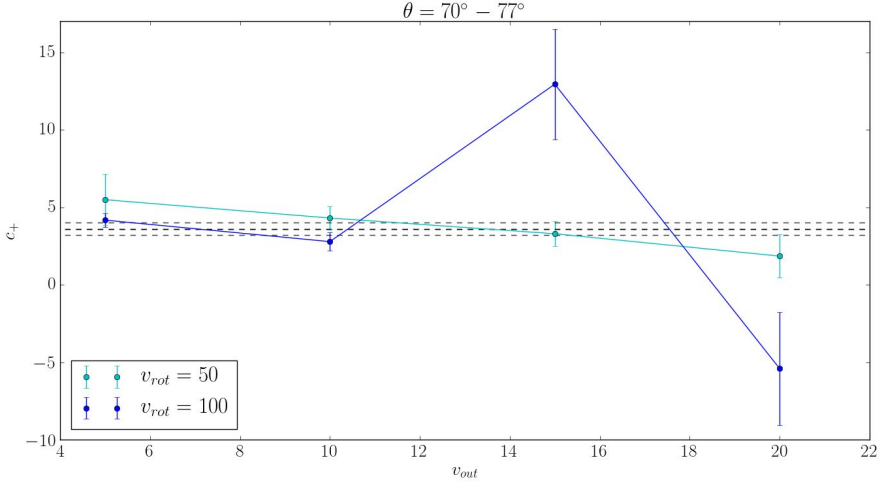

θ ≃0°
θ ≃45°
θ ≃90°
Intensity
1200
800
400
0
−300
0
300
600
V (km s−1)

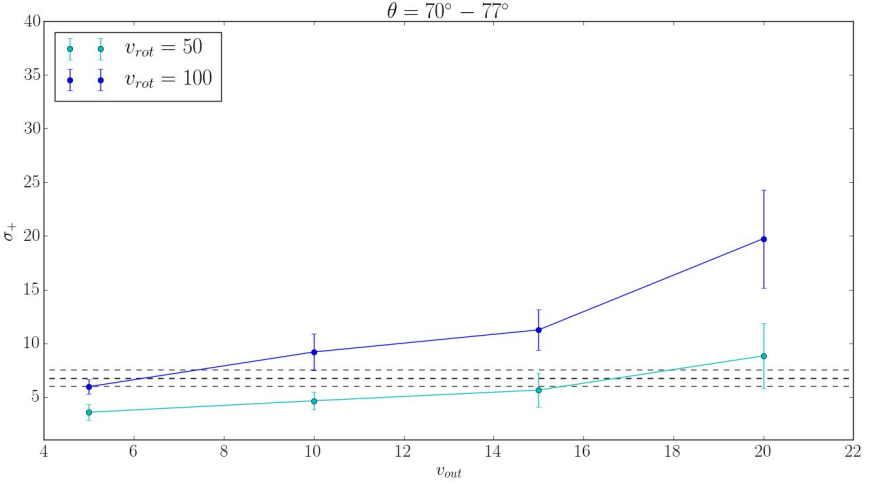

v_{rot} = 50 km s^{-1}
v_{rot} = 100 km s^{-1}
v_{out} = 5 km s^{-1}
v_{out} = 10 km s^{-1}
v_{out} = 15 km s^{-1}
v_{out} = 20 km s^{-1}
v_{out} = 25 km s^{-1}
Intensity
0.000
0.004
0.008
0.012
−300
−100
0
100
300
V (km s^{-1})
$\tau_H = 10^5$ $\theta \simeq 90°$
$\tau_H = 10^6$ $\theta \simeq 90°$
$\tau_H = 10^7$ $\theta \simeq 90°$

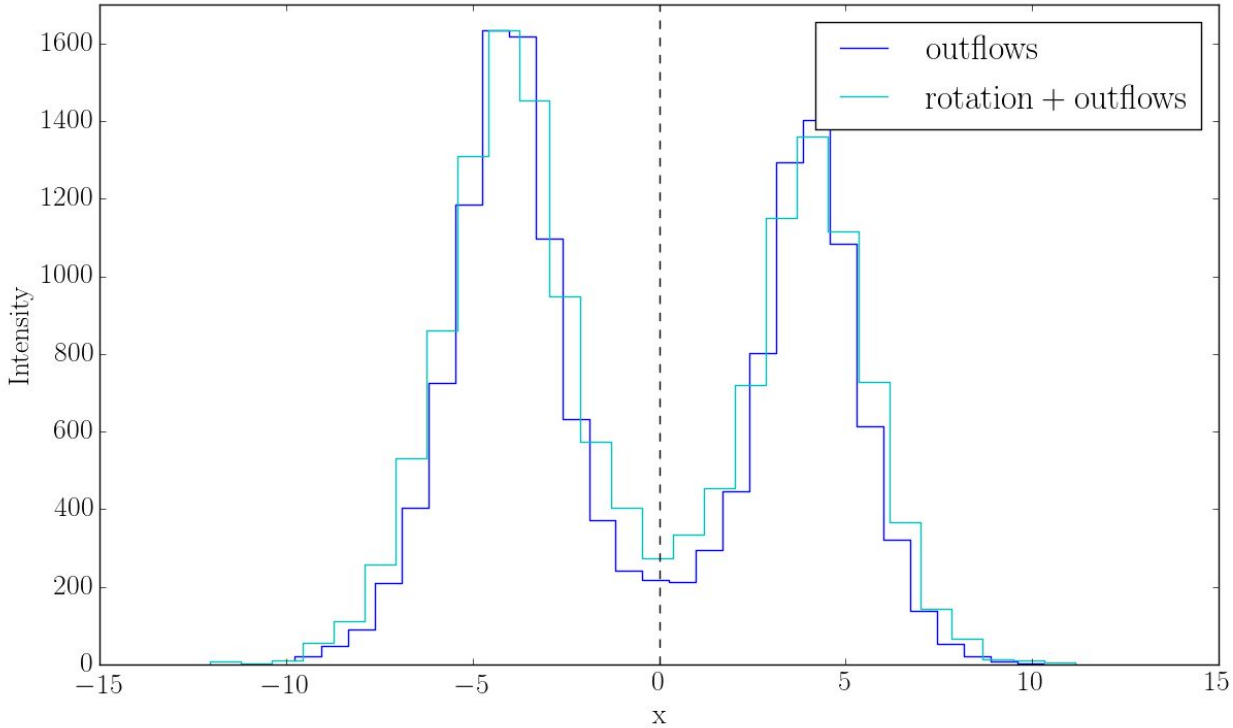

Flux (10^{-29} erg s^{-1} cm^{-2} Hz^{-1})
x
6
5
4
3
2
1
0
−30
−20
−10
0
10
20
30


$\theta = 70° - 77°$
c_-
v_{out}
$v_{rot} = 50$
$v_{rot} = 100$


$\theta = 70° - 77°$
σ_-
v_{out}
$v_{rot} = 50$
$v_{rot} = 100$


$\theta = 70° - 77°$
c_+
v_{out}
$v_{rot} = 50$
$v_{rot} = 100$


$\theta = 70° - 77°$
σ_+
v_{out}
$v_{rot} = 50$
$v_{rot} = 100$



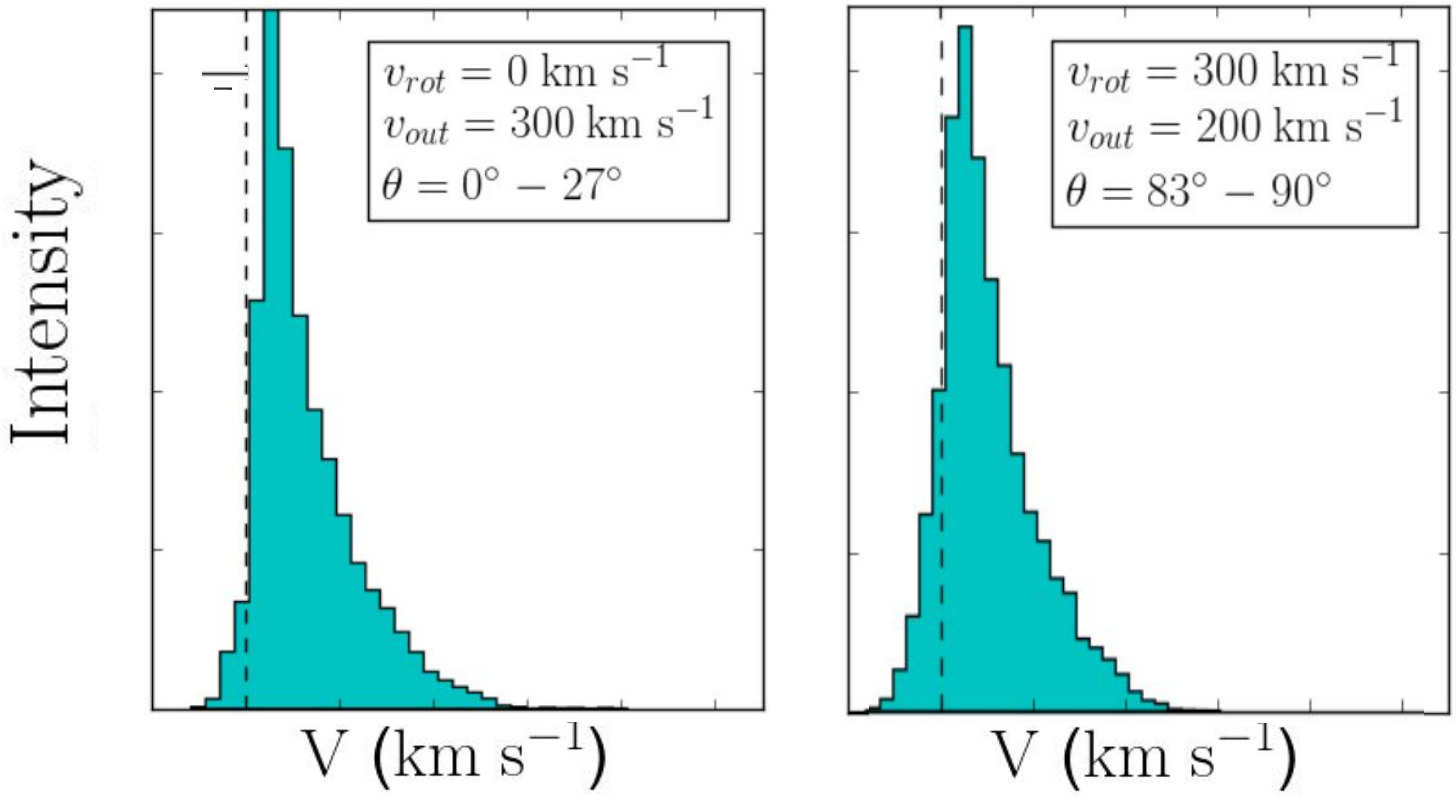
Outflows

v_{out} = 5 km/s

Rotation + Outflows

v_{out} = 5 km/s

v_{rot} = 10 km/s


Intensity
$v_{rot} = 0$ km s^{-1}
$v_{out} = 300$ km s^{-1}
$\theta = 0° - 27°$
V (km s^{-1})
$v_{rot} = 300$ km s^{-1}
$v_{out} = 200$ km s^{-1}
$\theta = 83° - 90°$
V (km s^{-1})