

The Galactic dynamics revealed by the filamentary structure in the atomic and molecular emission

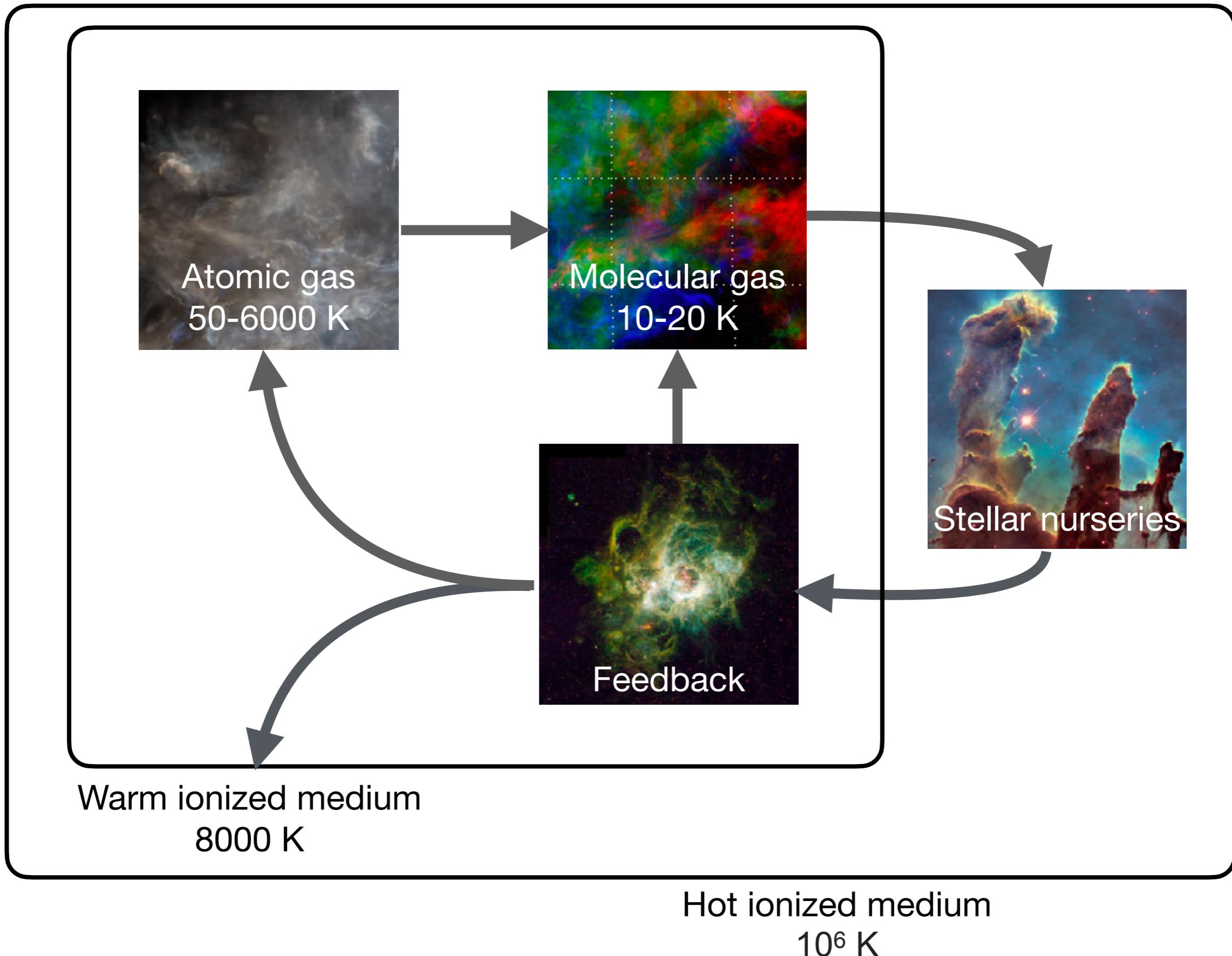
Juan Diego Soler

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THOR collaboration: [H. Beuther](#), Y. Wang, J. Syed, Th. Henning, L. D. Anderson, N. M. McClure-Griffiths, P. F. Goldsmith, M. Heyer, K. M. Menten, M. Rugel, S. N. Longmore, J. S. Urquhart, J. Stil, R. Shanahan

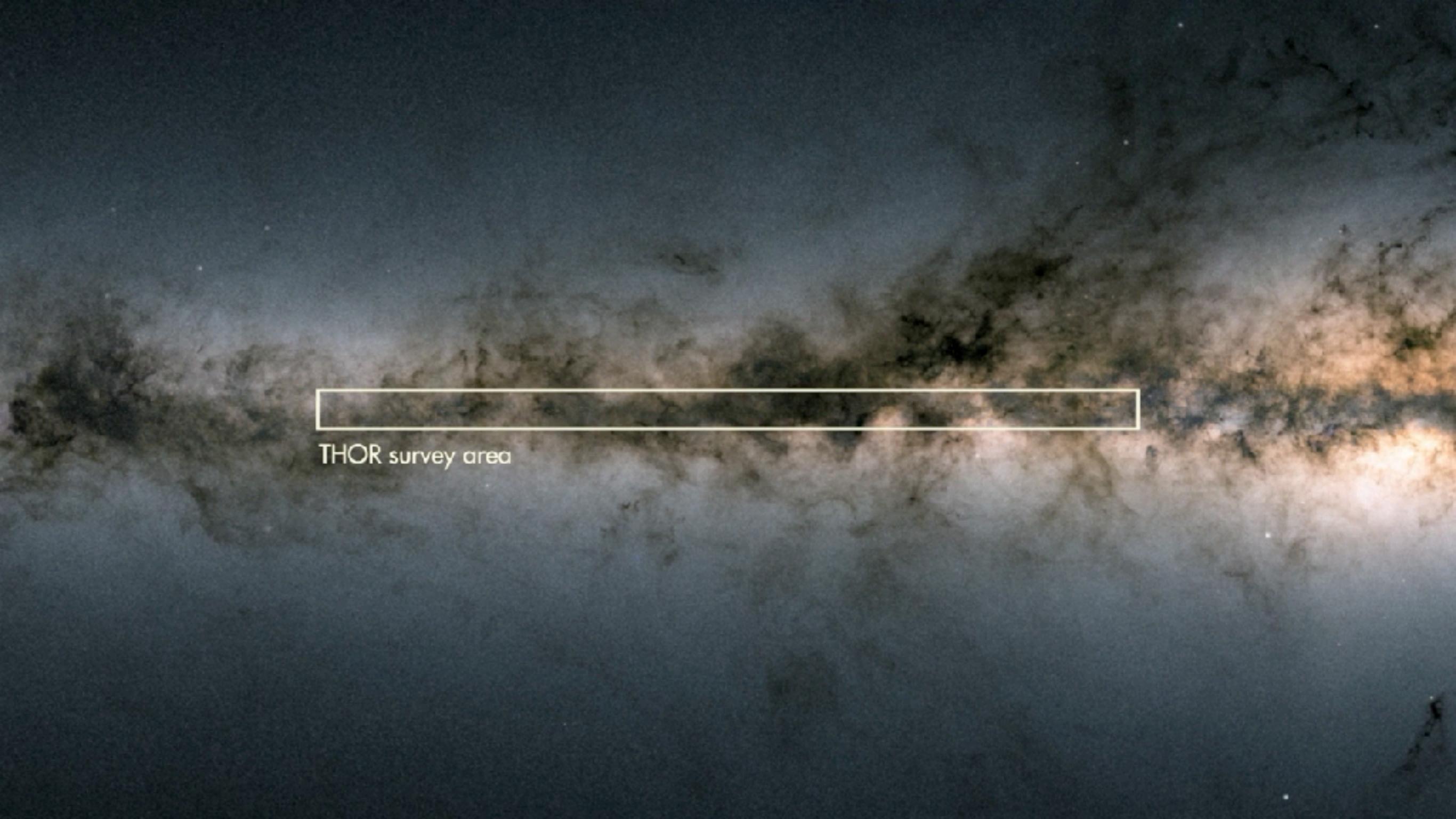
ECOgal collaboration: S. Molinari, [R. S. Klessen](#), [P. Hennebelle](#), S. C. O. Glover, [A. Trafficante](#), E. Schisano, D. Elia, M. Sormani, R., Tress, P. Girichidis, R. J. Smith, T. Colman

The baryon lifecycle



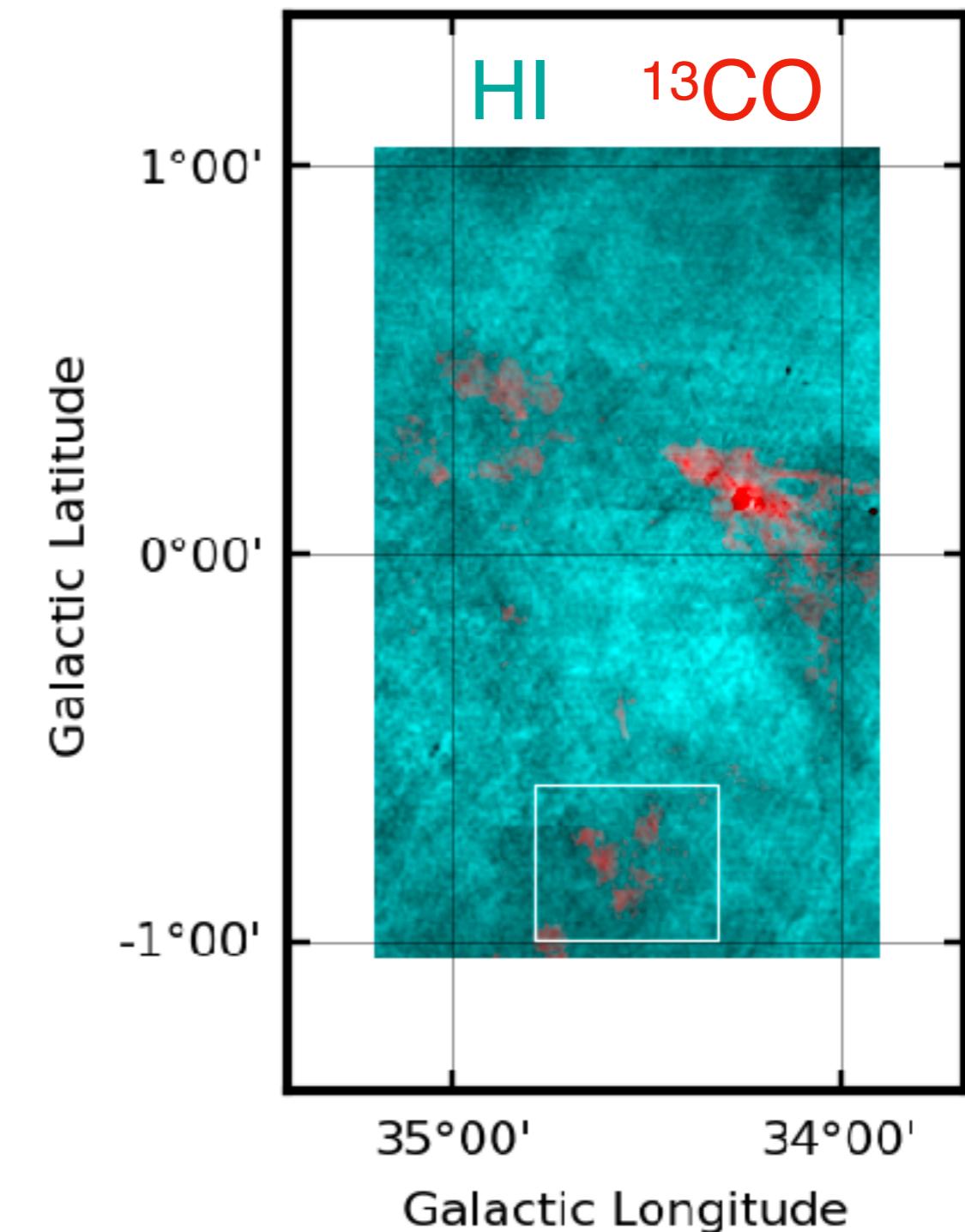
The HI, OH, and Recombination-line (THOR) survey

Wang, Y., et al (including JDS). A&A 2020; HI emission, 40" resolution (GBT+VLA D+VLA C)



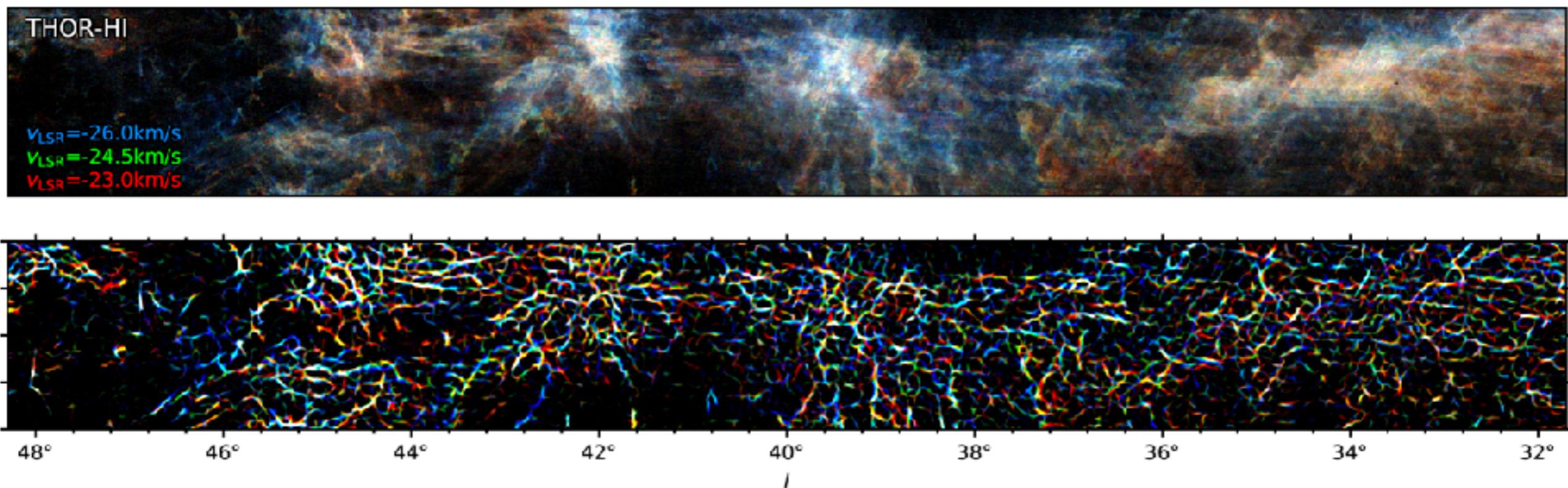
Atomic counterpart of molecular clouds (March, 2020)

Soler, J.D. et al. (2019) - Histograms of oriented gradients (astroHOG) technique



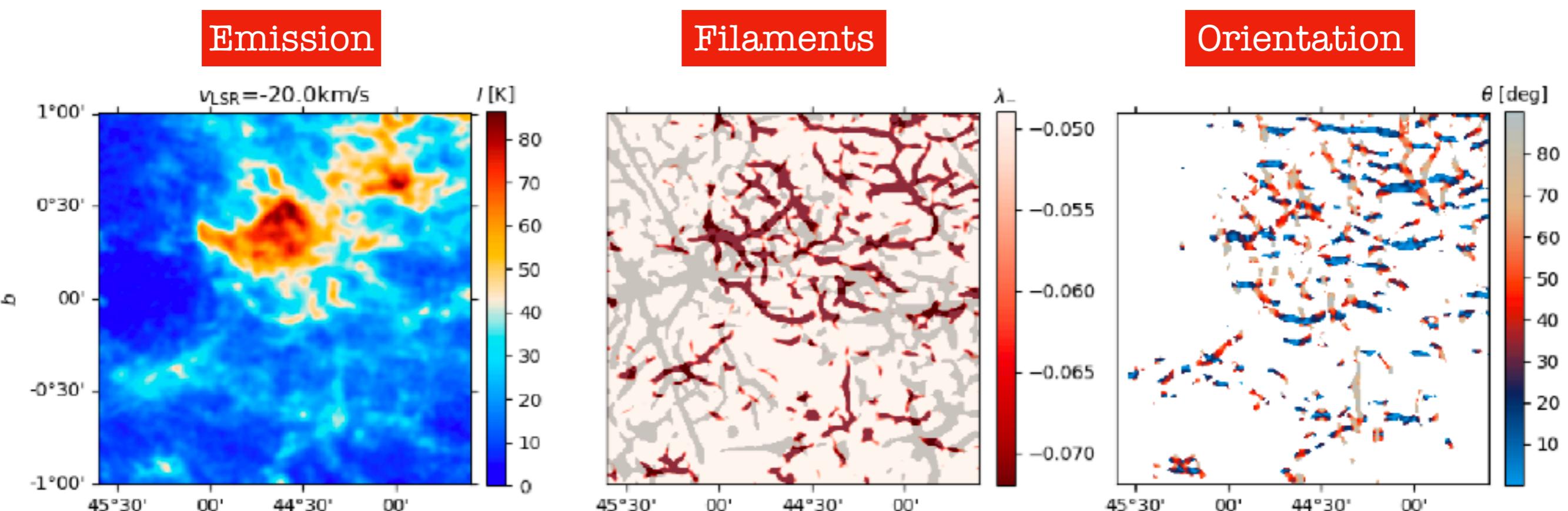
Atomic hydrogen filaments

Soler, J.D. et al. A&A (2020)



HI filaments - Hessian matrix method

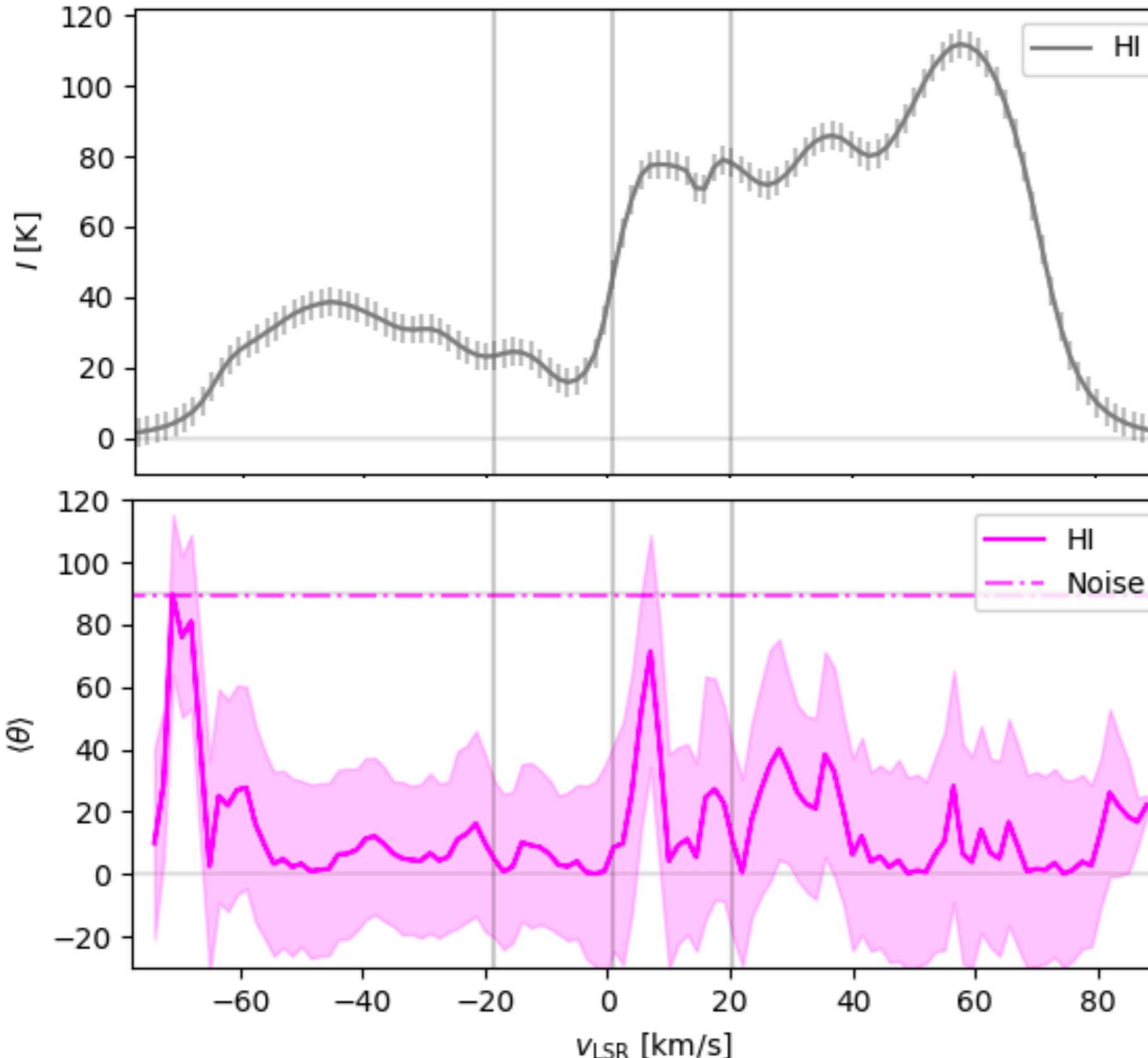
Soler, J.D. et al. A&A (2020)



HI filament orientation

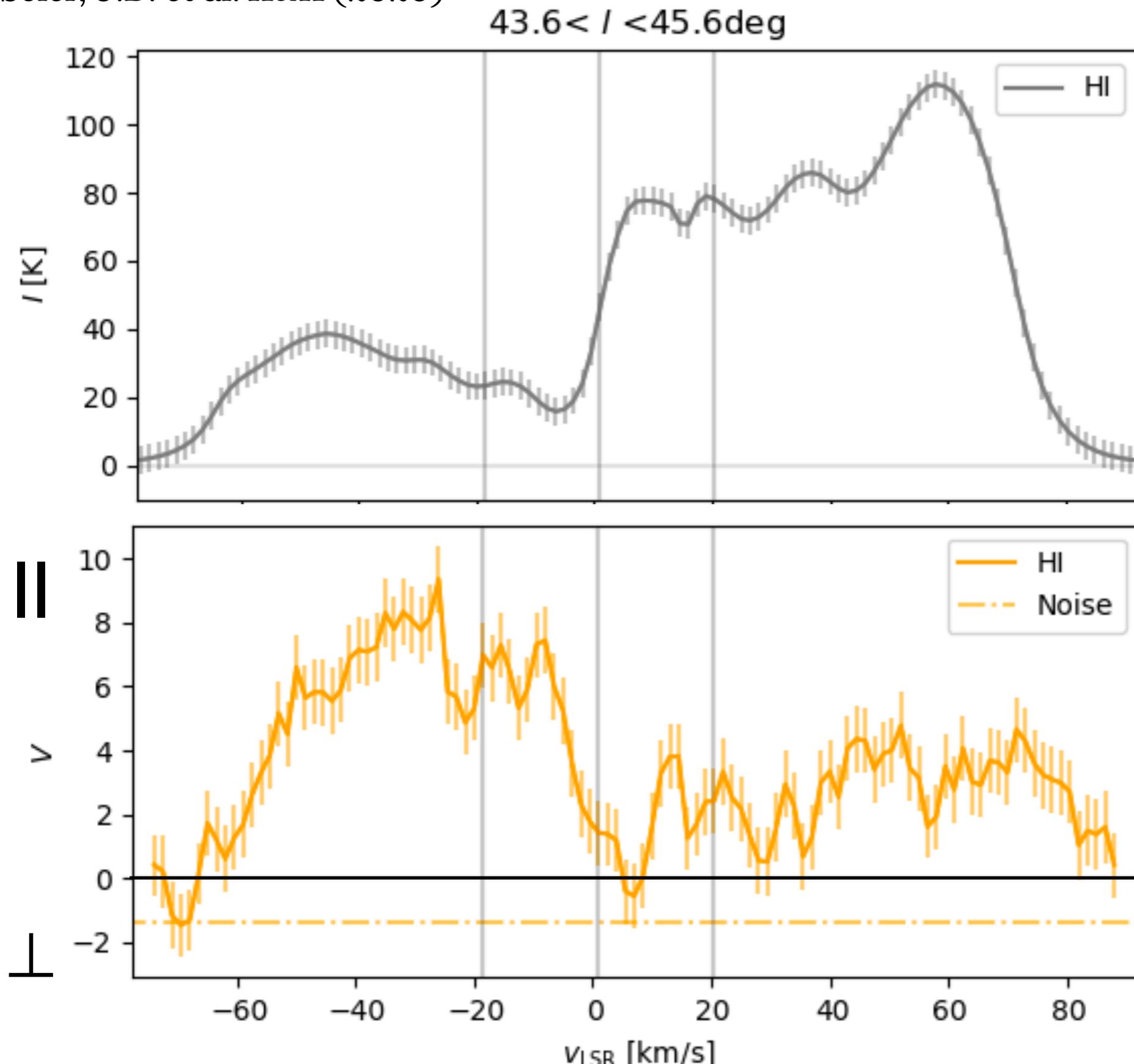
Soler, J.D. et al. A&A (2020)

$43.6 < l < 45.6 \text{deg}$



HI filament orientation

Soler, J.D. et al. A&A (2020)

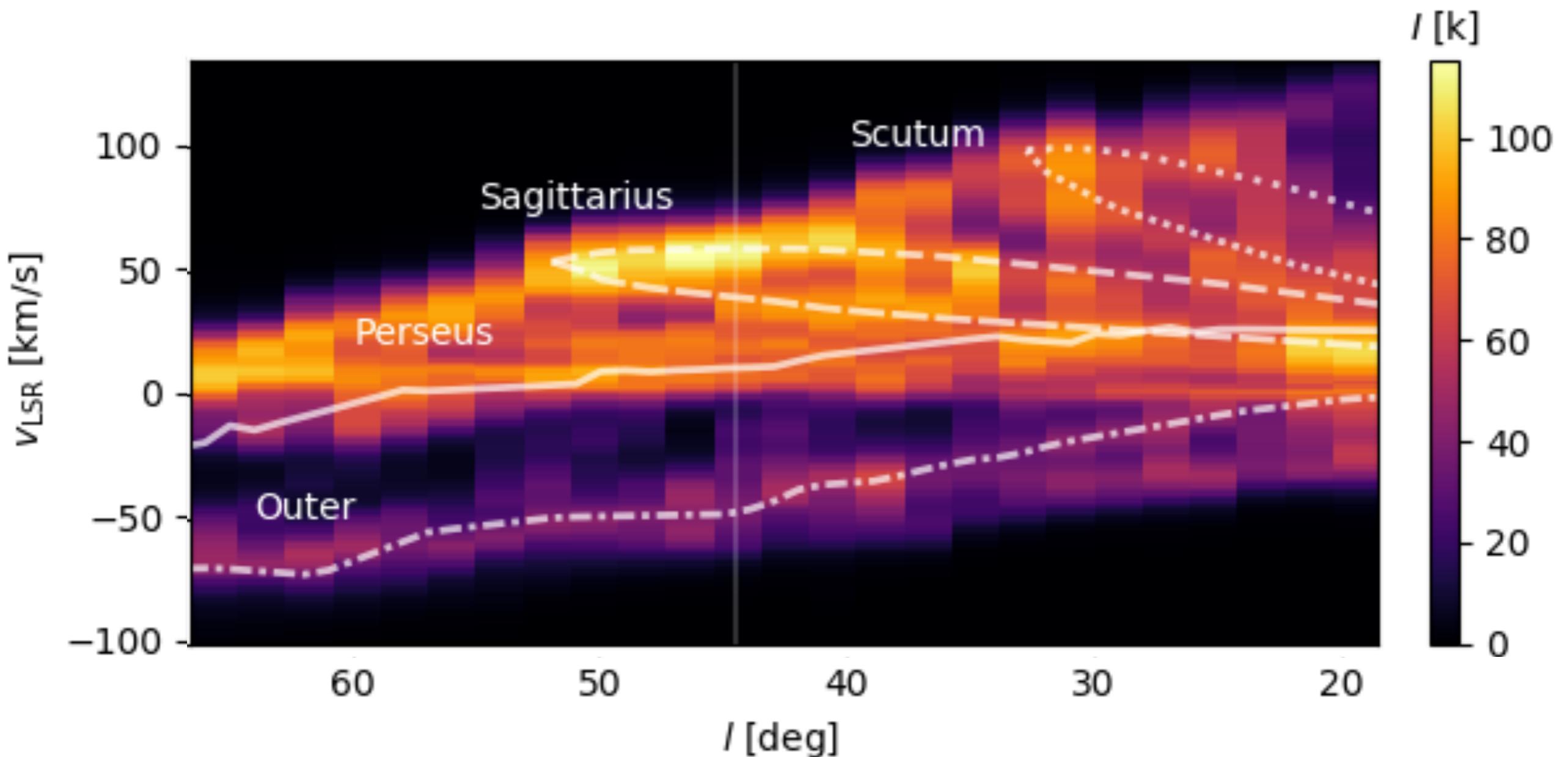


Projected Rayleigh statistic
(Jow et al. 2018)

$$V = \frac{\sum_{ij}^{n,m} w_{ij} \cos(2\theta_{ij})}{\sqrt{\sum_{ij}^{n,m} w_{ij}/2}}$$

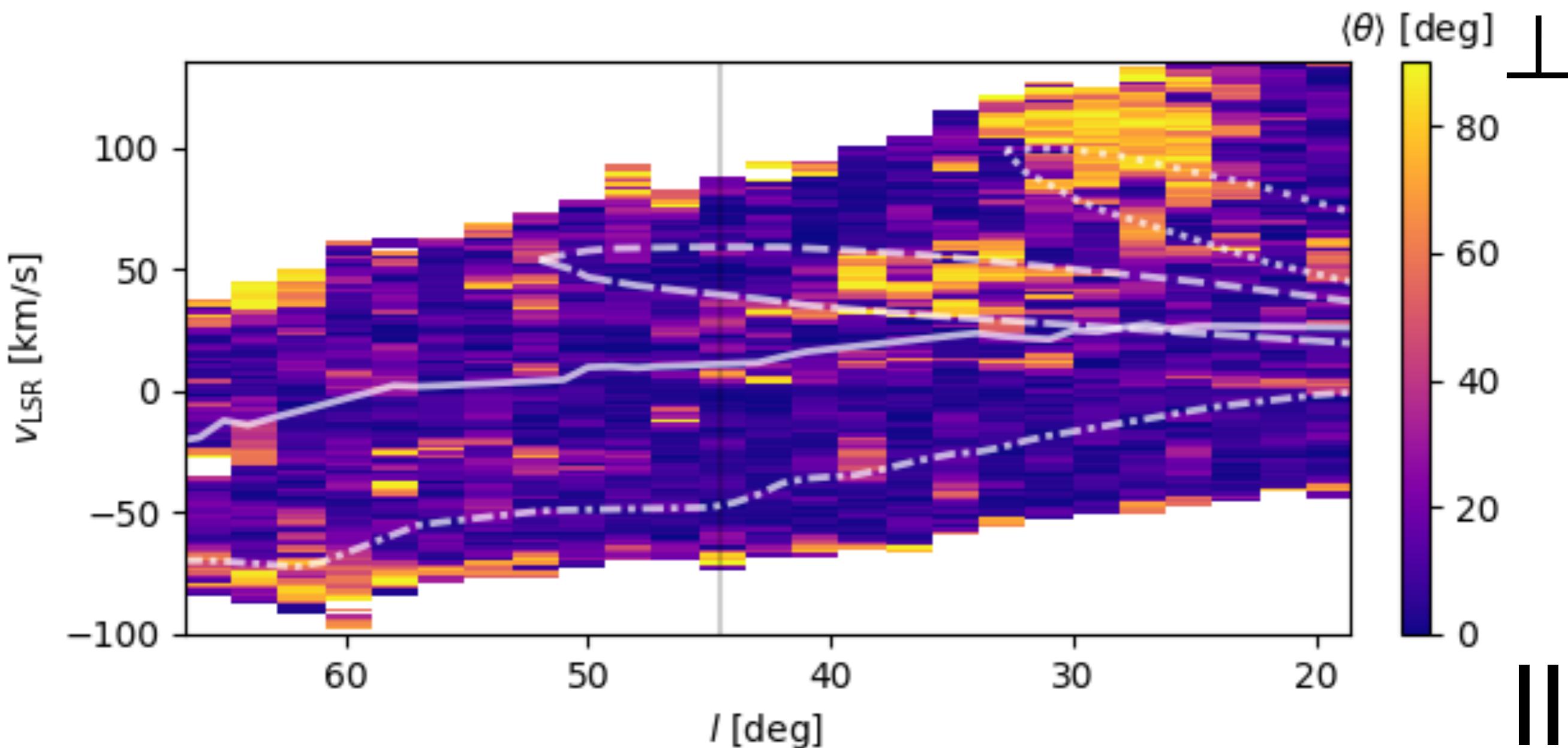
HI emission

Soler, J.D. et al. A&A (2020)



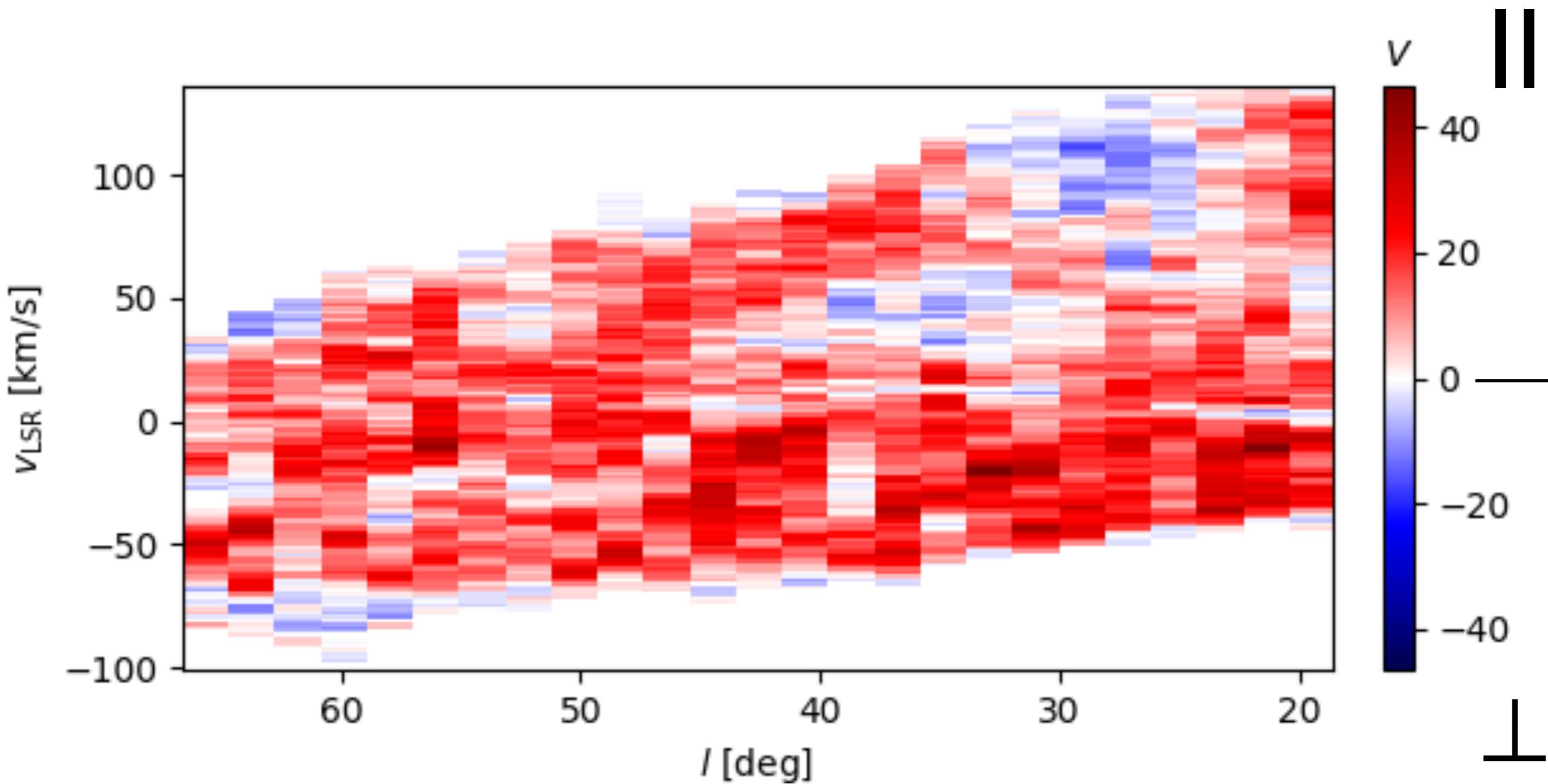
HI filament orientation

Soler, J.D. et al. A&A (2020)



HI filament orientation

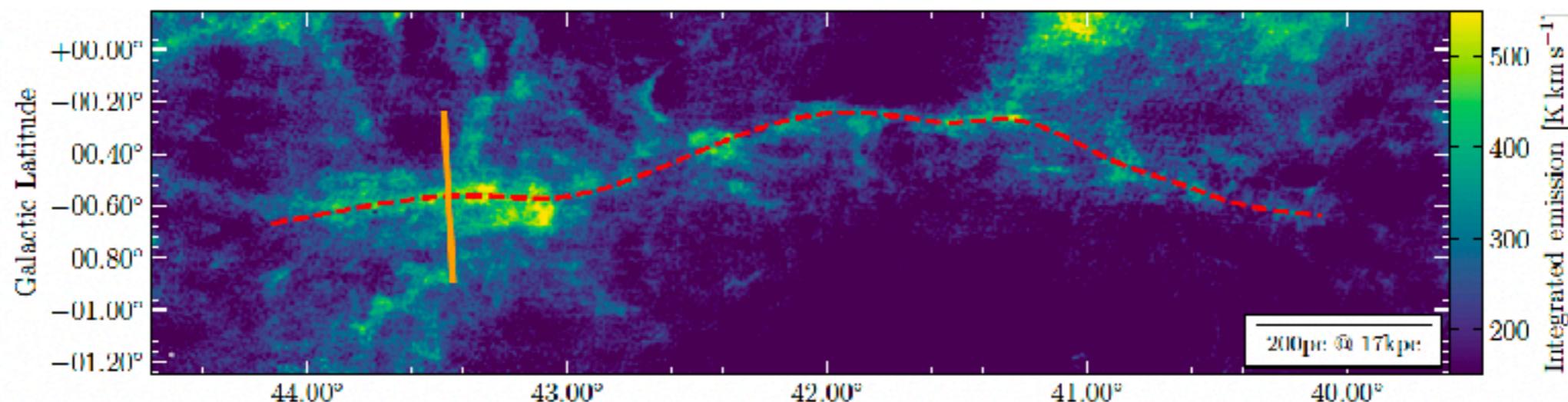
Soler, J.D. et al. A&A (2020)



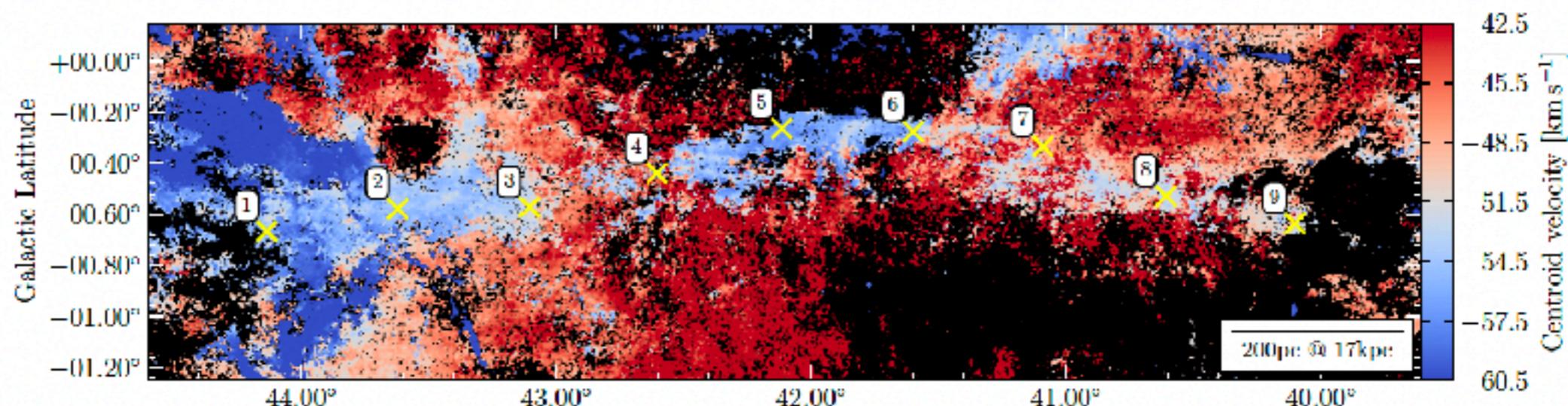
The Magdalena filament

Syed, J., et al. (2022), Soler, J.D. et al. (2020)

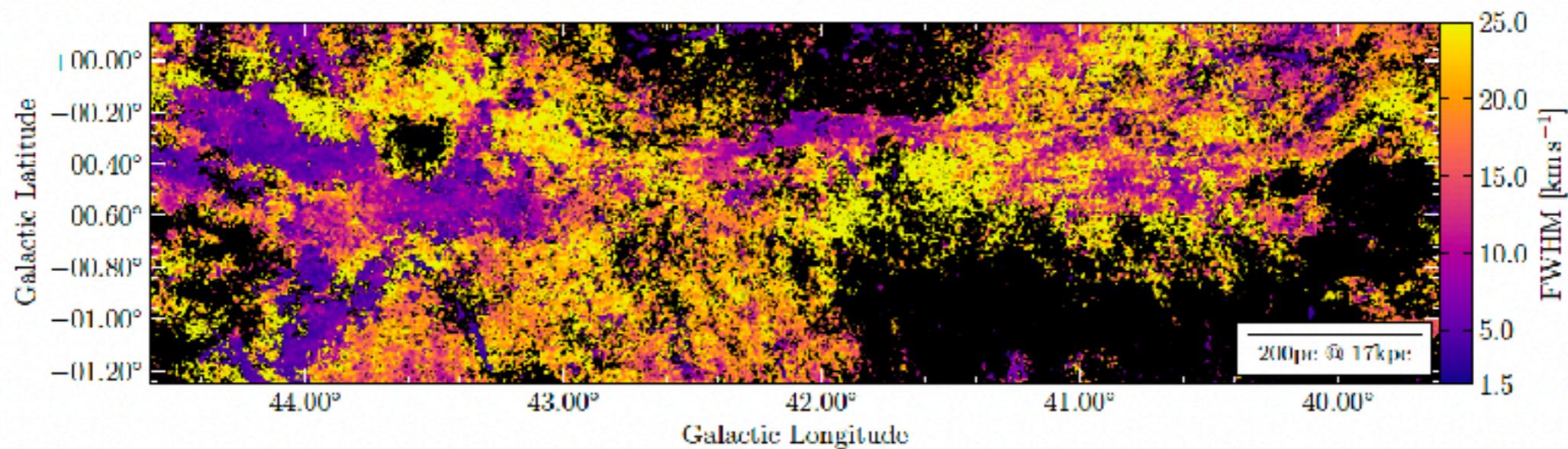
N_{H}



$\langle v \rangle$

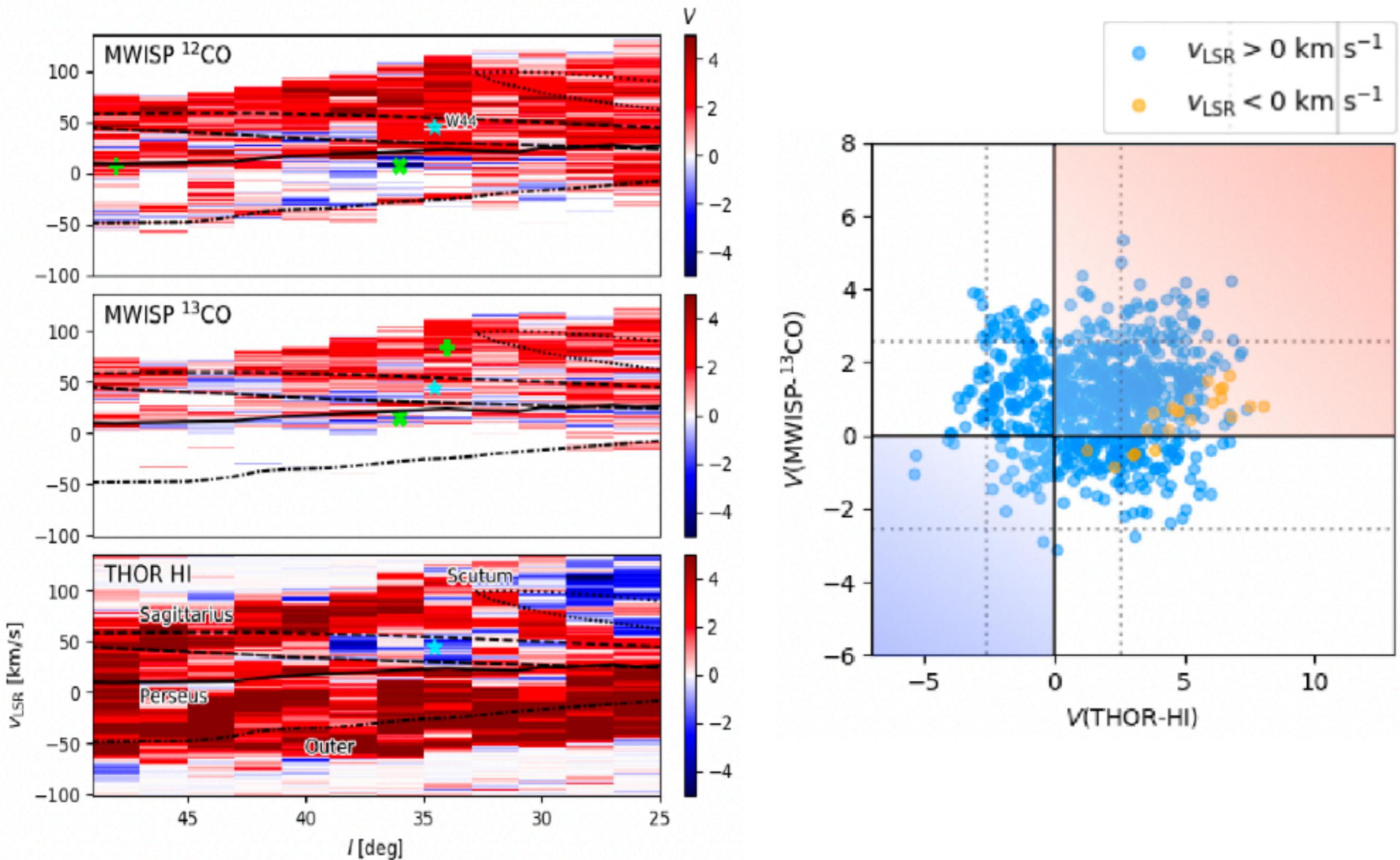


σ_v



CO filament orientation

Soler, J.D. et al. A&A 2021

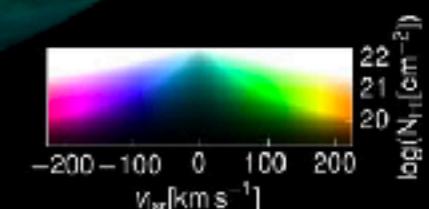


Atomic hydrogen emission

HI4PI Collaboration. A&A (2016)

16.5' HI4PI (2016)

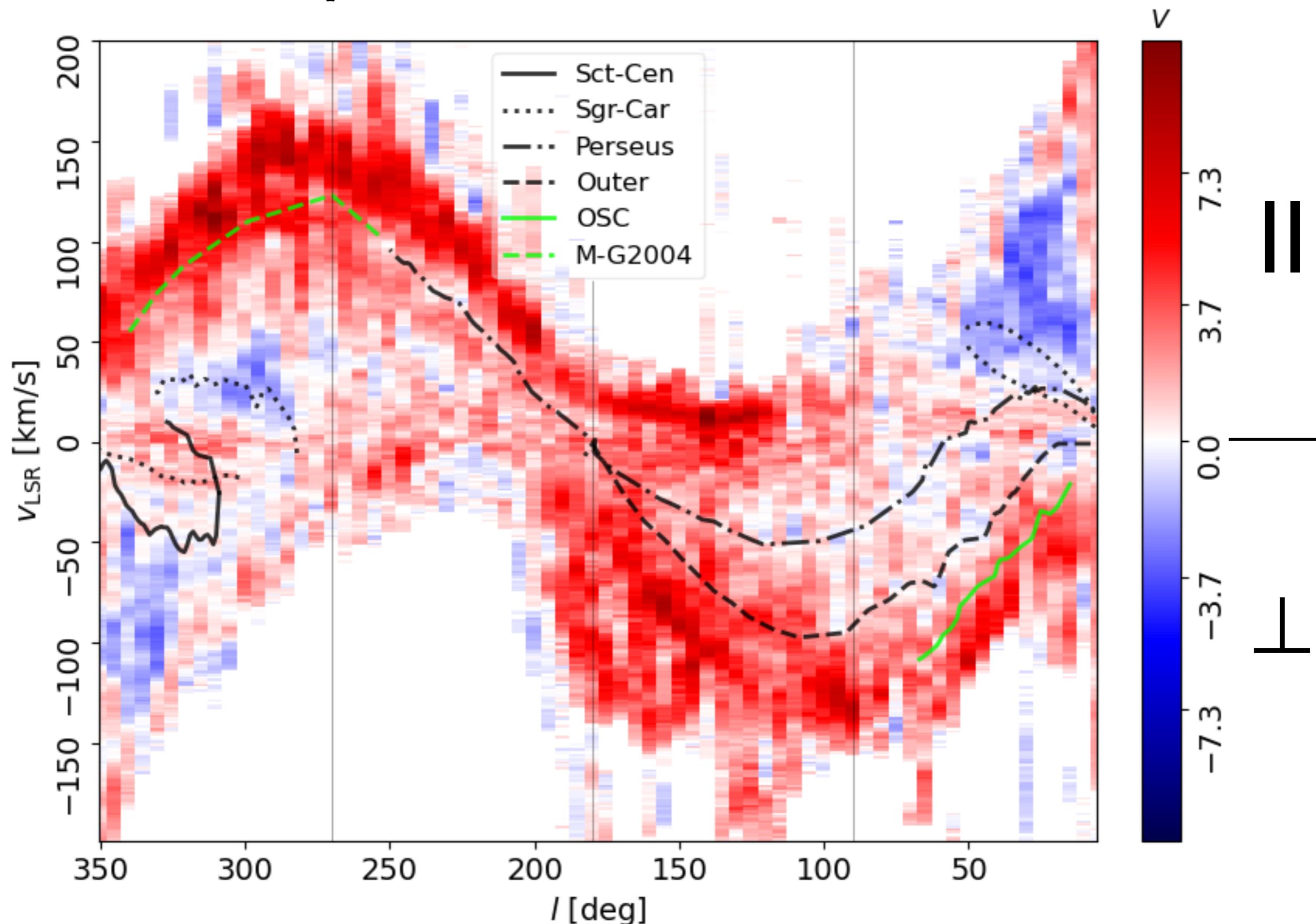
$|b| \leq 10 \text{ deg}$



Benjamin Winkel & HI4PI Collaboration

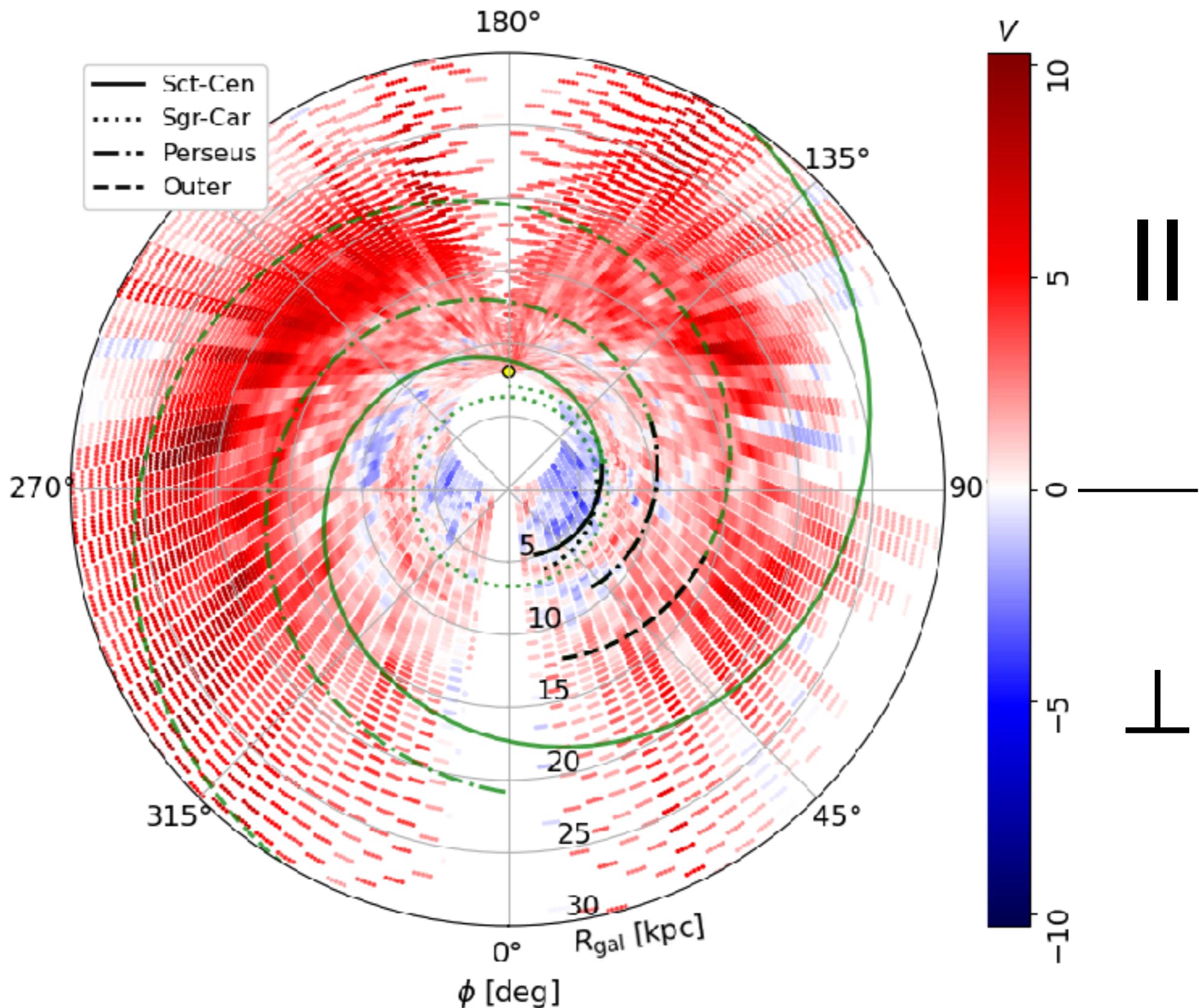
Orientation of atomic filaments

Soler, J.D. et al. 2022. A&A in press.



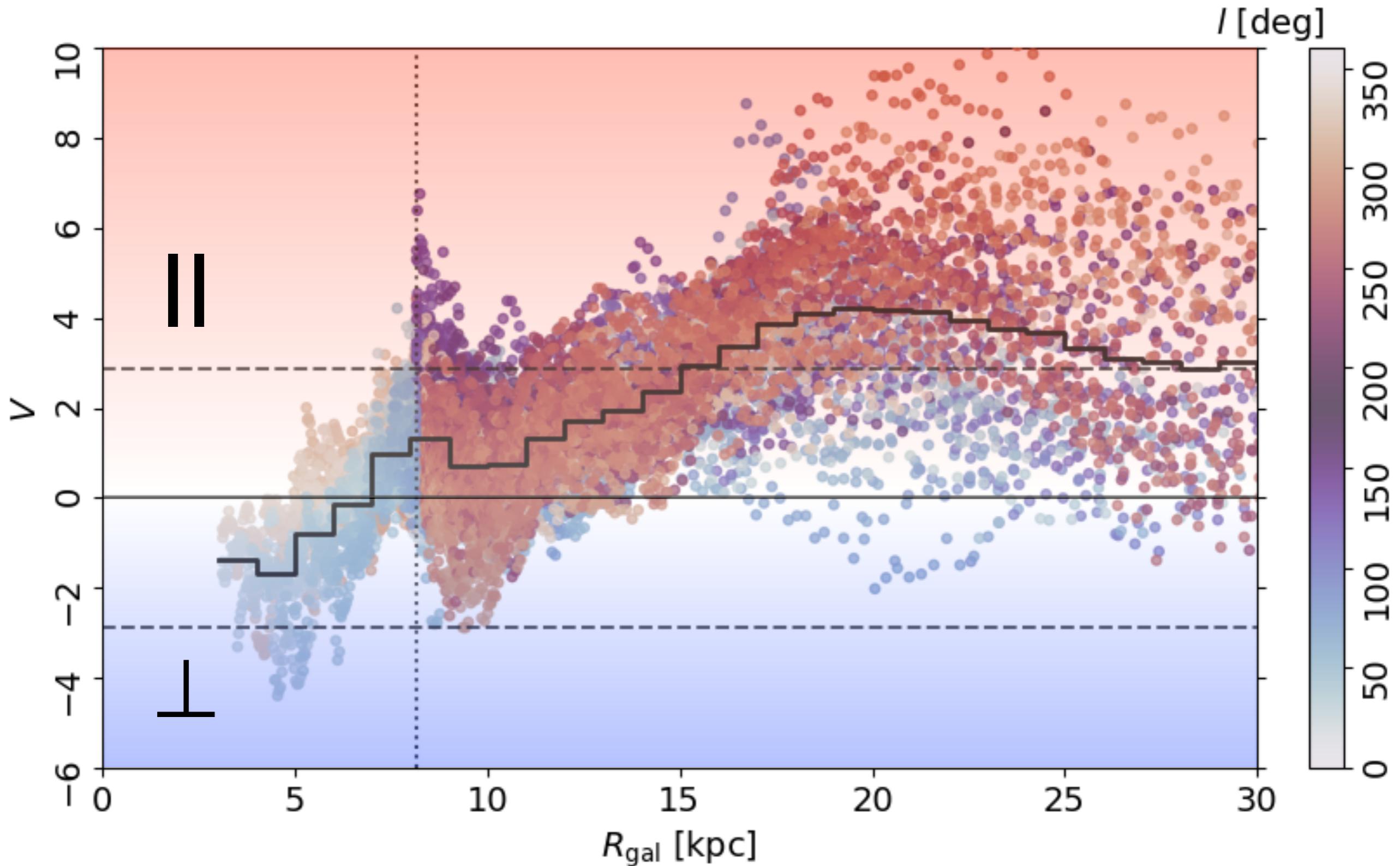
Orientation of atomic filaments

Soler, J.D. et al. 2022. A&A in press.



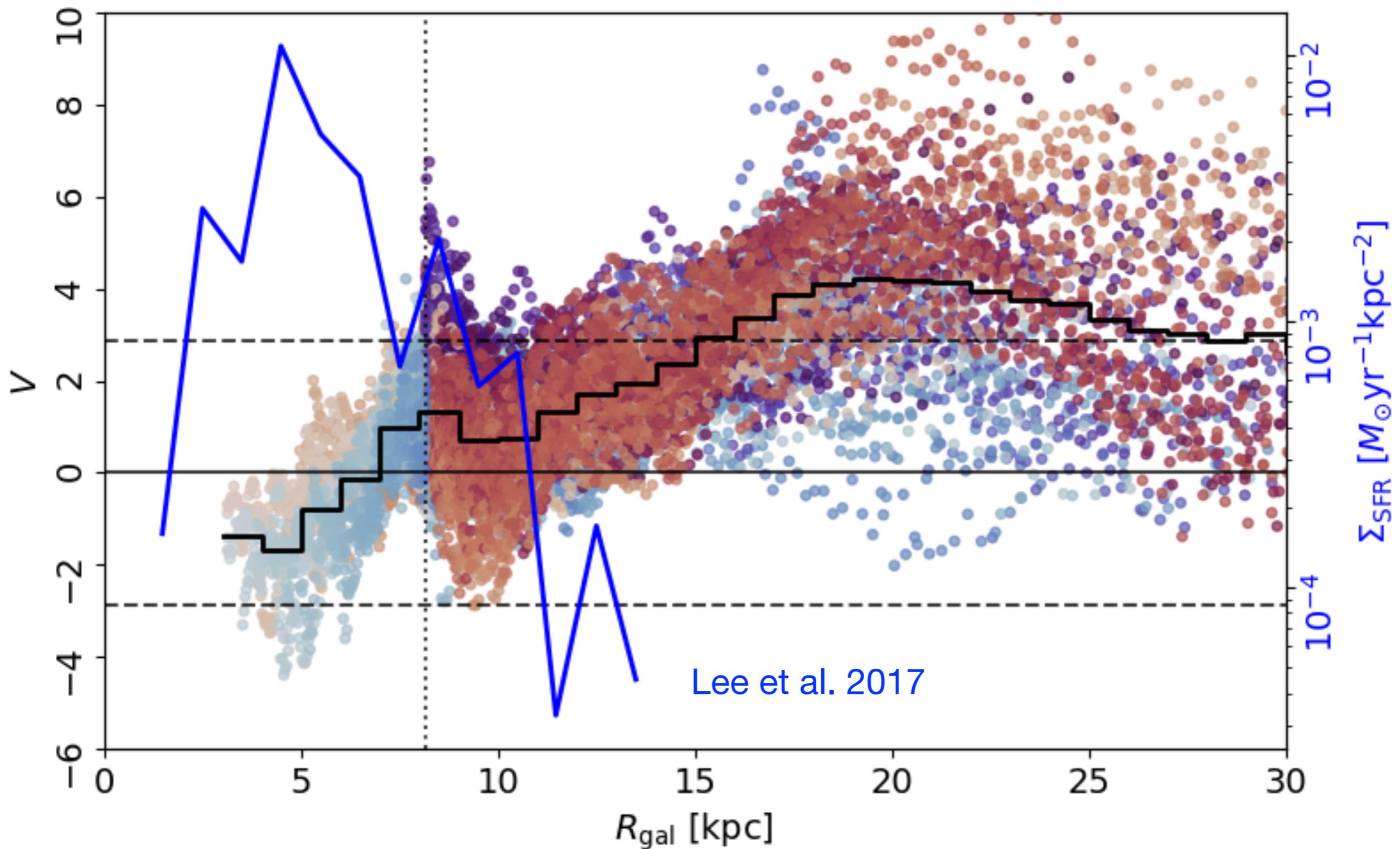
Atomic filament orientation

Soler, J.D. et al. 2022. A&A in press.



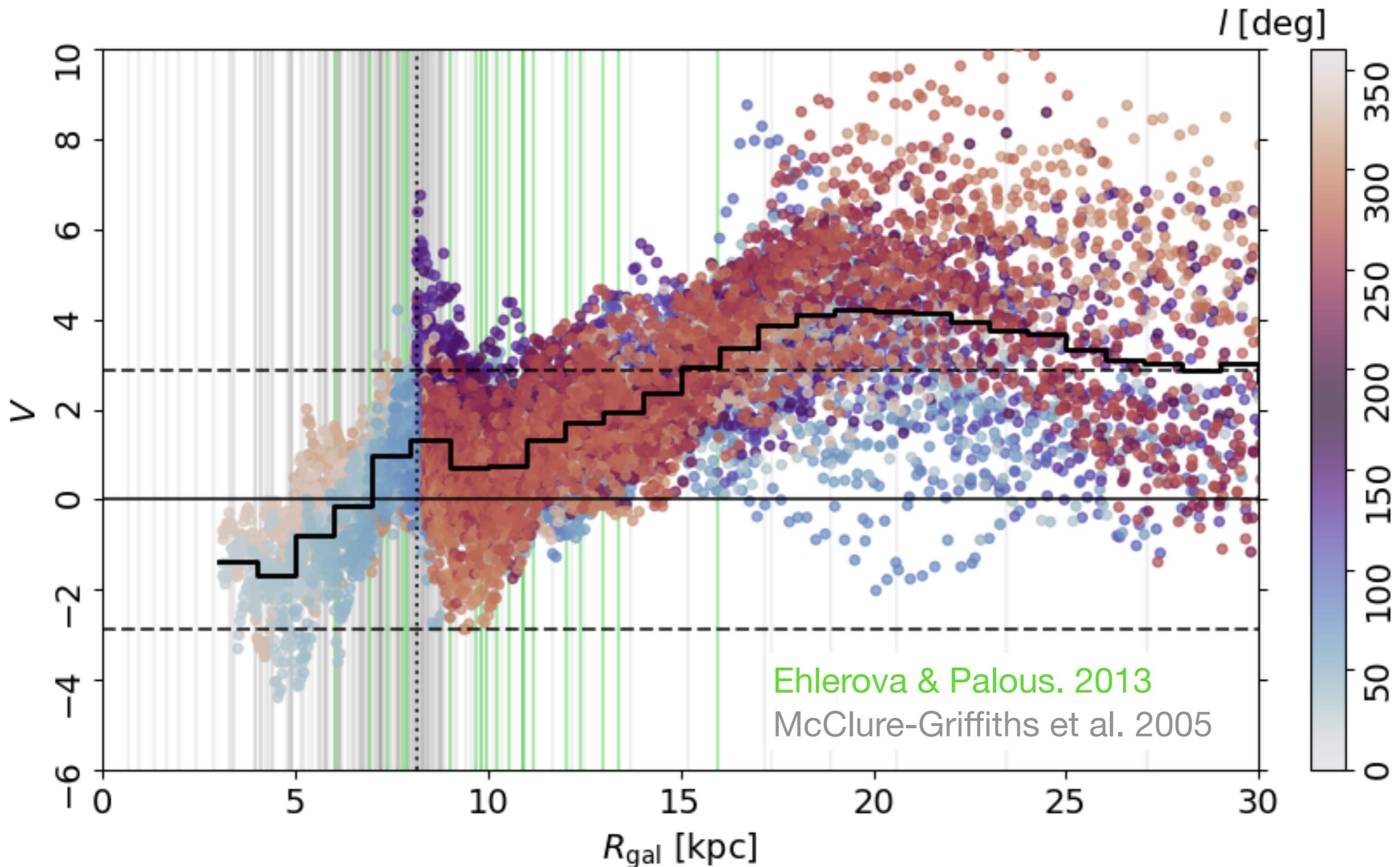
Atomic filament orientation and star formation

Soler, J.D. et al. 2022. A&A in press.



Atomic filament orientation and HI bubbles

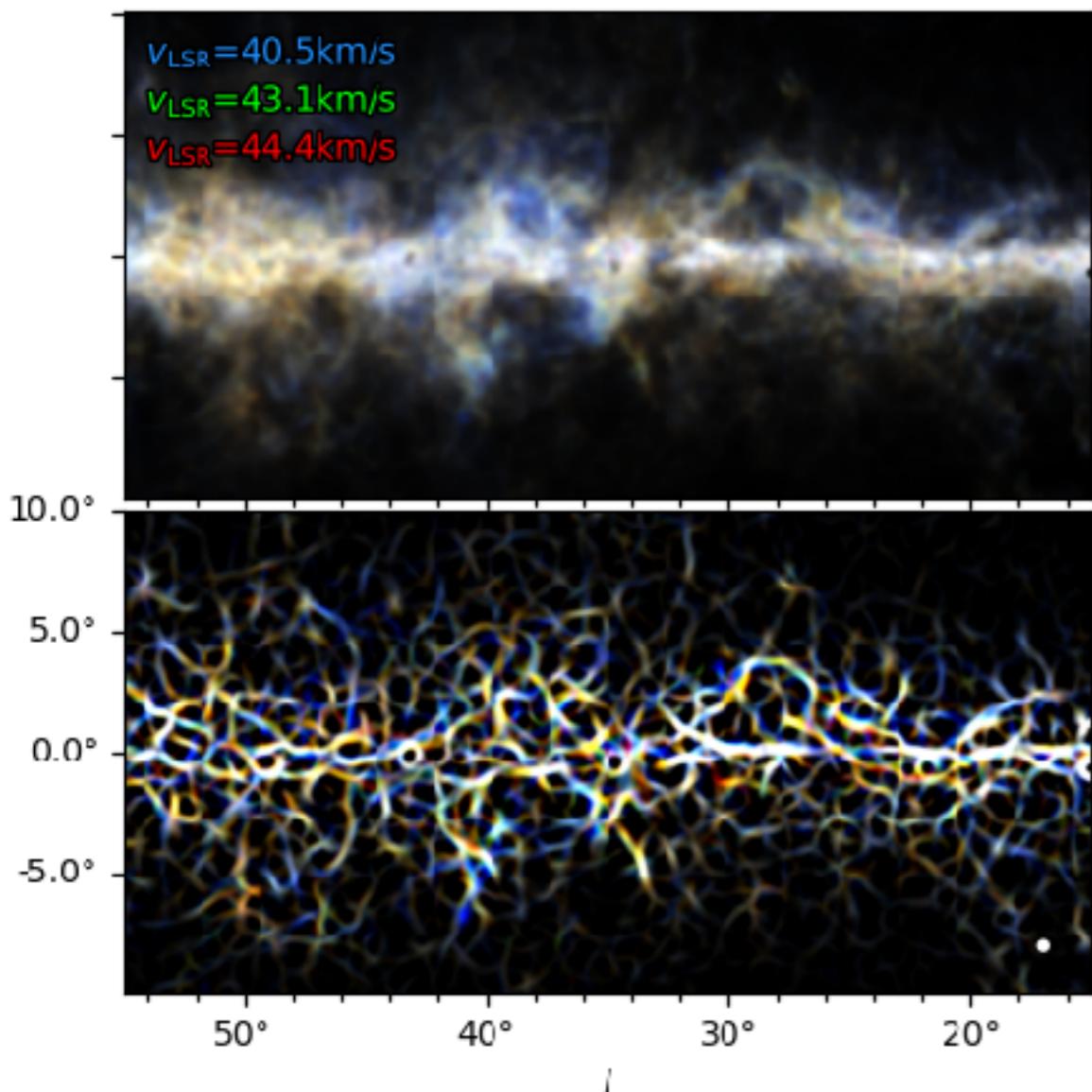
Soler, J.D. et al. 2022. A&A in press.



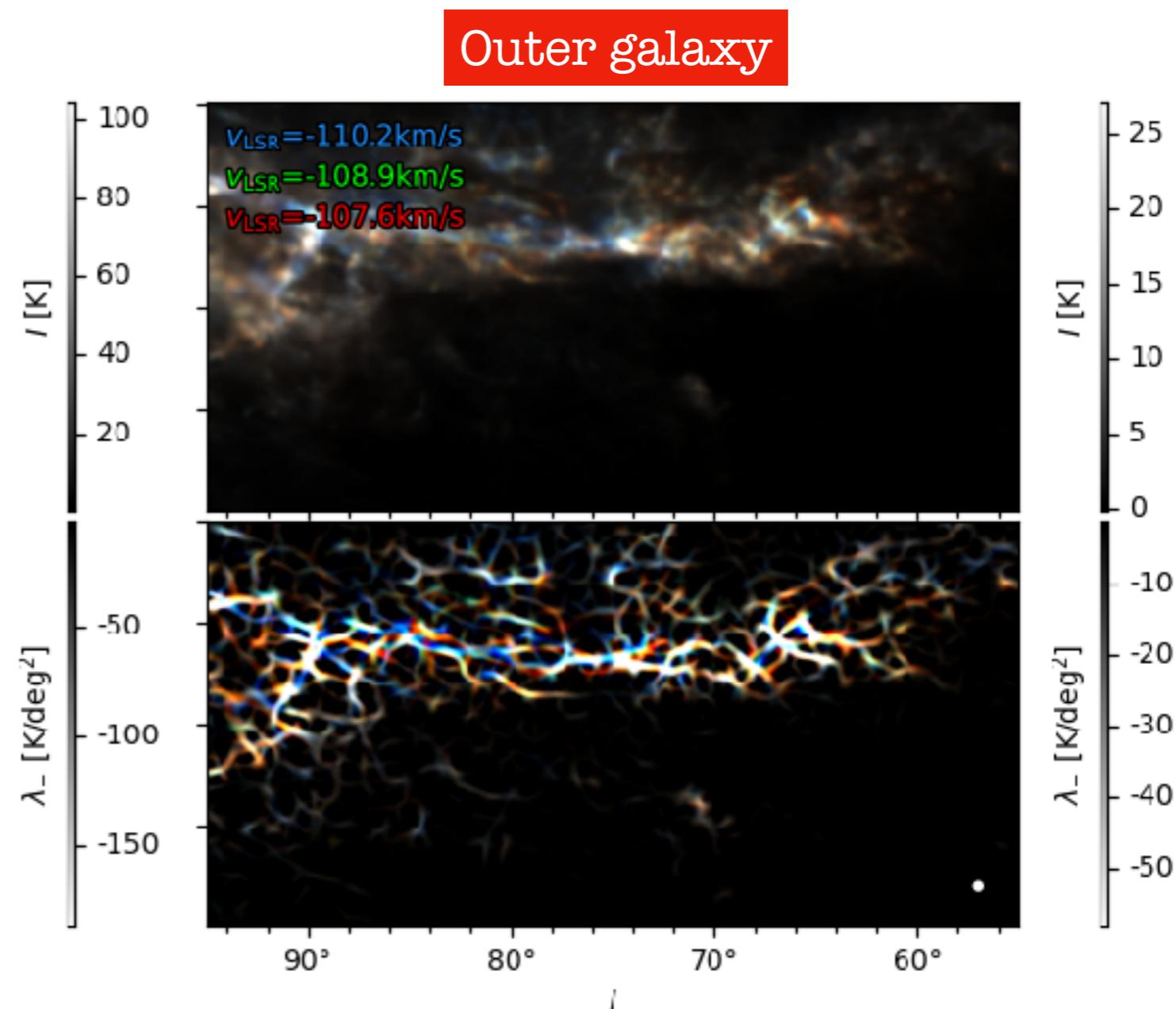
Atomic filament orientation

Soler, J.D. et al. 2022. A&A in press.

Inner galaxy



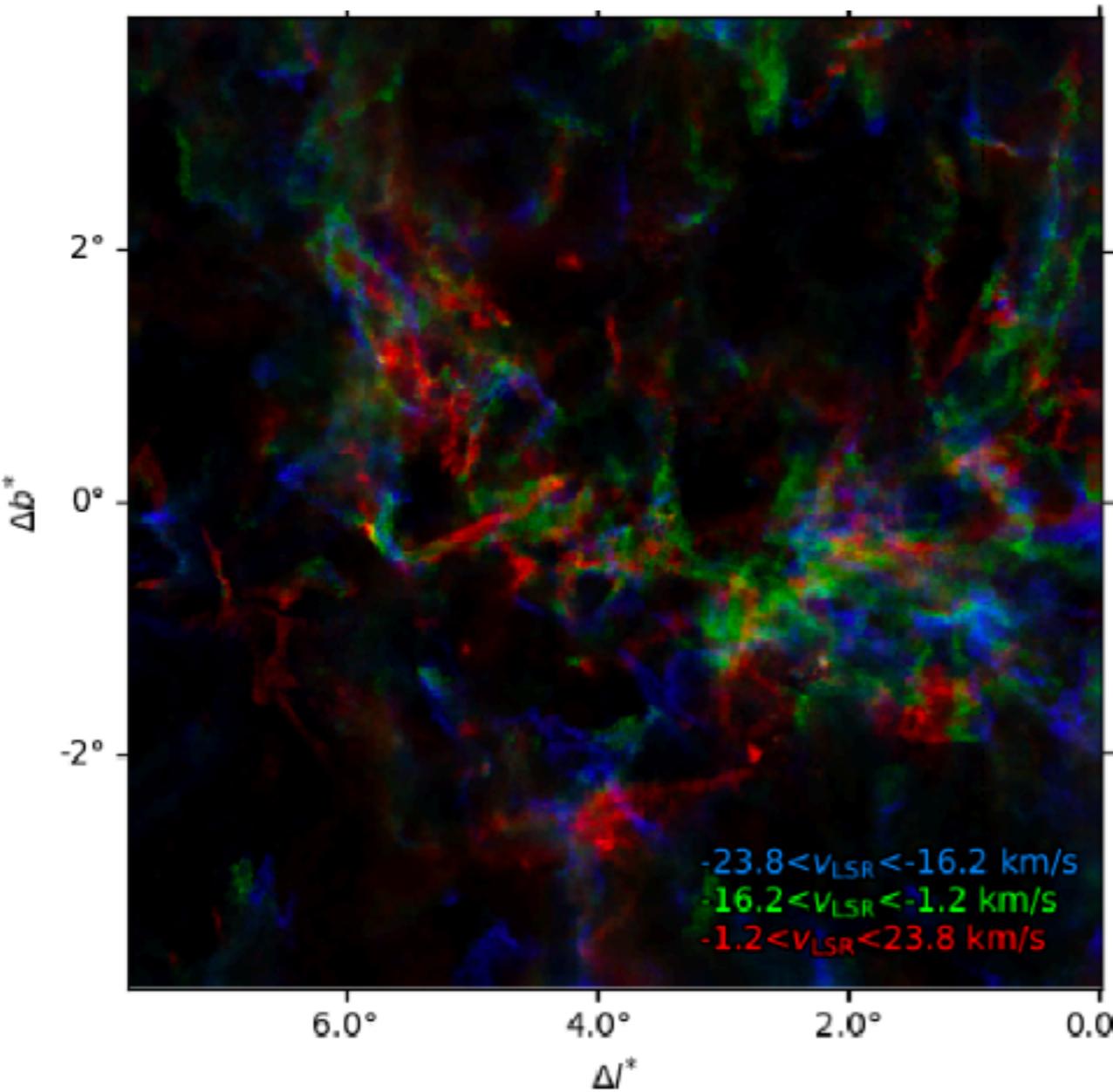
Outer galaxy



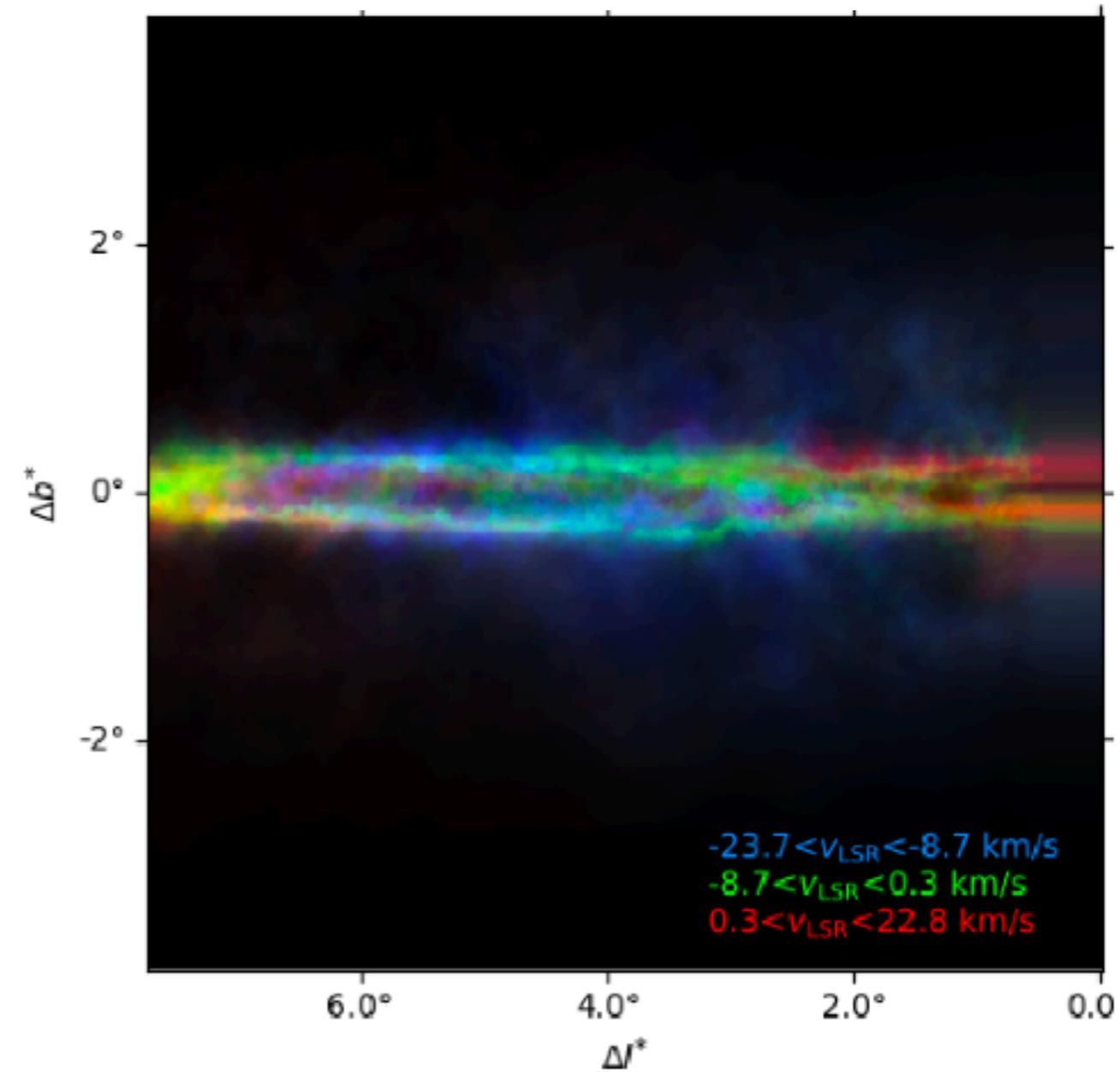
HI filaments - MHD simulations

CloudFactory simulations (Smith et al. A&A 2020)
Soler, J.D. et al. A&A 2020

Feedback-dominated



Potential-dominated



The Galactic history revealed by HI and CO emission



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We found that the **HI filament orientation** changes from no preferential orientation to mostly parallel to the Galactic plane with increasing distance from the Galactic center.



The change in the **HI filament orientation** is most likely due to the energy and moment input from **supernova feedback**.

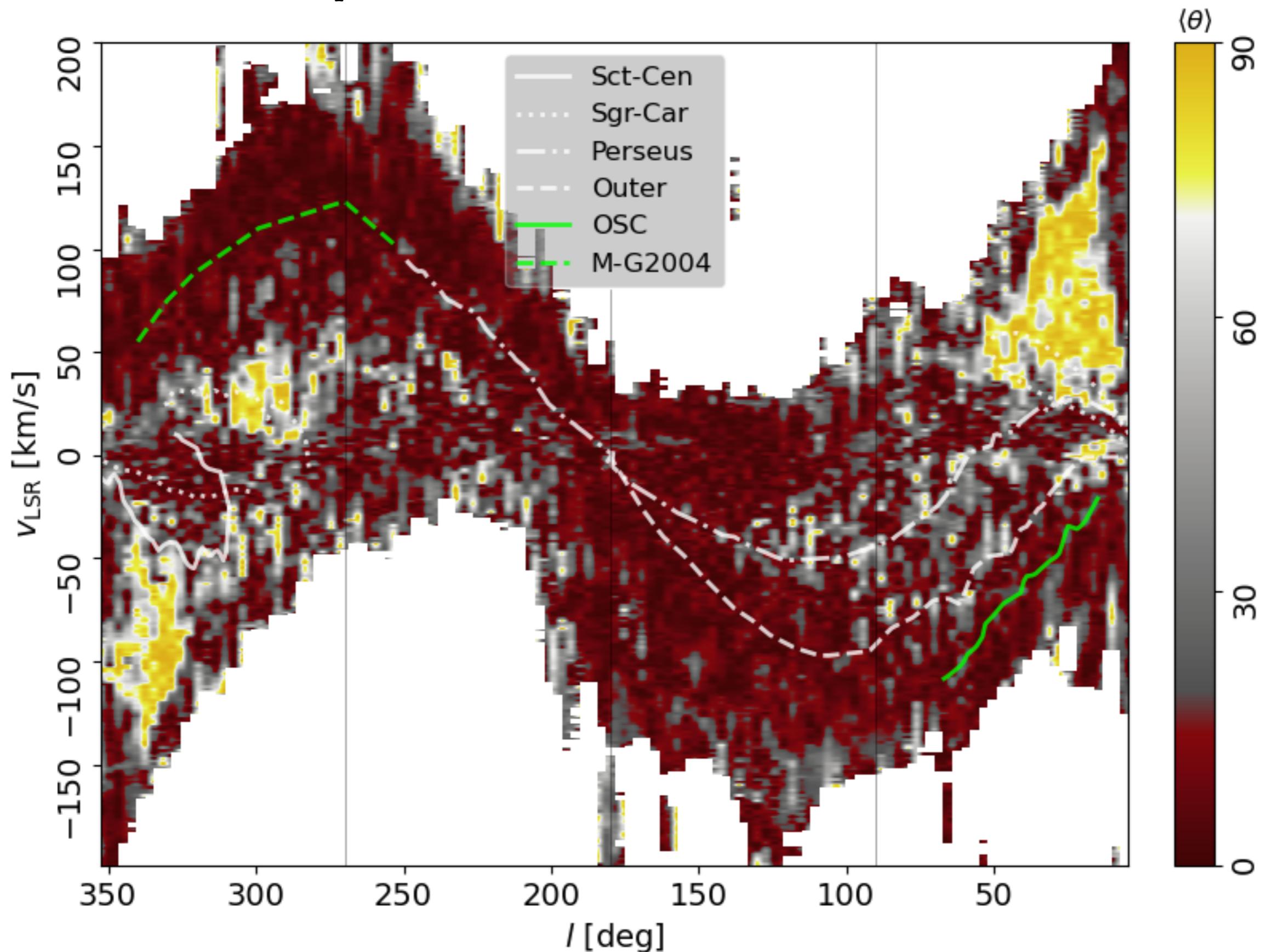


In general, the prevalent **HI filament orientation** is **not inherited** by the **CO filaments**.

Extra slides

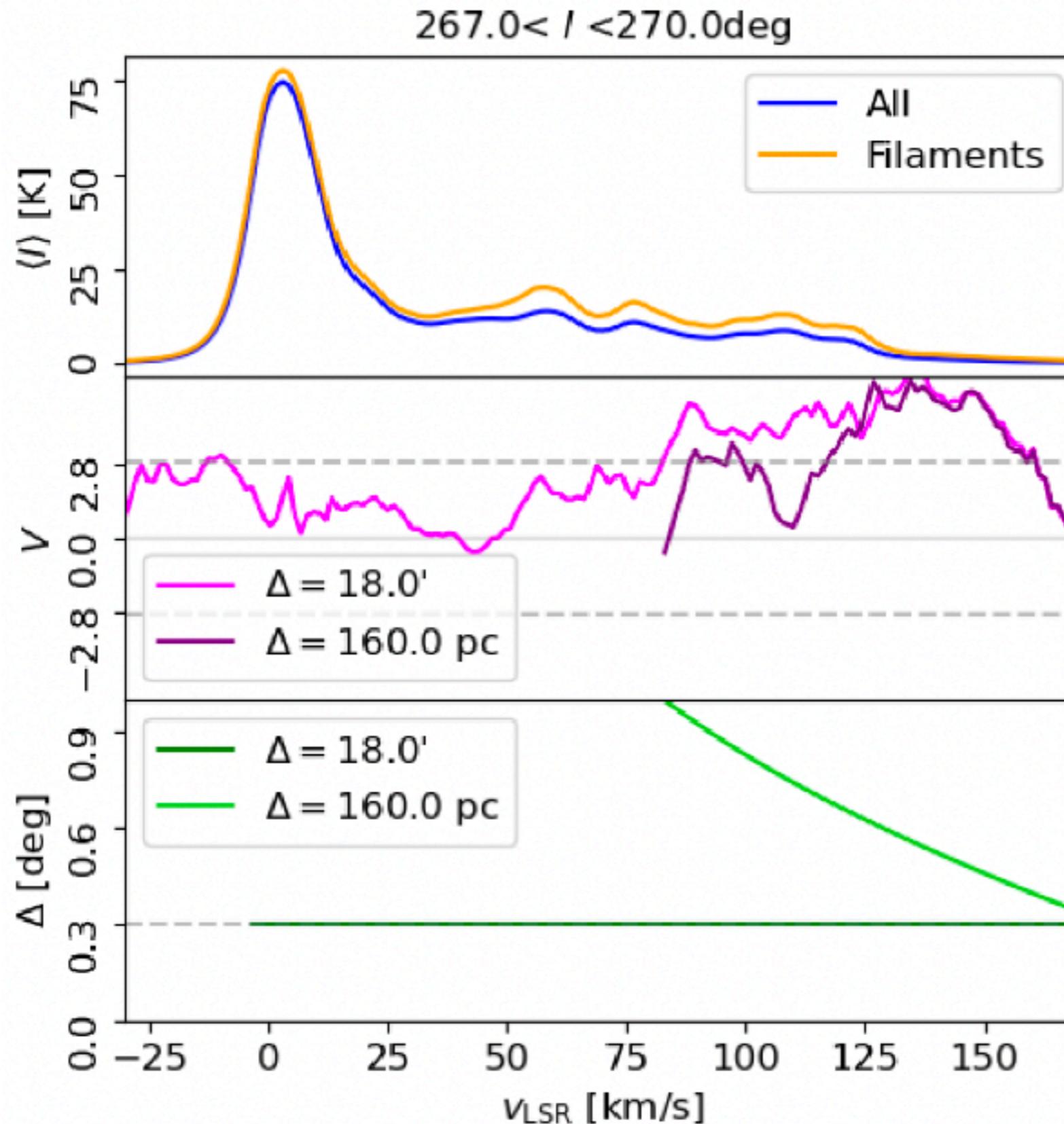
Orientation of atomic filaments

Soler, J.D. et al. 2022. A&A in press.



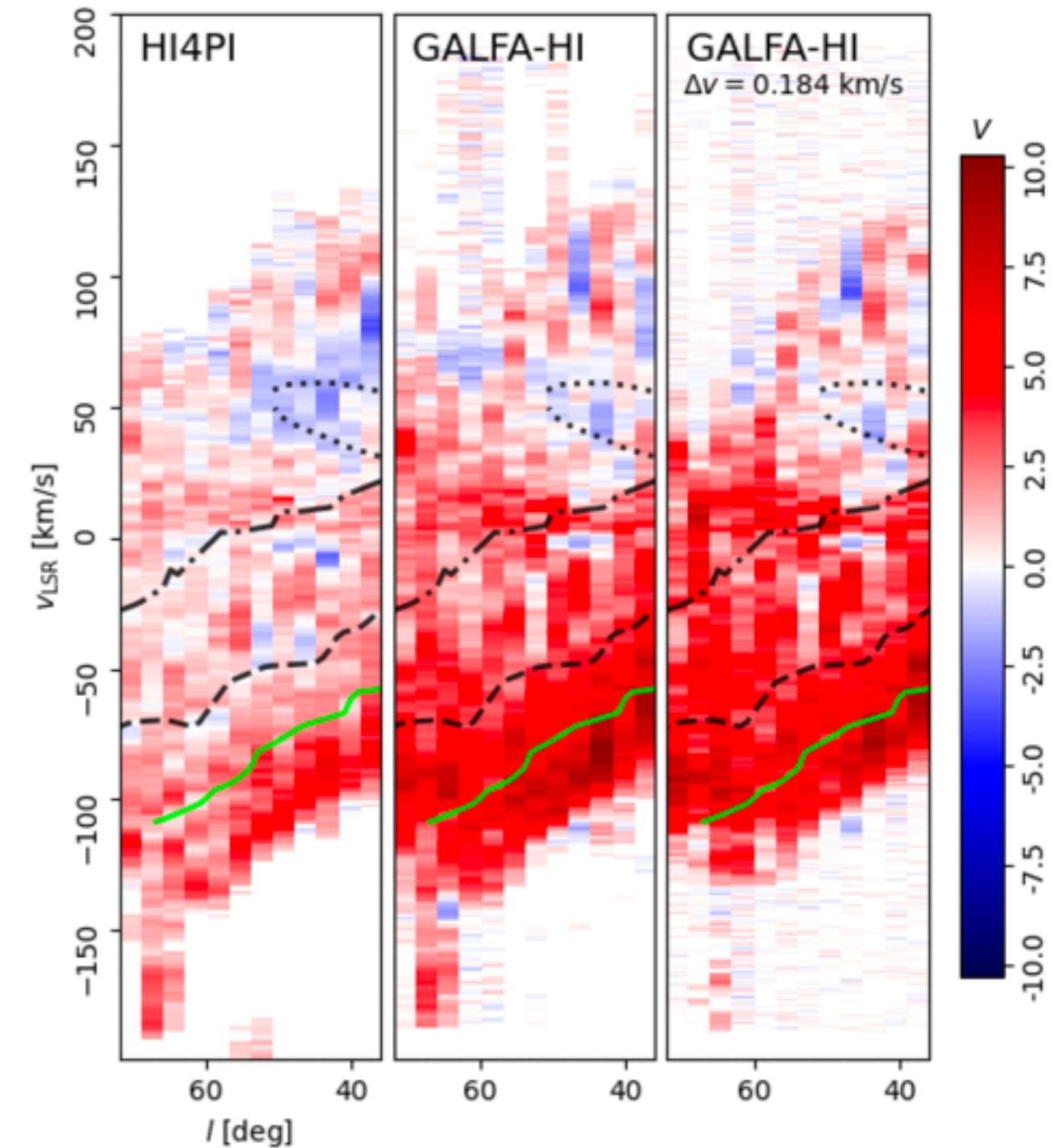
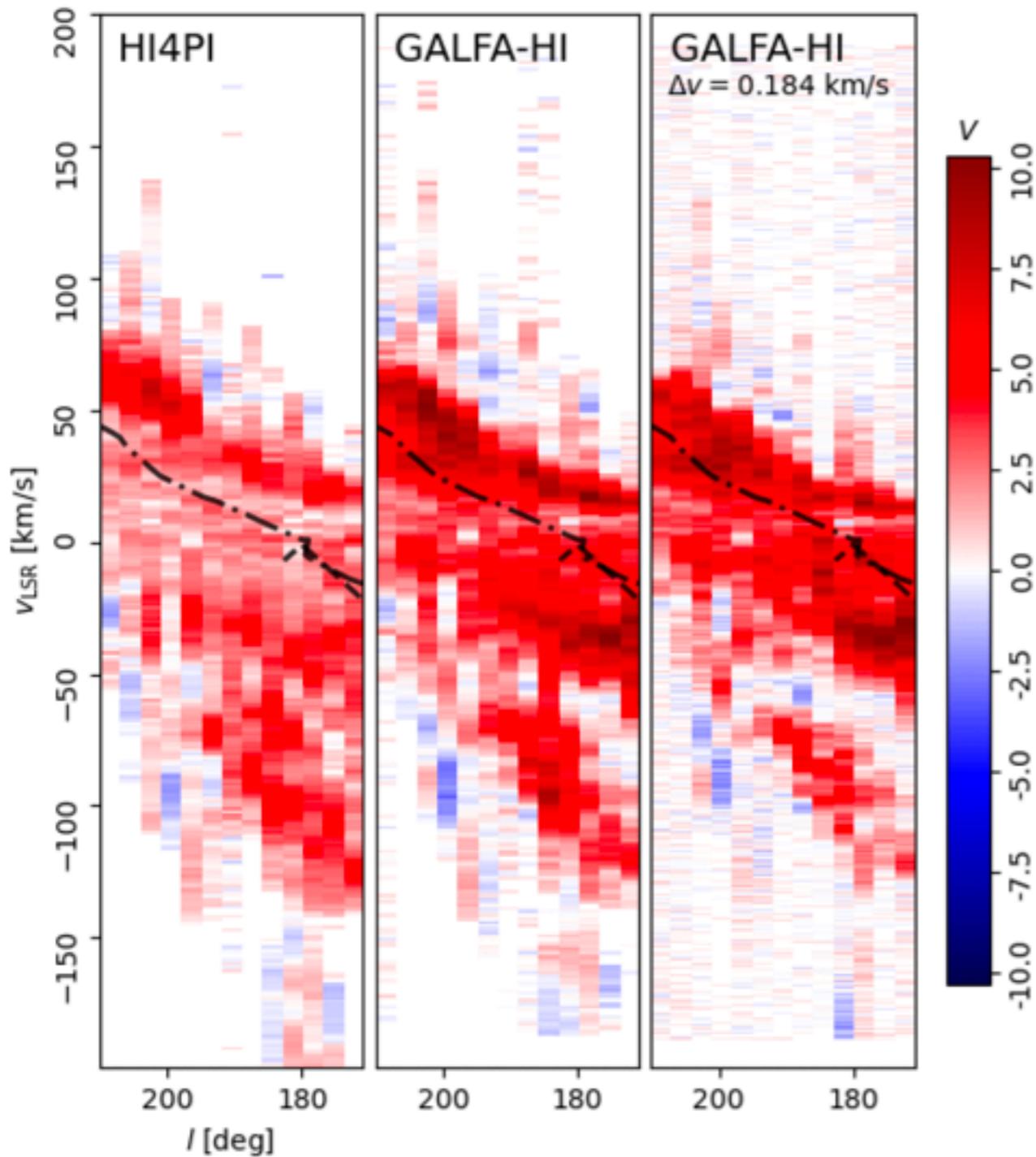
Fixed-scale derivative kernel

Soler, J.D. et al. 2022. A&A in press.



Effect of angular resolution: comparison to GALFA-HI (4')

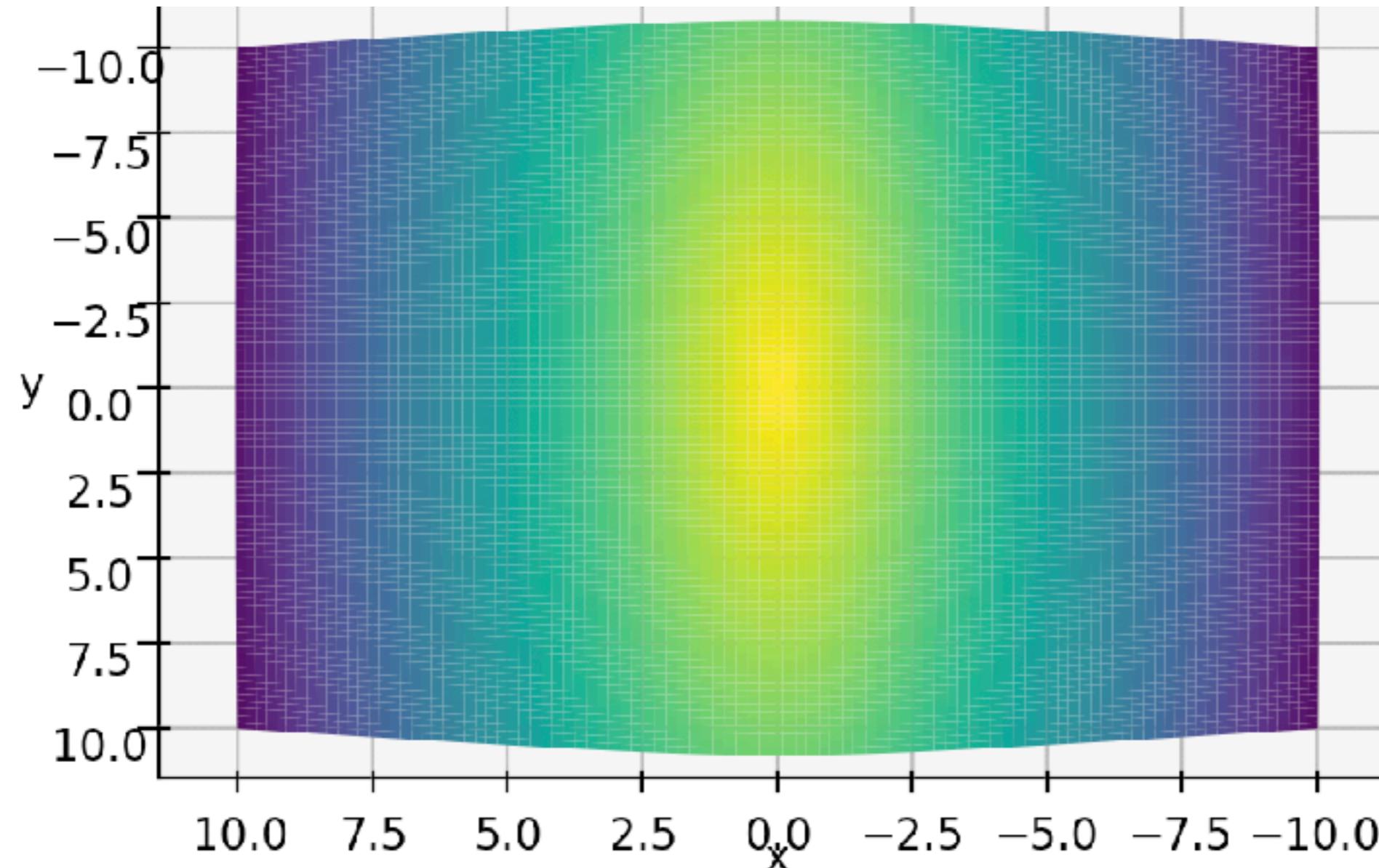
Soler, J.D. et al. 2022. A&A in press.



Machine vision: Hessian matrix method

Soler, J.D. et al. A&A. 2020

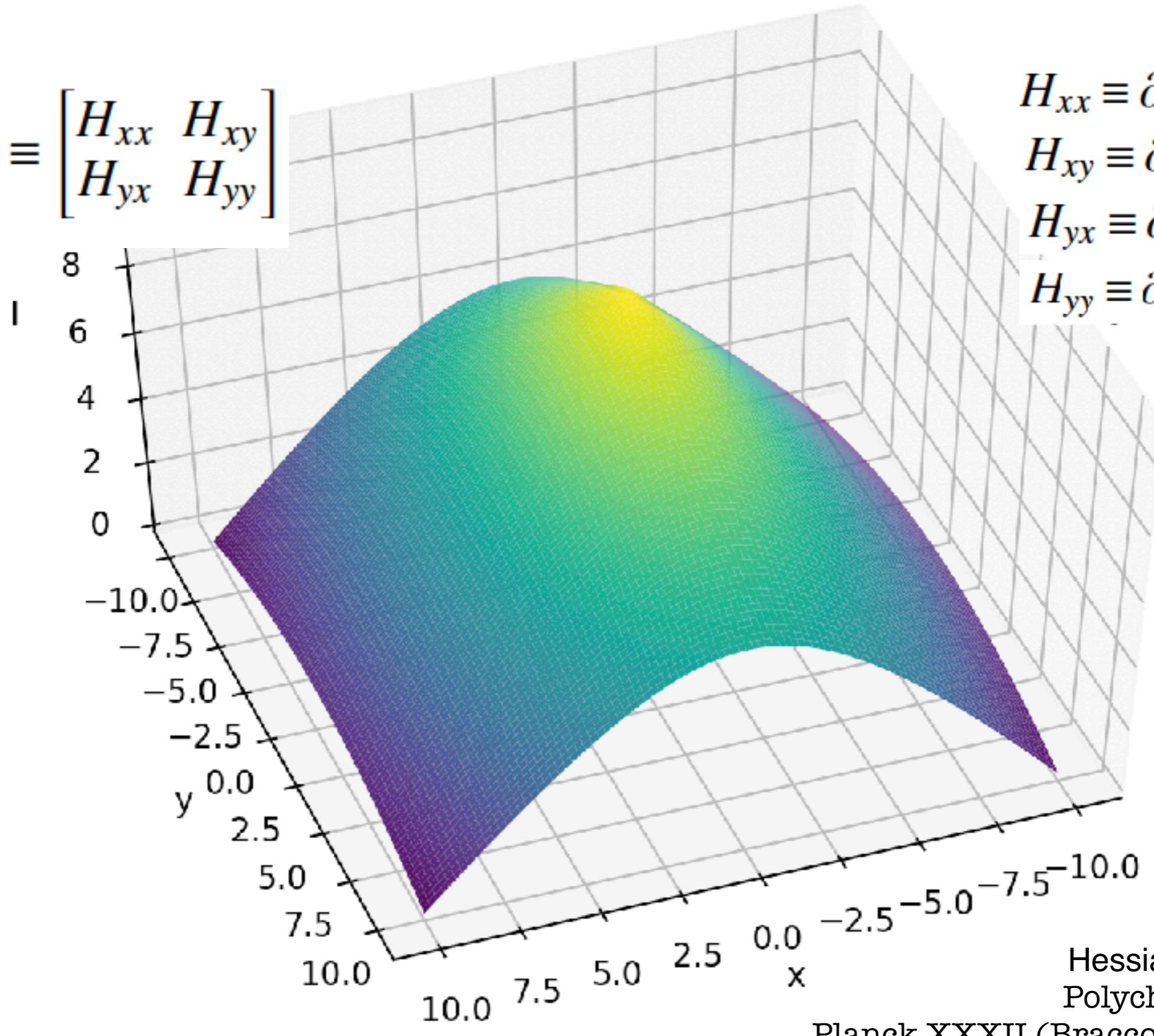
Polychroni et al. 2013
Planck XXXII (Bracco, A. et al.), 2016



Machine vision: Hessian matrix method

Soler, J.D. et al. A&A. 2020

$$\mathbf{H}(x, y) \equiv \begin{bmatrix} H_{xx} & H_{xy} \\ H_{yx} & H_{yy} \end{bmatrix}$$



$$H_{xx} \equiv \partial^2 I / \partial x^2$$
$$H_{xy} \equiv \partial^2 I / \partial x \partial y$$
$$H_{yx} \equiv \partial^2 I / \partial y \partial x$$
$$H_{yy} \equiv \partial^2 I / \partial y^2$$

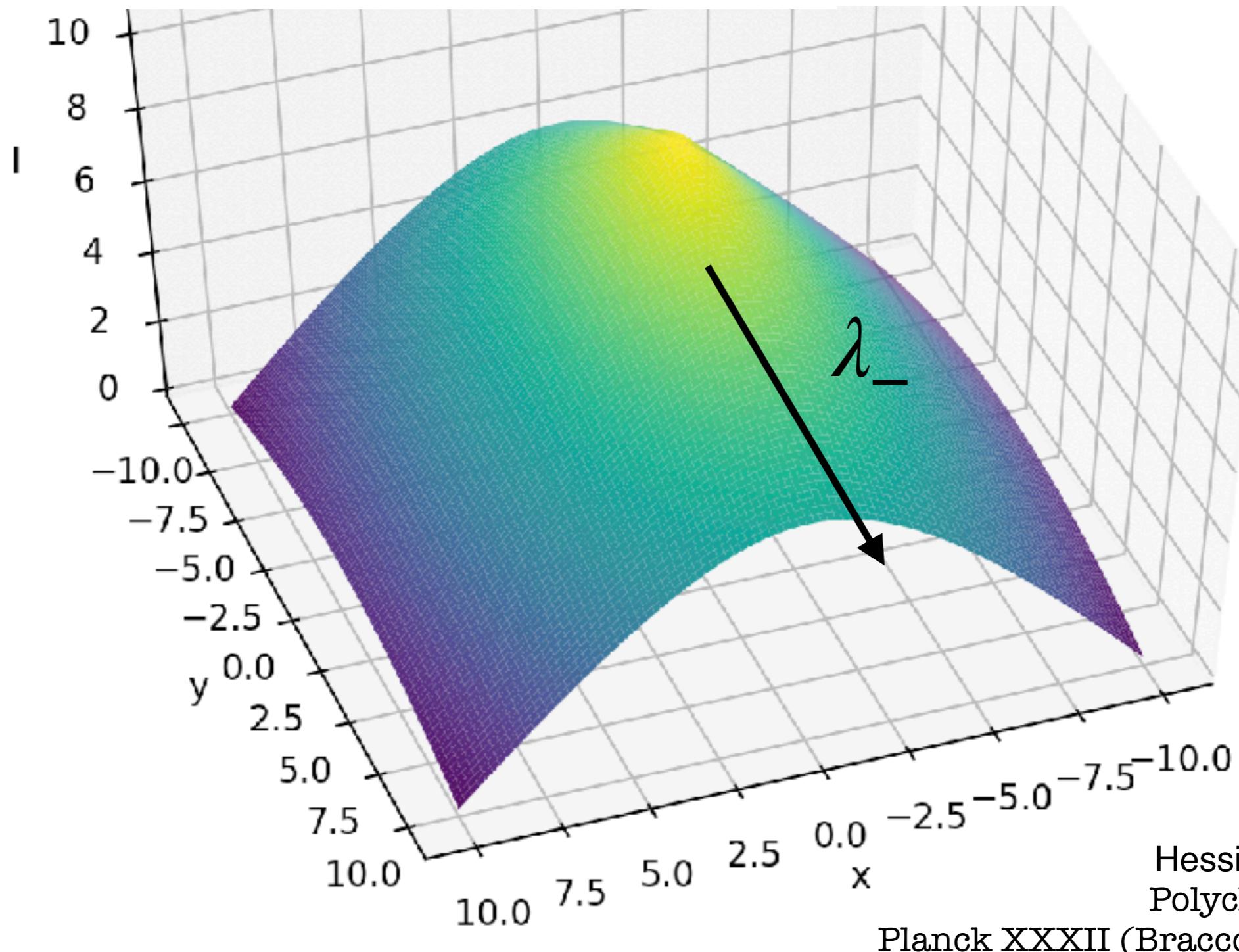
Hessian matrix method
Polychroni et al. 2013
Planck XXXII (Bracco, A. et al.), 2016

Machine vision: Hessian matrix method

Soler, J.D. et al. A&A. 2020

$$\lambda_{\pm} = \frac{(H_{xx} + H_{yy}) \pm \sqrt{(H_{xx} - H_{yy})^2 + 4H_{xy}H_{yx}}}{2}$$

$$\theta = \frac{1}{2} \tan^{-1} \frac{H_{xy} - H_{yx}}{H_{xx} - H_{yy}}$$



Hessian matrix method
Polychroni et al. 2013
Planck XXXII (Bracco, A. et al.), 2016

HI filament orientation: random walk interpretation

Soler, J.D. et al. A&A. 2020

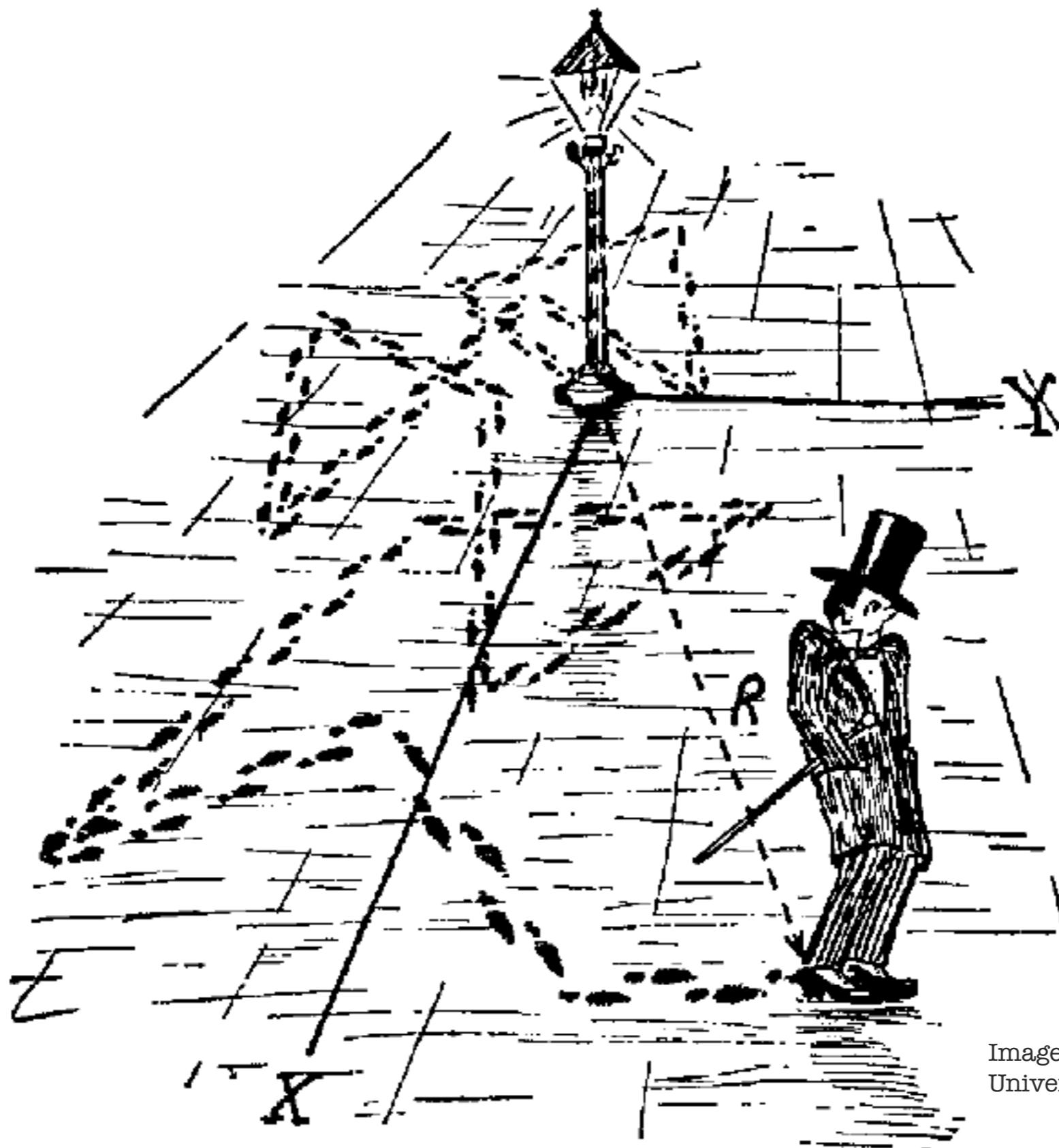
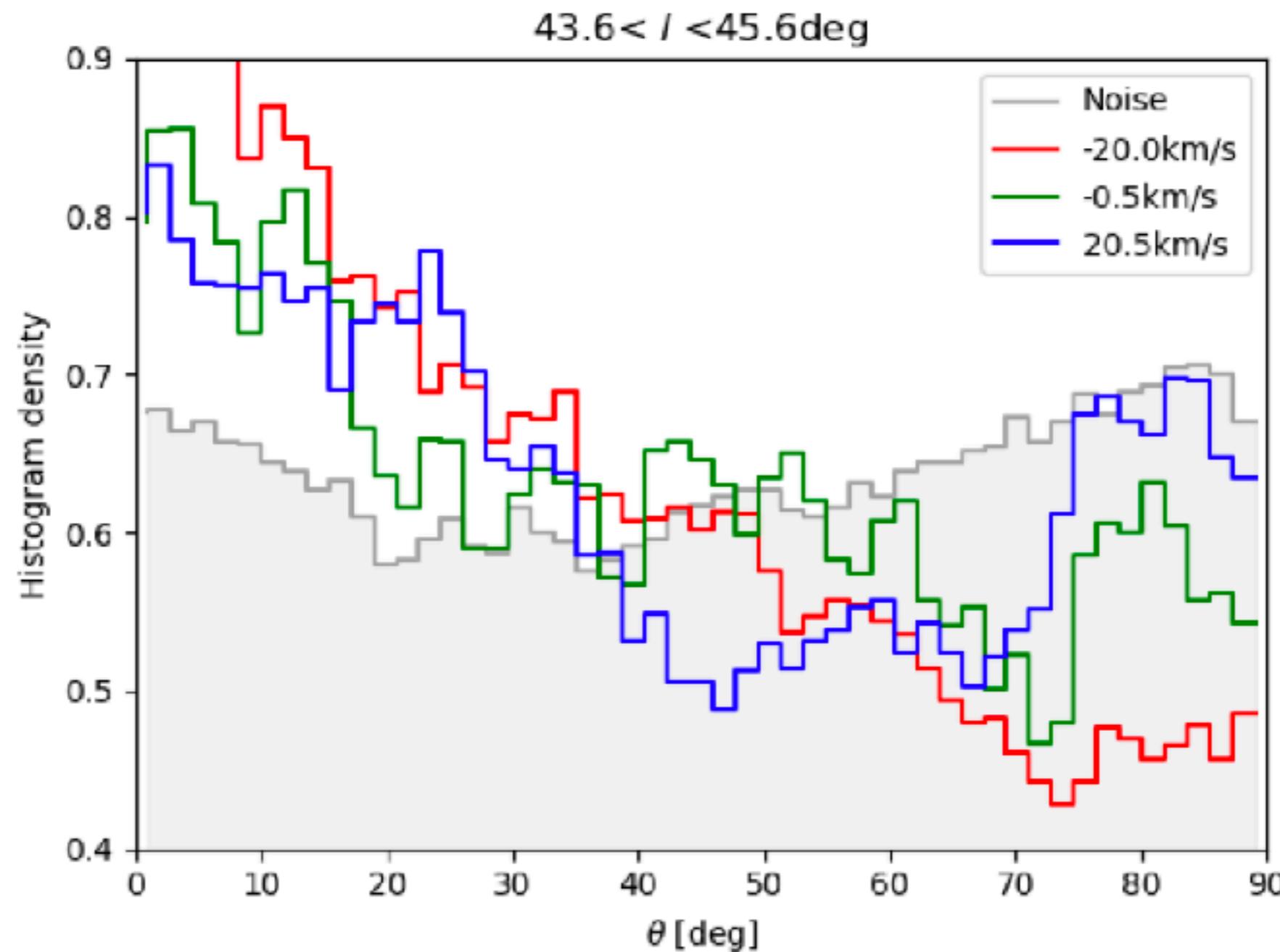


Image: Advanced Design Studies
University of Tokyo

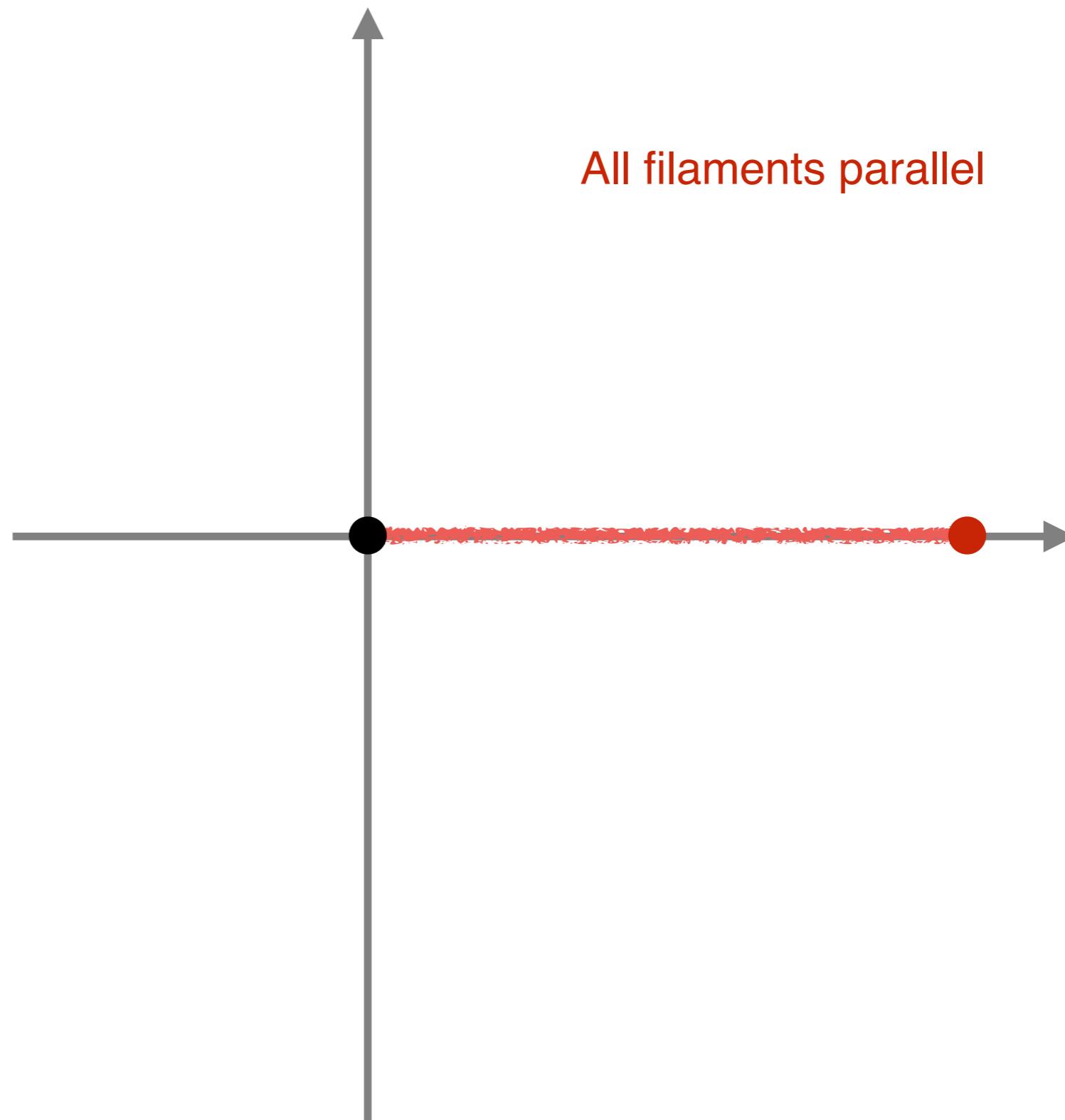
Histograms of HI filament orientation

Soler, J.D. et al. A&A. 2020



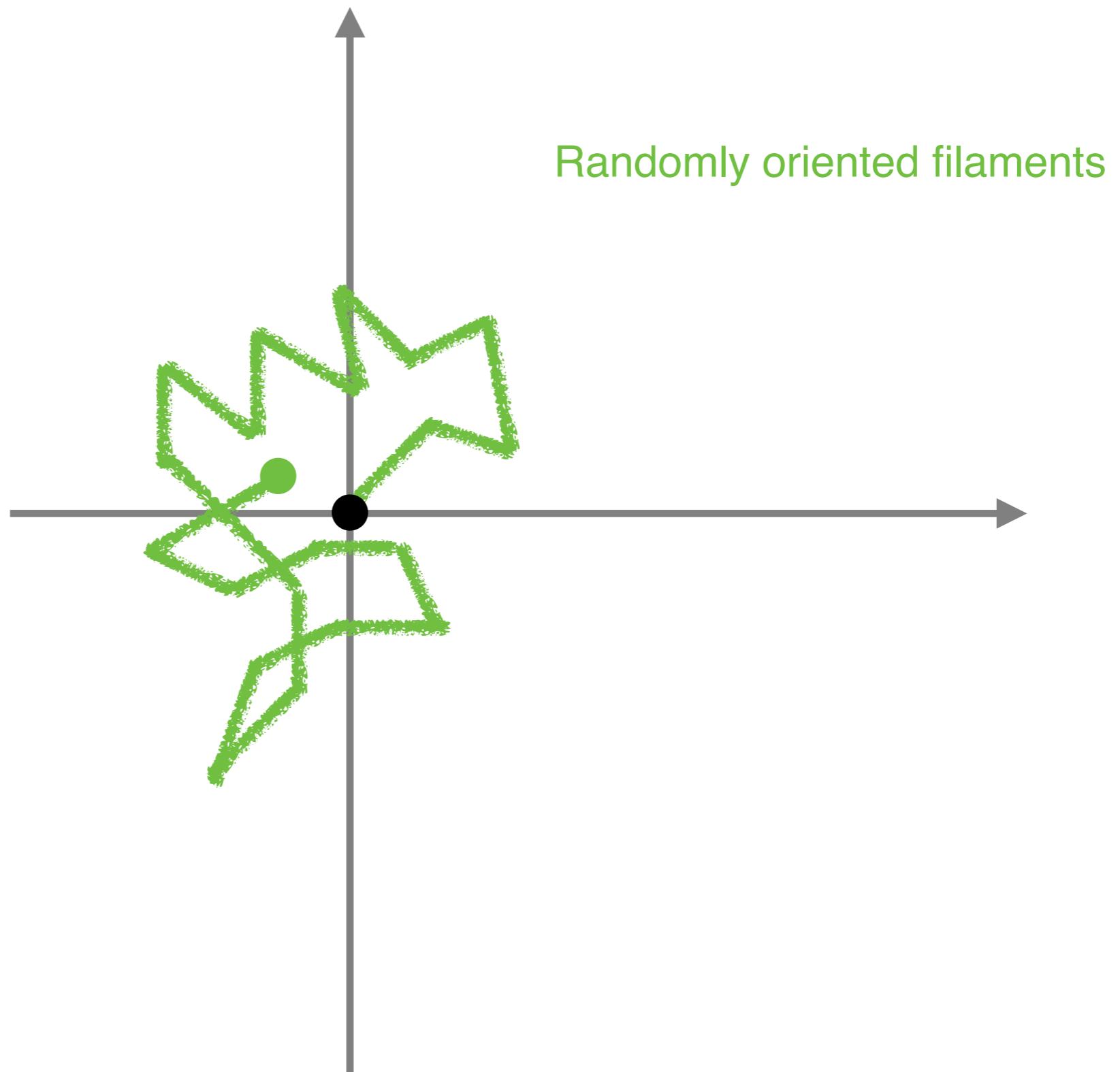
HI filament orientation: random walk interpretation

Soler, J.D. et al. A&A. 2020



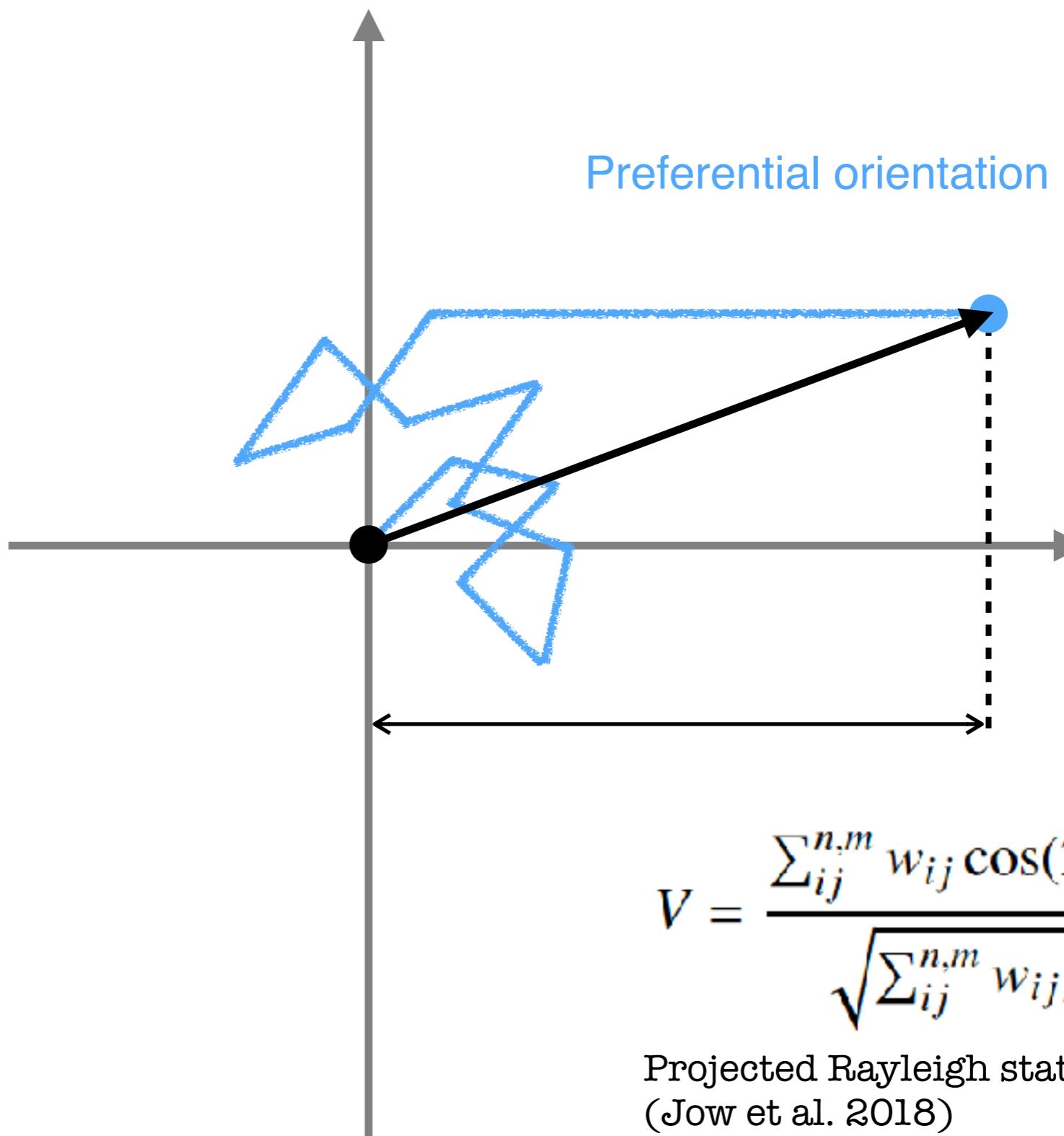
HI filament orientation: random walk interpretation

Soler, J.D. et al. A&A. 2020



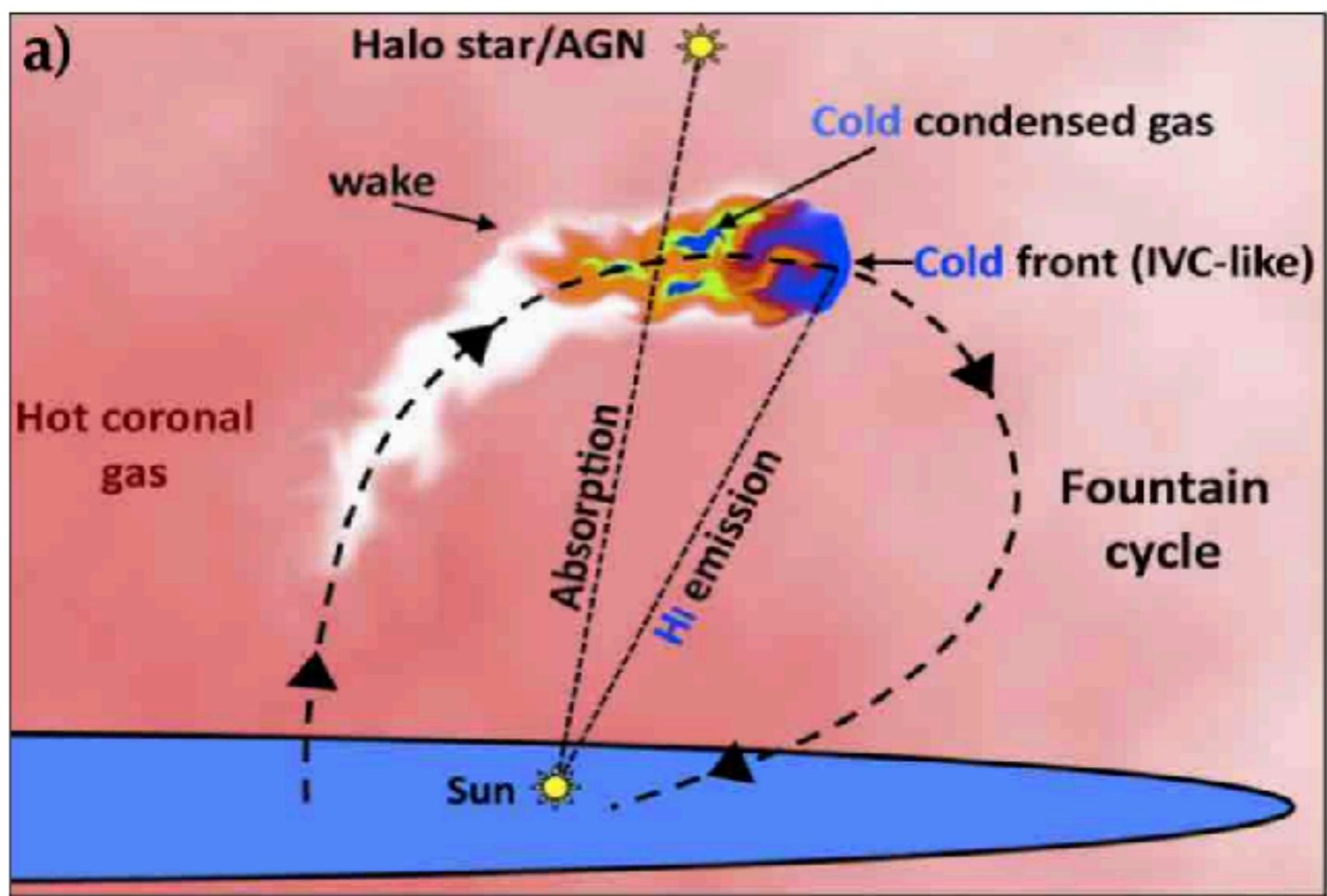
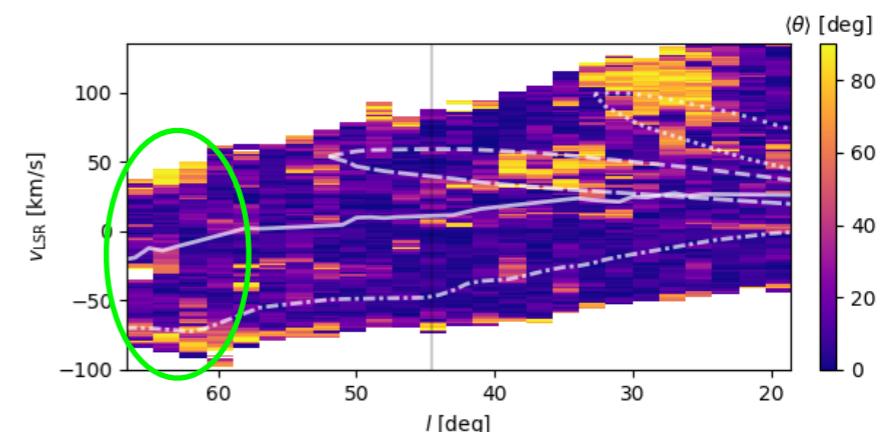
HI filament orientation: random walk interpretation

Soler, J.D. et al. A&A. 2020



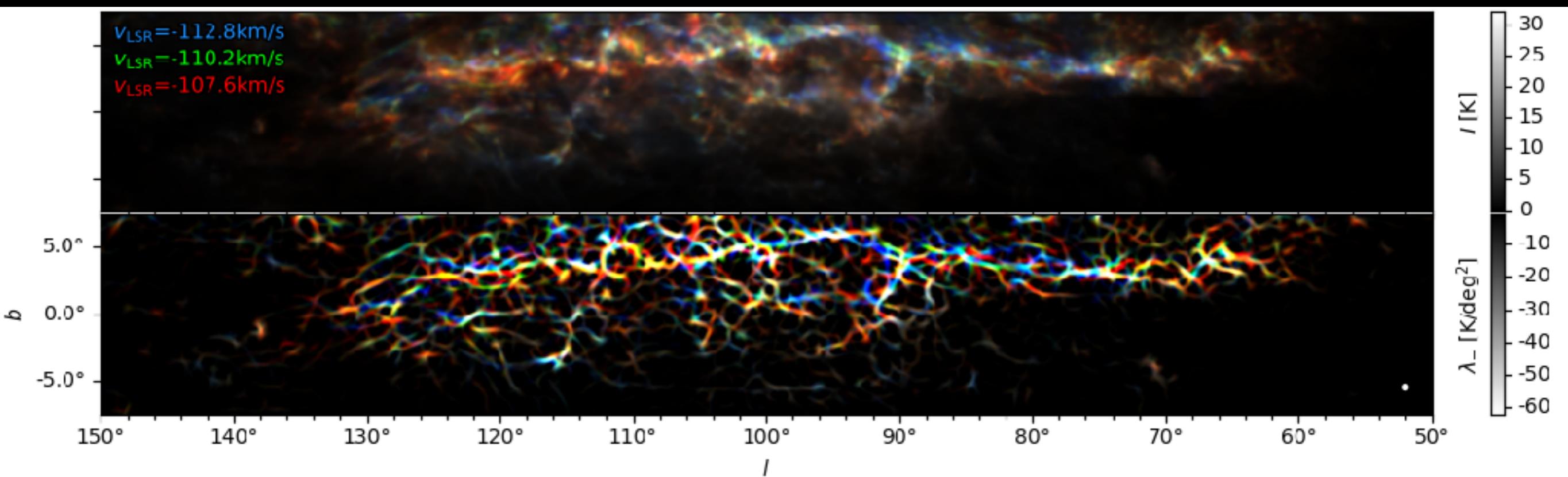
Extrapolanar gas

Fraternali, F. & Binney, J.J. MNRAS, 2008



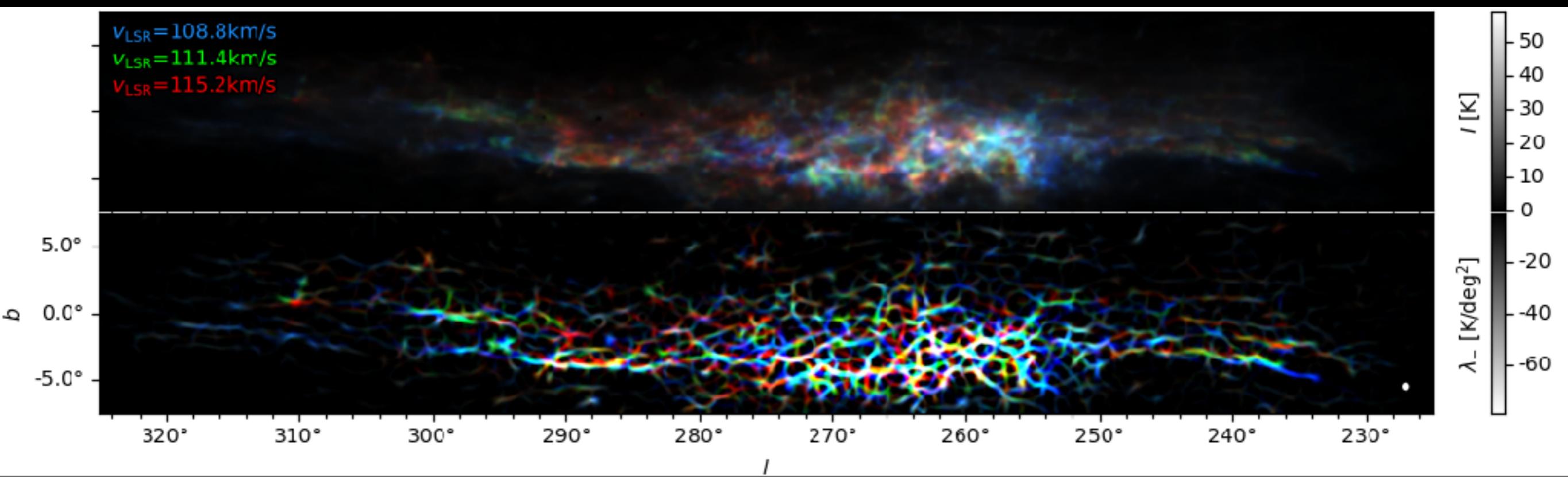
Atomic hydrogen emission

Soler, J.D. et al. 2022. A&A submitted.



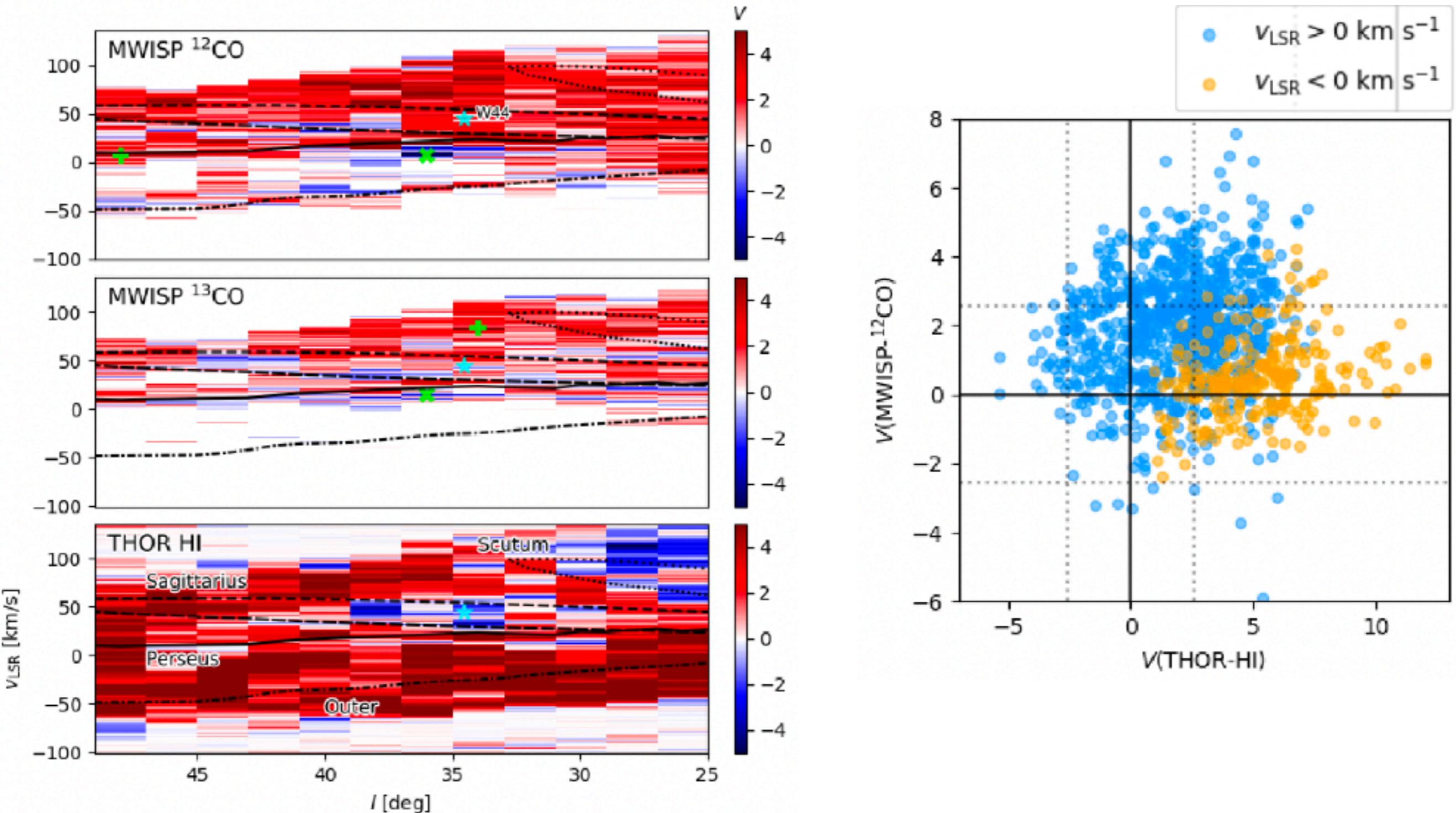
Atomic hydrogen emission

Soler, J.D. et al. 2022. A&A submitted.



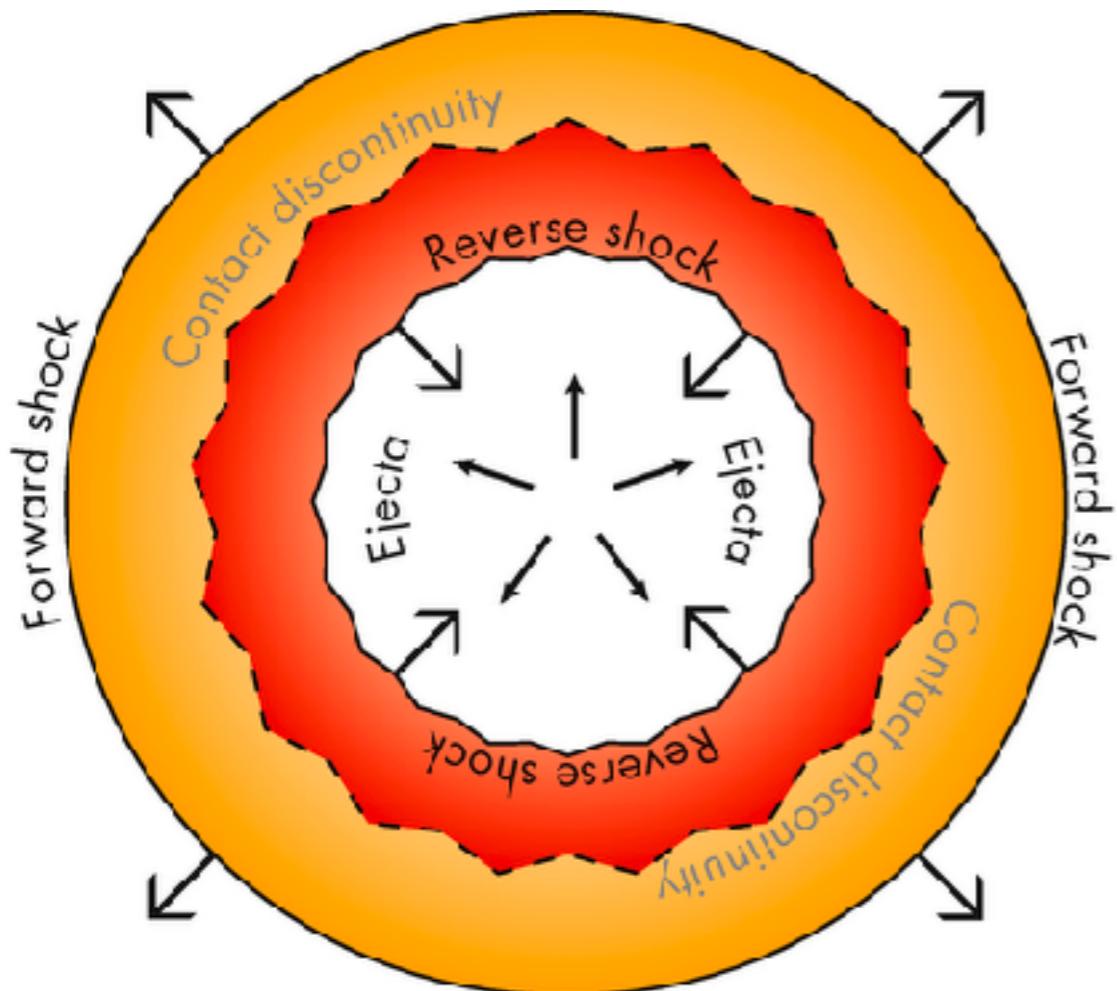
What is next?

Soler, J.D. et al. A&A 2021

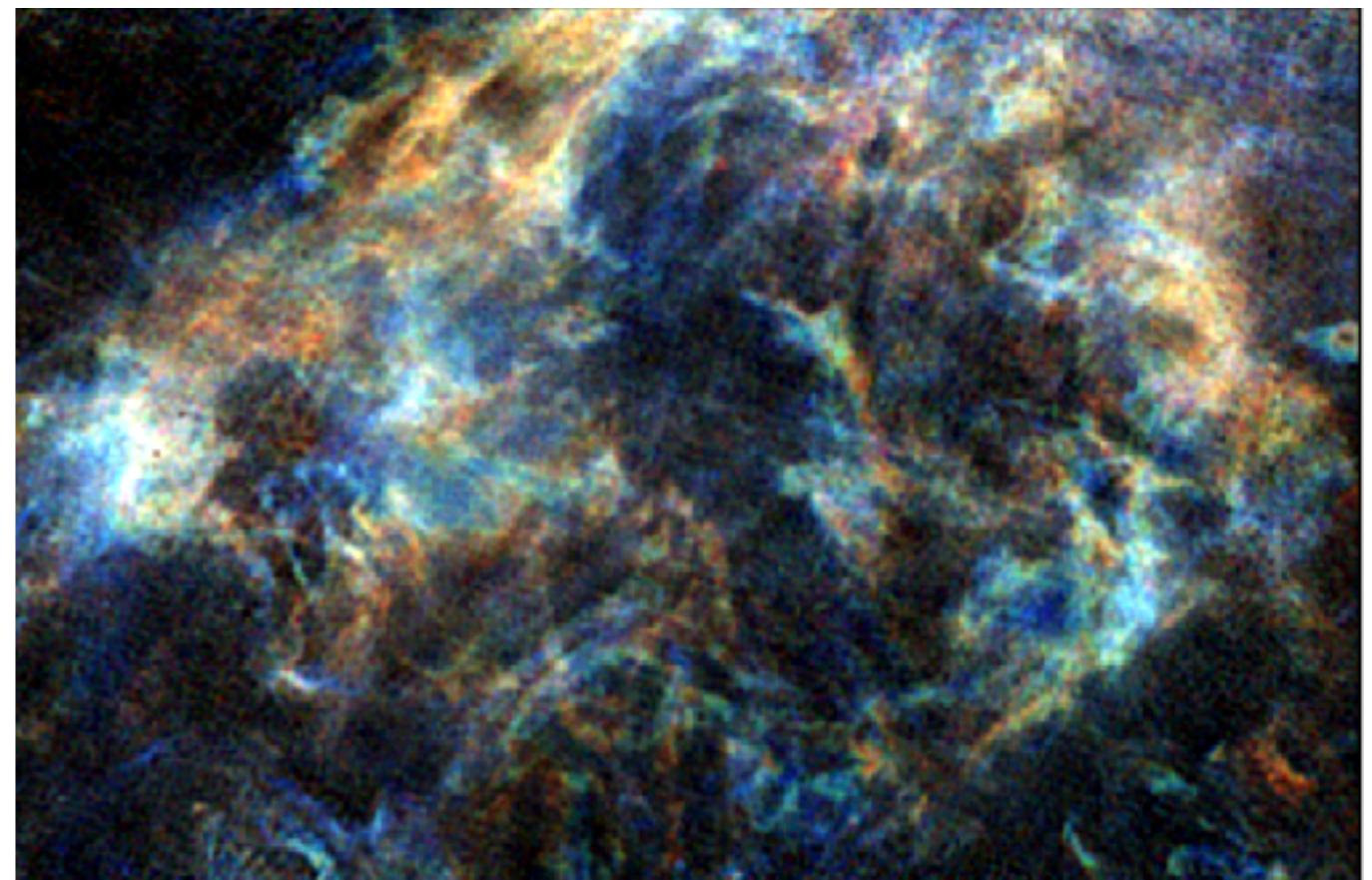


Atomic shells pushed by supernovae

Supernova Remnant Evolution. Vink, 2020.

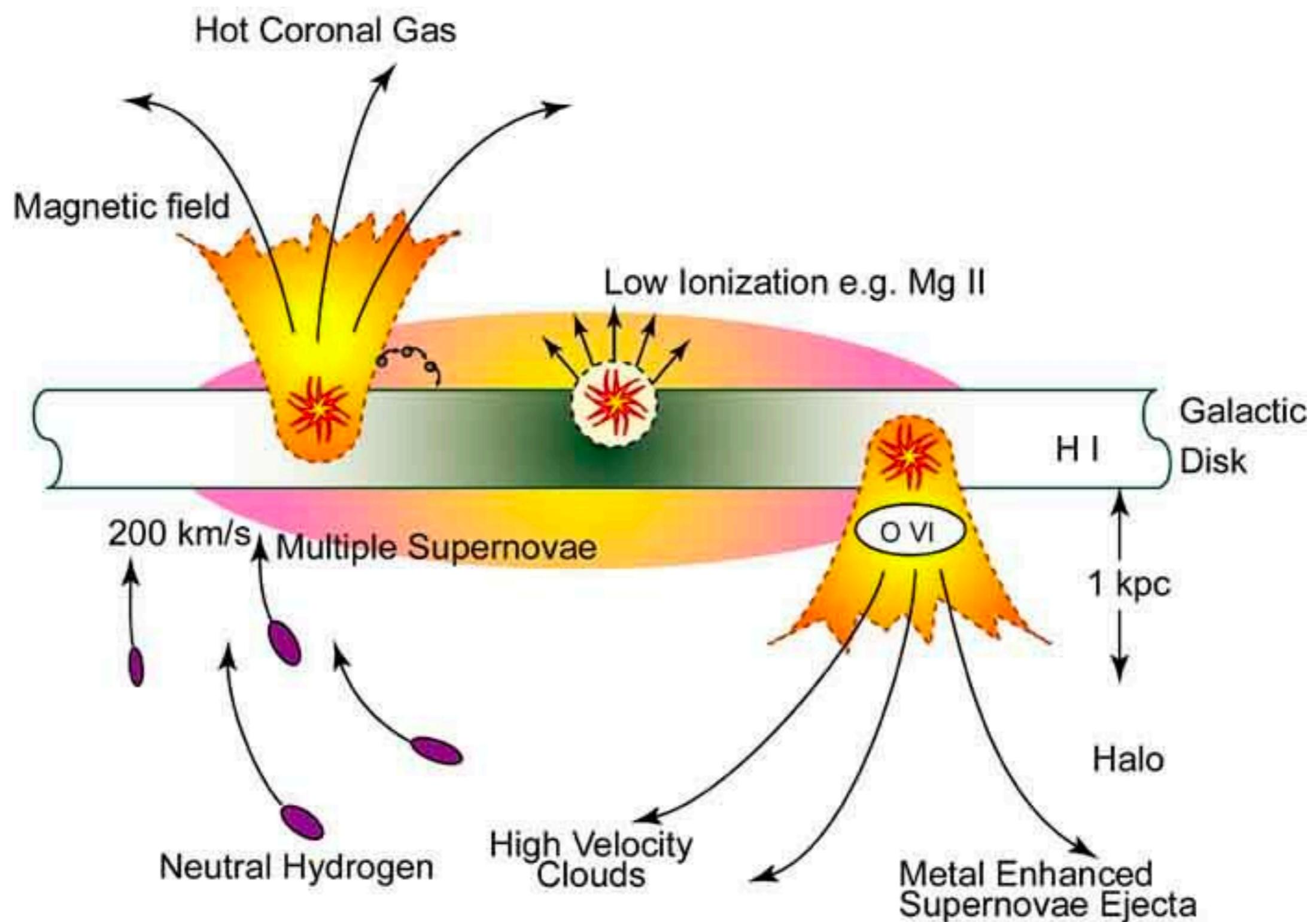


HI shell in THOR



Atomic worms and chimneys

Heiles, 1994

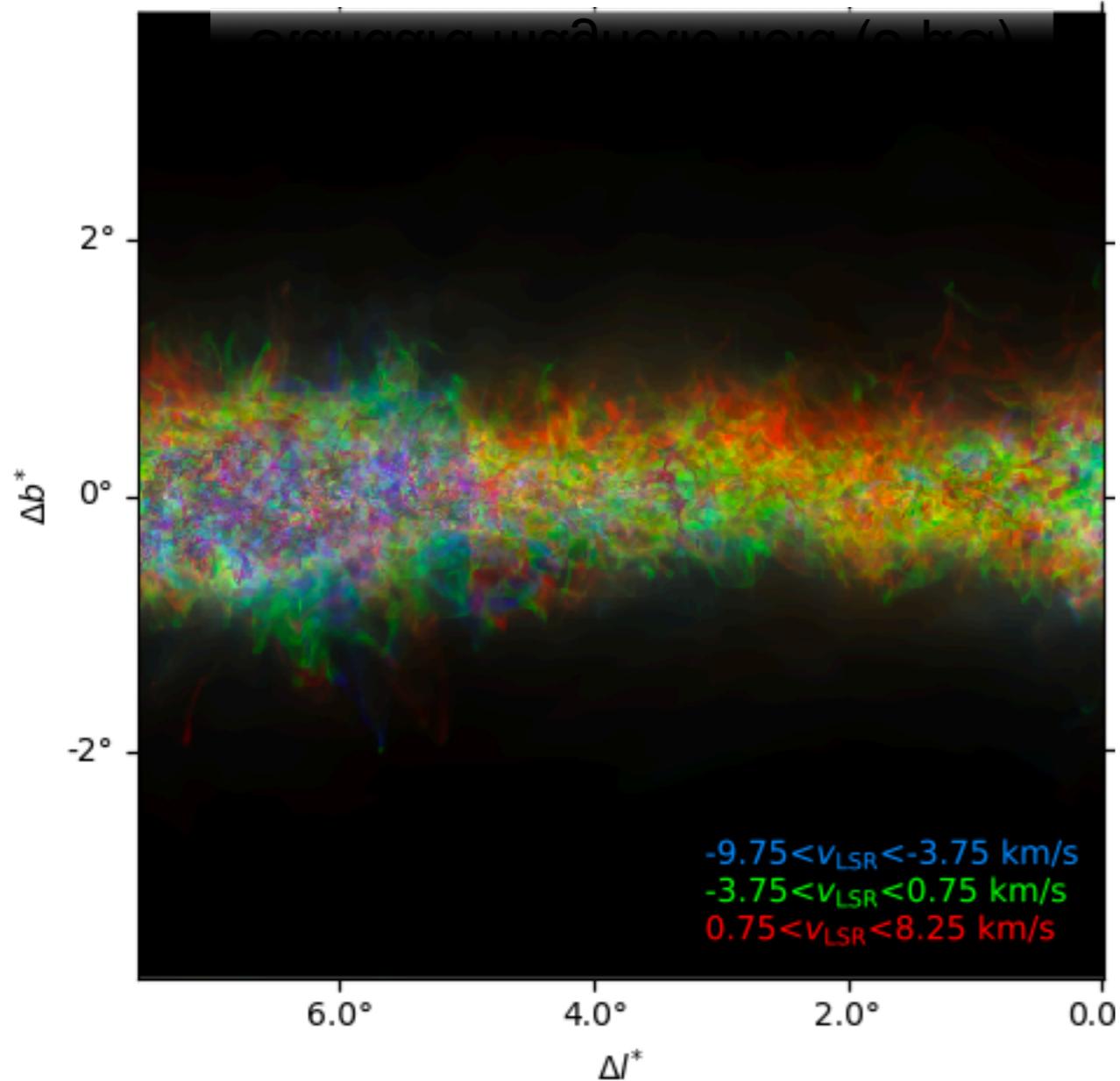


HI filaments in MHD simulations

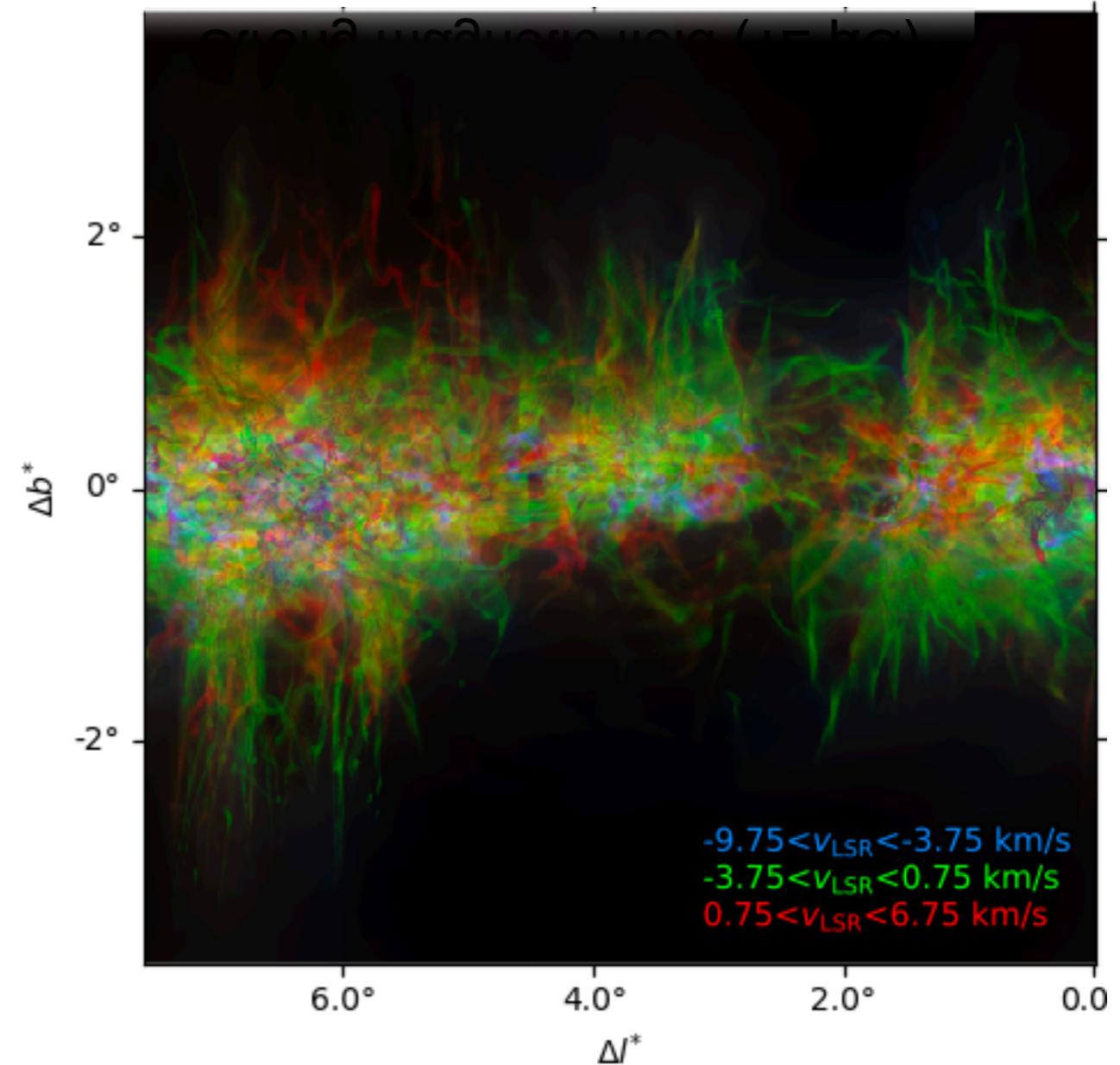
FRIGG simulations (Hennebelle et al. A&A 2018)

Soler, J.D. et al. A&A. 2020

Standard magnetic field (3 μG)



Strong magnetic field (12 μG)



HI holes in the spiral galaxy NGC6946

Boomsma et al. A&A 2008

