

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

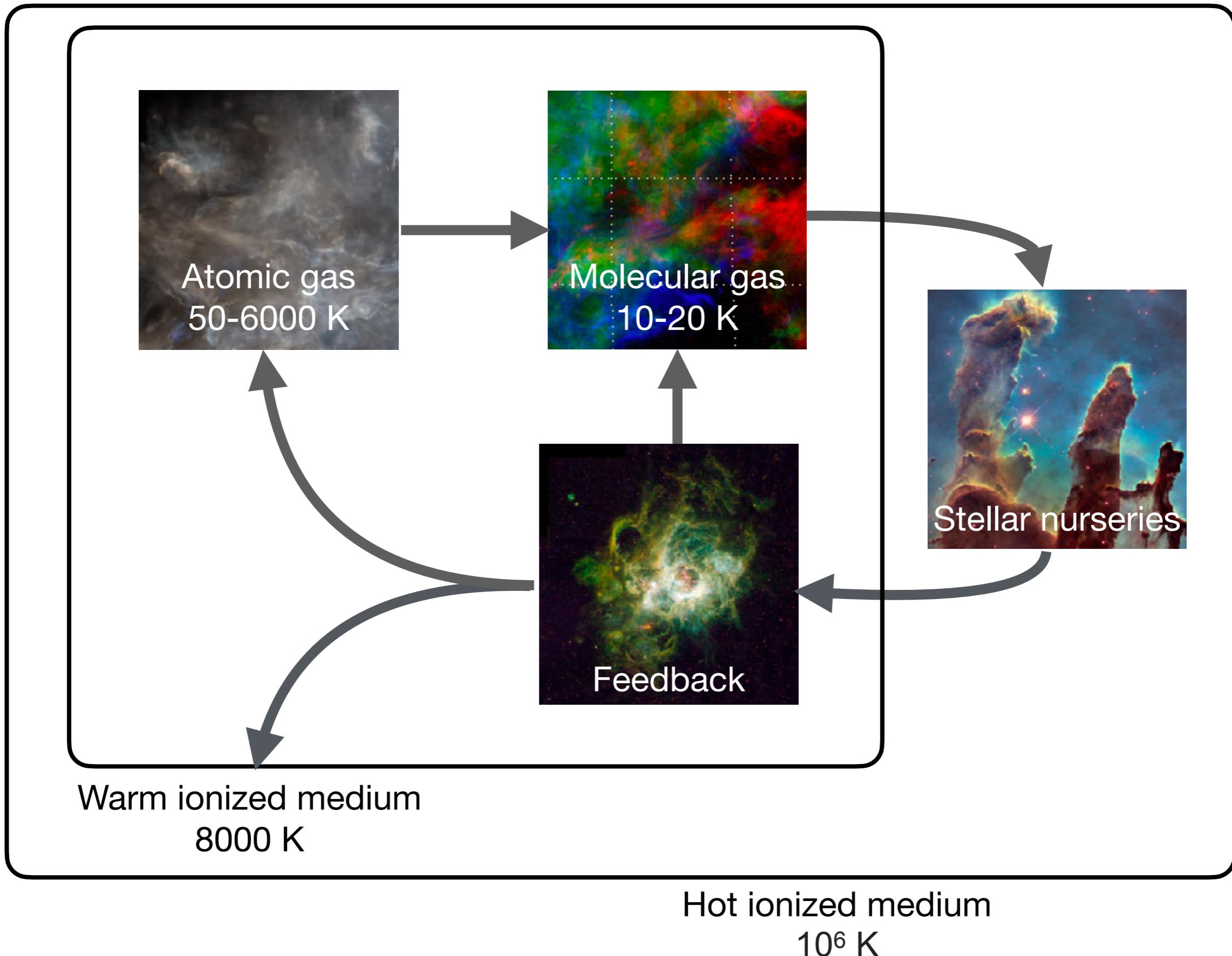
Juan Diego Soler

Istituto di Astrofisica e Planetologia Spaziali

THOR collaboration: H. Beuther, J. Syed, Y. Wang, 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

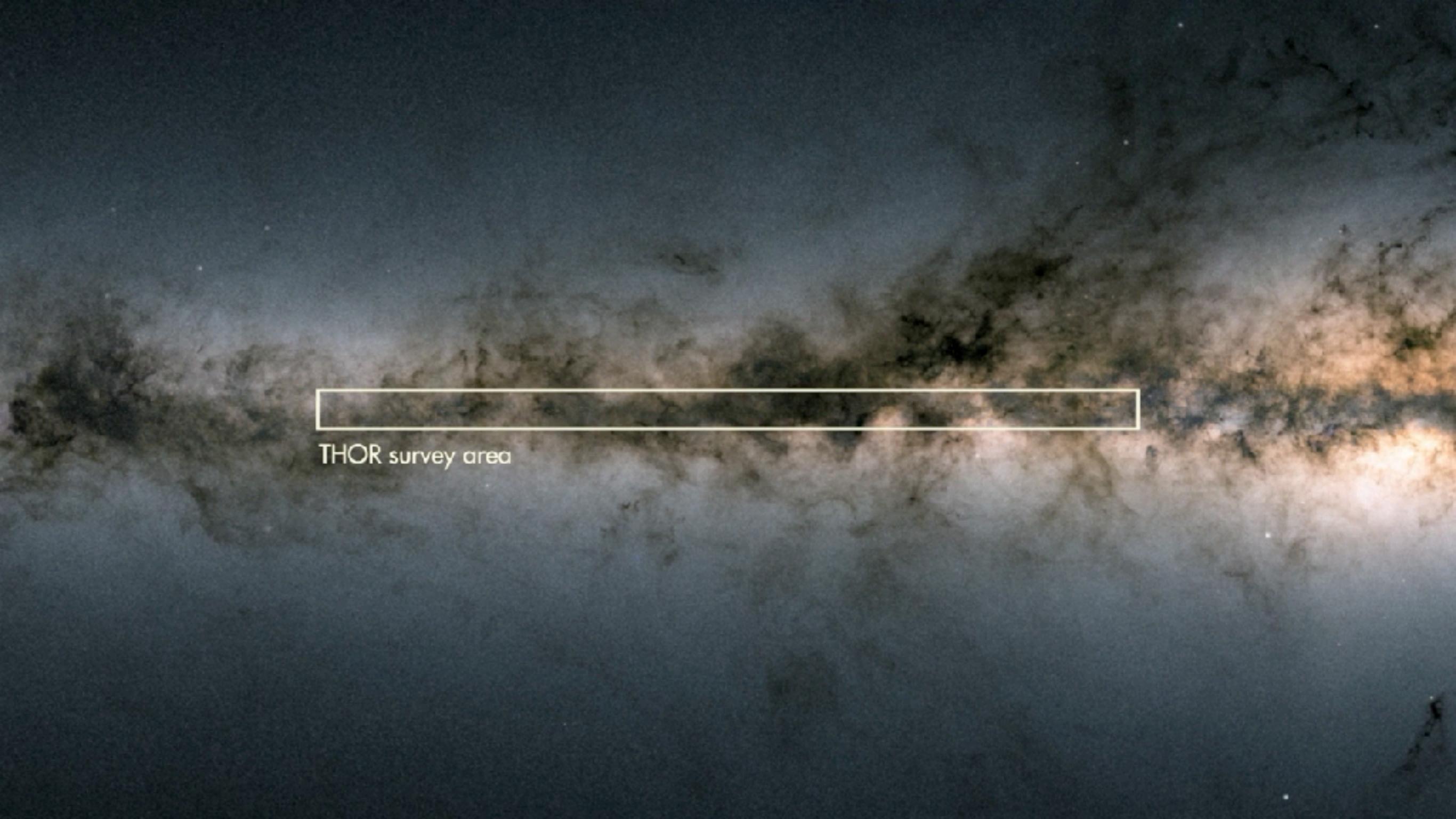
ECOgal collaboration: S. Molinari, R. S. Klessen, P. Hennebelle, S. C. O. Glover, A. Trafficante, E. Schisano, D. Elia, M. Sormani, R., Tress, P. Girichidis, R. J. Smith, T. Colman

The baryon lifecycle



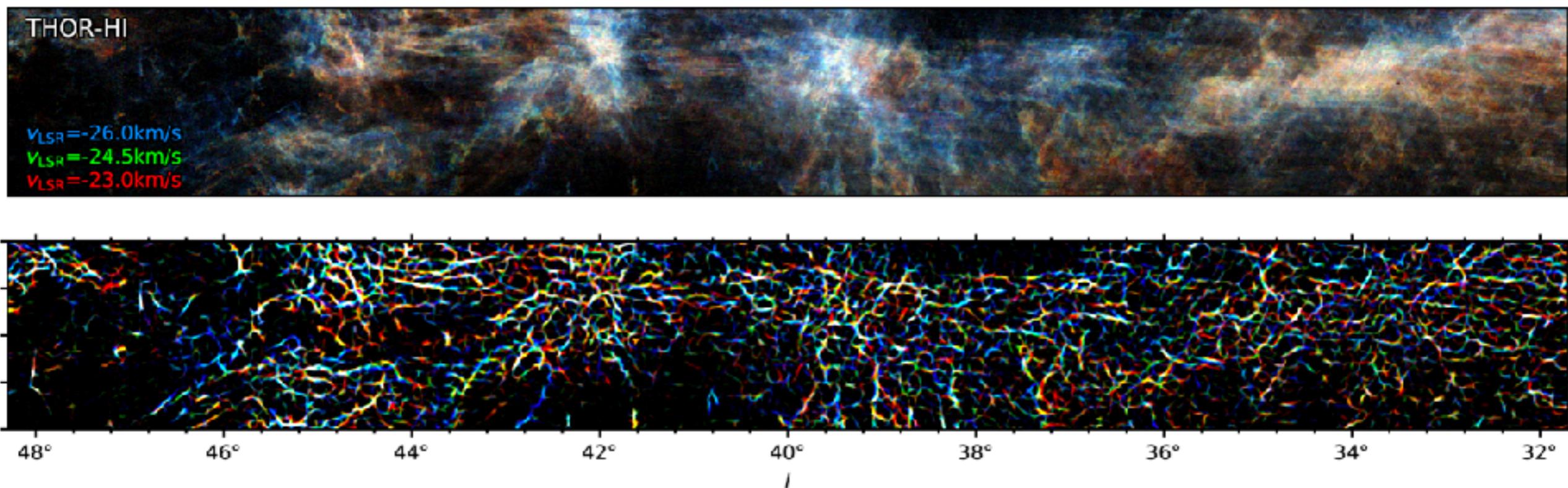
The HI, OH, and Recombination-line (THOR) survey

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



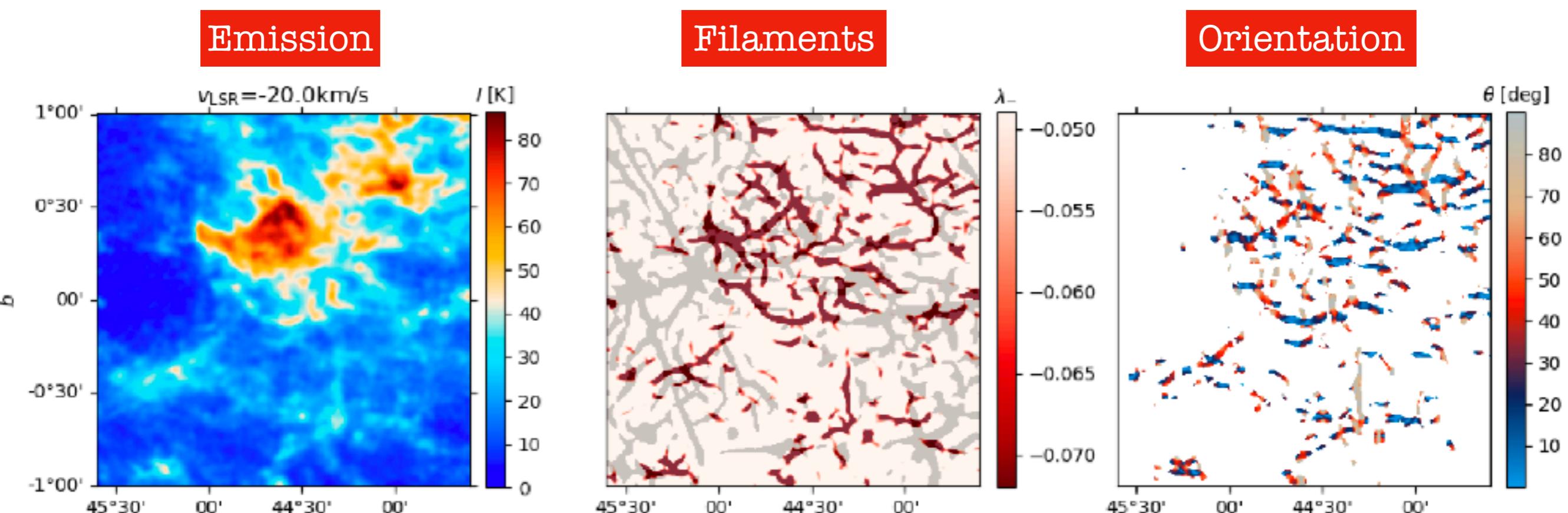
Atomic hydrogen filaments

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



HI filaments - Hessian matrix method

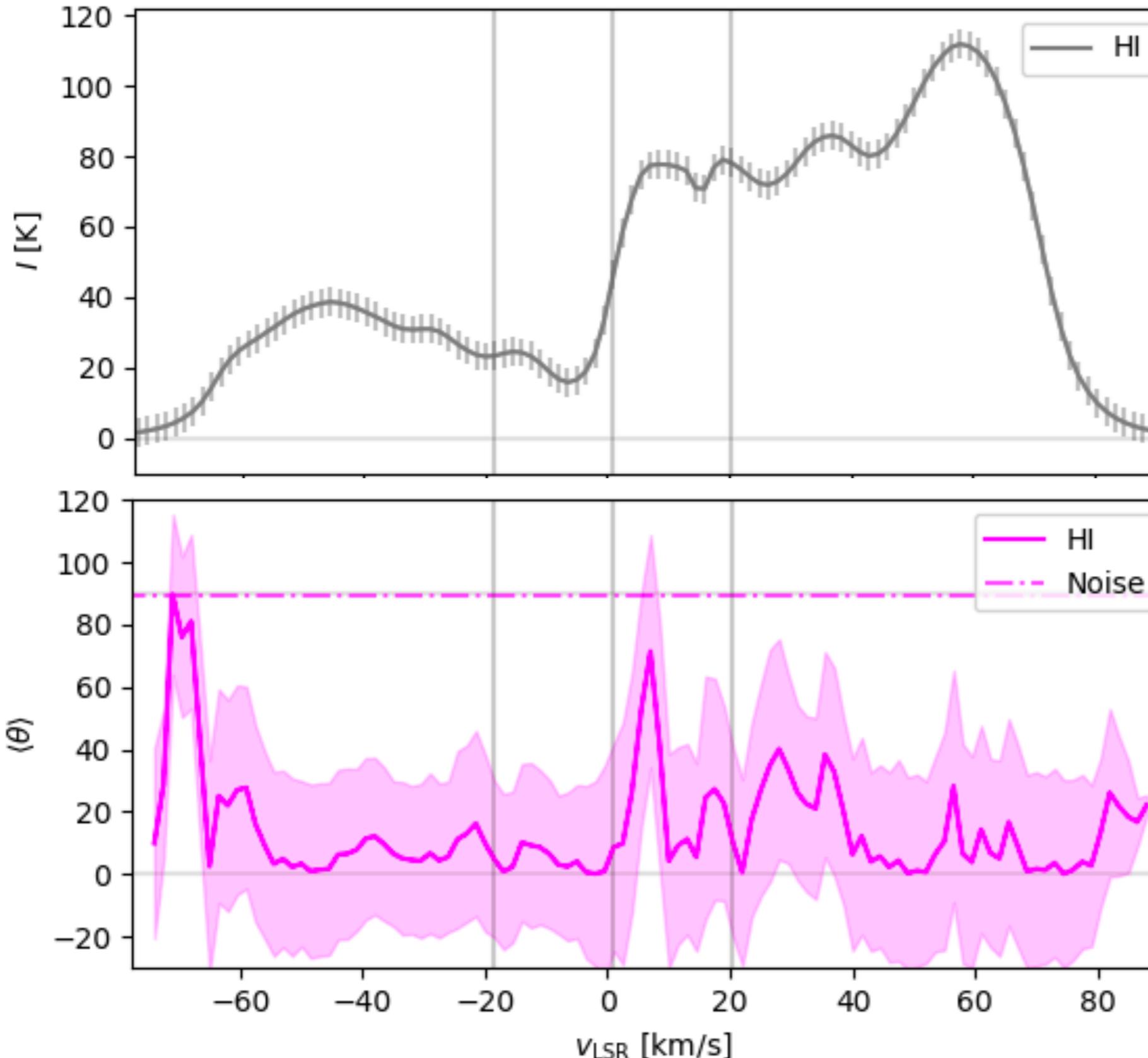
Soler, J.D. et al. A&A (2020)



HI filament orientation

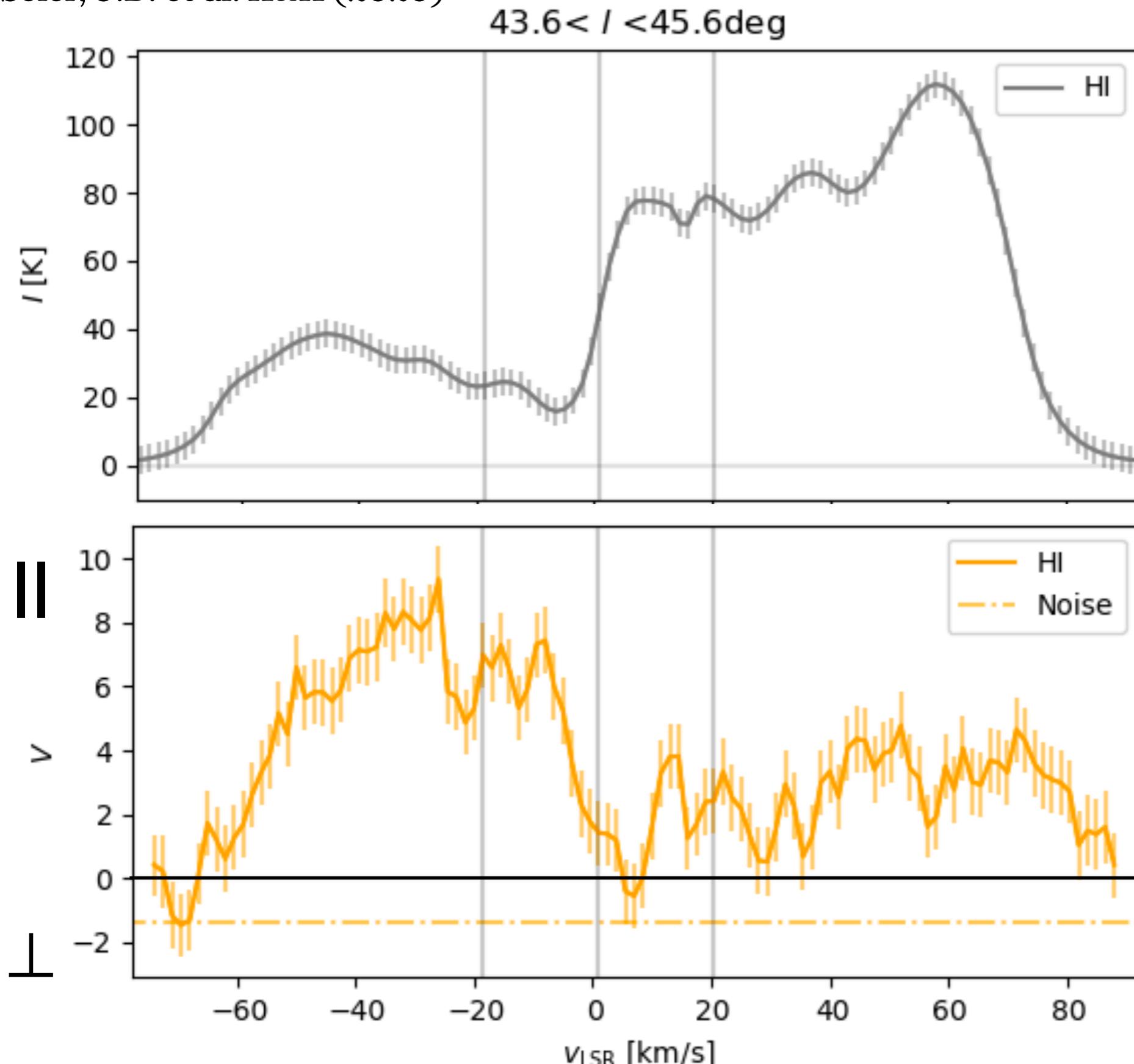
Soler, J.D. et al. A&A (2020)

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



HI filament orientation

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

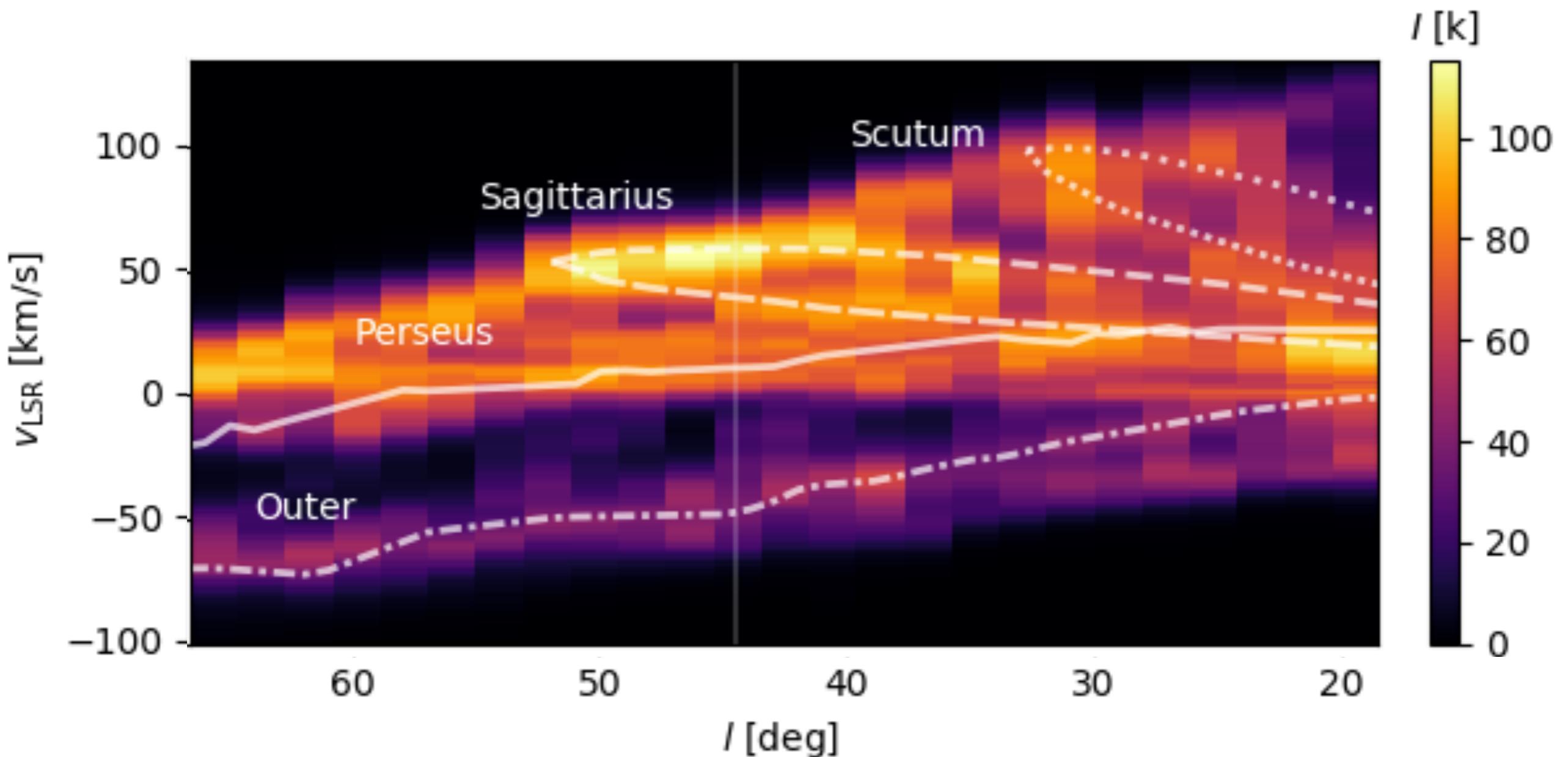


Projected Rayleigh statistic
(Jow et al. 2018)

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

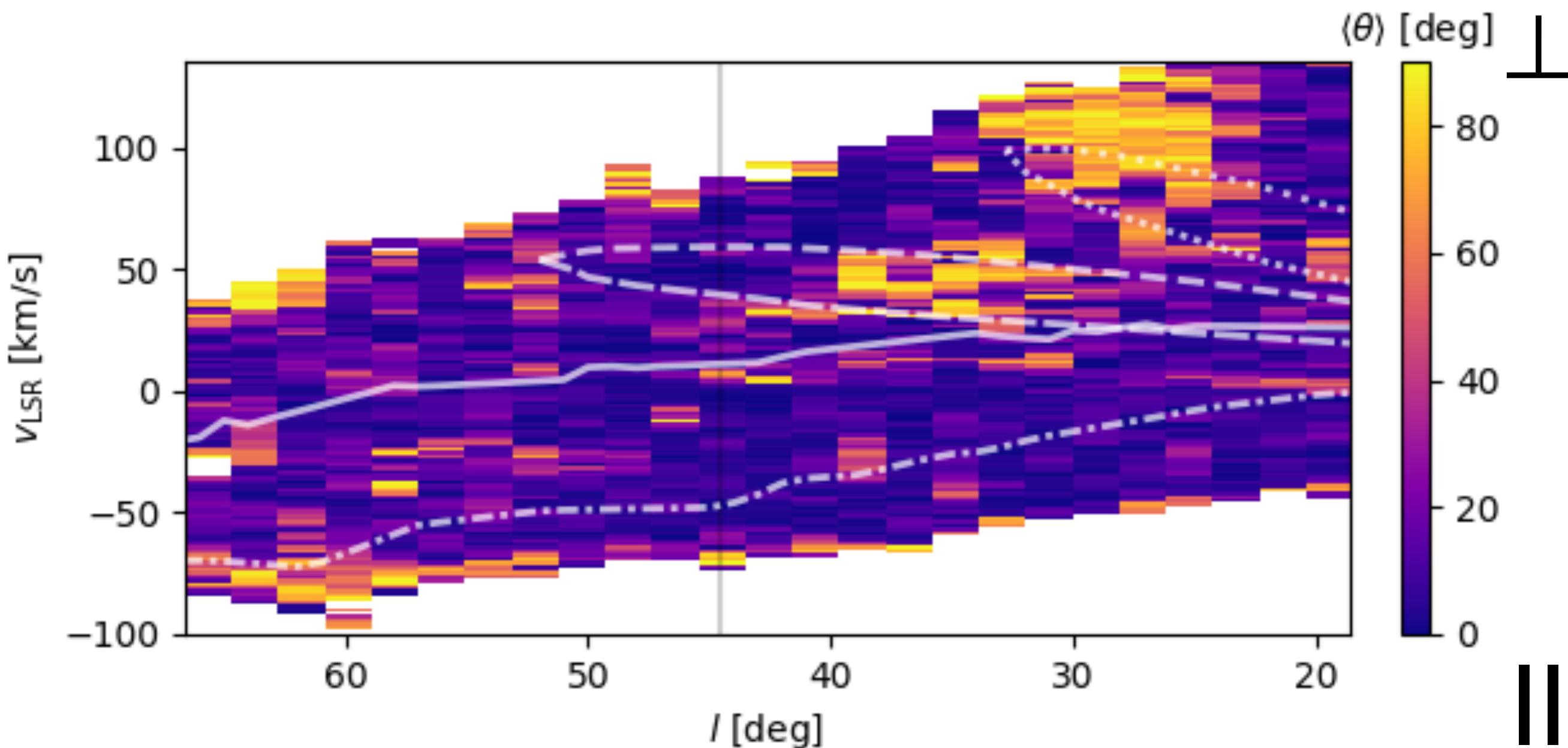
HI emission

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



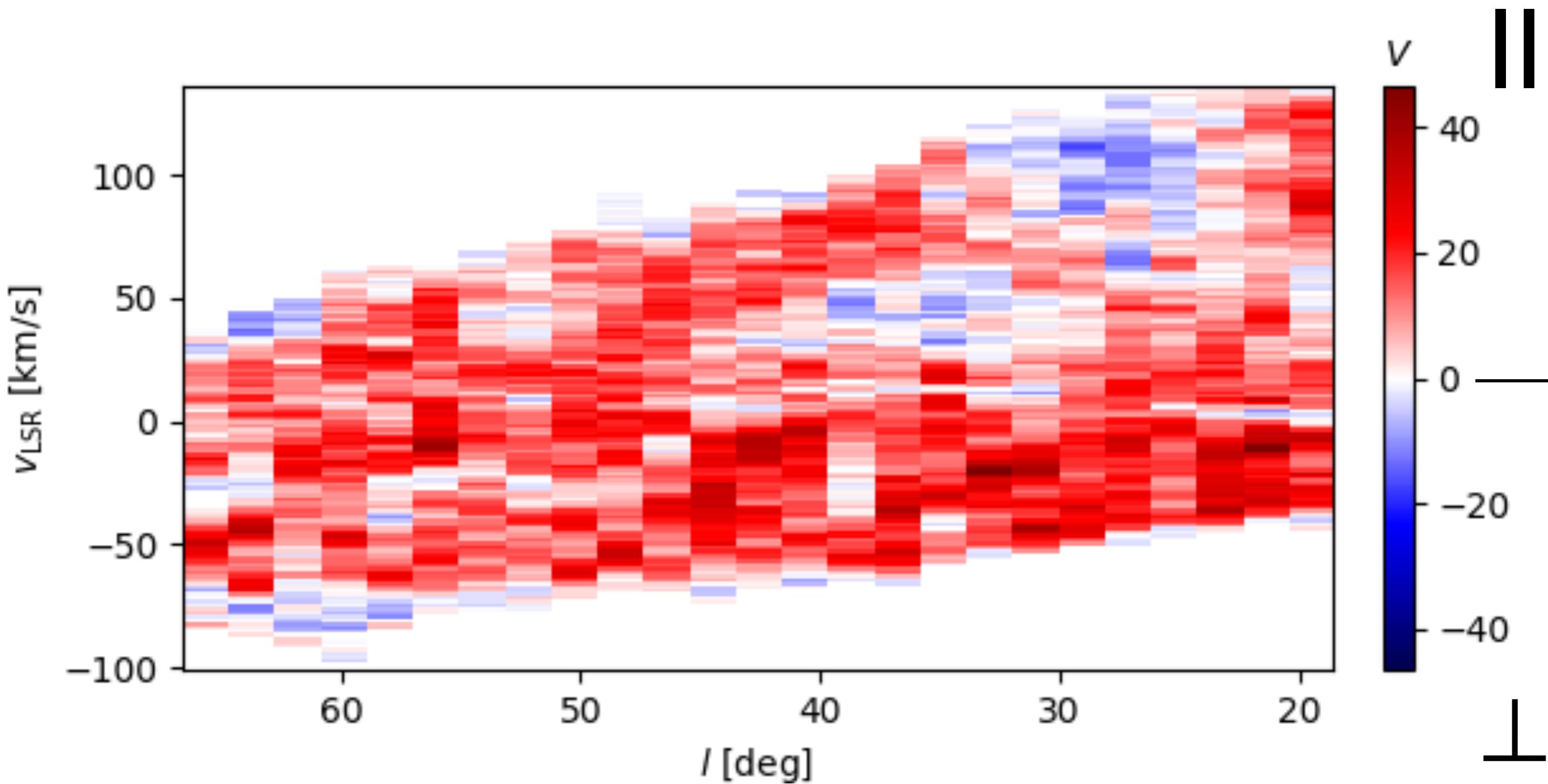
HI filament orientation

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



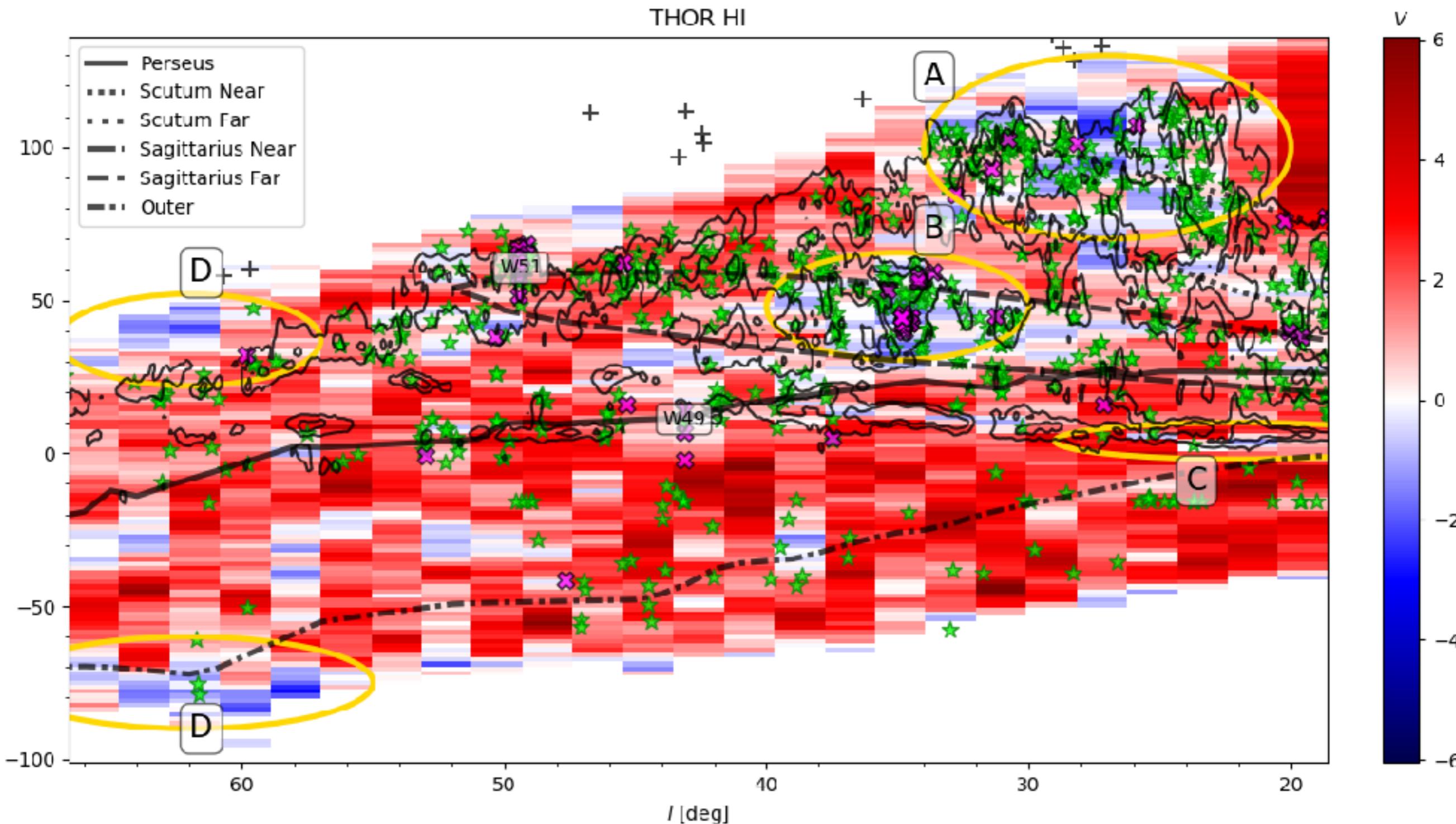
HI filament orientation

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



HI filament orientation

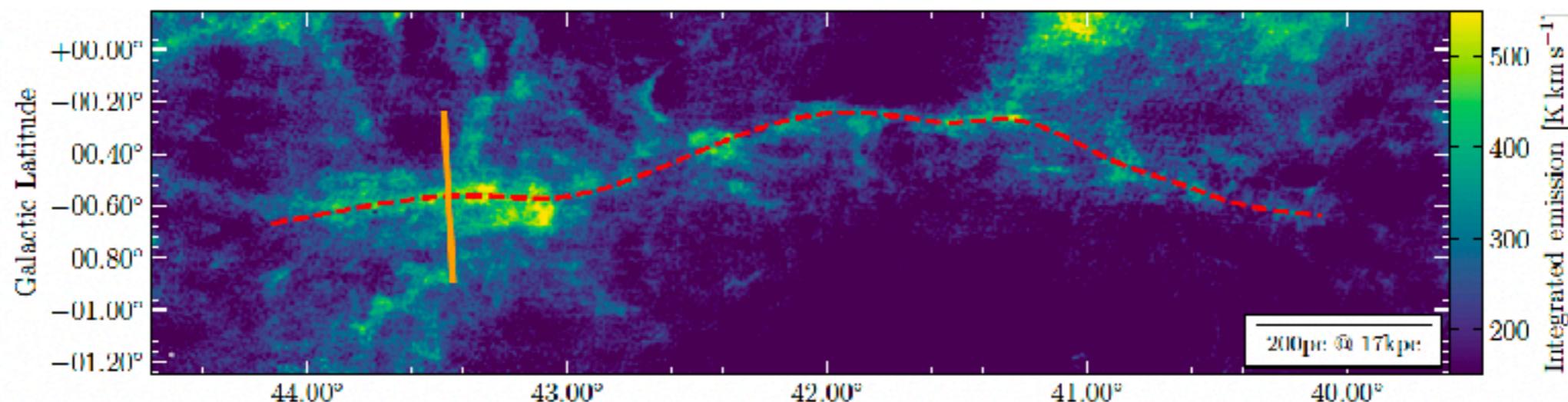
Soler, J.D. et al. 2020



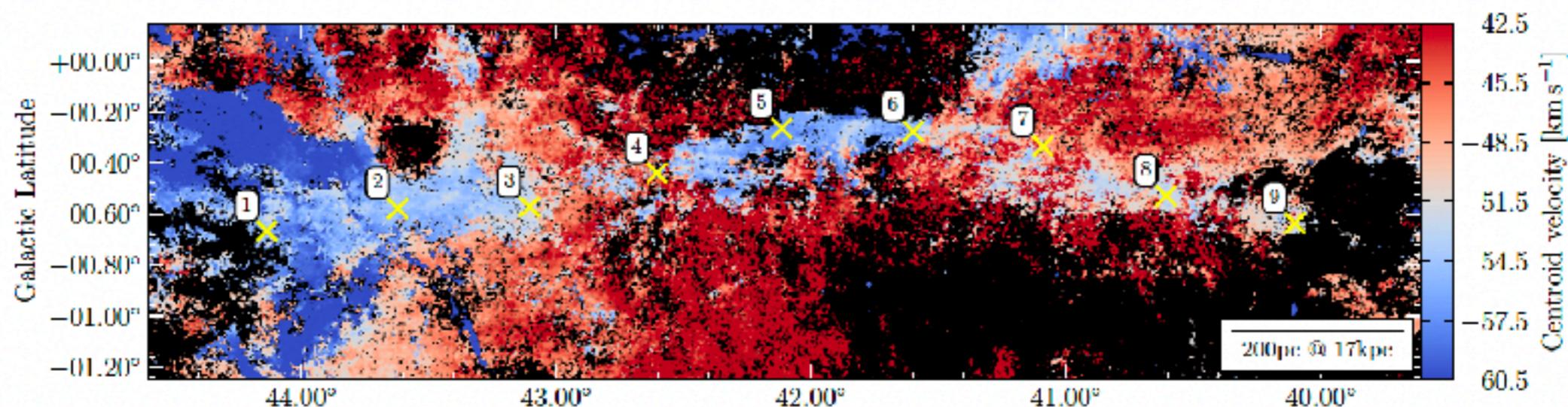
The Magdalena filament

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

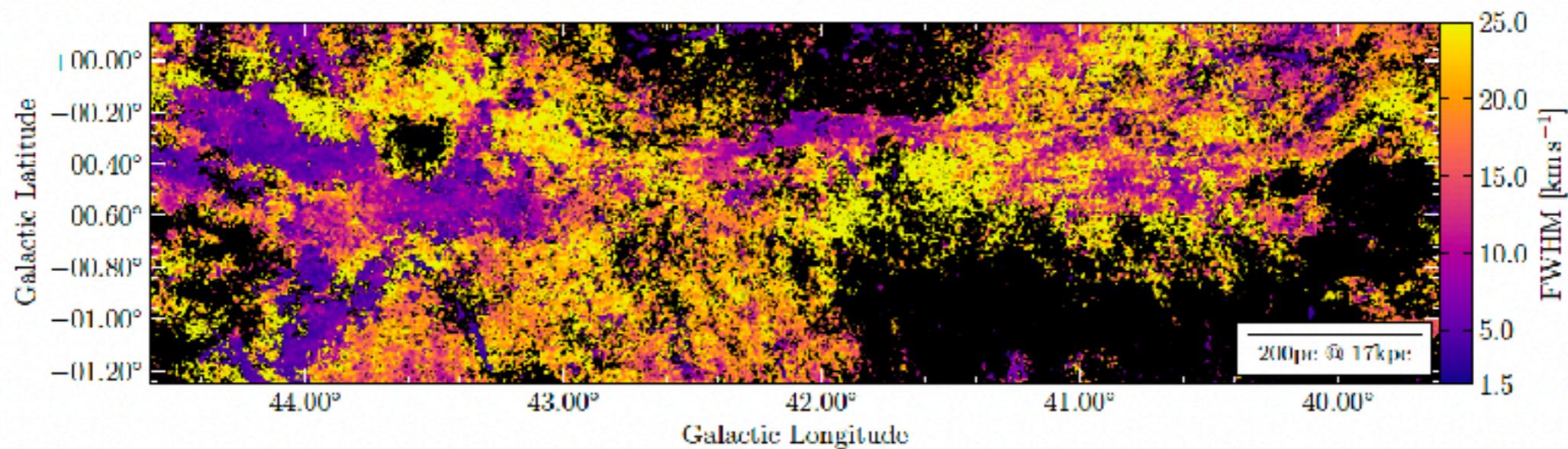
N_{H}



$\langle v \rangle$

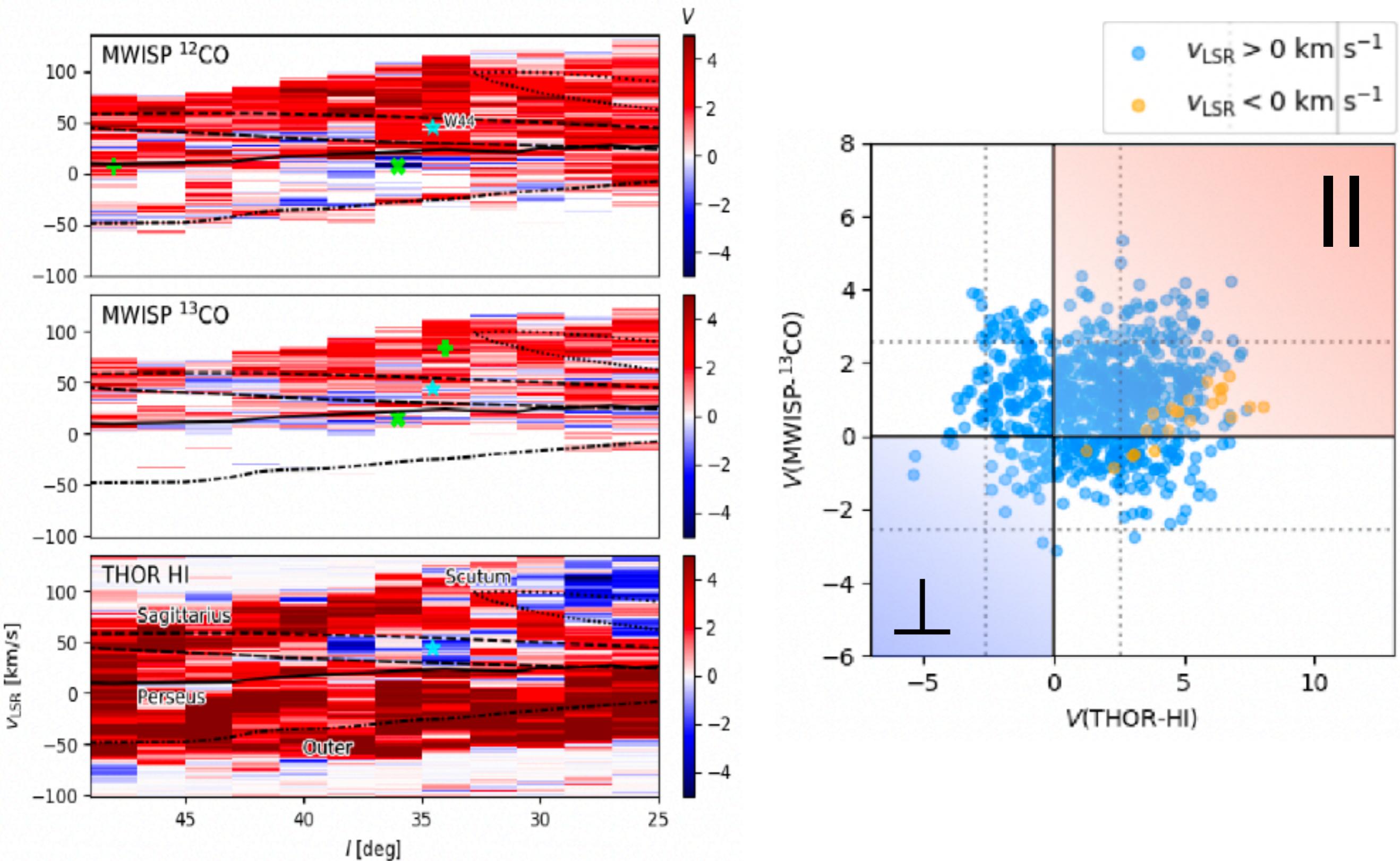


σ_v



CO filament orientation

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

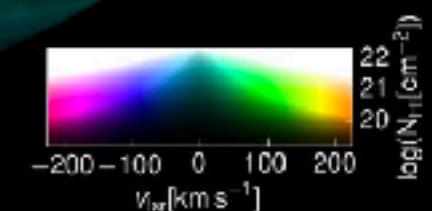


Atomic hydrogen emission

HI4PI Collaboration. A&A (2016)

16.5' HI4PI (2016)

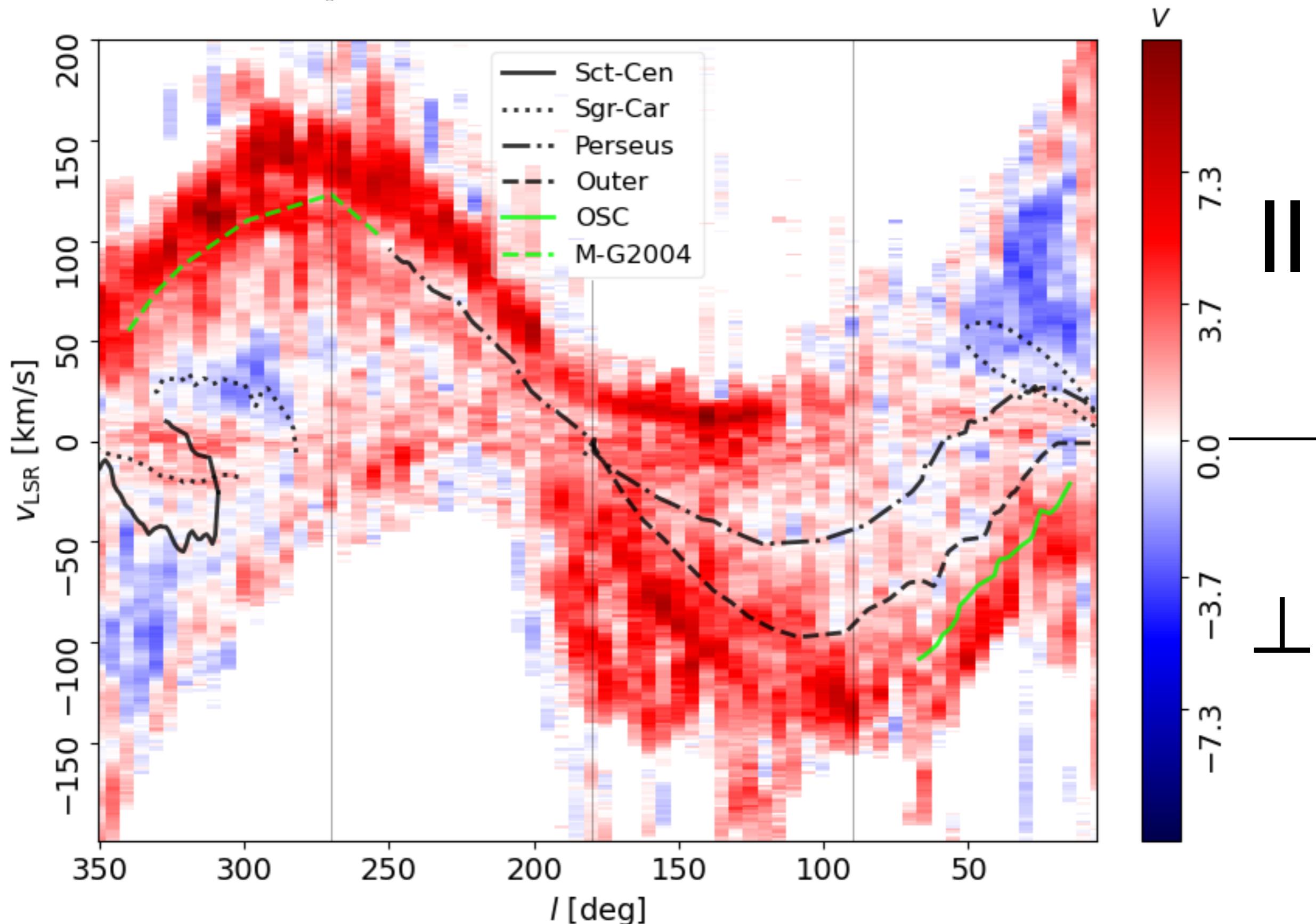
$|b| \leq 10 \text{ deg}$



Benjamin Winkel & HI4PI Collaboration

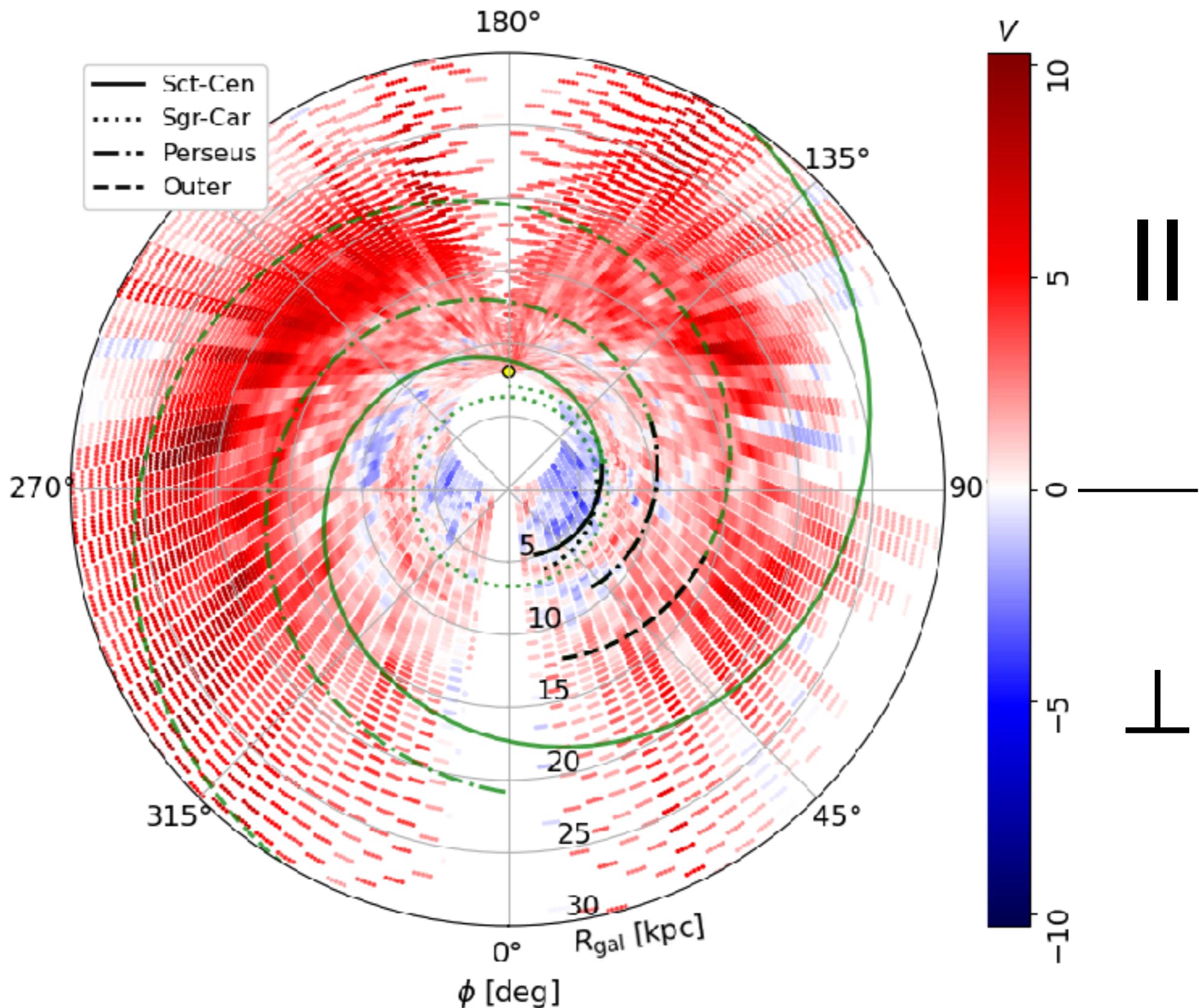
Orientation of atomic filaments

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



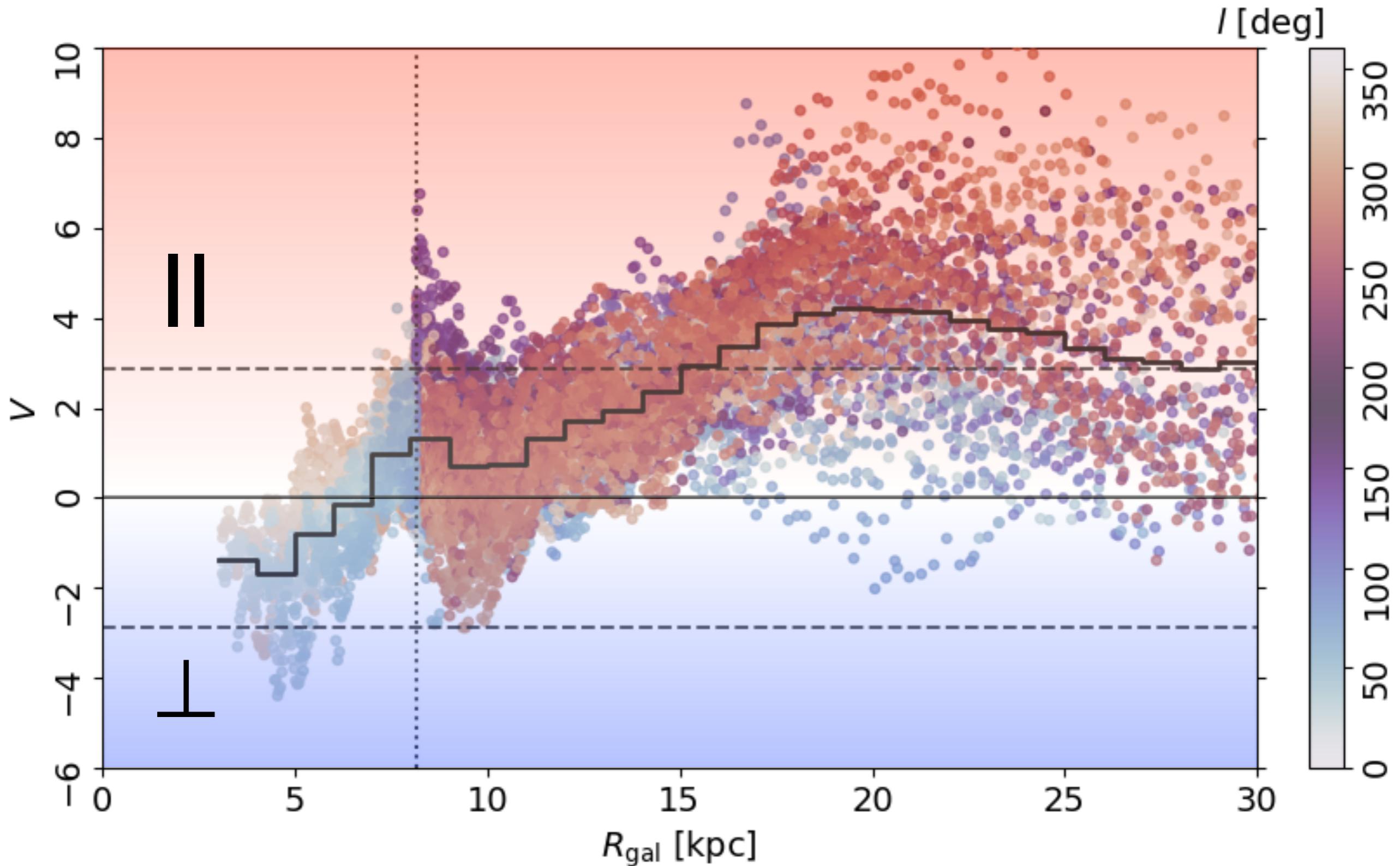
Orientation of atomic filaments

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



Atomic filament orientation

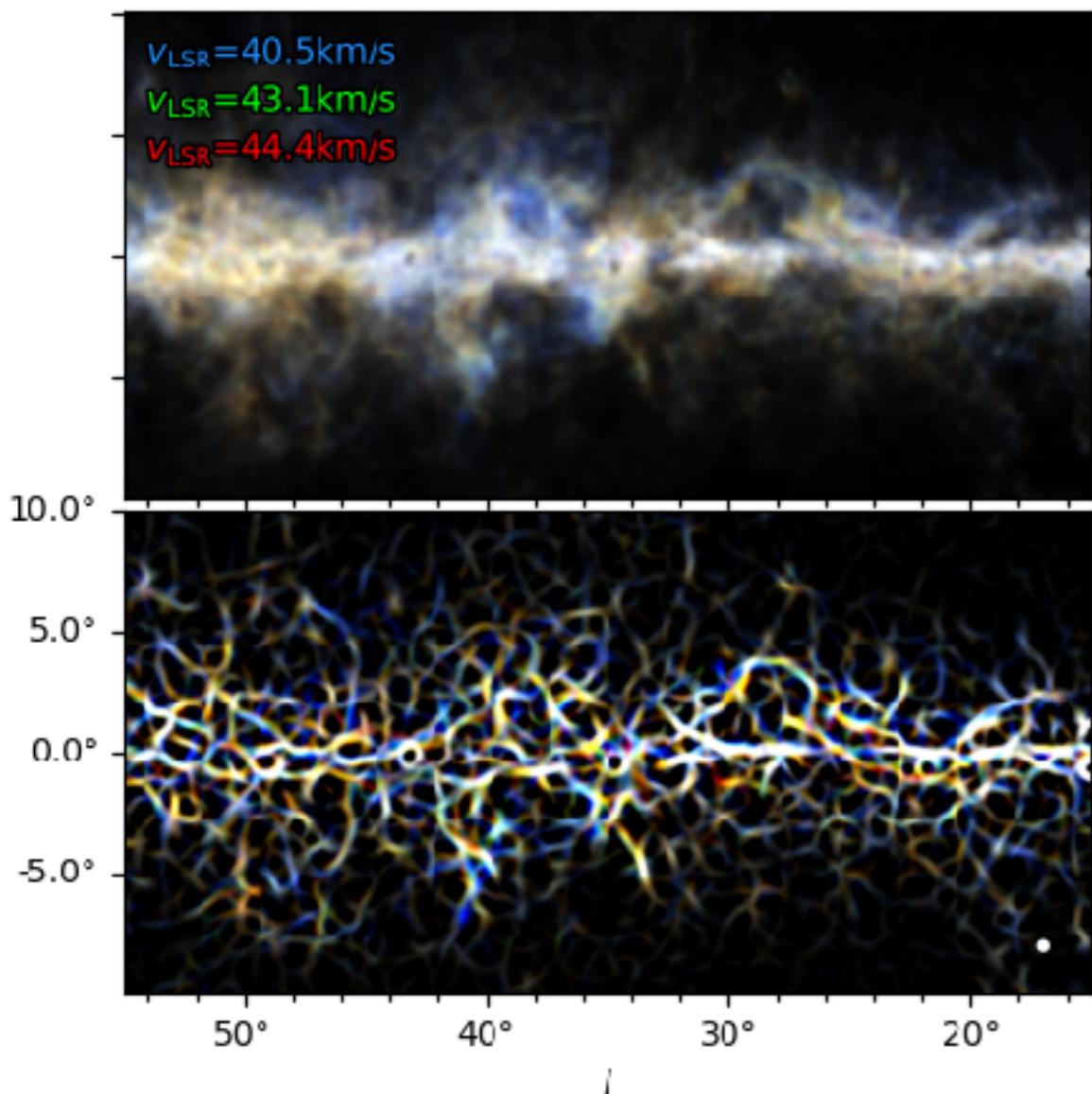
Soler, J.D. et al. 2022. A&A in press.



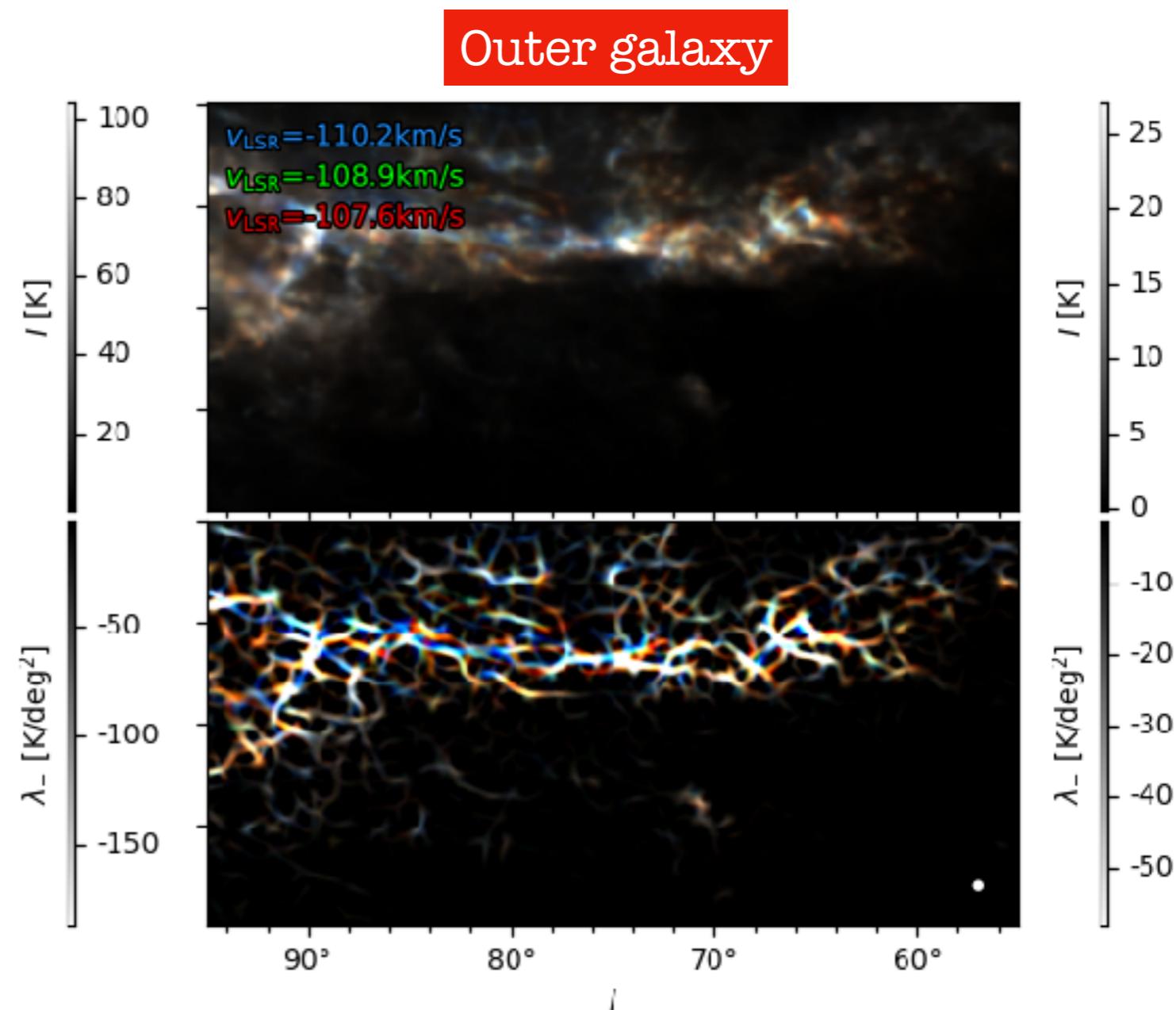
Atomic filament orientation

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

Inner galaxy

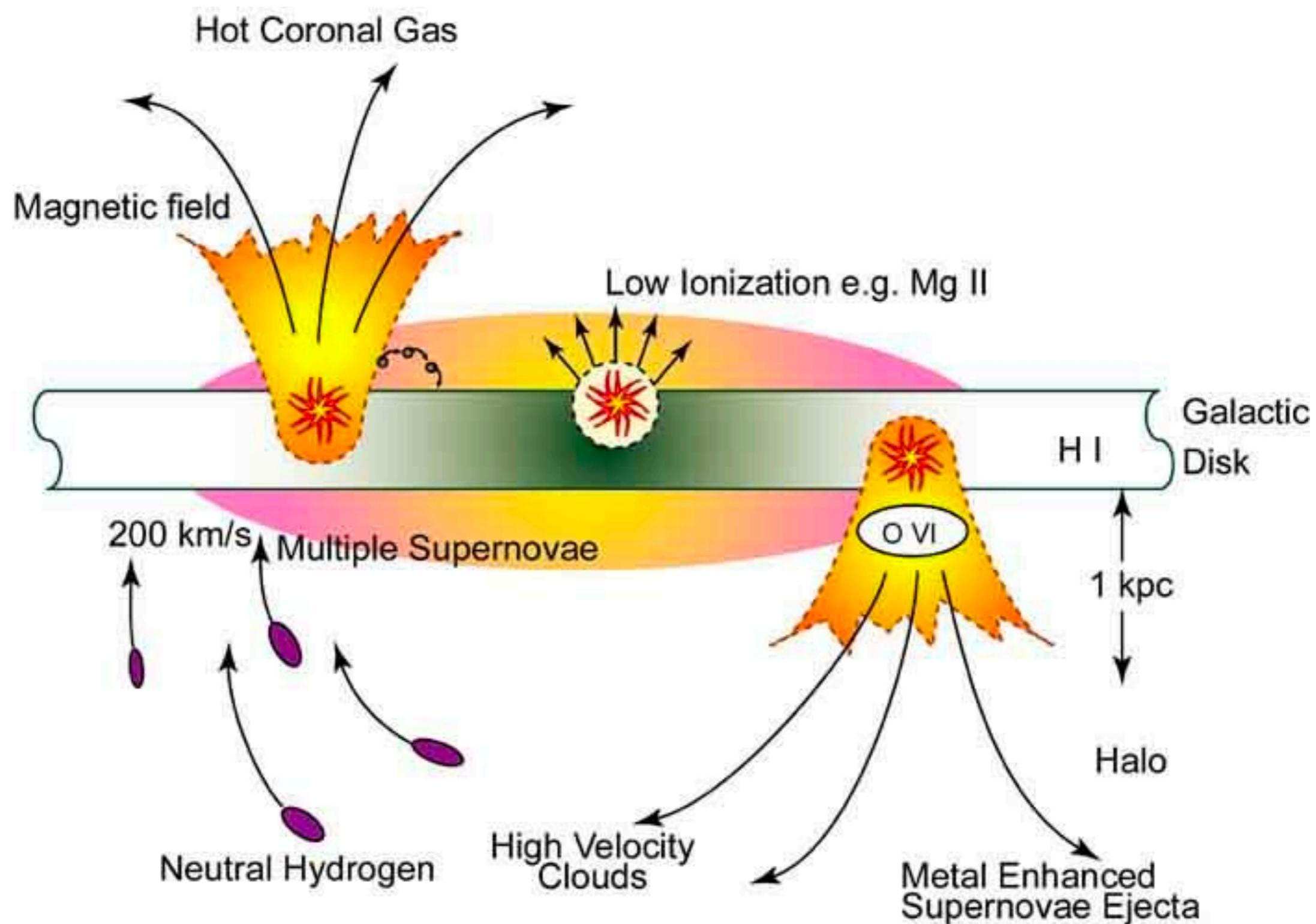


Outer galaxy



Atomic worms and chimneys

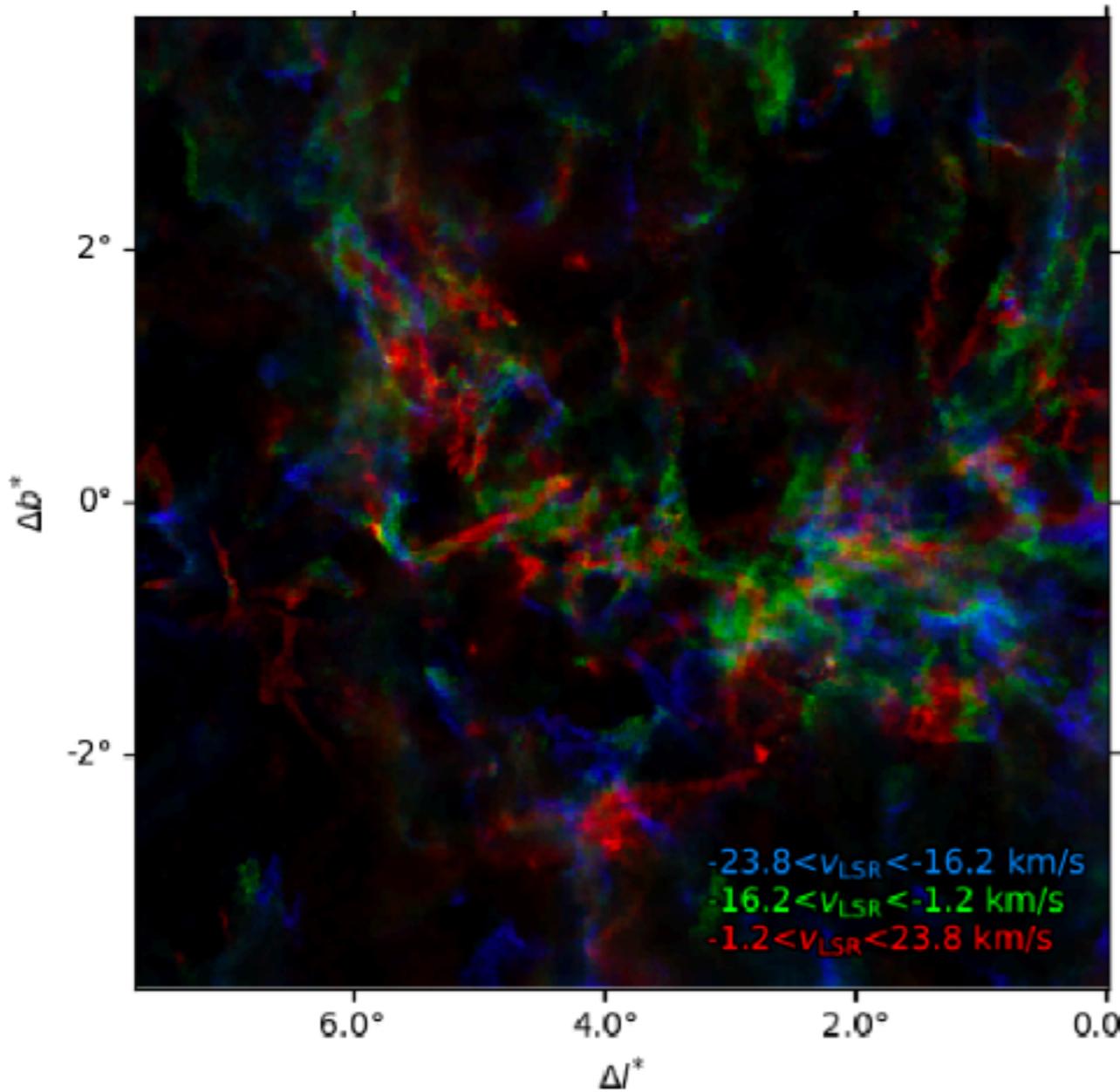
Heiles, 1994



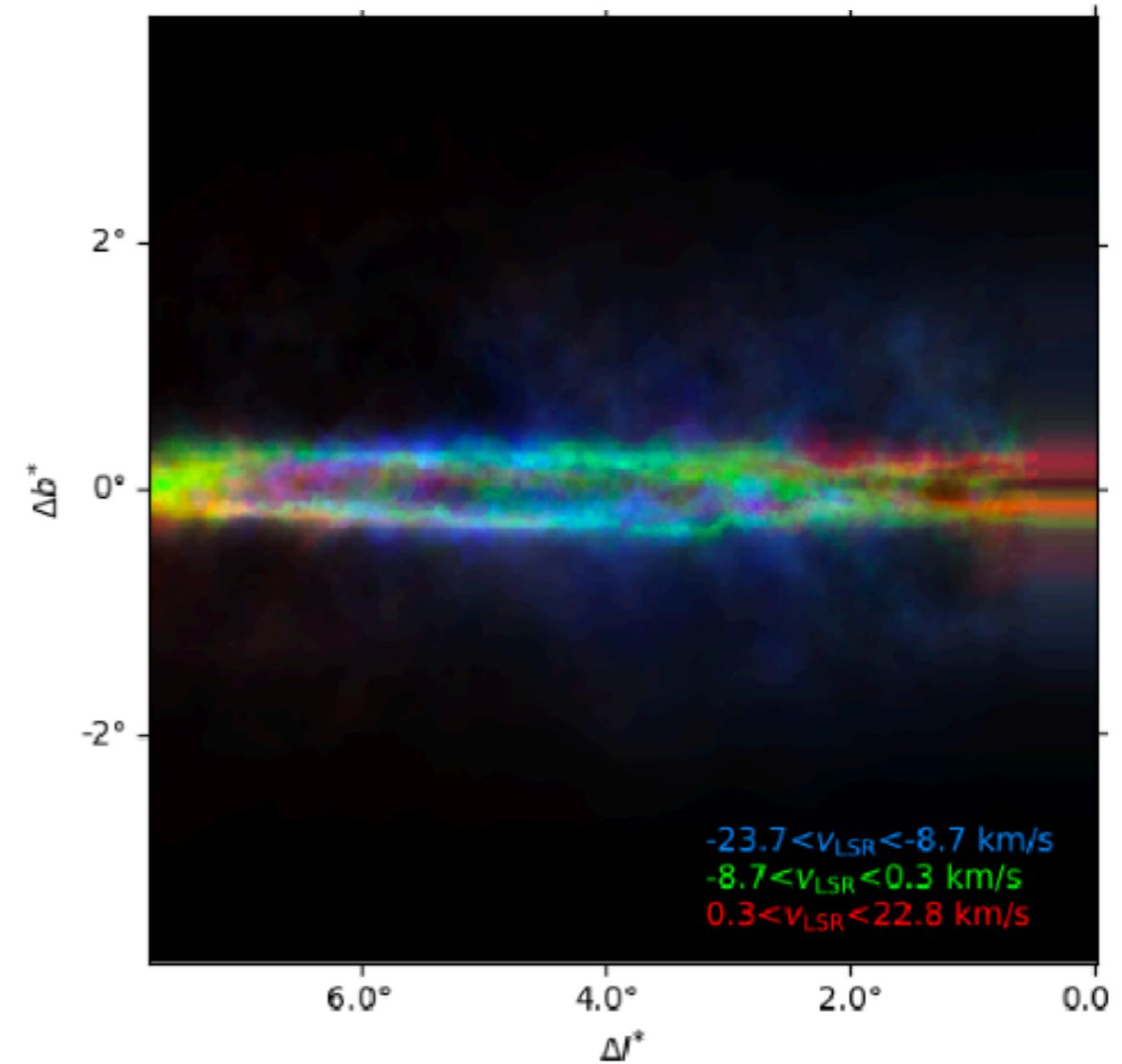
HI filaments - HD simulations

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

Feedback-dominated



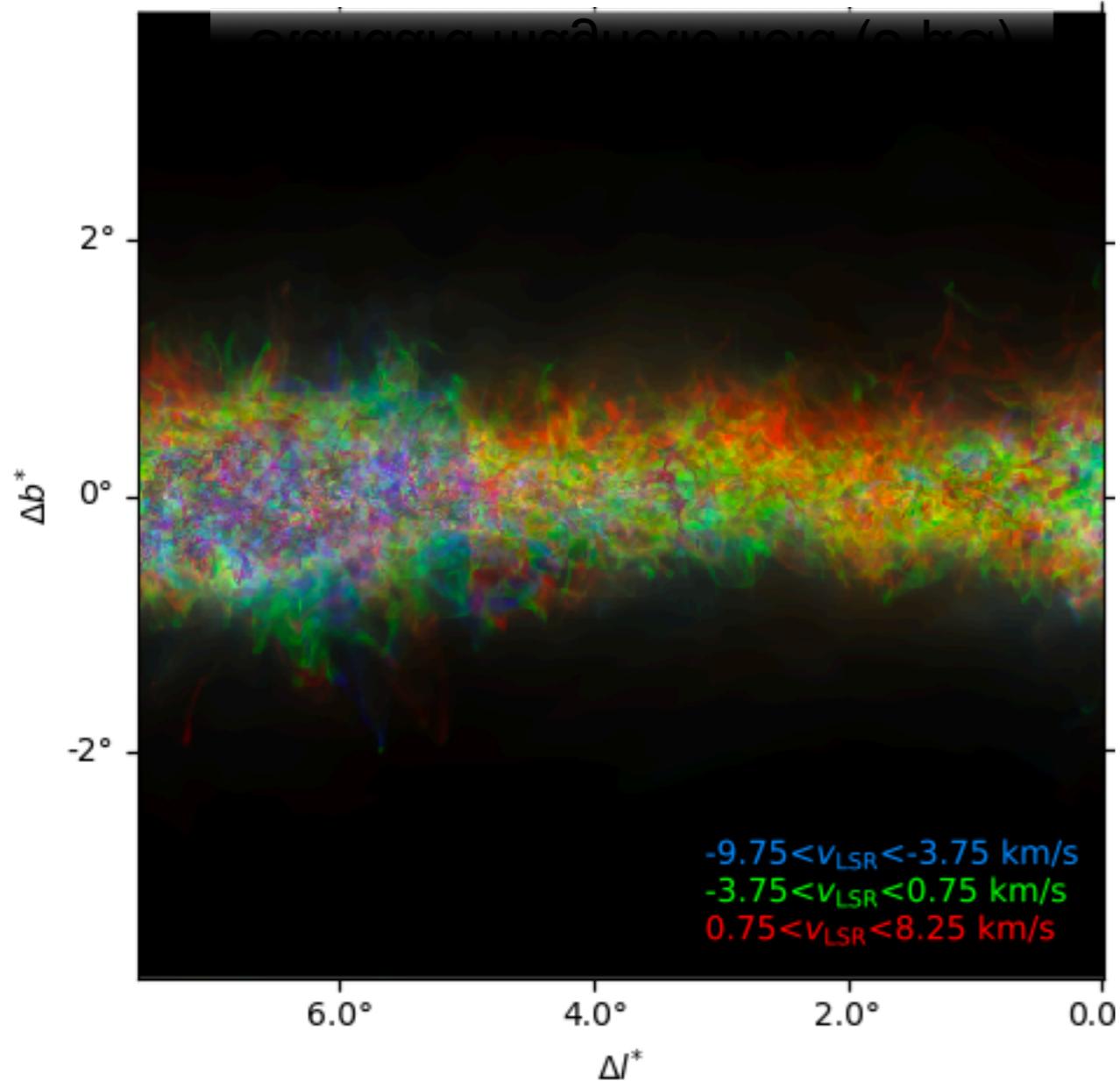
Potential-dominated



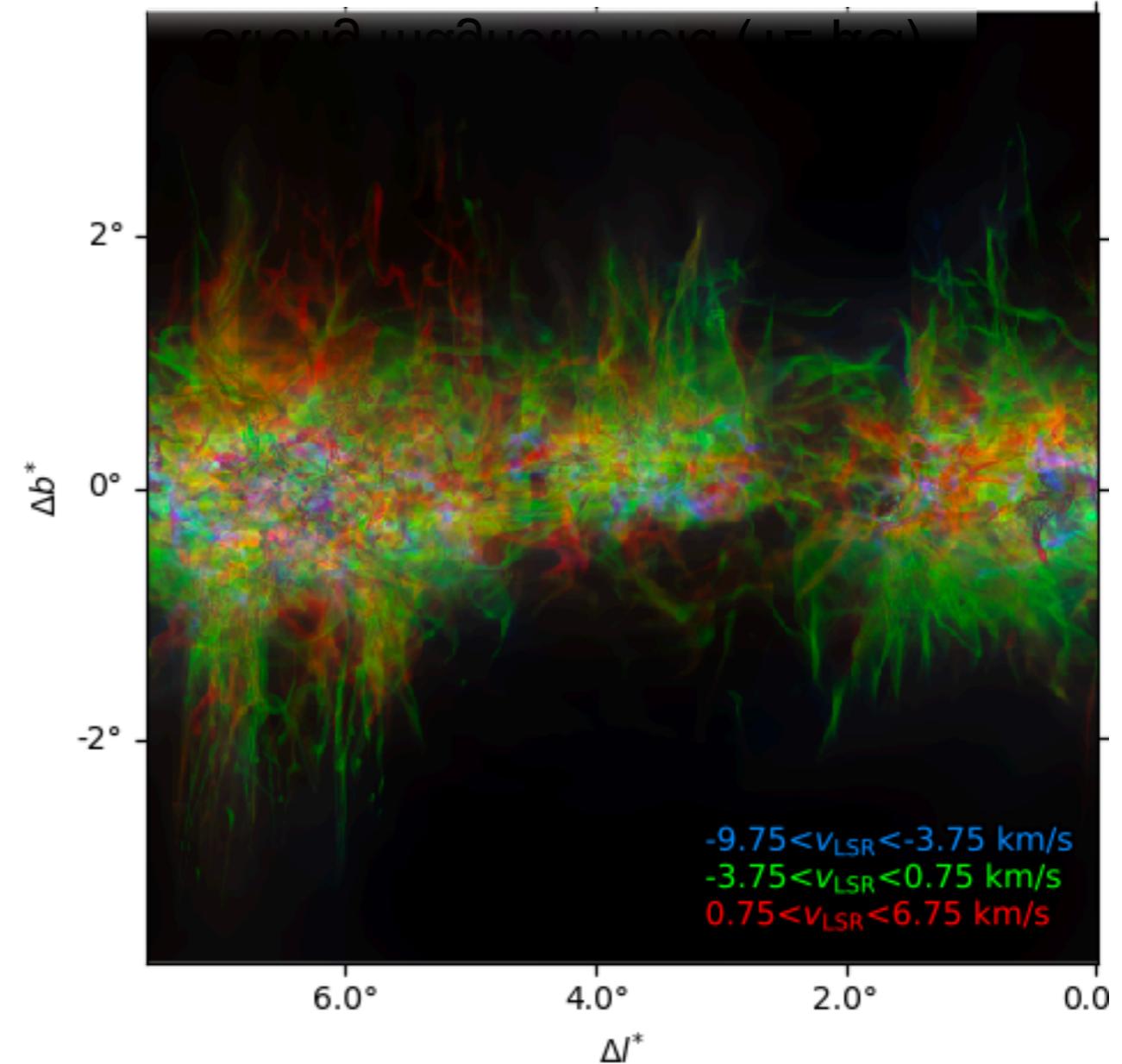
HI filaments in MHD simulations

FRIGG simulations (Hennebelle et al. A&A 2018)
Soler, J.D. et al. A&A. 2020

Standard magnetic field (3 μG)

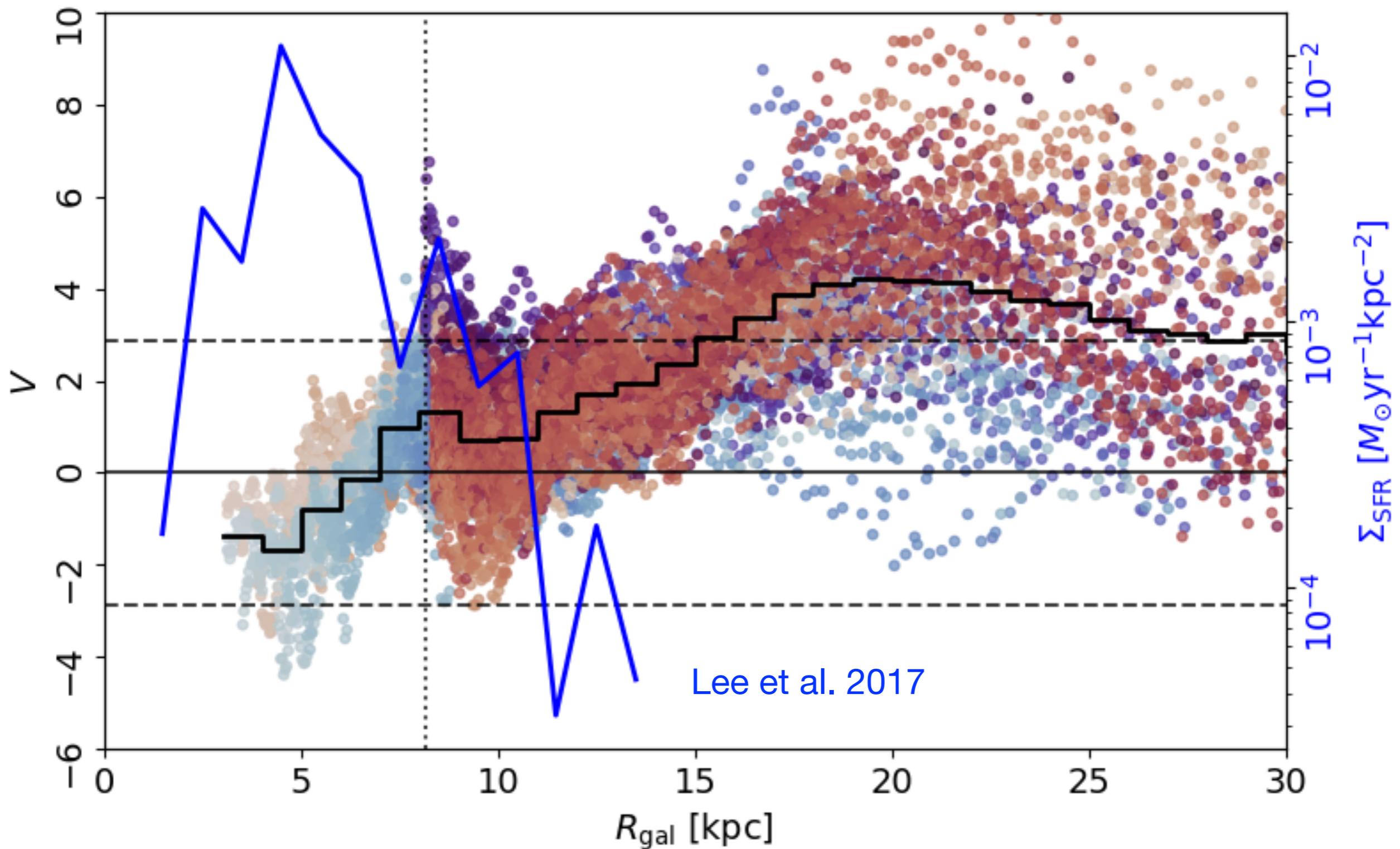


Strong magnetic field (12 μG)



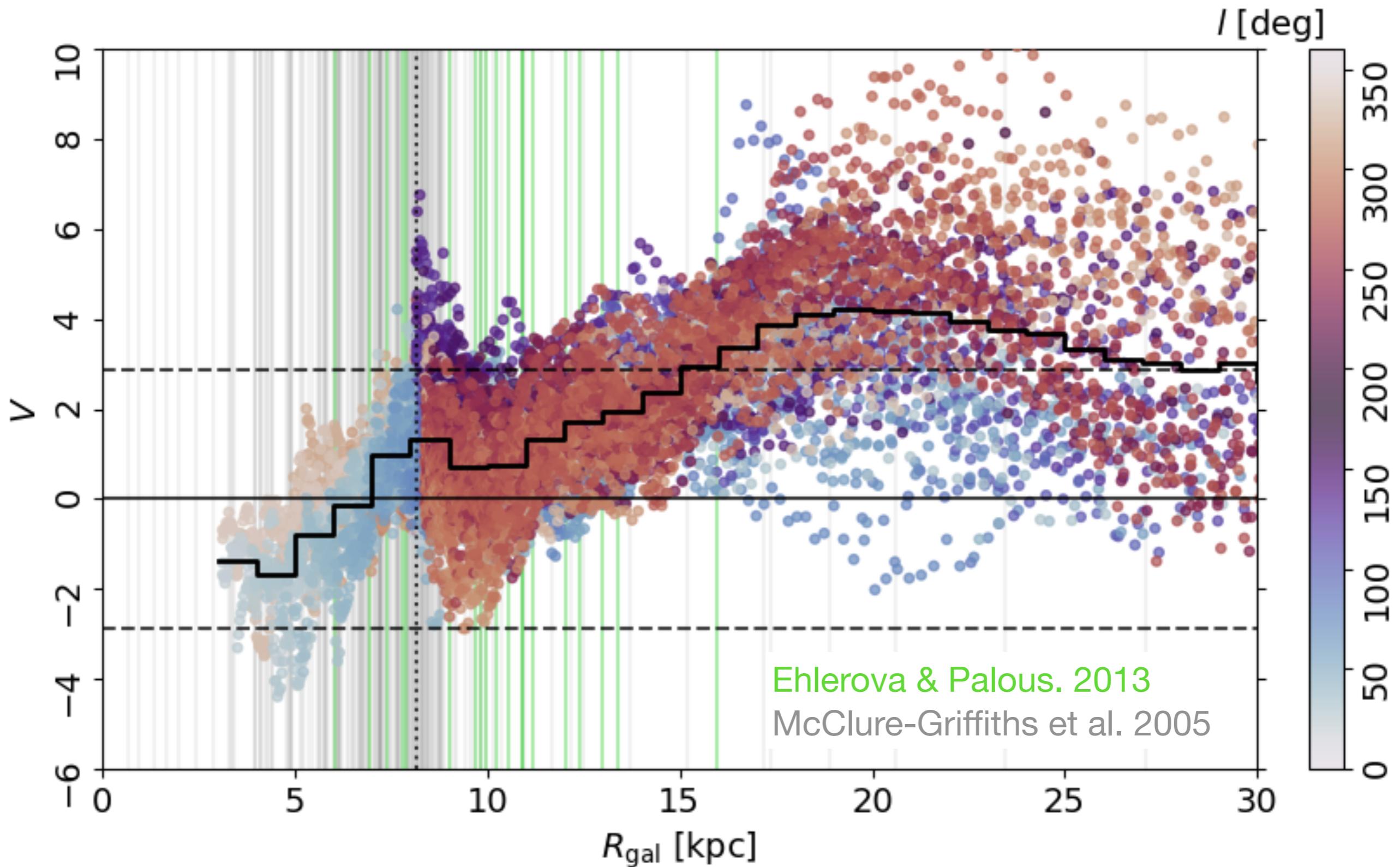
Atomic filament orientation and star formation

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.



The Galactic dynamics revealed by HI and CO emission



We found that the **HI filament orientation** changes from no preferential orientation to mainly 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 **HI filament orientation** is **not inherited** by the **CO filaments**, which may be the result of stellar feedback and magnetic fields.

Soler, J.D. et al. 2019. A&A

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

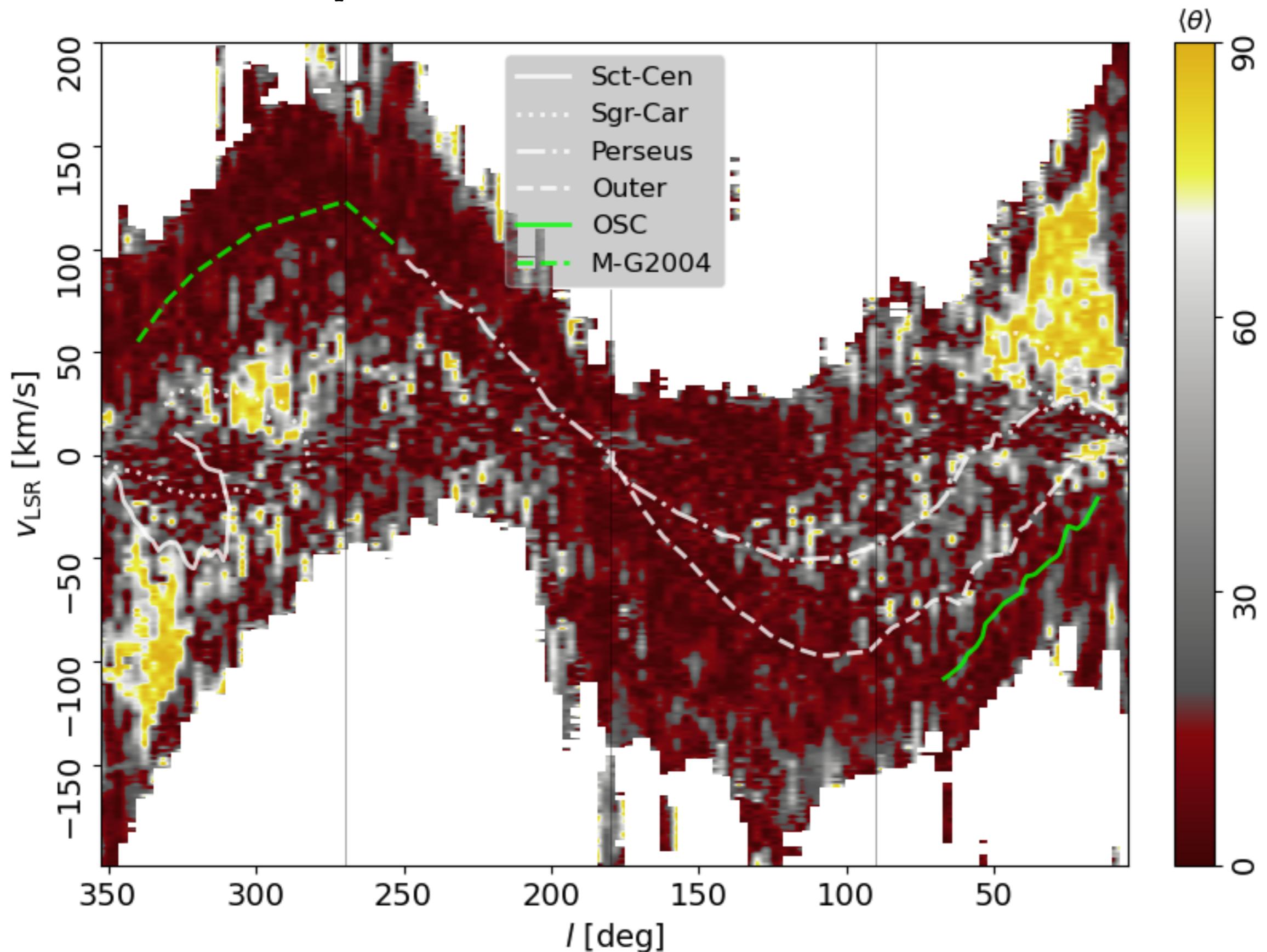
Soler, J.D. et al. 2022. A&A in press.

juandiegosolerp@gmail.com

Extra slides

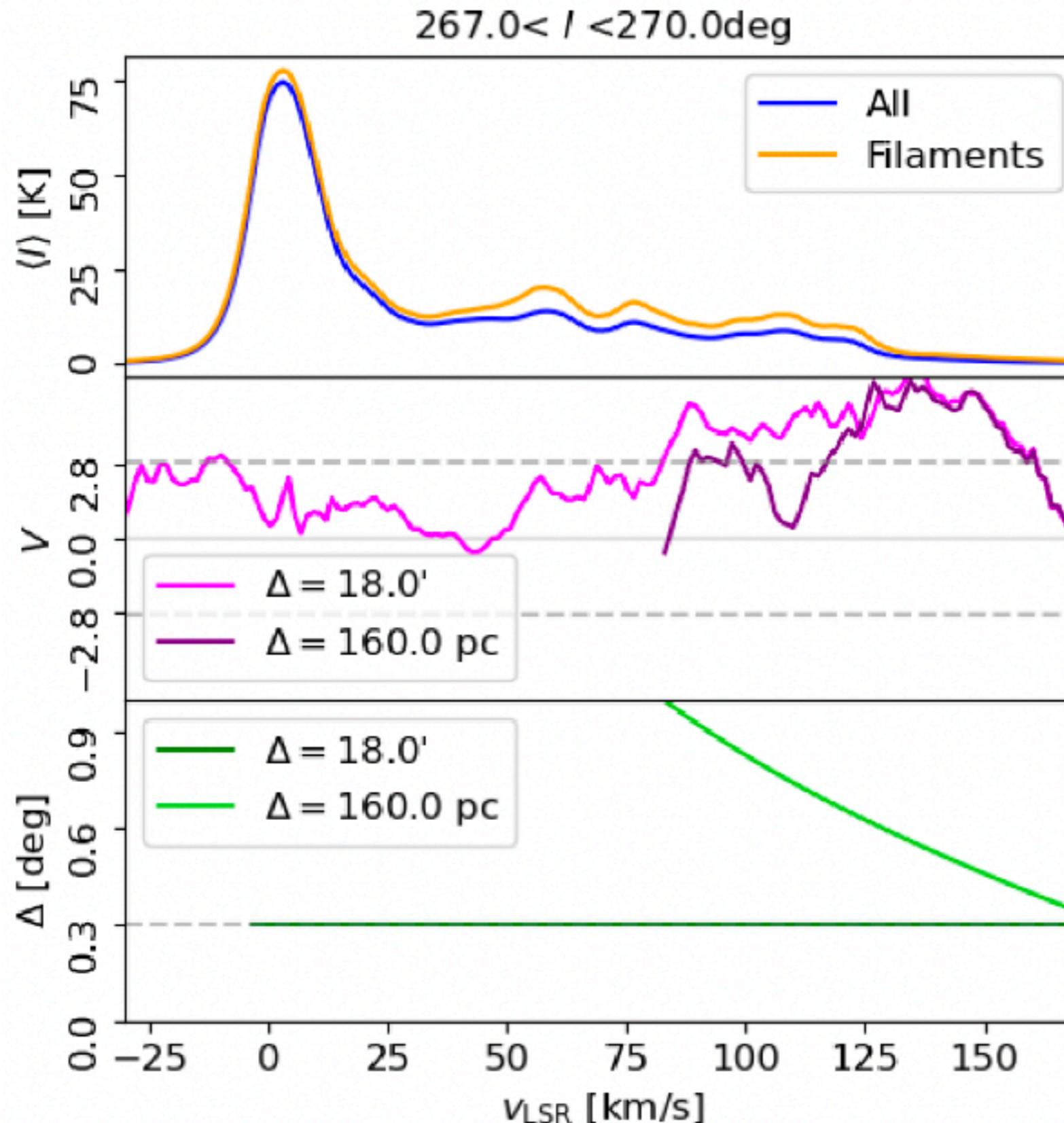
Orientation of atomic filaments

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



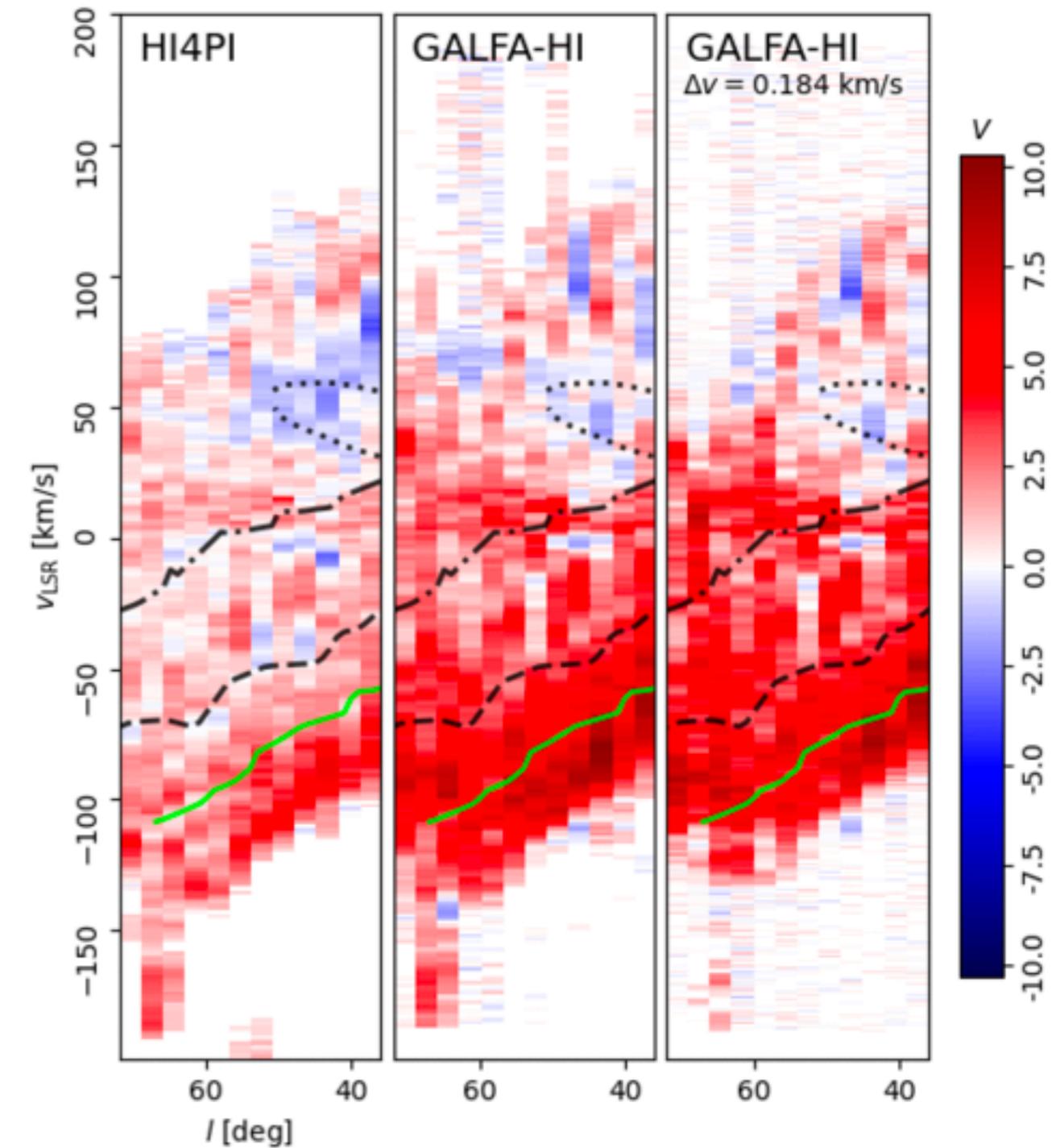
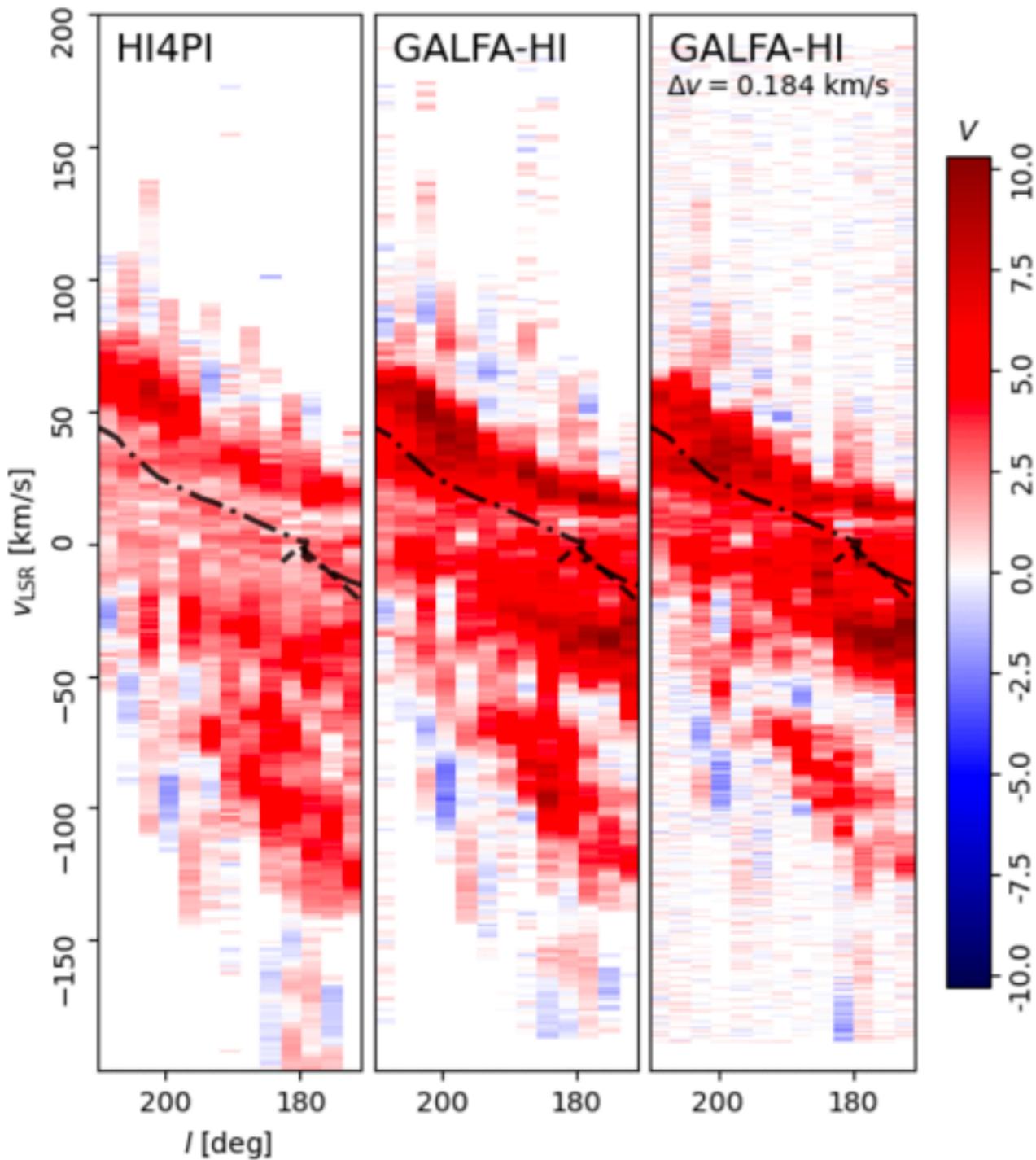
Fixed-scale derivative kernel

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



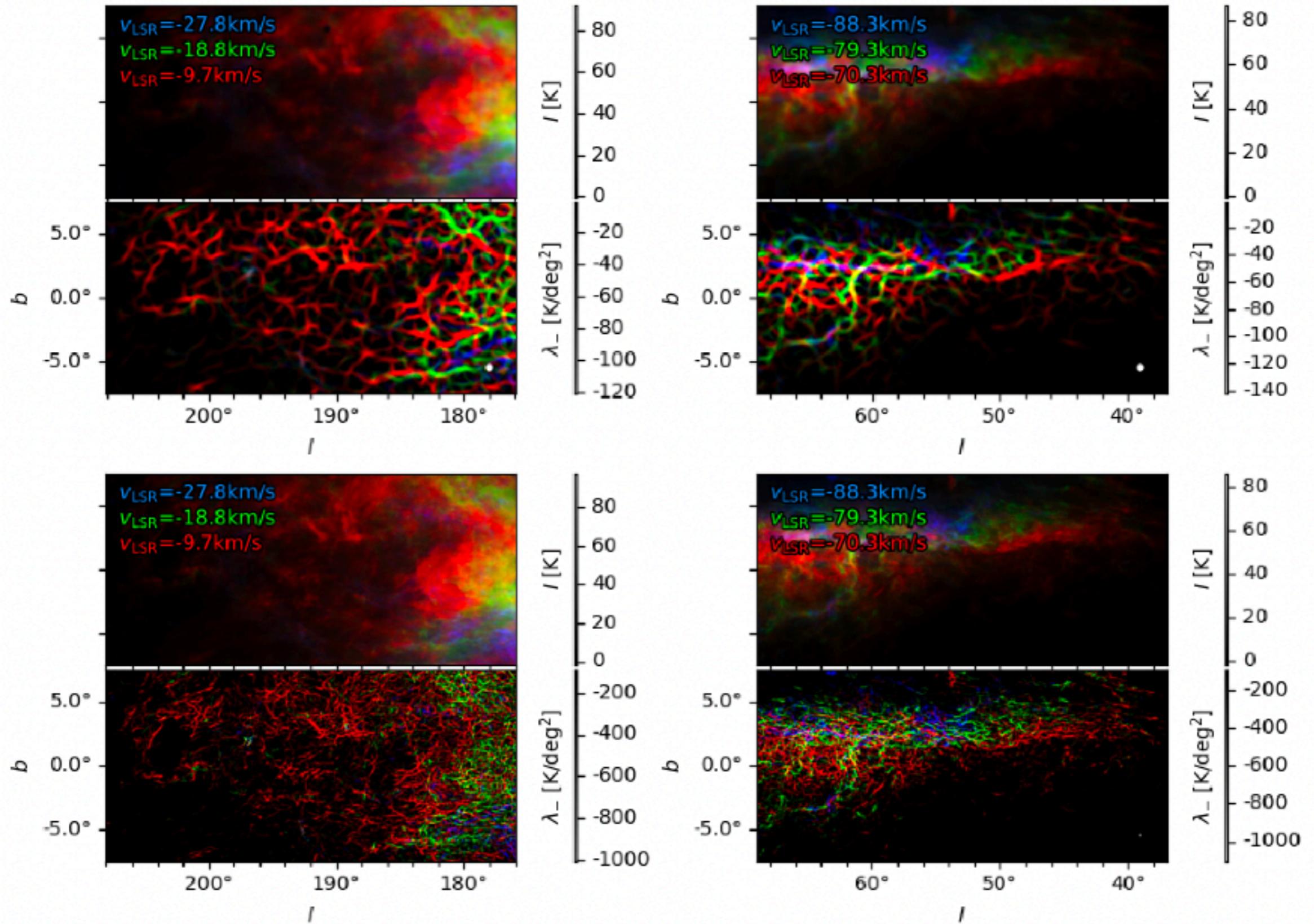
Effect of angular resolution: comparison to GALFA-HI (4')

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



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

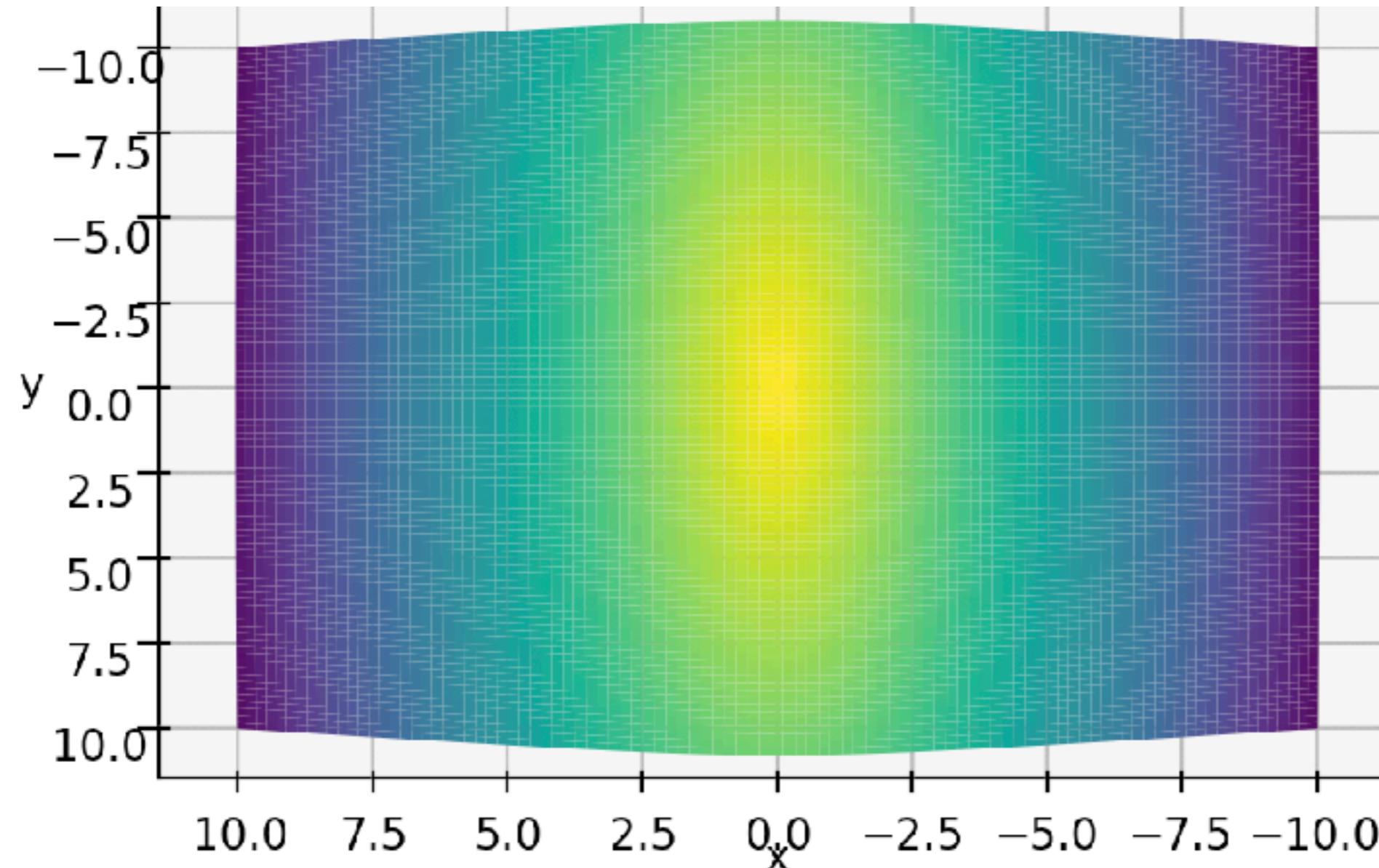
Soler, J.D. et al. 2022. A&A in press.



Machine vision: Hessian matrix method

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

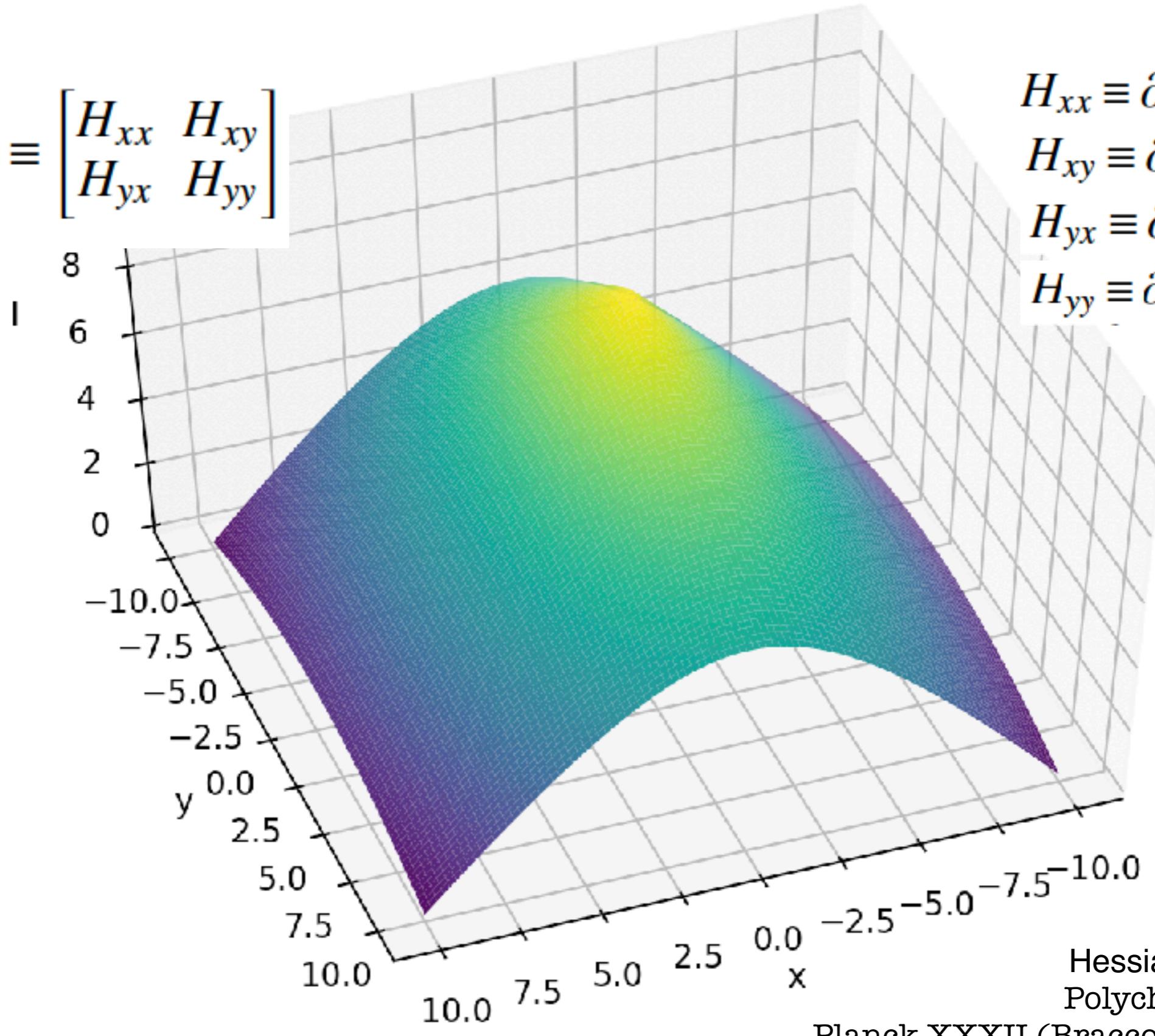
Polychroni et al. 2013
Planck XXXII (Bracco, A. et al.), 2016



Machine vision: Hessian matrix method

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

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



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

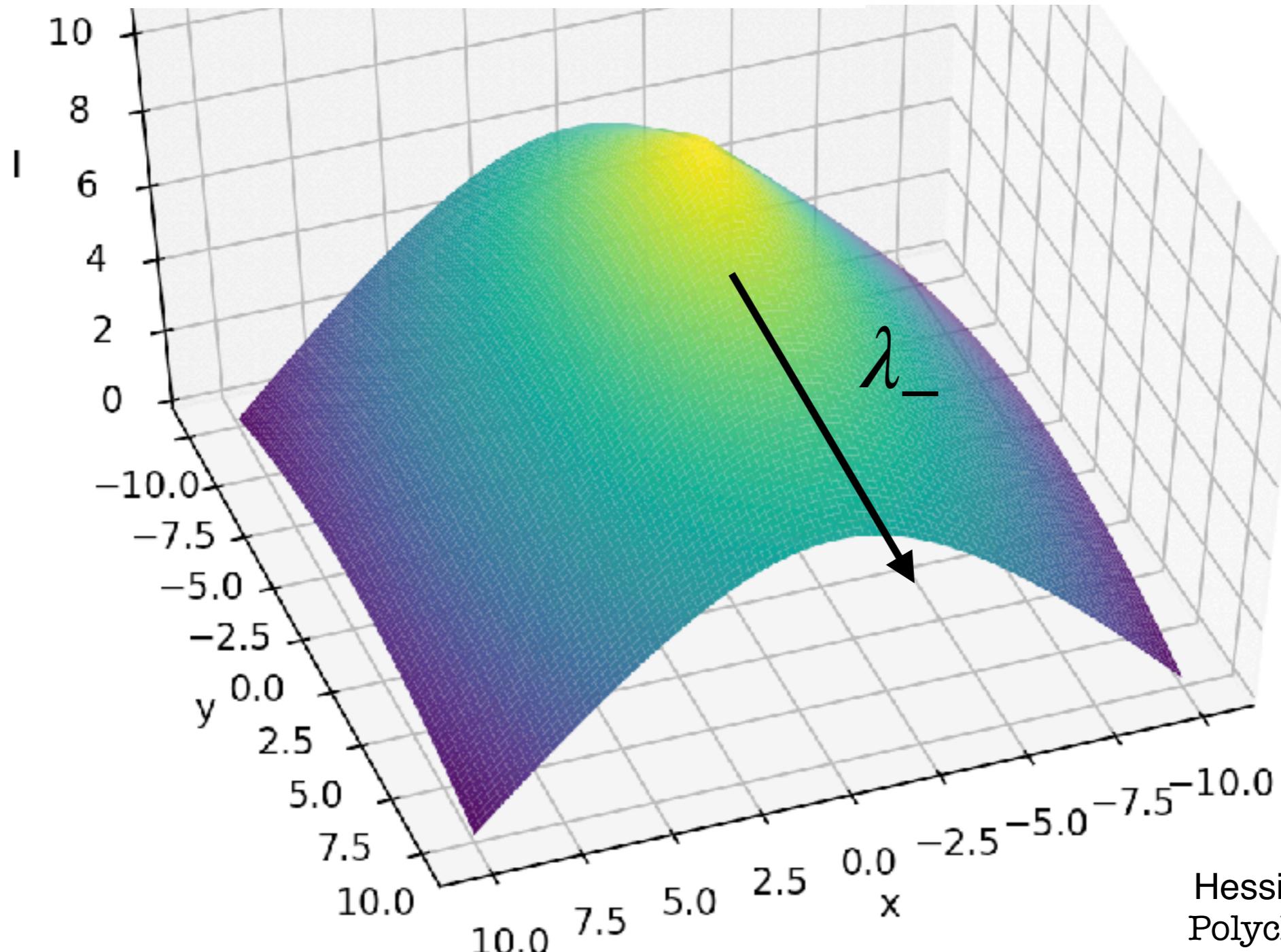
Hessian matrix method
Polychroni et al. 2013
Planck XXXII (Bracco, A. et al.), 2016

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

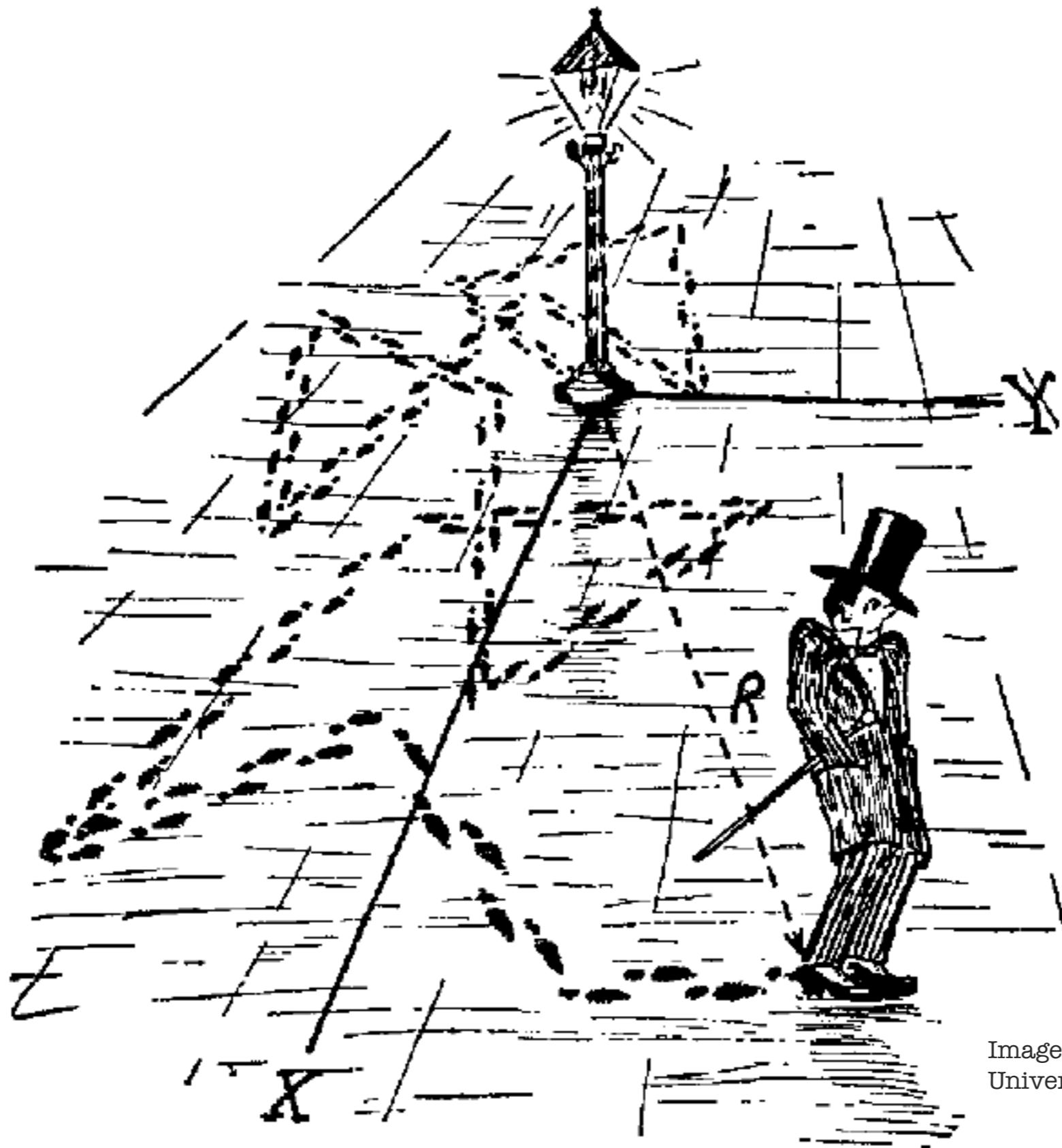
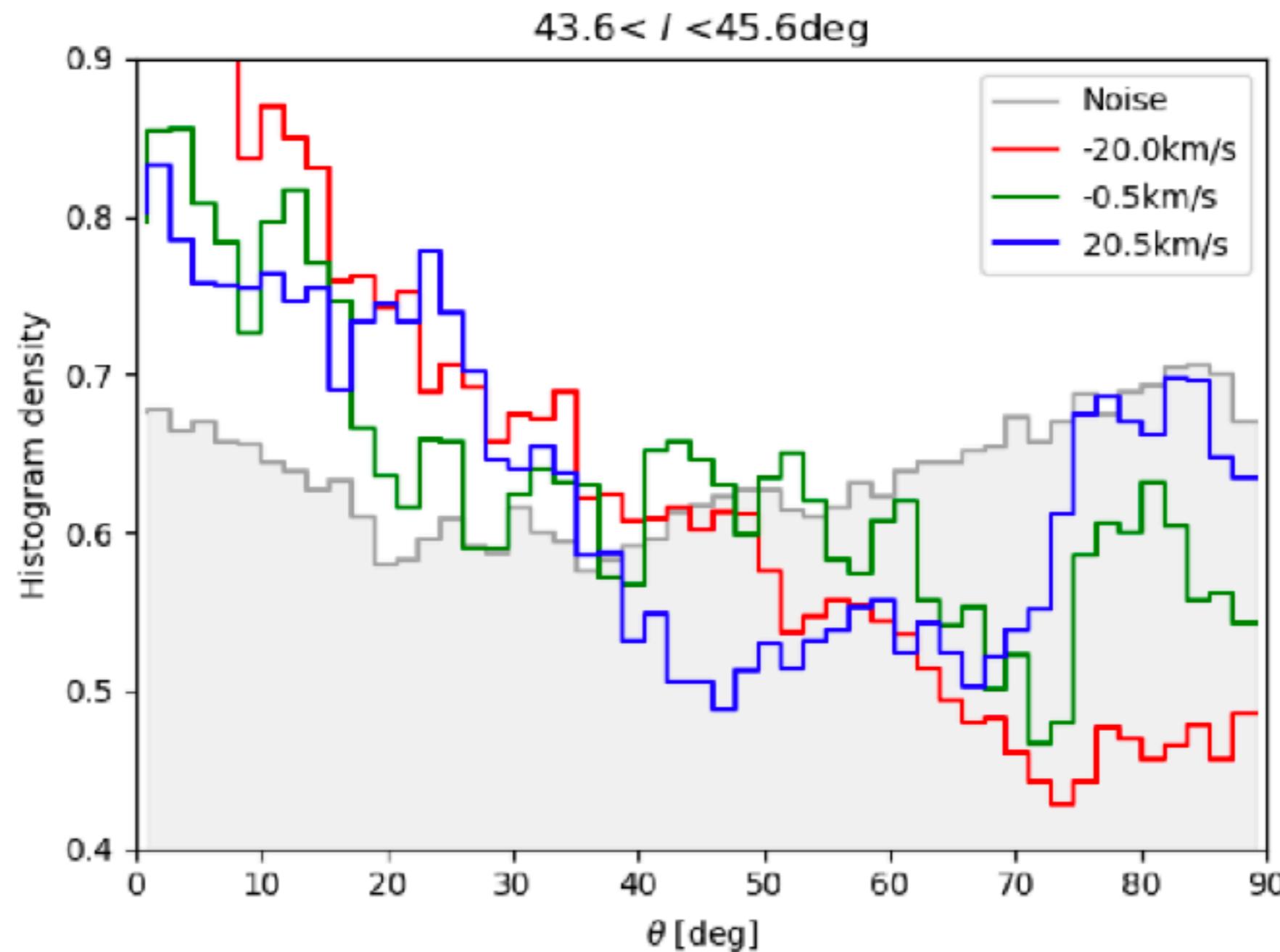


Image: Advanced Design Studies
University of Tokyo

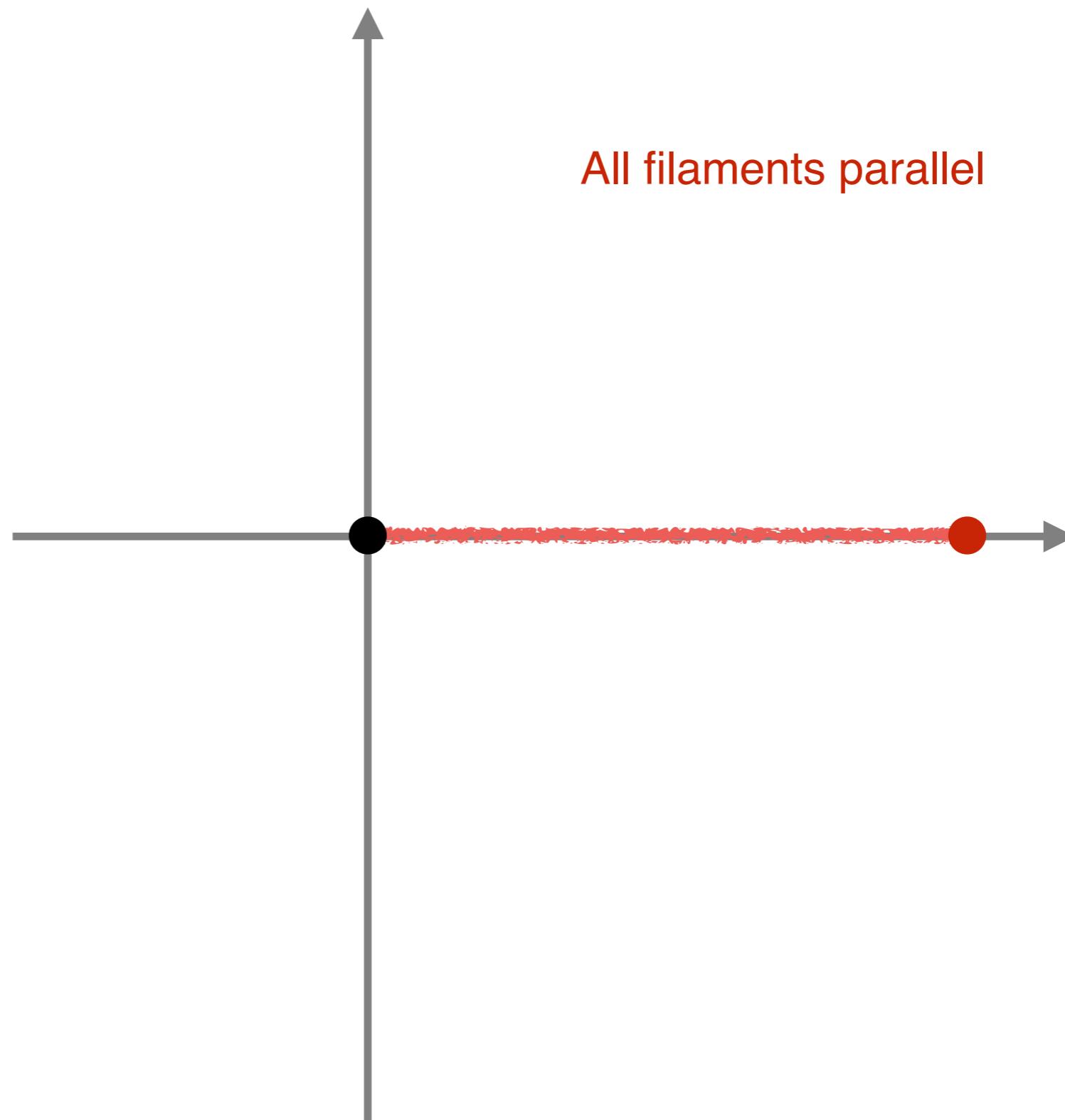
Histograms of HI filament orientation

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



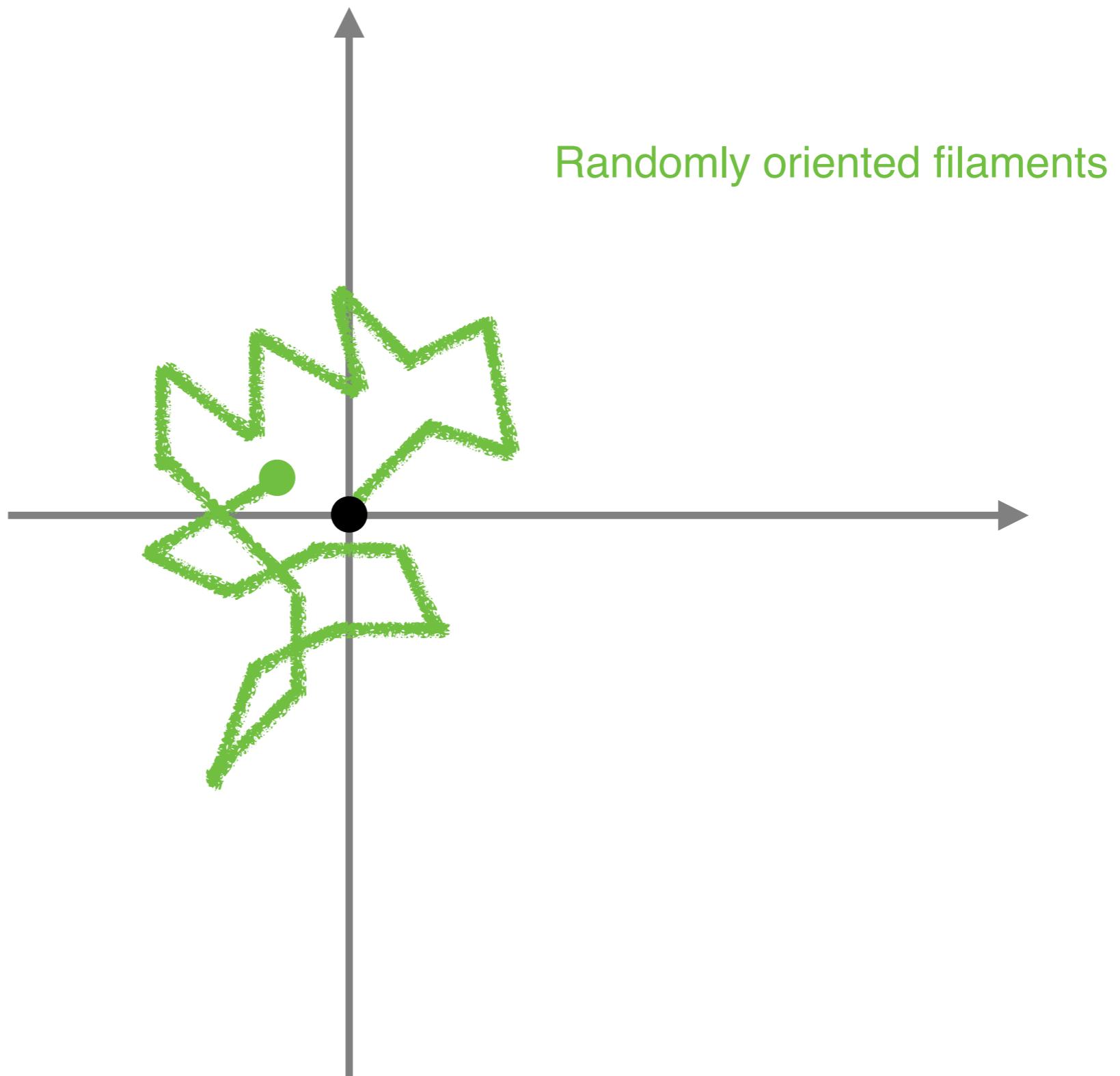
HI filament orientation: random walk interpretation

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



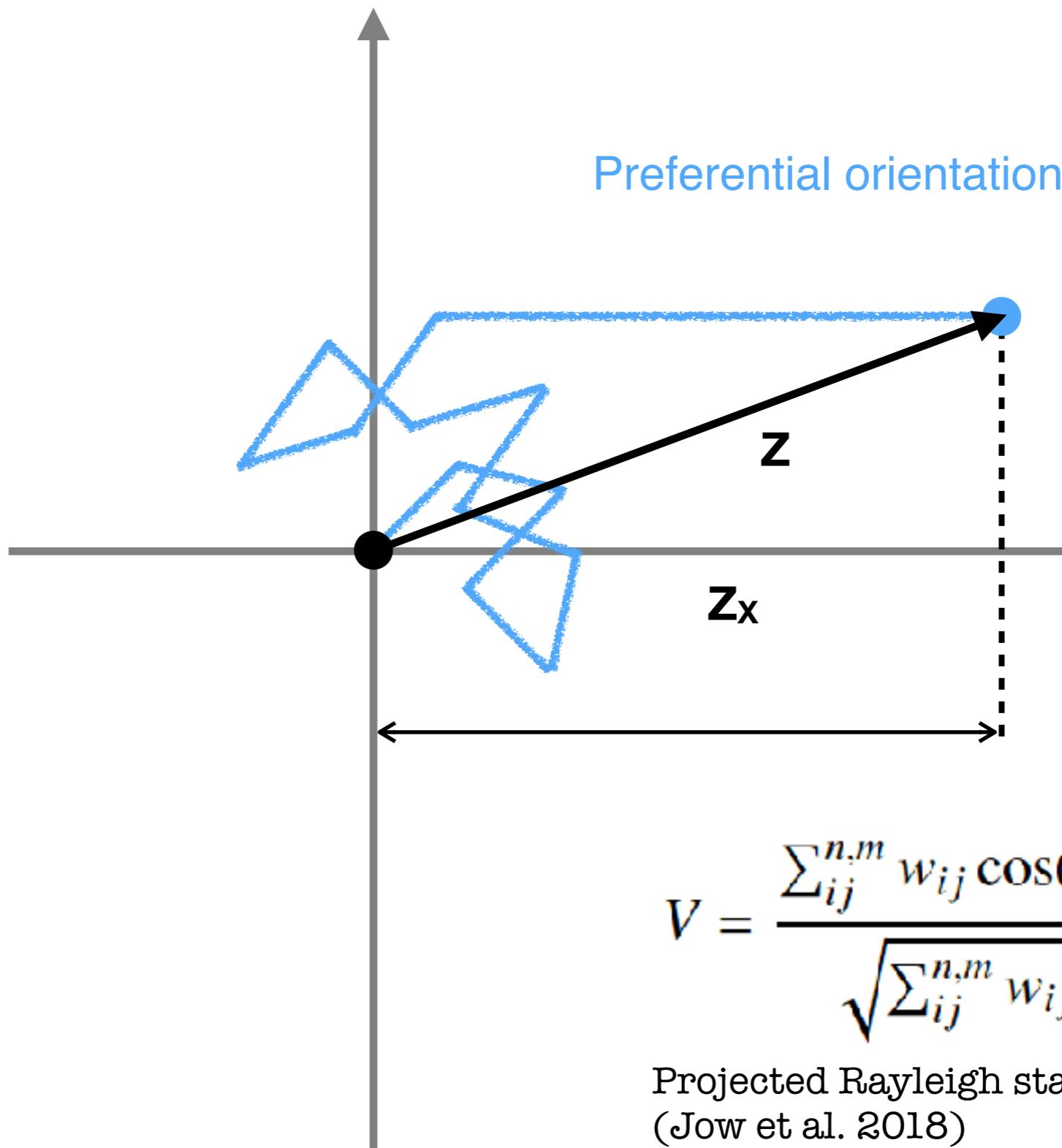
HI filament orientation: random walk interpretation

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



HI filament orientation: random walk interpretation

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

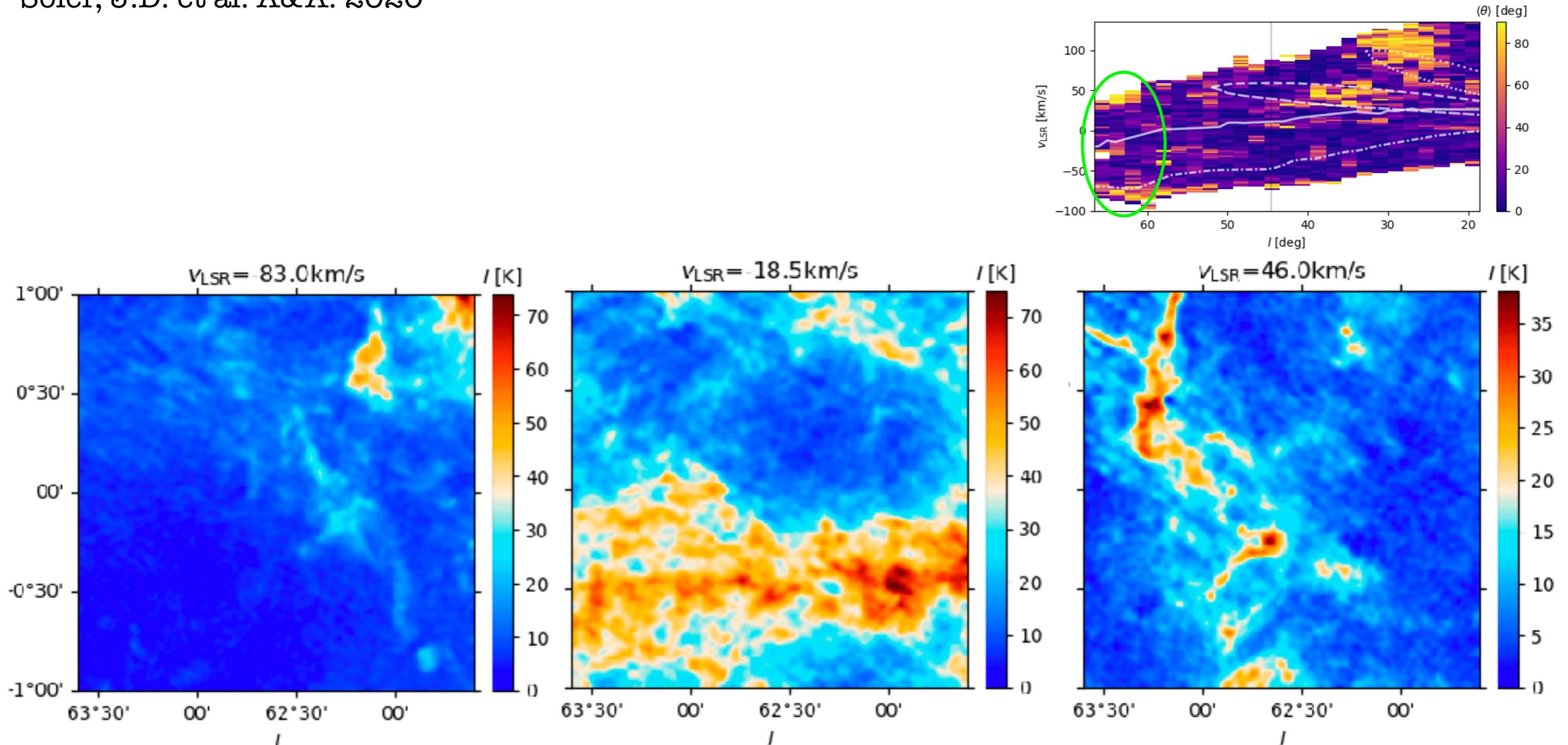


$$V = \frac{\sum_{ij}^{n,m} w_{ij} \cos(2\theta_{ij})}{\sqrt{\sum_{ij}^{n,m} w_{ij}/2}}$$

Projected Rayleigh statistic
(Jow et al. 2018)

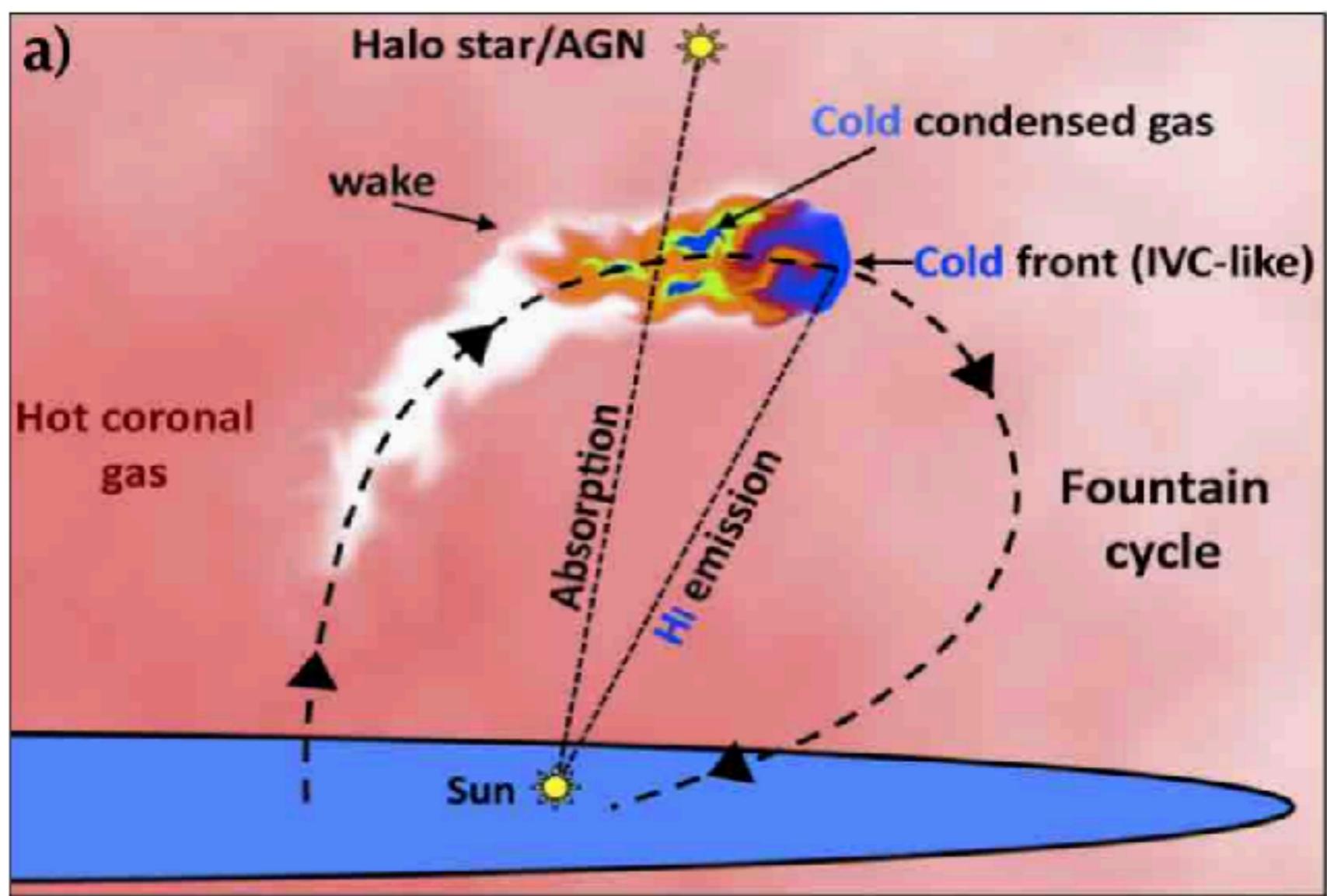
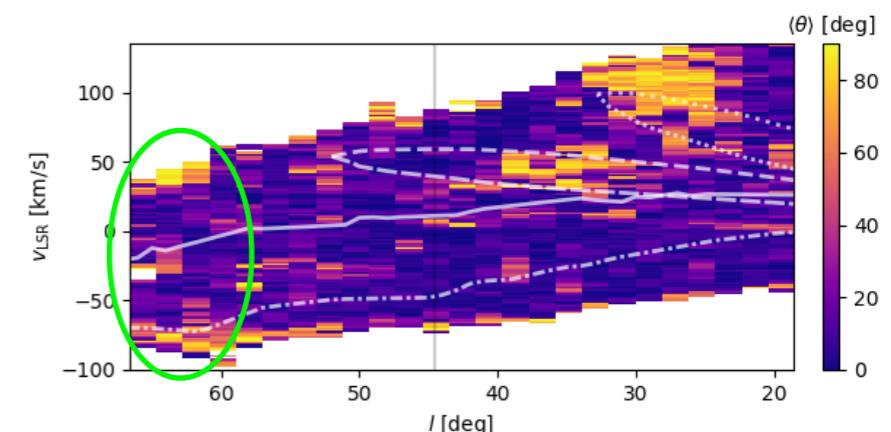
HI filaments - terminal velocities

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



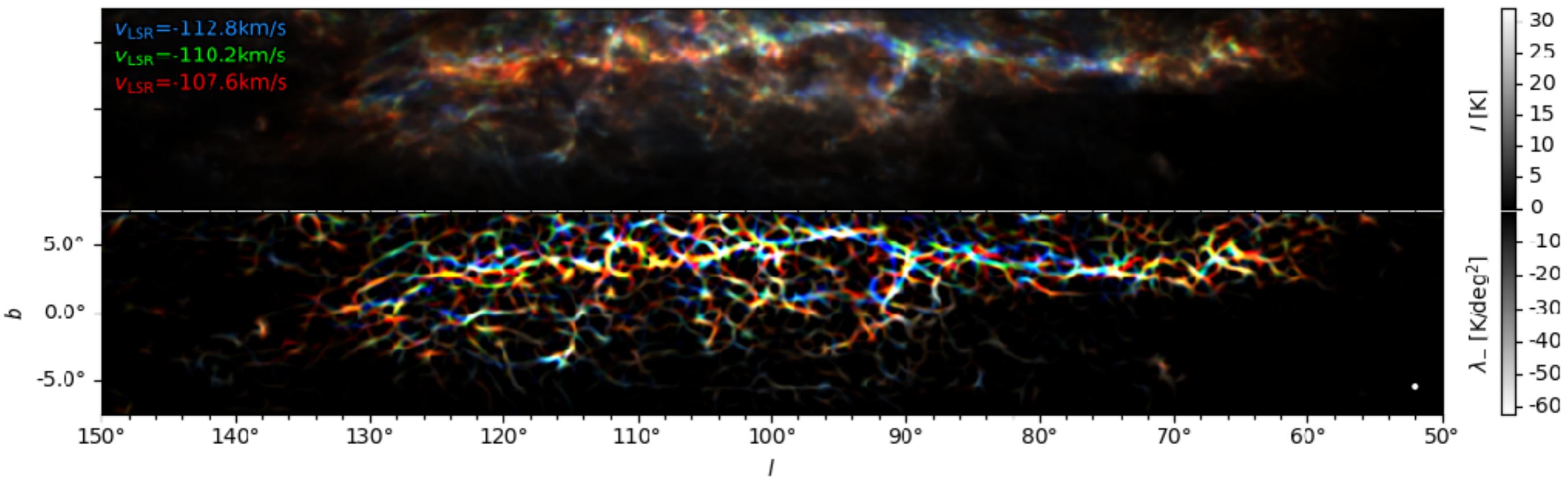
Extrapolanar gas

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



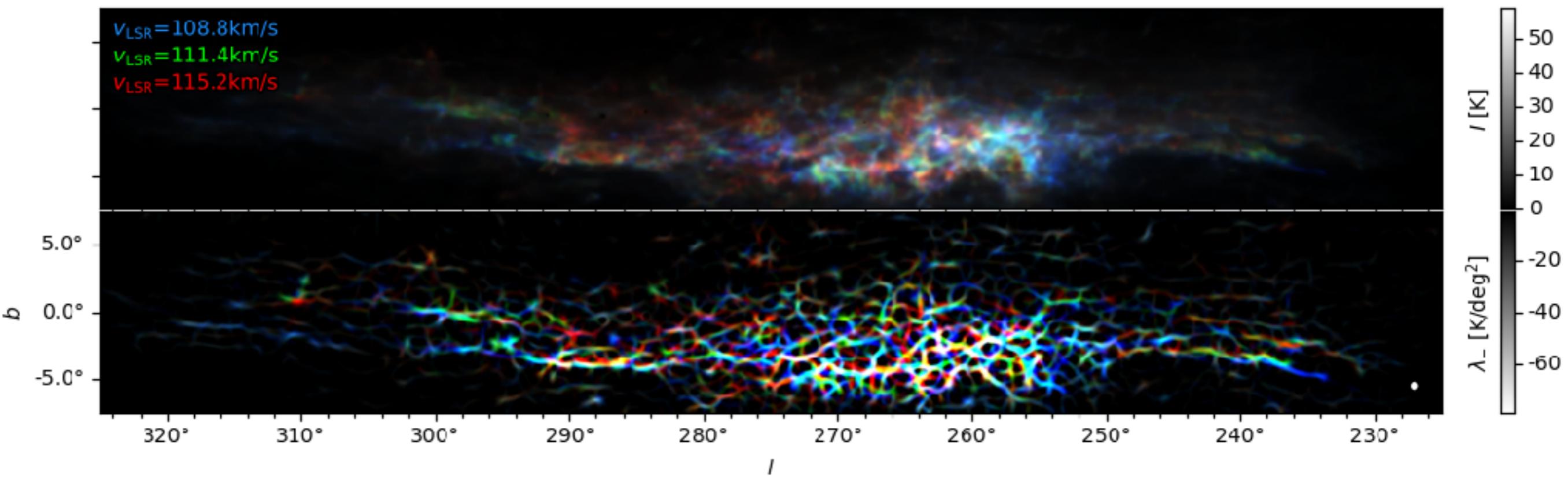
Atomic filaments

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



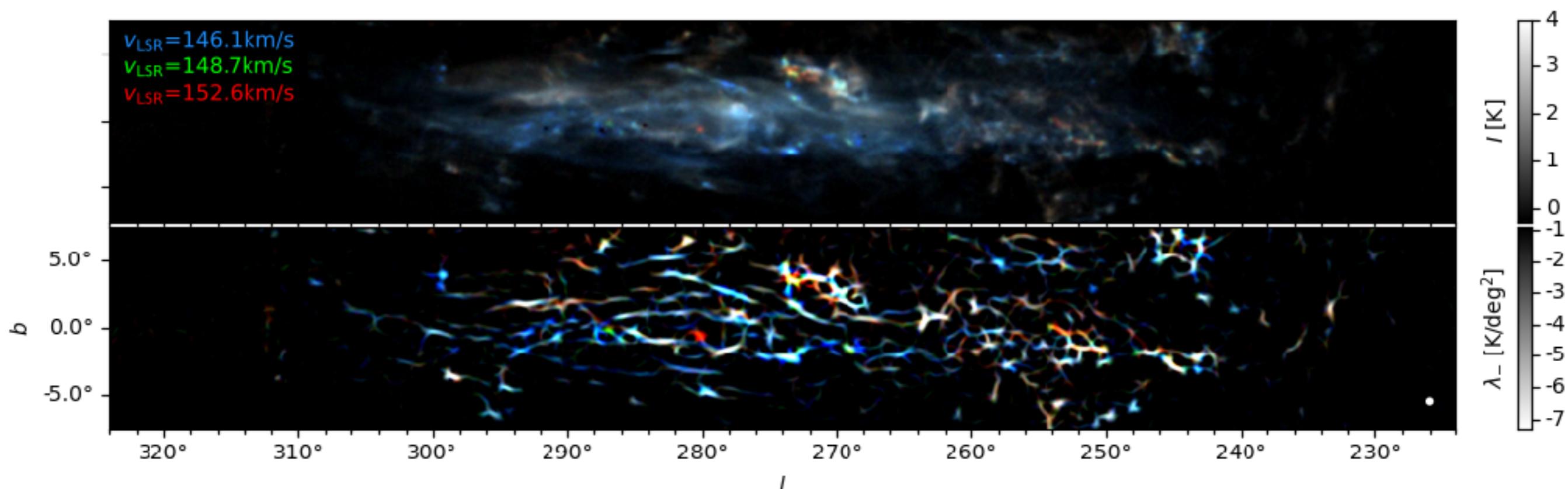
Atomic filaments

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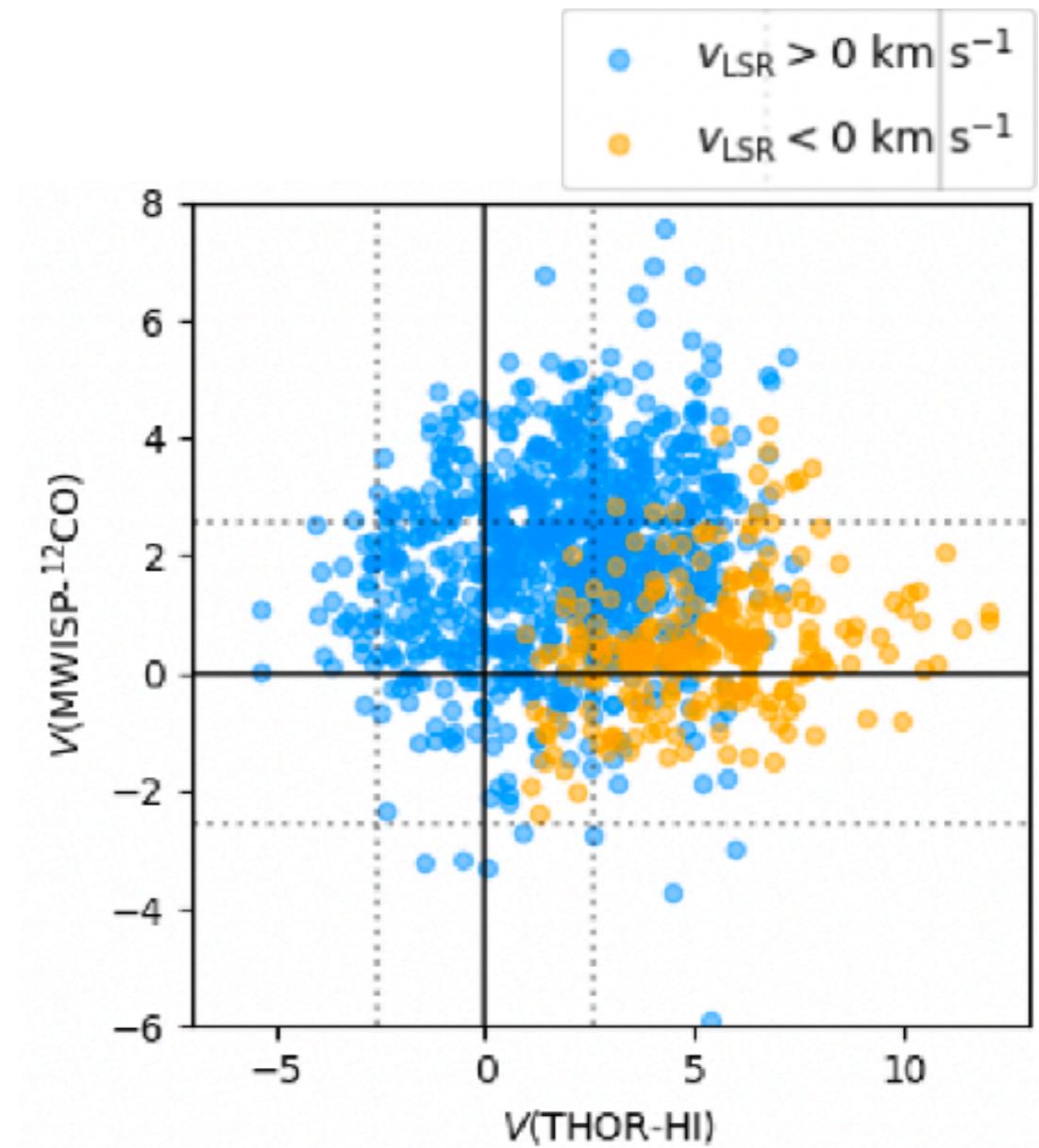
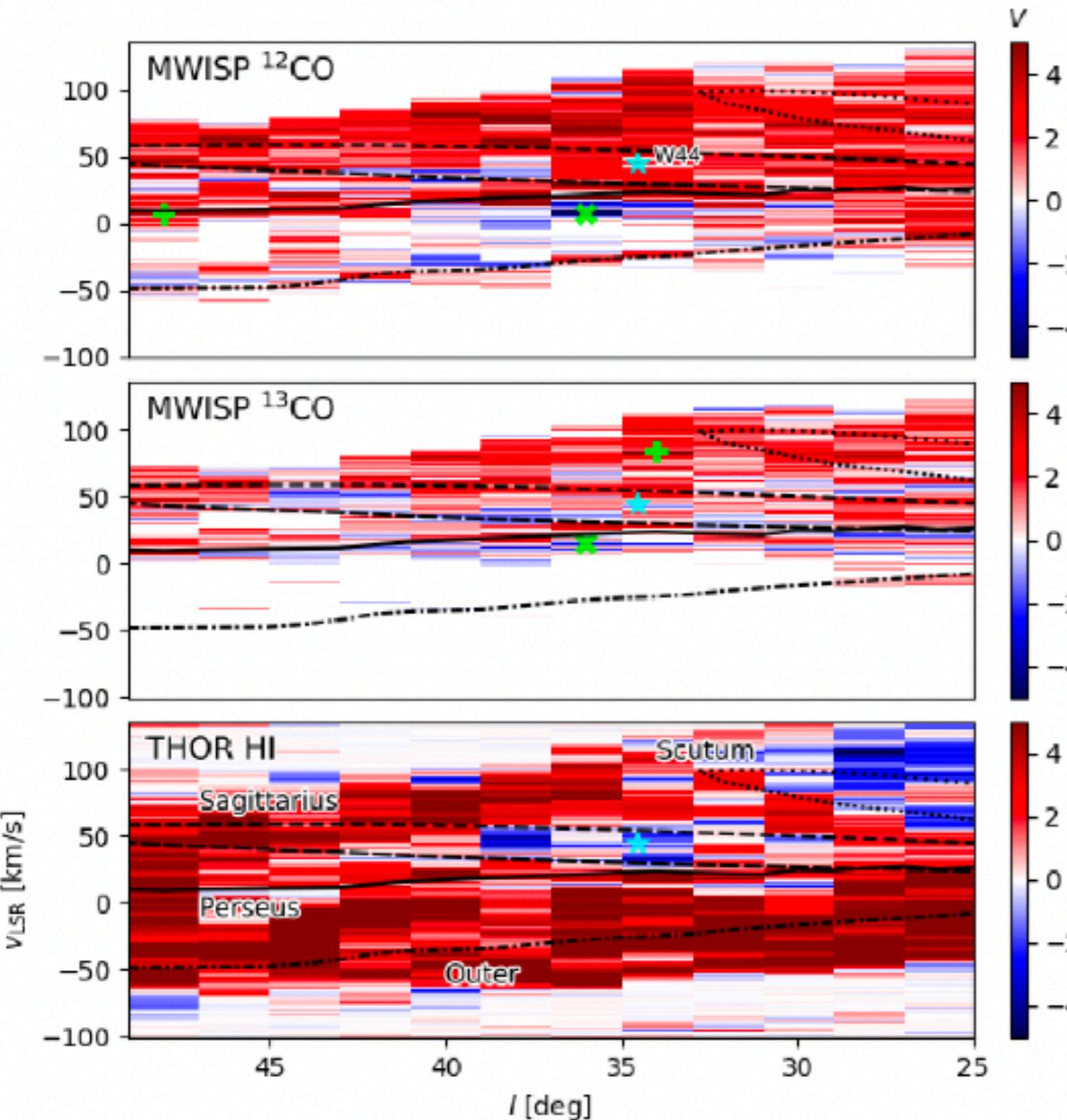
Atomic filaments

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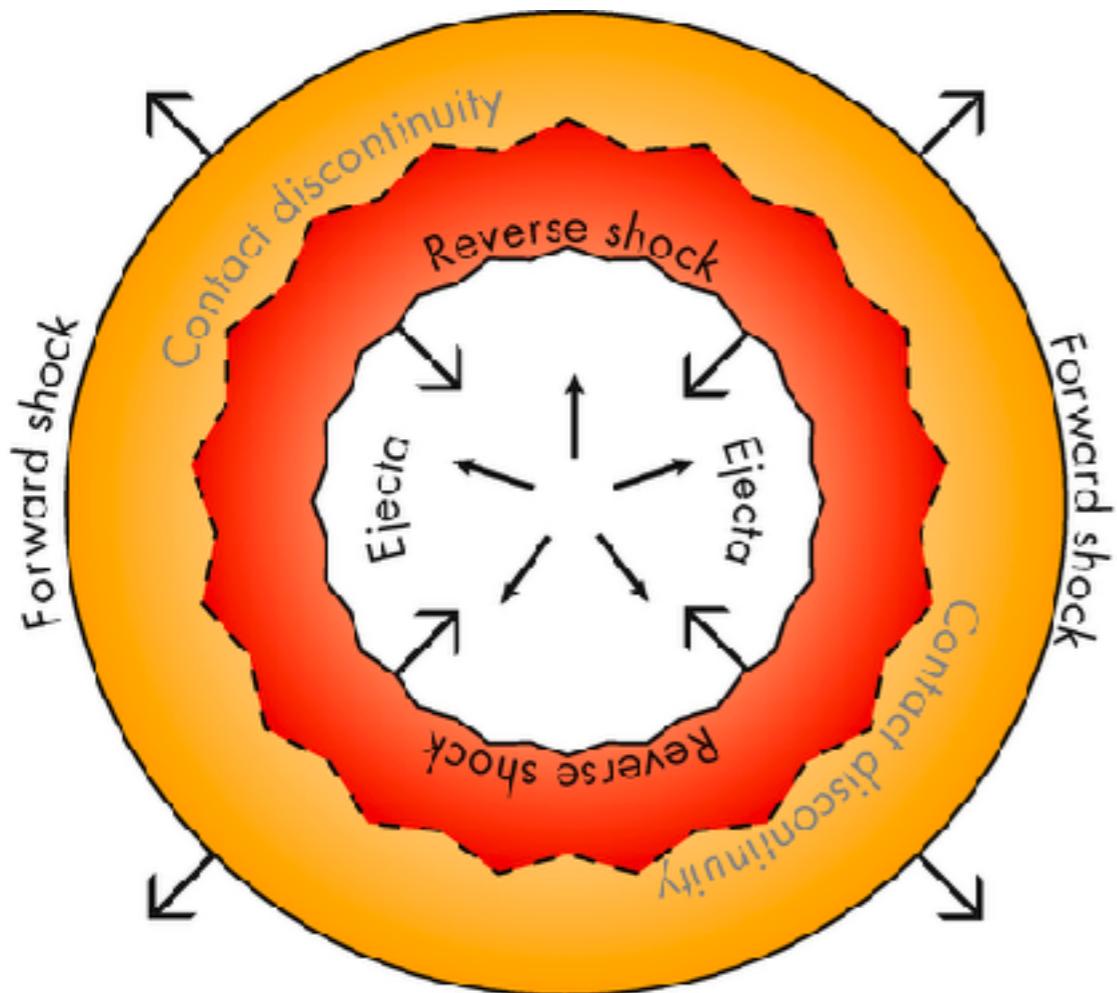
CO filament orientation

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

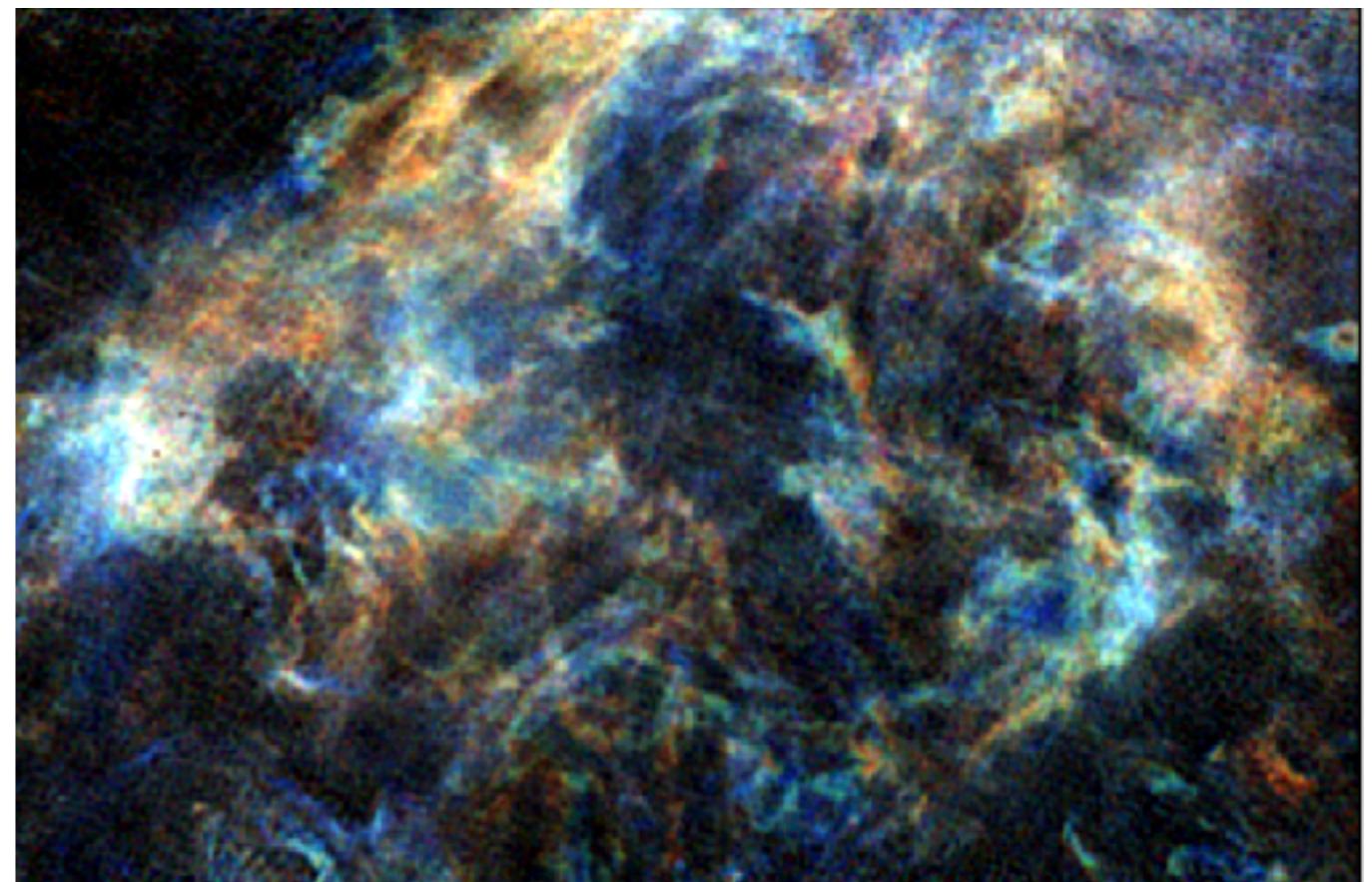


Atomic shells pushed by supernovae

Supernova Remnant Evolution. Vink, 2020.

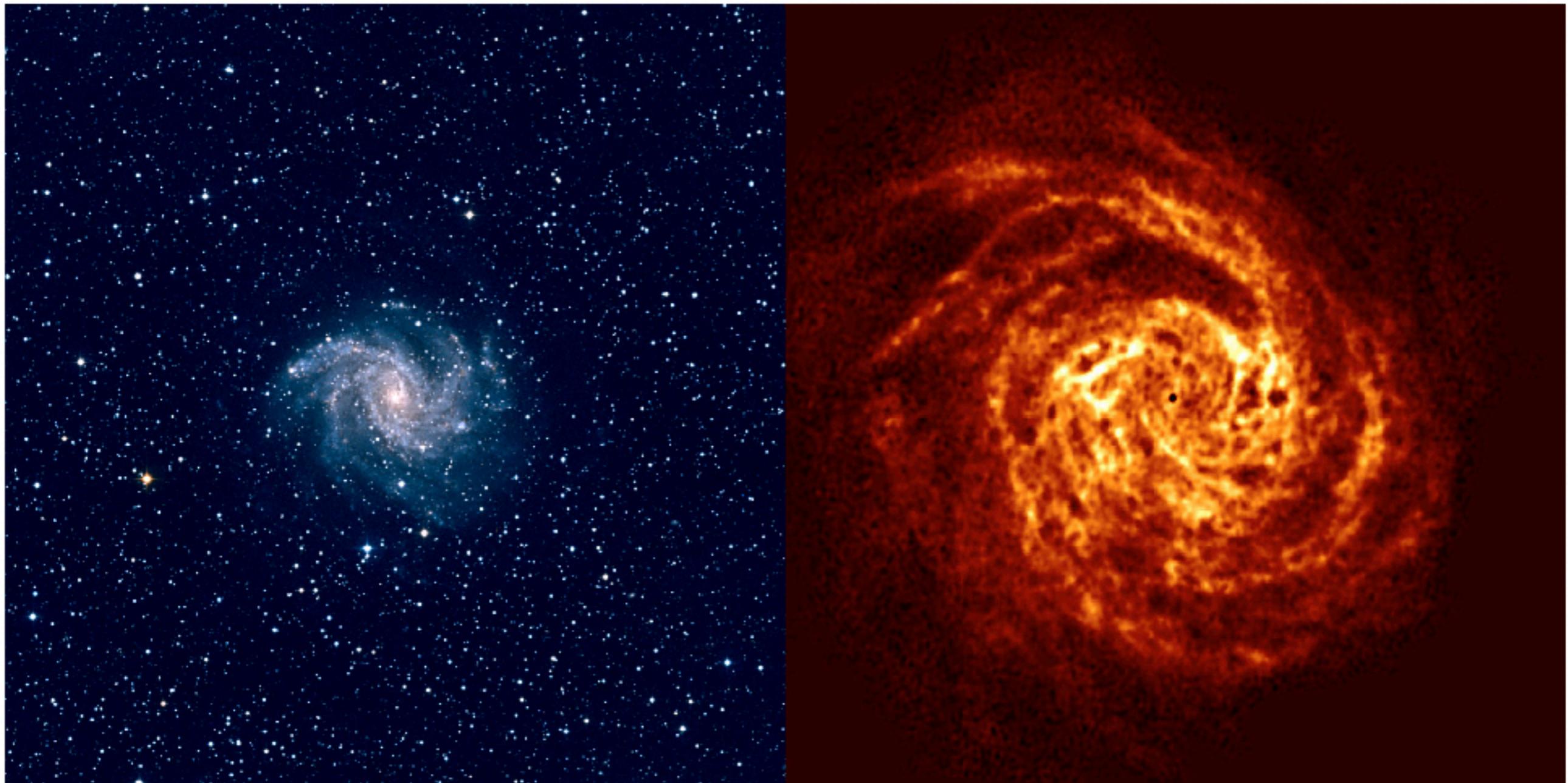


HI shell in THOR



HI holes in the spiral galaxy NGC6946

Boomsma et al. A&A 2008



Atomic counterpart of molecular clouds (March, 2020)

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

