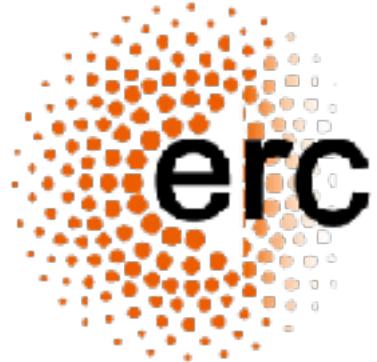


The Galactic dynamics revealed by the filamentary structure in the atomic and molecular gas emission

Juan Diego Soler

Istituto di Astrofisica e Planetologia Spaziali



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

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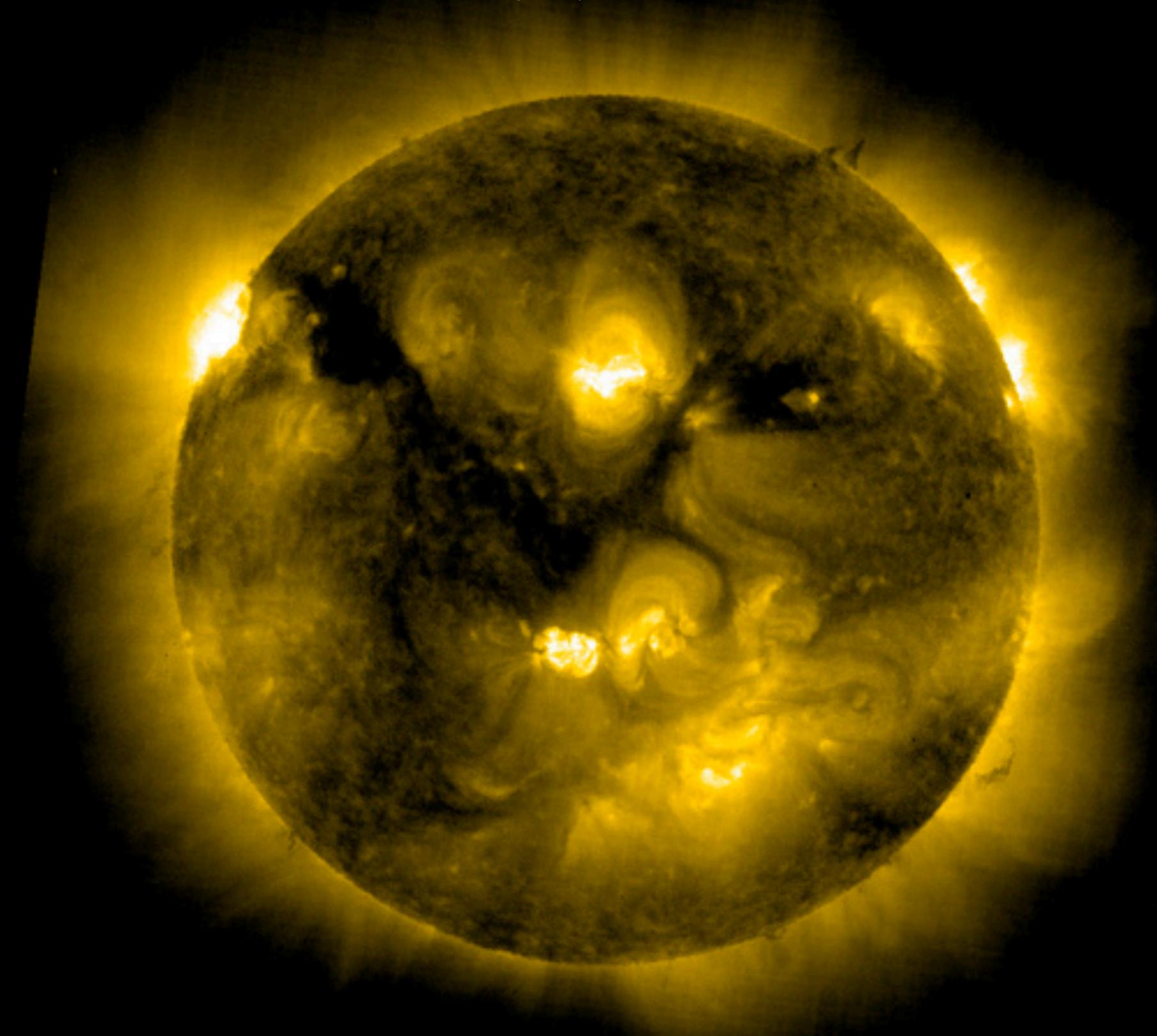
Istituto di Astrofisica e Planetologia Spaziali

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 Sun

SOHO Extreme ultraviolet Imaging Telescope (EIT) - $\lambda = 284$ Angstrom



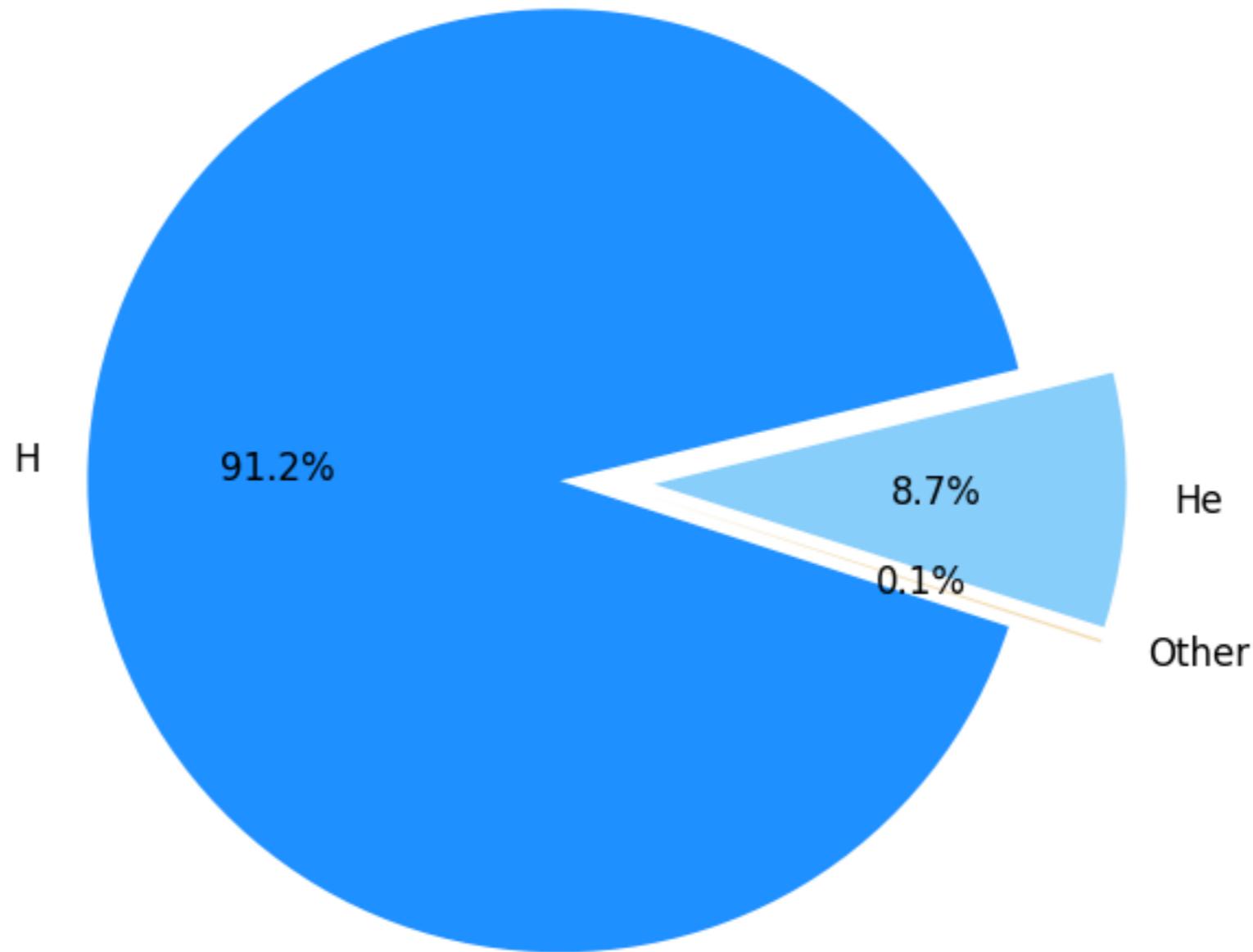
2022/11/23 01:06

Juan D. Soler (IAPS, Rome)

The Sun

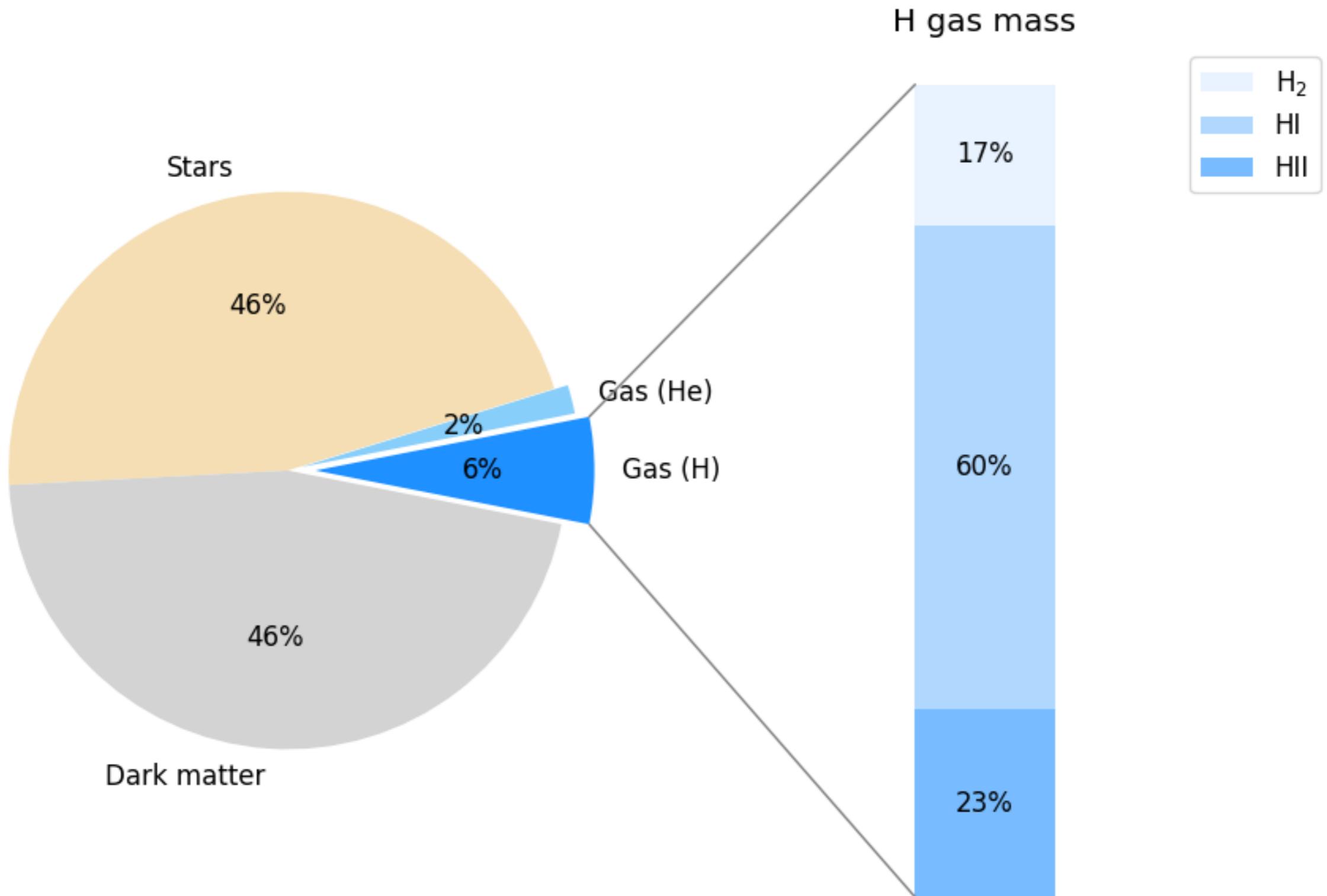
M. Asplund, A. Amarsi, and N. Grevesse 2021, A&A, 653, A141

Sun composition by number of atoms

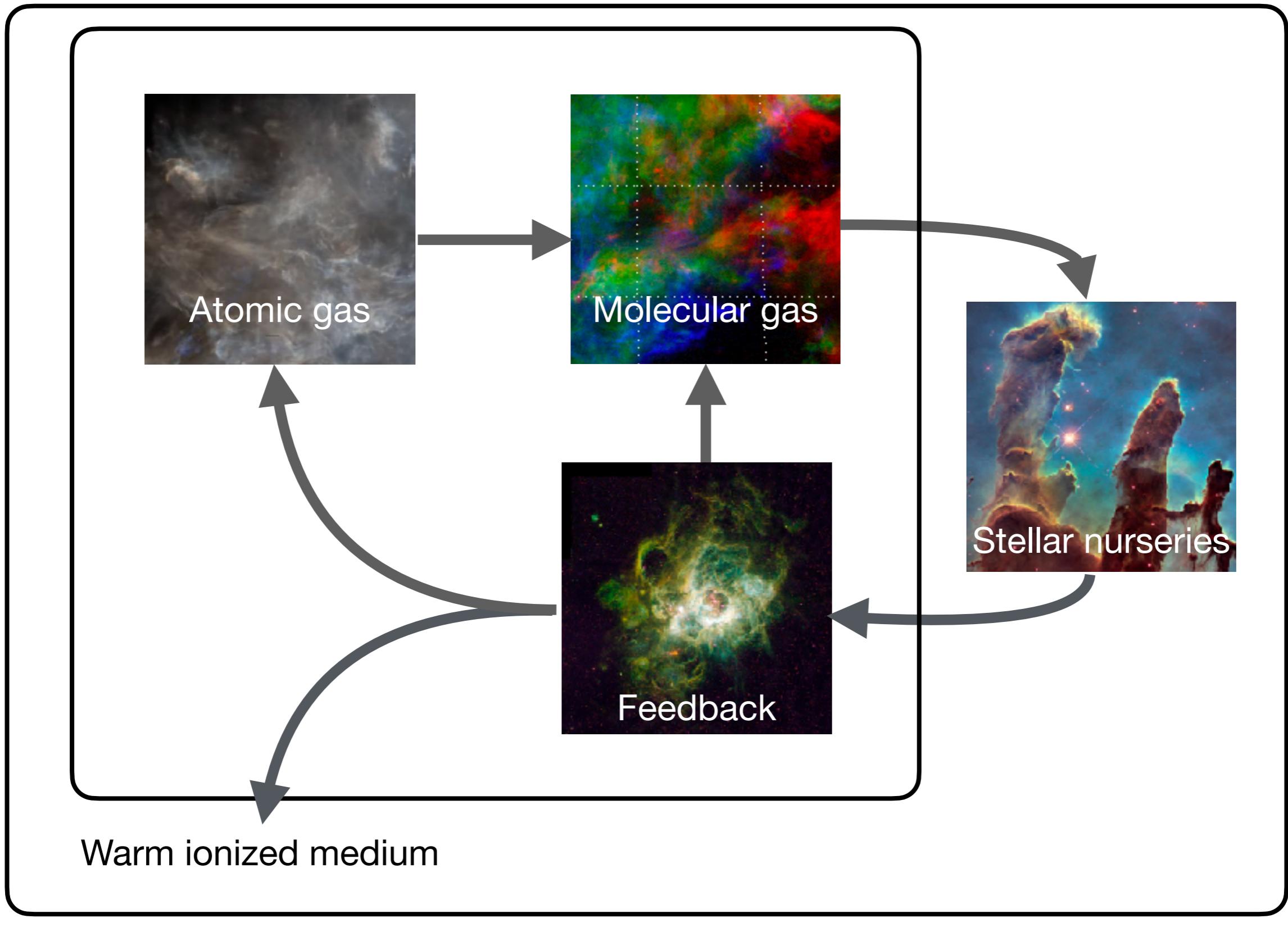


Milky Way's mass budget

Draine, B. T. Physics of the Interstellar and Intergalactic Medium (2011)



Hydrogen lifecycle in the interstellar medium

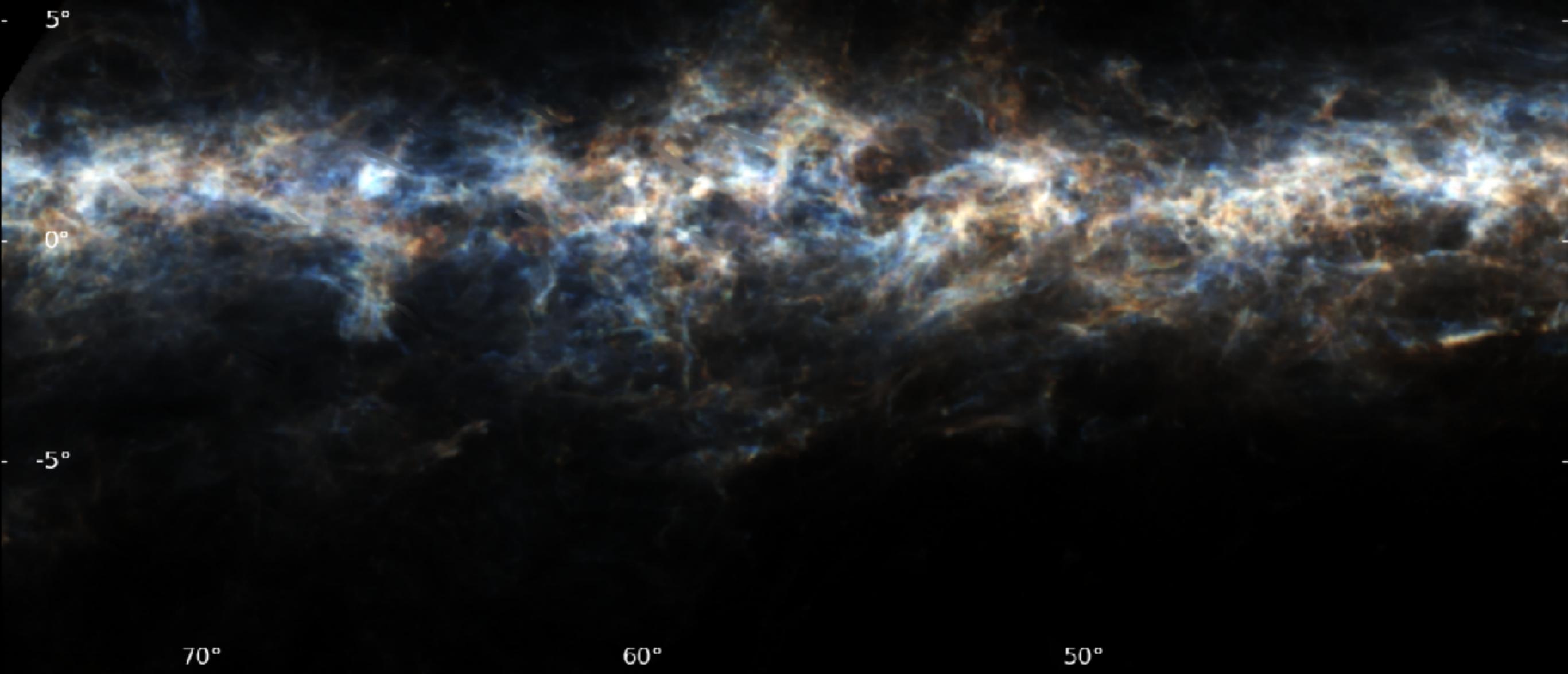


Hot ionized medium

Atomic hydrogen clouds

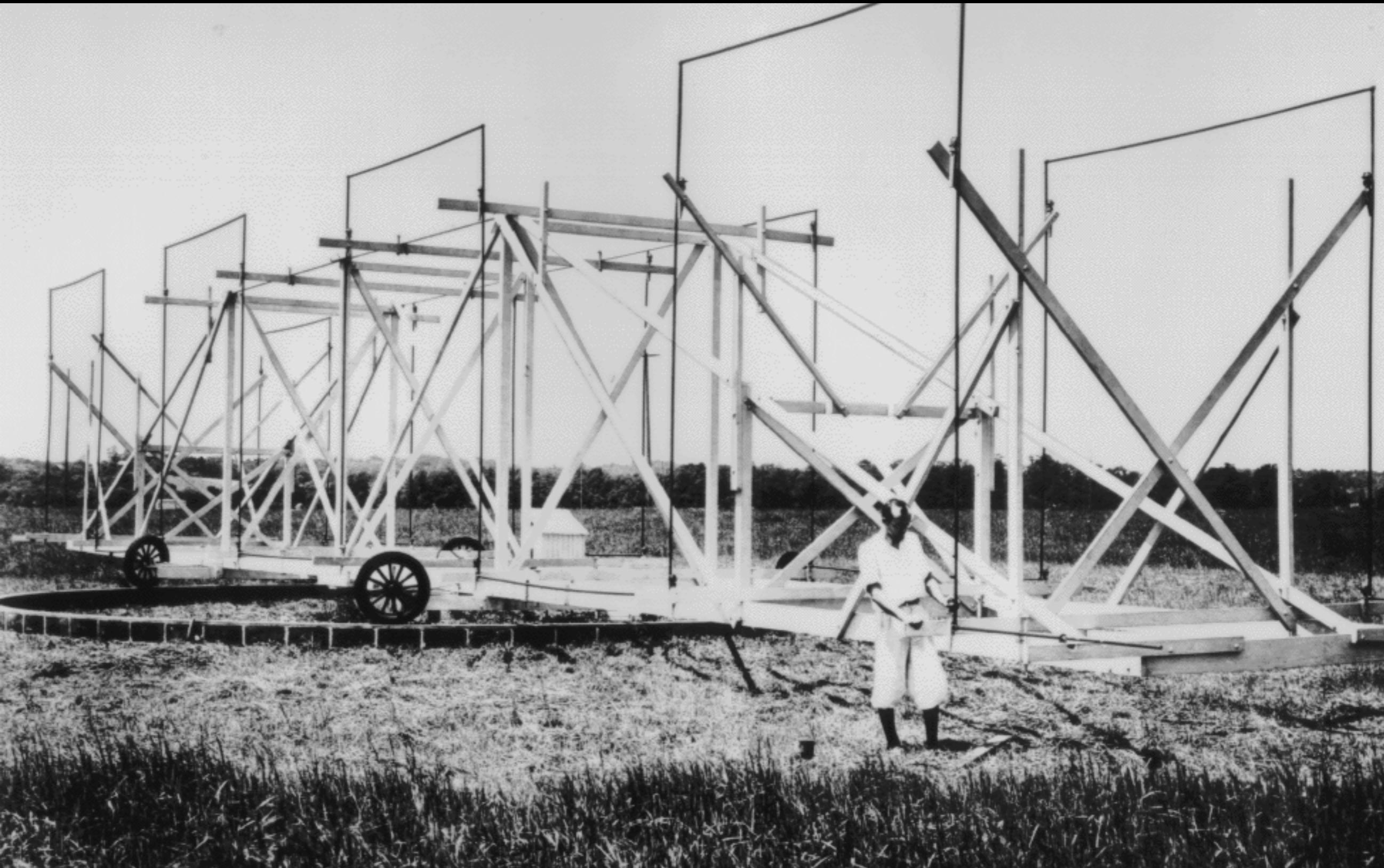
J.D. Soler; GALFA-HI, Peek et al, 2018

Radial velocity: -56.1 km/s
Galactic radius: 11.3 kpc (36942 lyrs)



Radioastronomy (20.5 MHz)

Karl Jansky. Bell Labs (1928-1933)



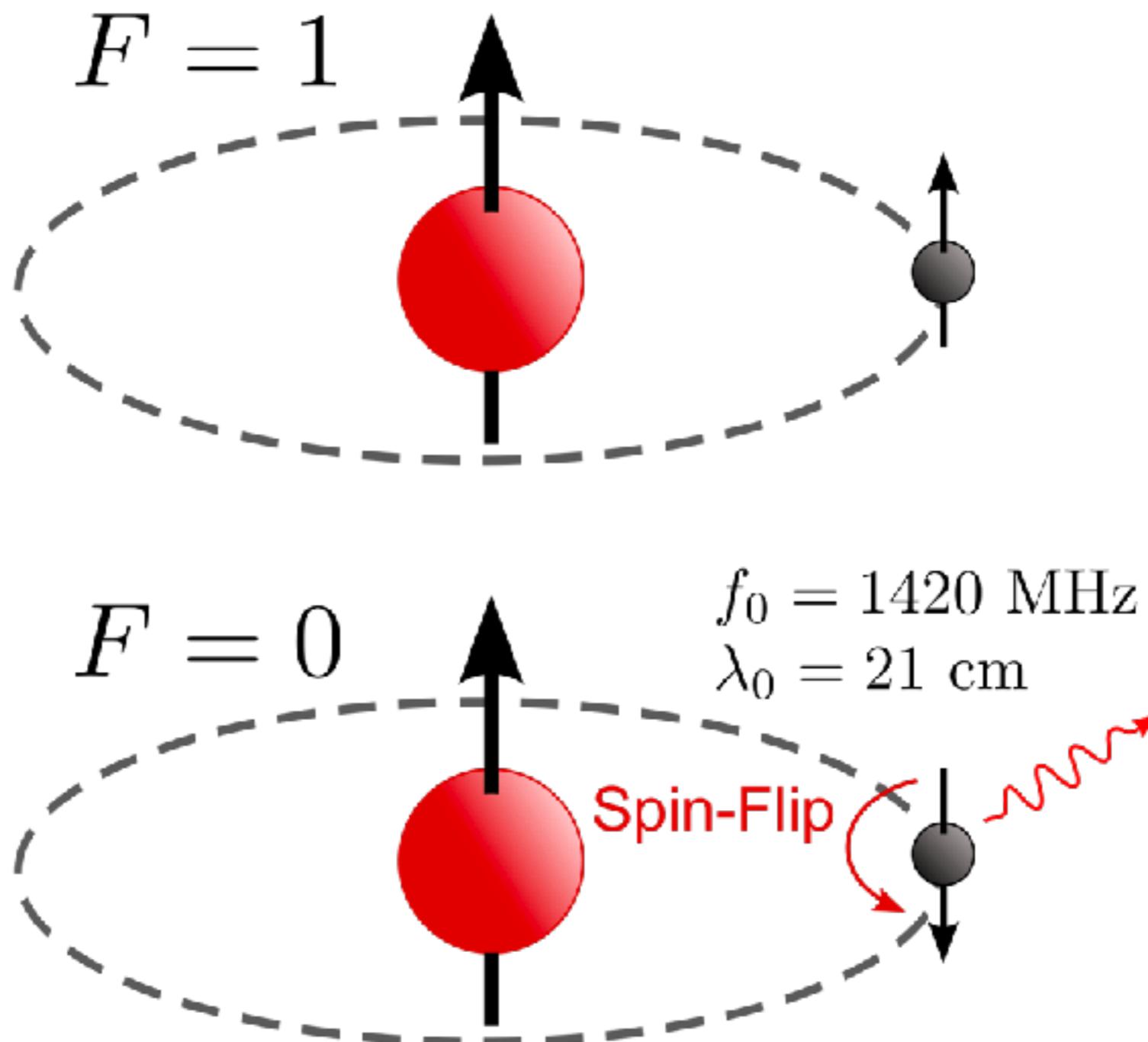
Atomic hydrogen emission

Netherlands. June, 1941.



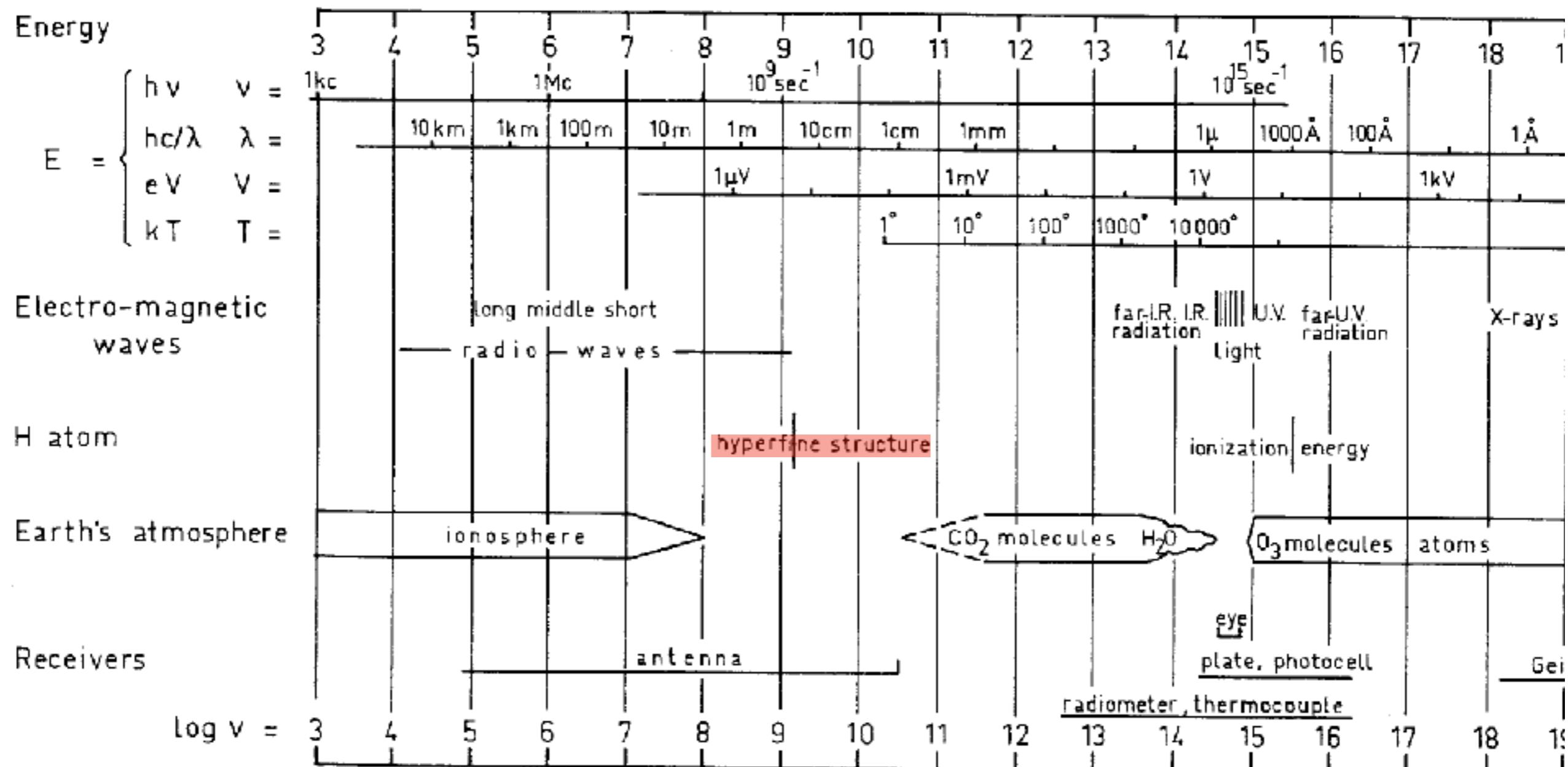
Hyperfine transition of neutral hydrogen

Origin of the radio waves from space. H.C. Van de Hulst (1945)



Hyperfine transition of neutral hydrogen

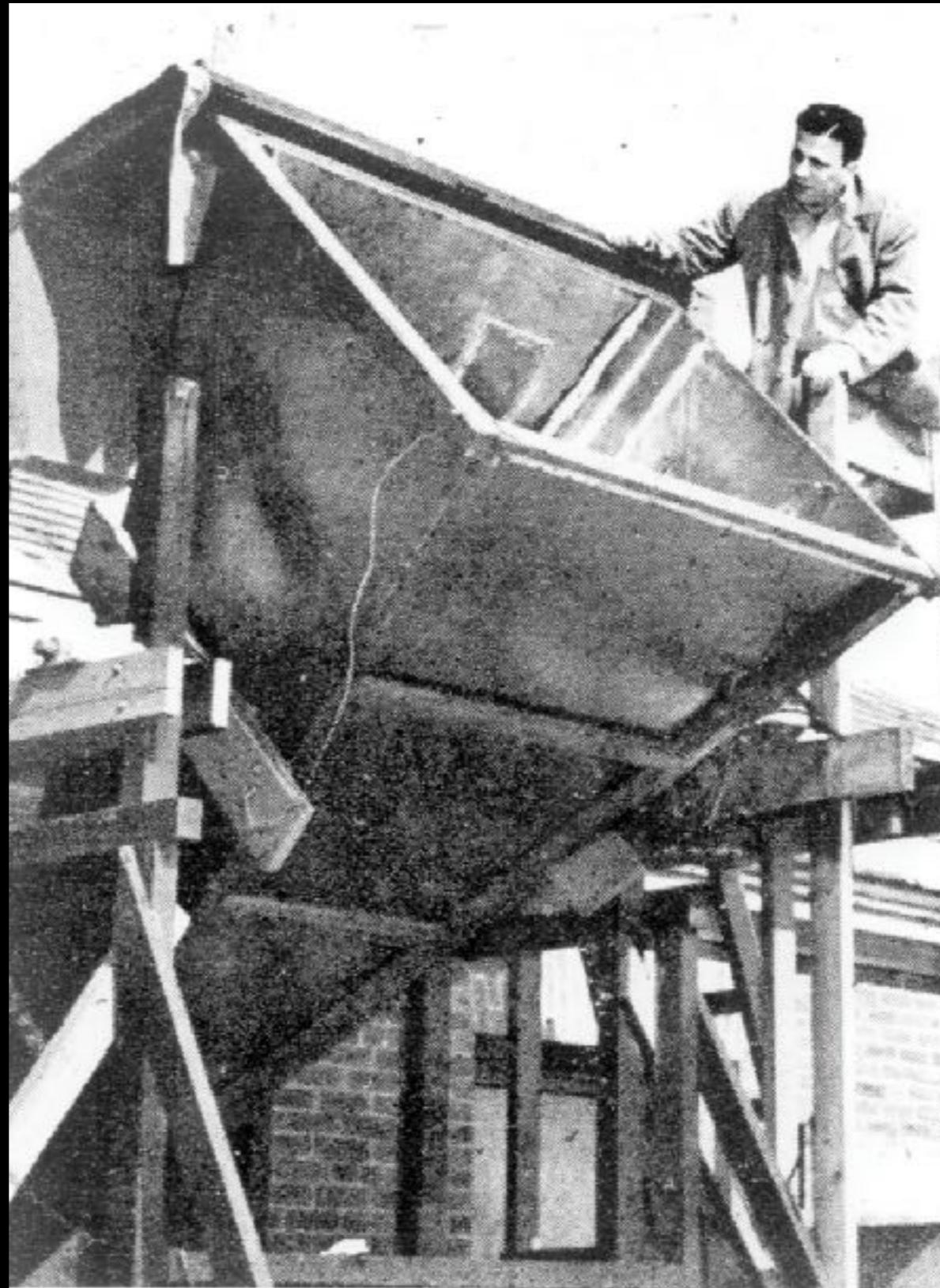
Origin of the radio waves from space. H.C. Van de Hulst (1945)



Atomic hydrogen emission

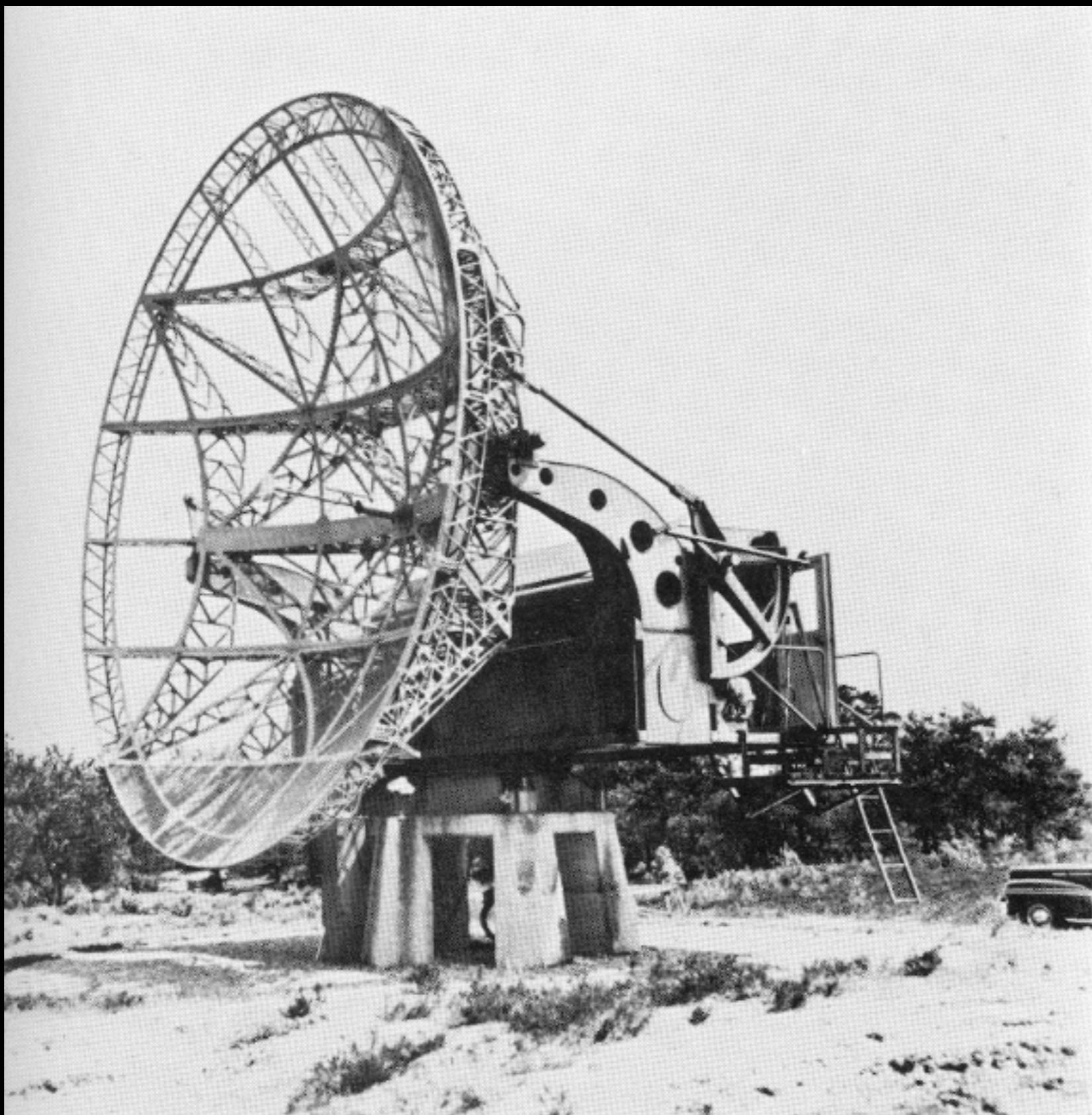
Harold Ewen y Edward Purcell.

Lyman Laboratory - Harvard University. March, 1951



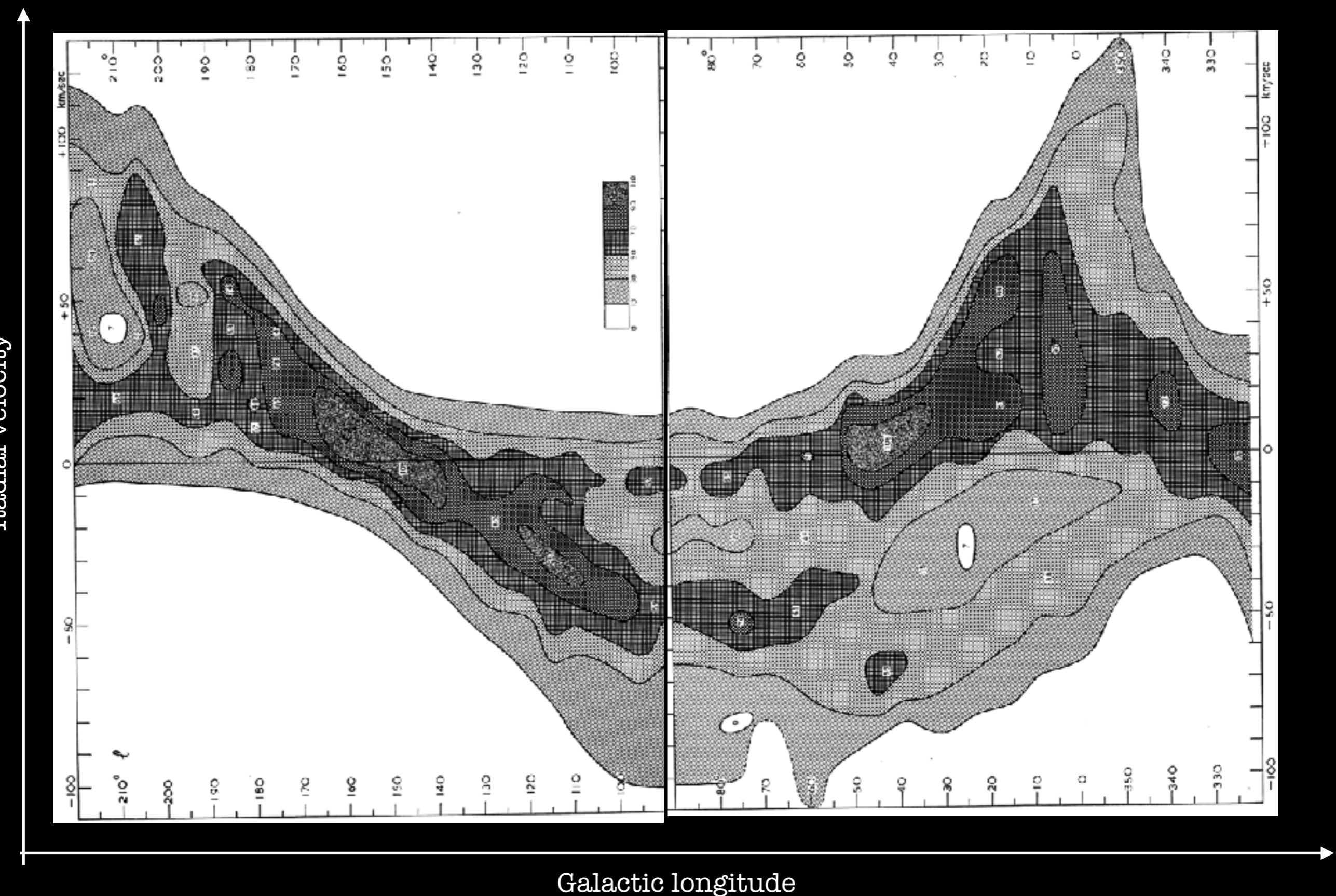
Atomic hydrogen emission

Würzburg radar antenna (7.5 m)



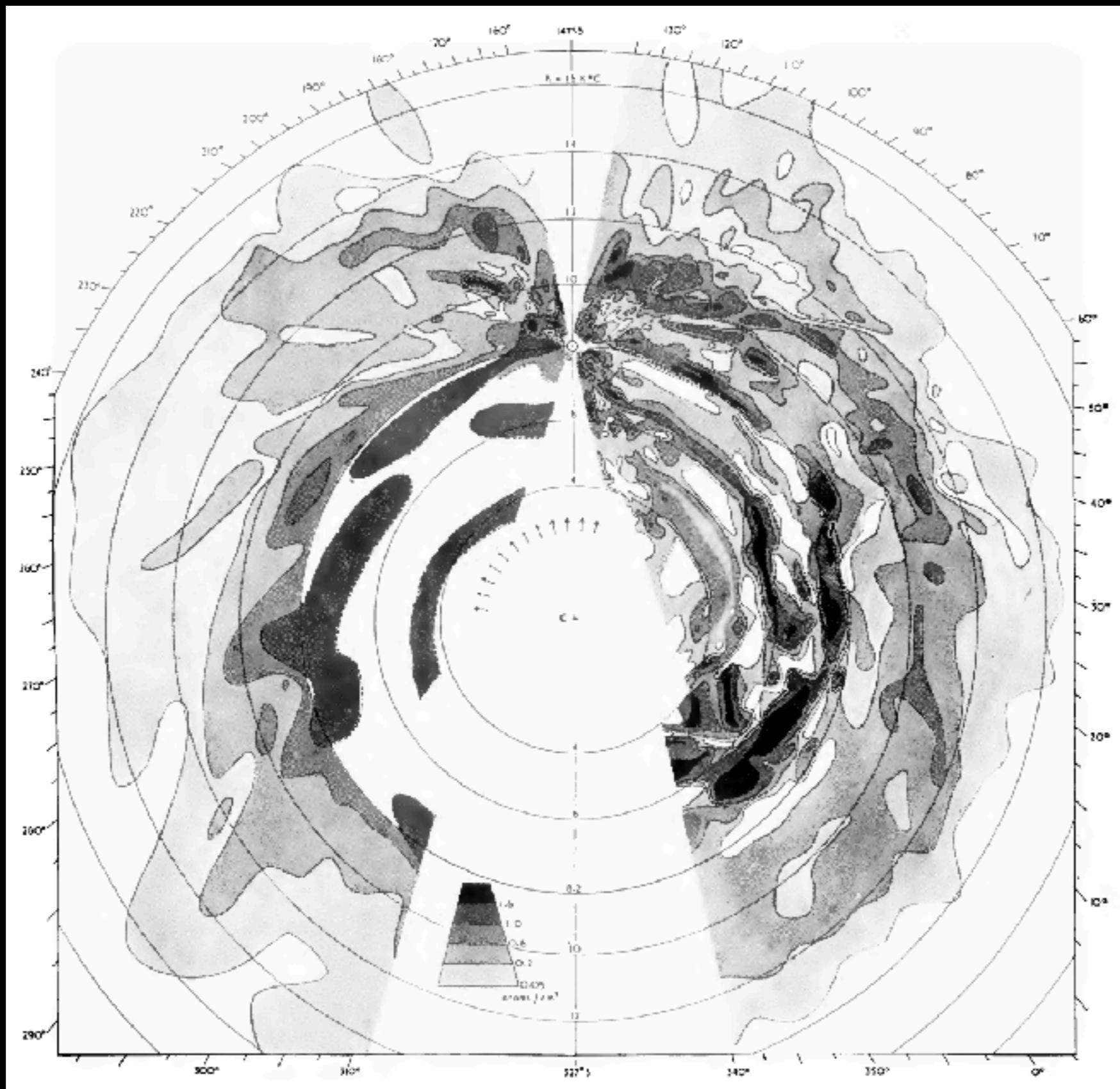
Atomic hydrogen emission toward the Milky Way

van de Hulst, Muller & Oort (1954).



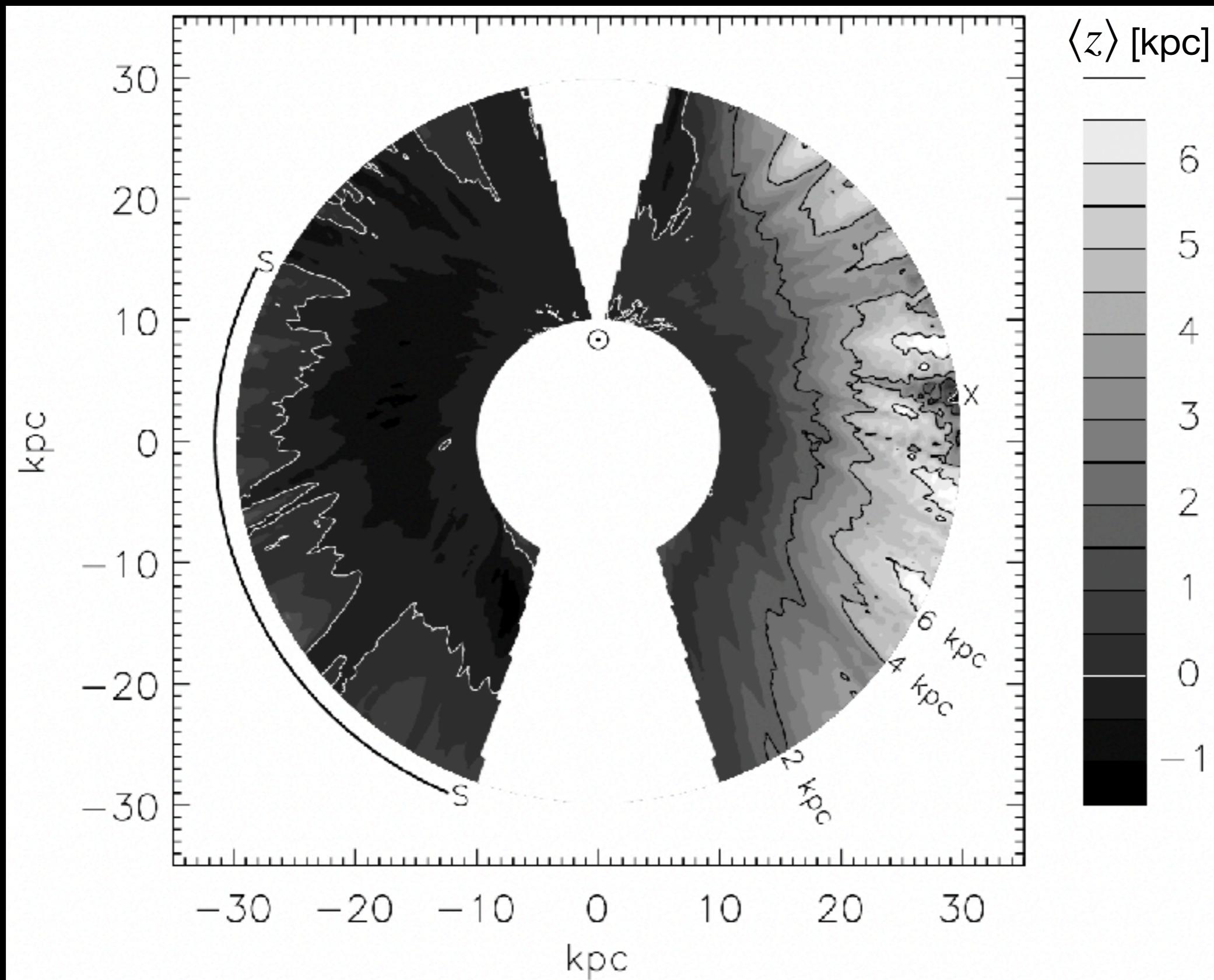
Atomic hydrogen emission toward the Milky Way

Oort,; Kerr & Westerhout (1958)



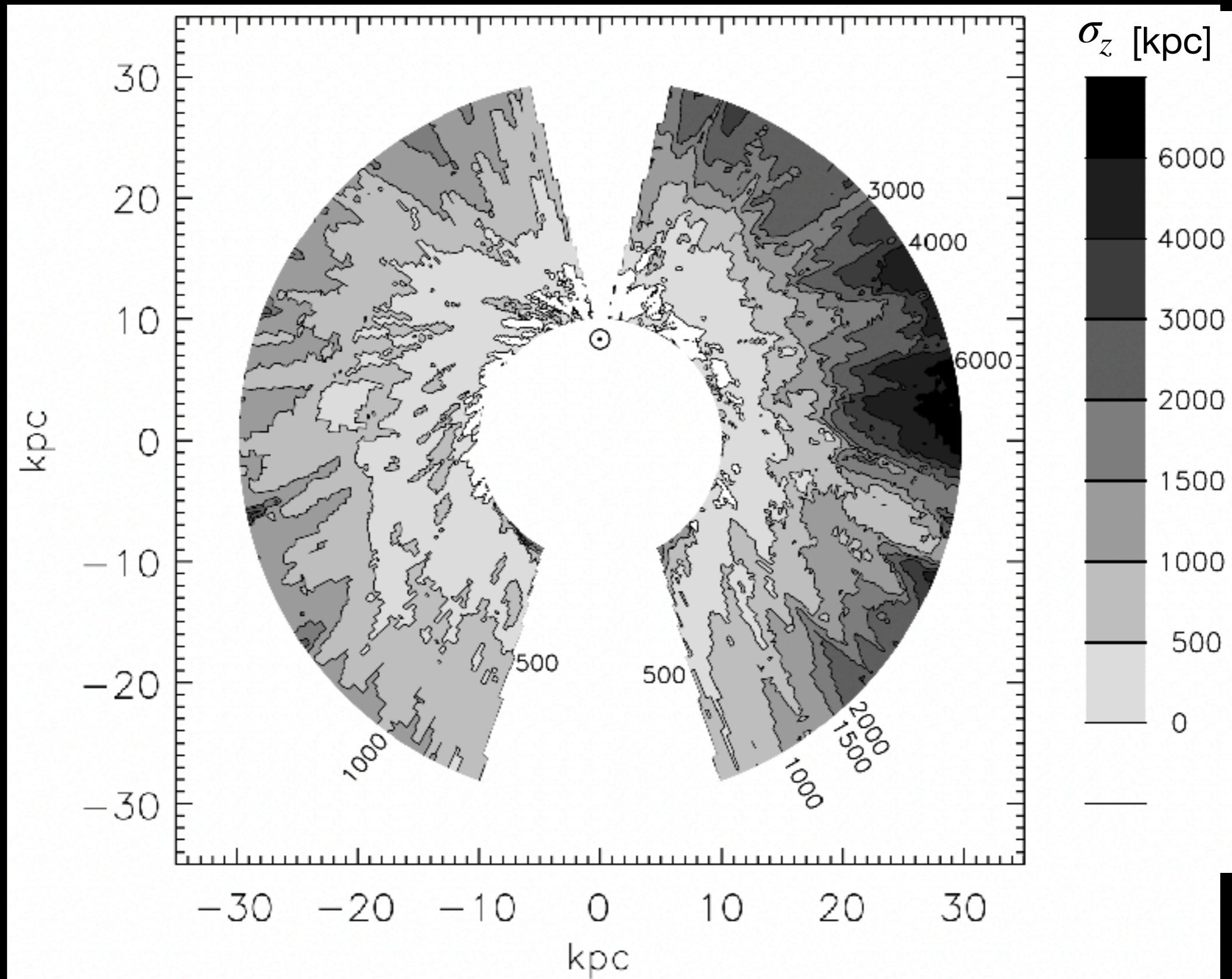
HI highlights: 1. Galactic disk warp and flaring

Levine, Blitz & Heiles (2006).



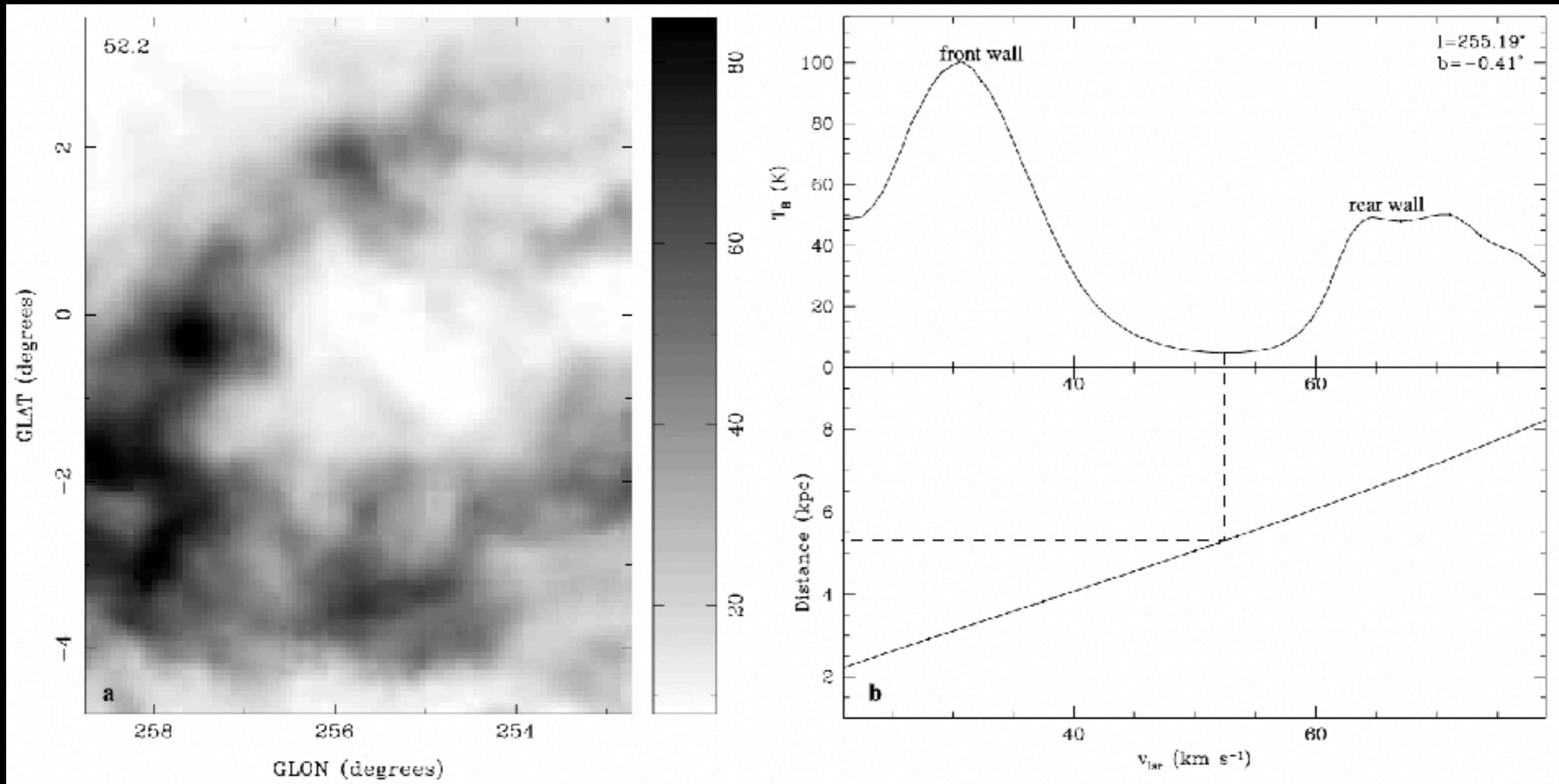
HI highlights: 1. Galactic disk warp and flaring

Levine, Blitz & Heiles (2006).



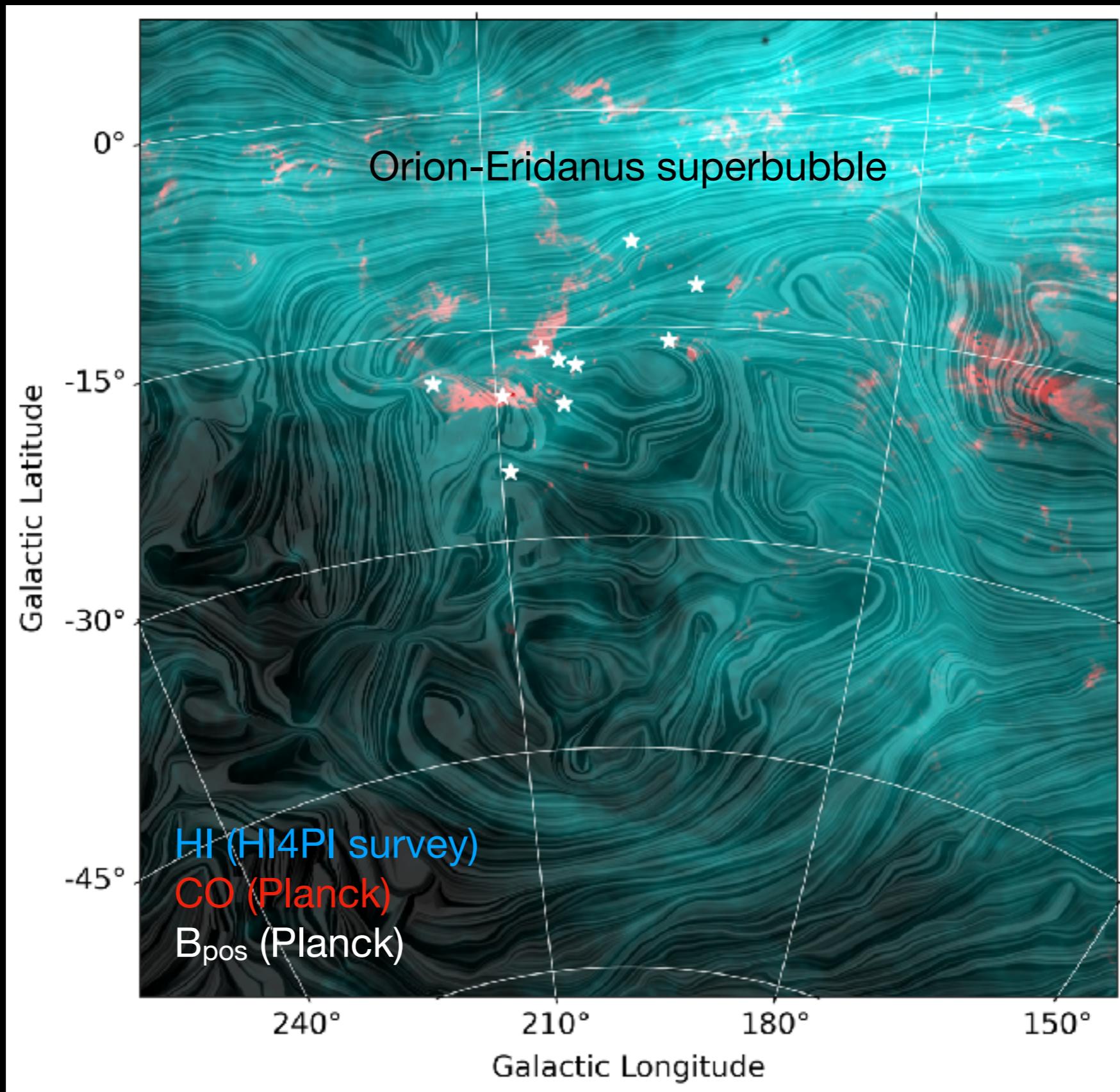
HI highlights: 2. Shells and supershells

Heiles (1984); McClure-Griffiths et al. (2006).



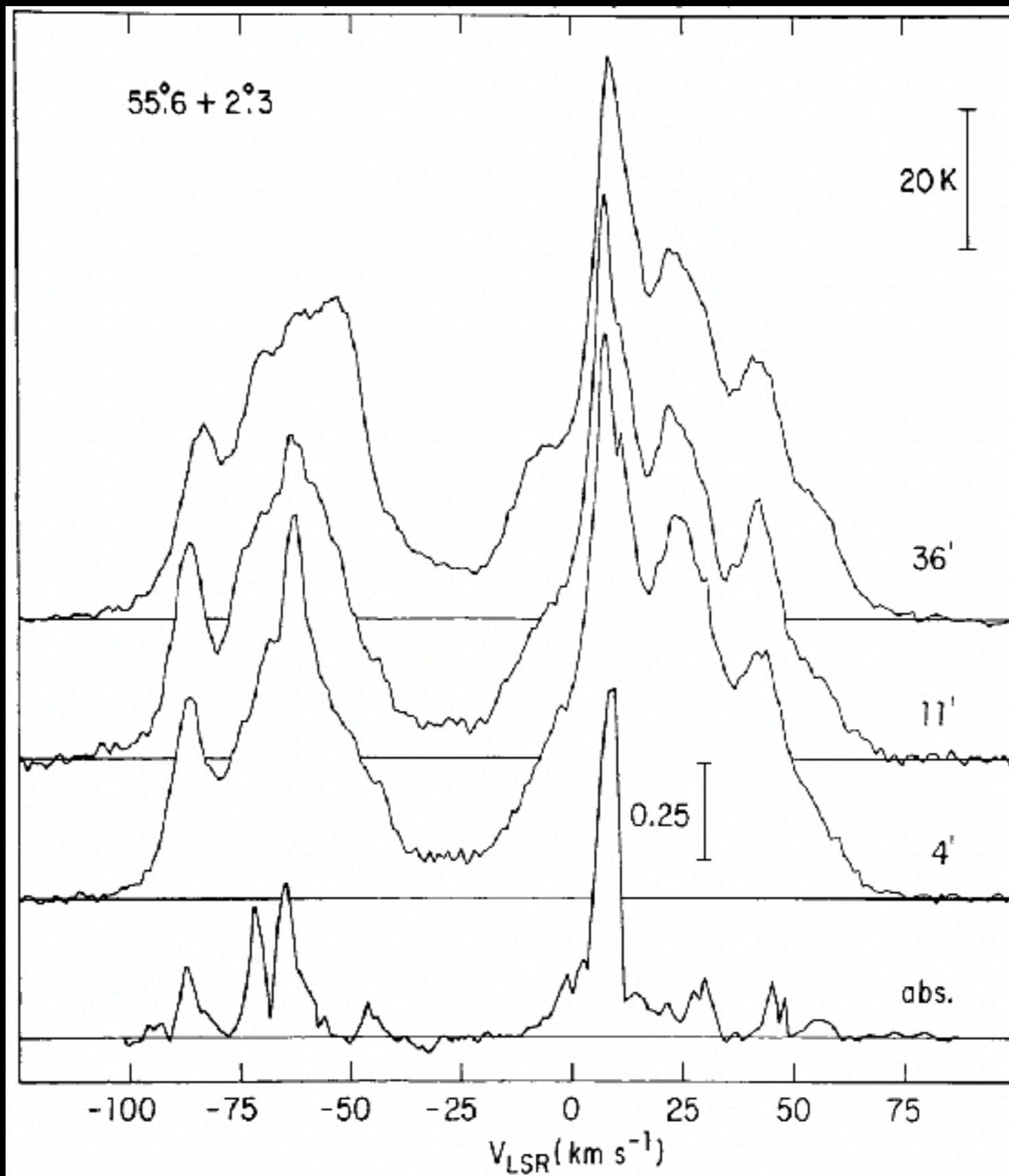
HI highlights: 2. Shells and supershells

Soler, Bracco & Pon (2018).



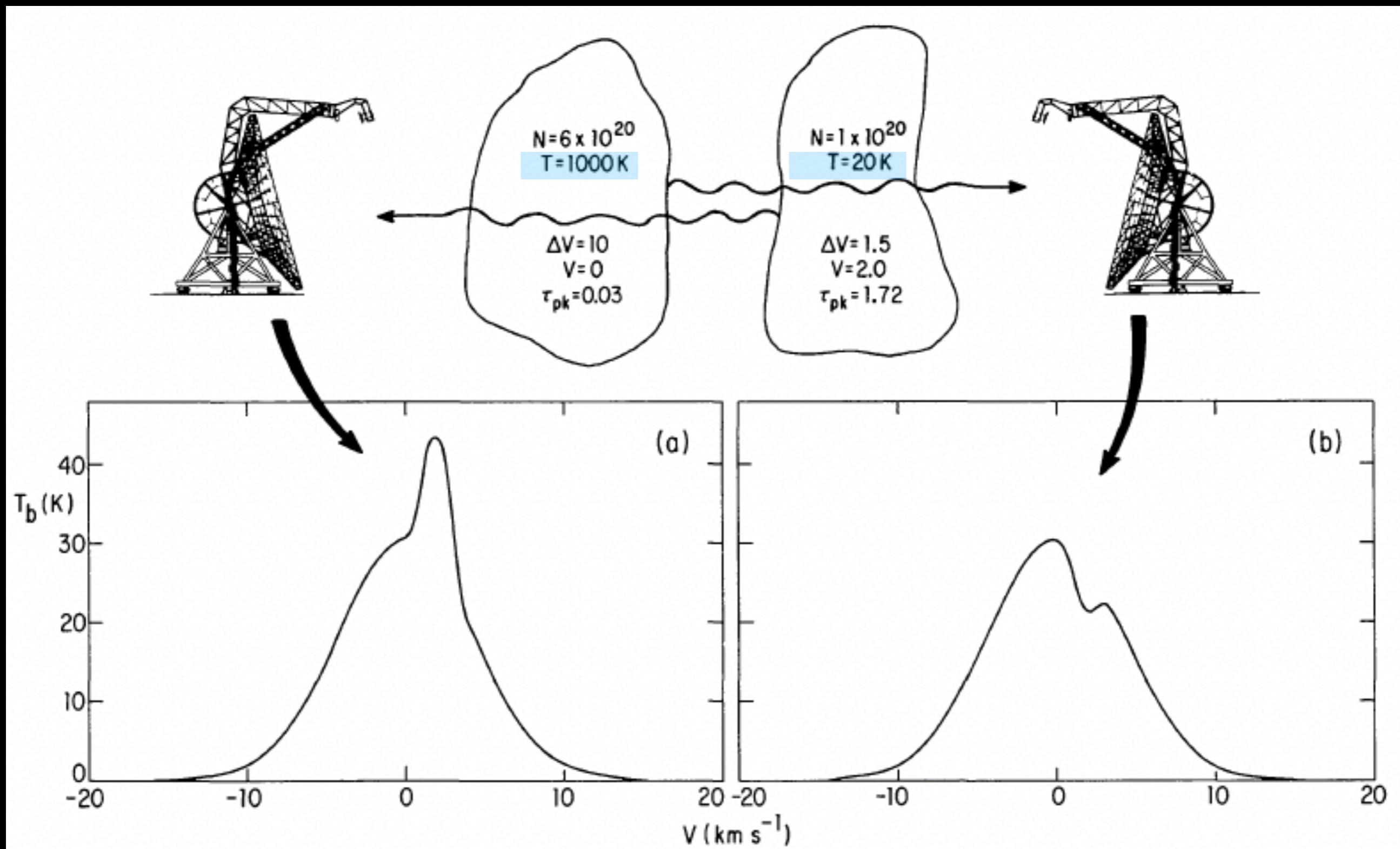
HI highlights: 3. Cold and warm neutral medium

Dickey & Lockman (1990) ;Heeschen (1955).



HI highlights: 3. Cold and warm neutral medium

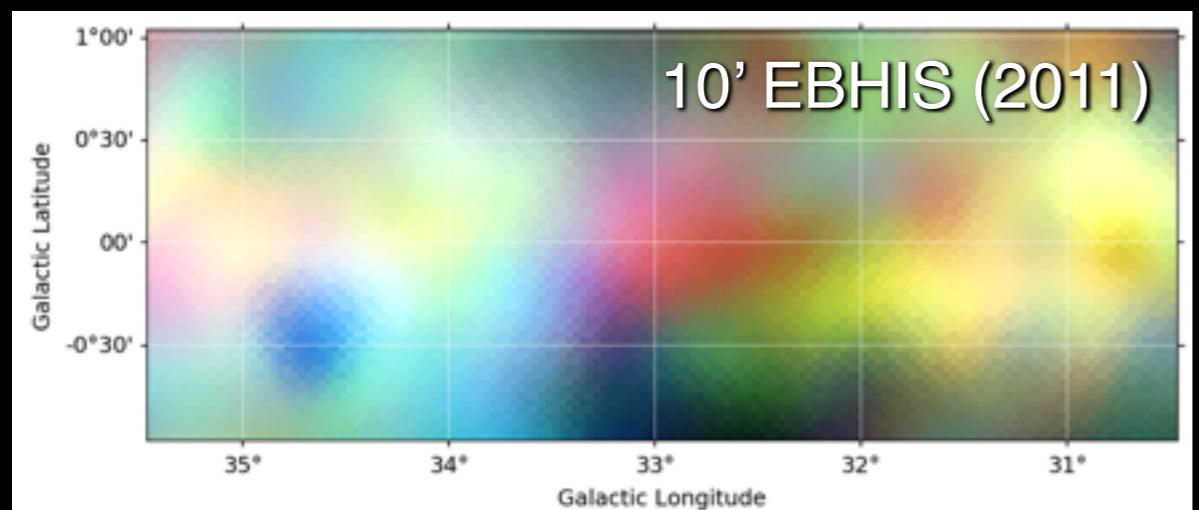
Dickey & Lockman (1990) ;Heeschen (1955).



Atomic hydrogen emission toward the Milky Way

The Effelsberg-Bonn HI Survey (EBHIS)
Kerp et al. 2011

Effelsberg 100-m Telescope

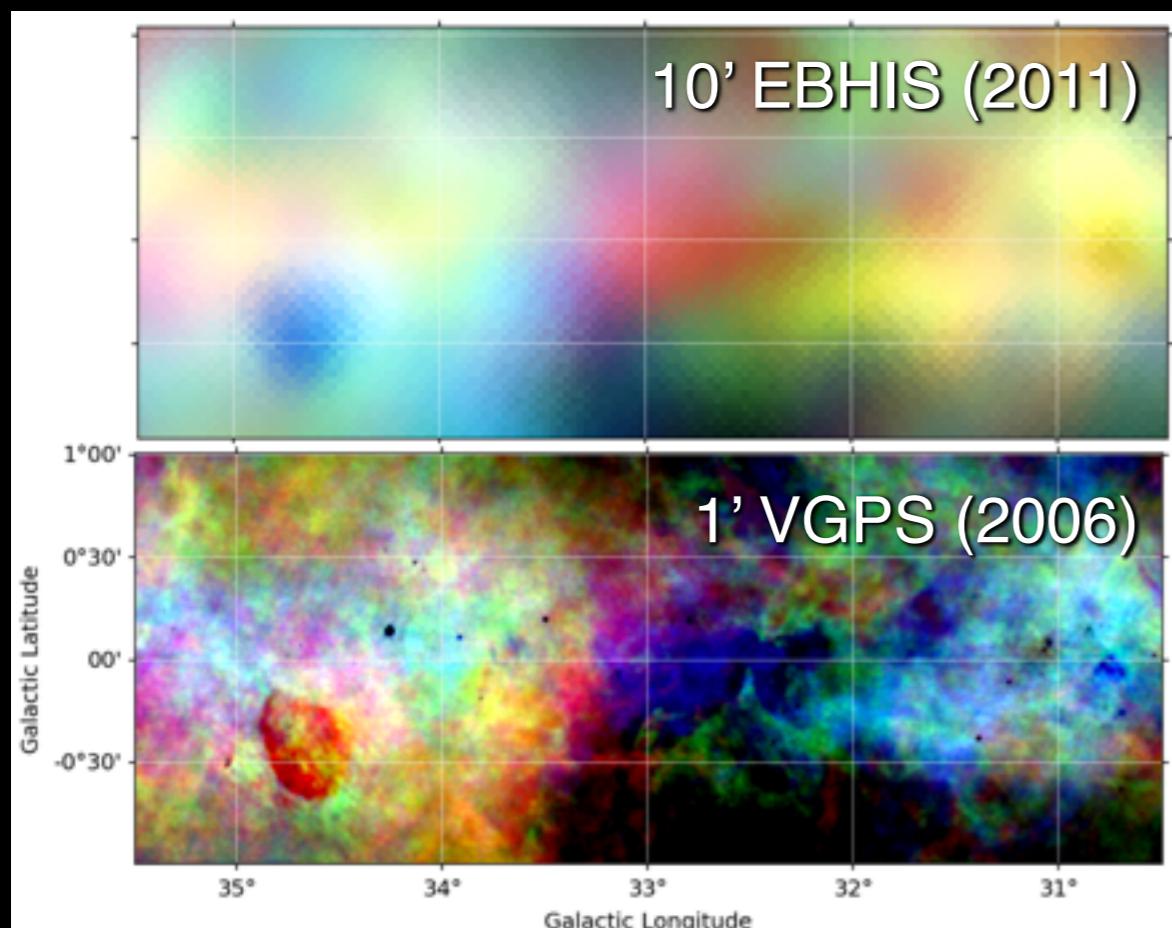


Atomic hydrogen emission toward the Milky Way

VLA Galactic Plane Survey (VGPS)

Stil et al. 2006

Jansky Very Large Array (VLA)



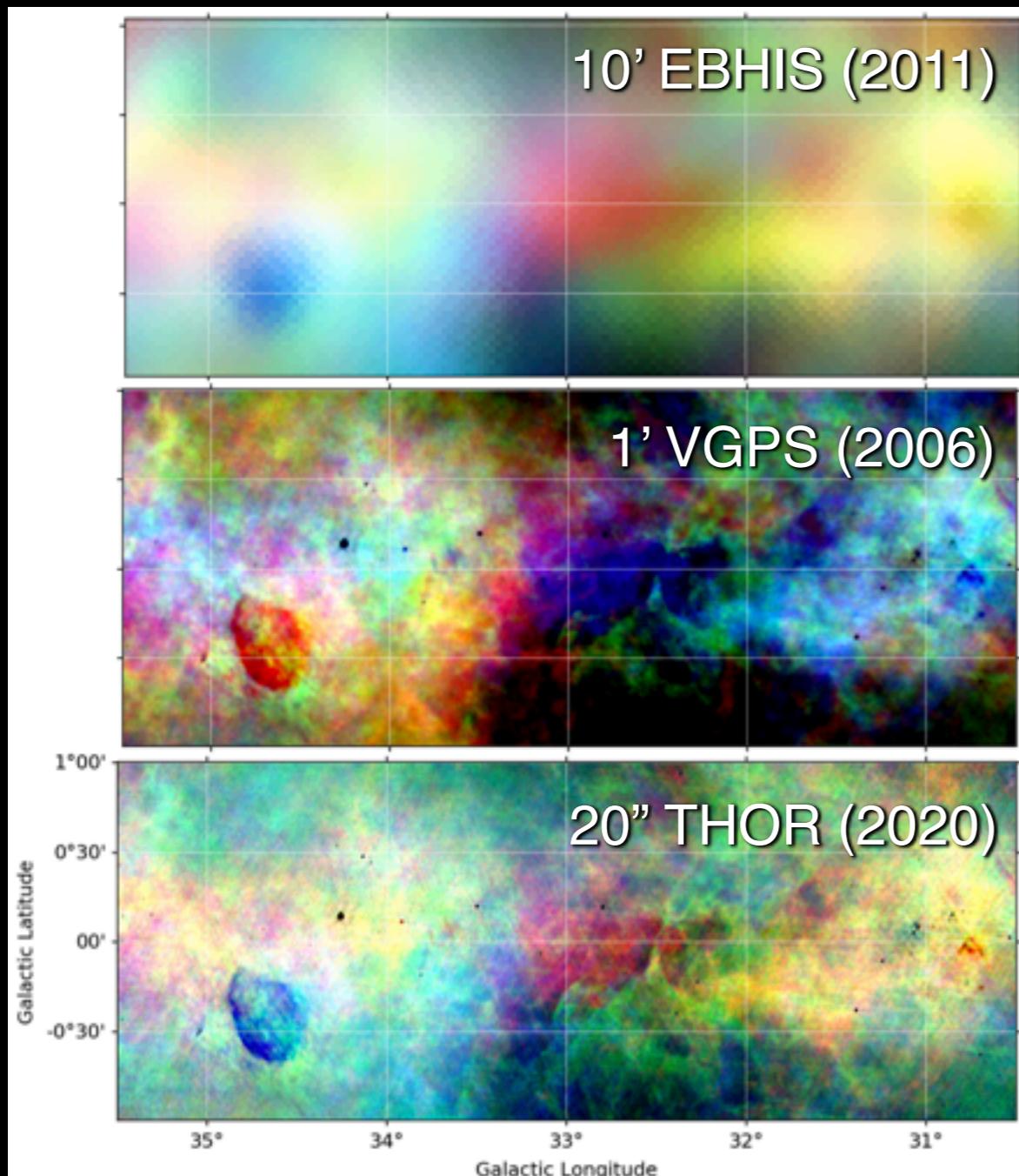
Atomic hydrogen emission toward the Milky Way

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

Beuther, JDS et al., 2016

Wang, JDS, et al., 2020.

Jansky Very Large Array (VLA)

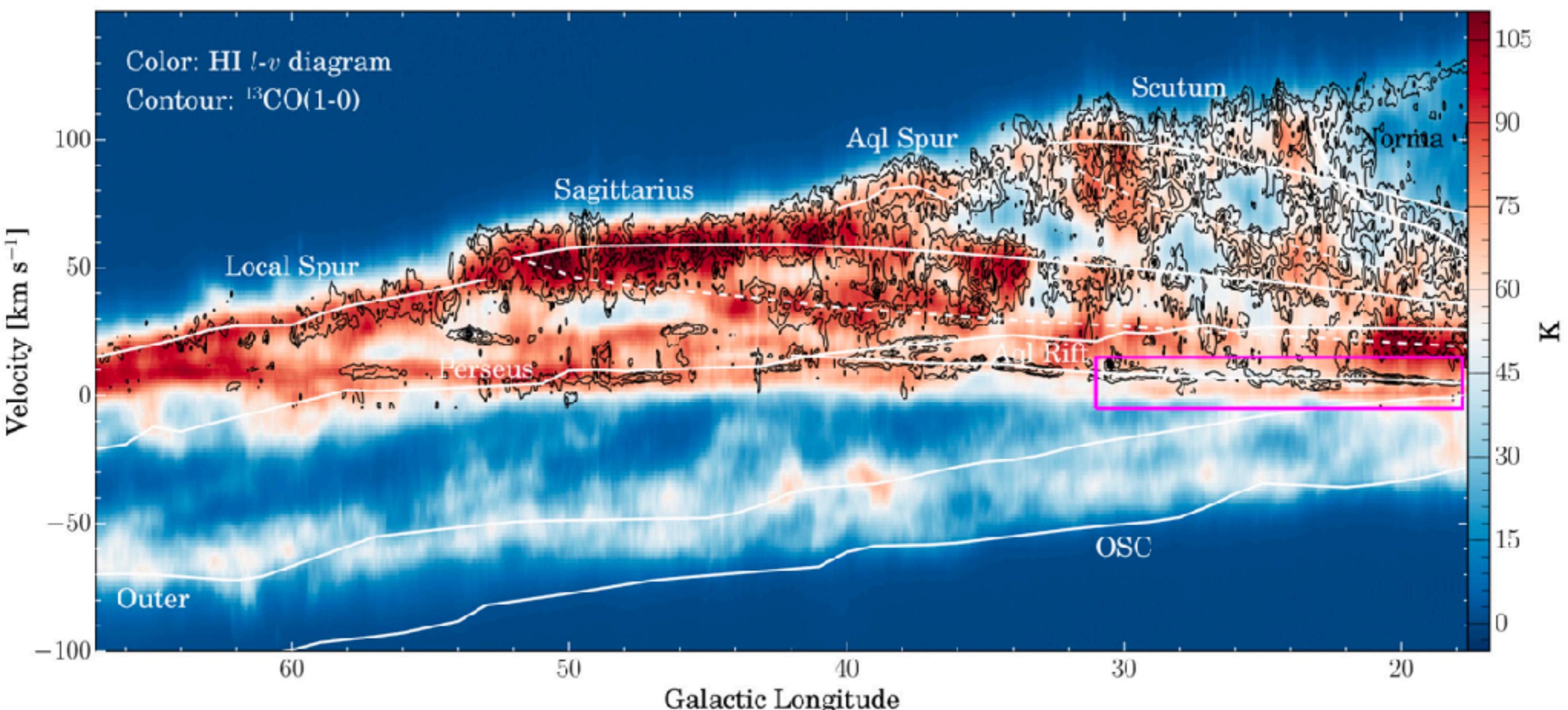


The HI, OH, and Recombination-line (THOR) survey

Wang, Y., et al. A&A 2020.

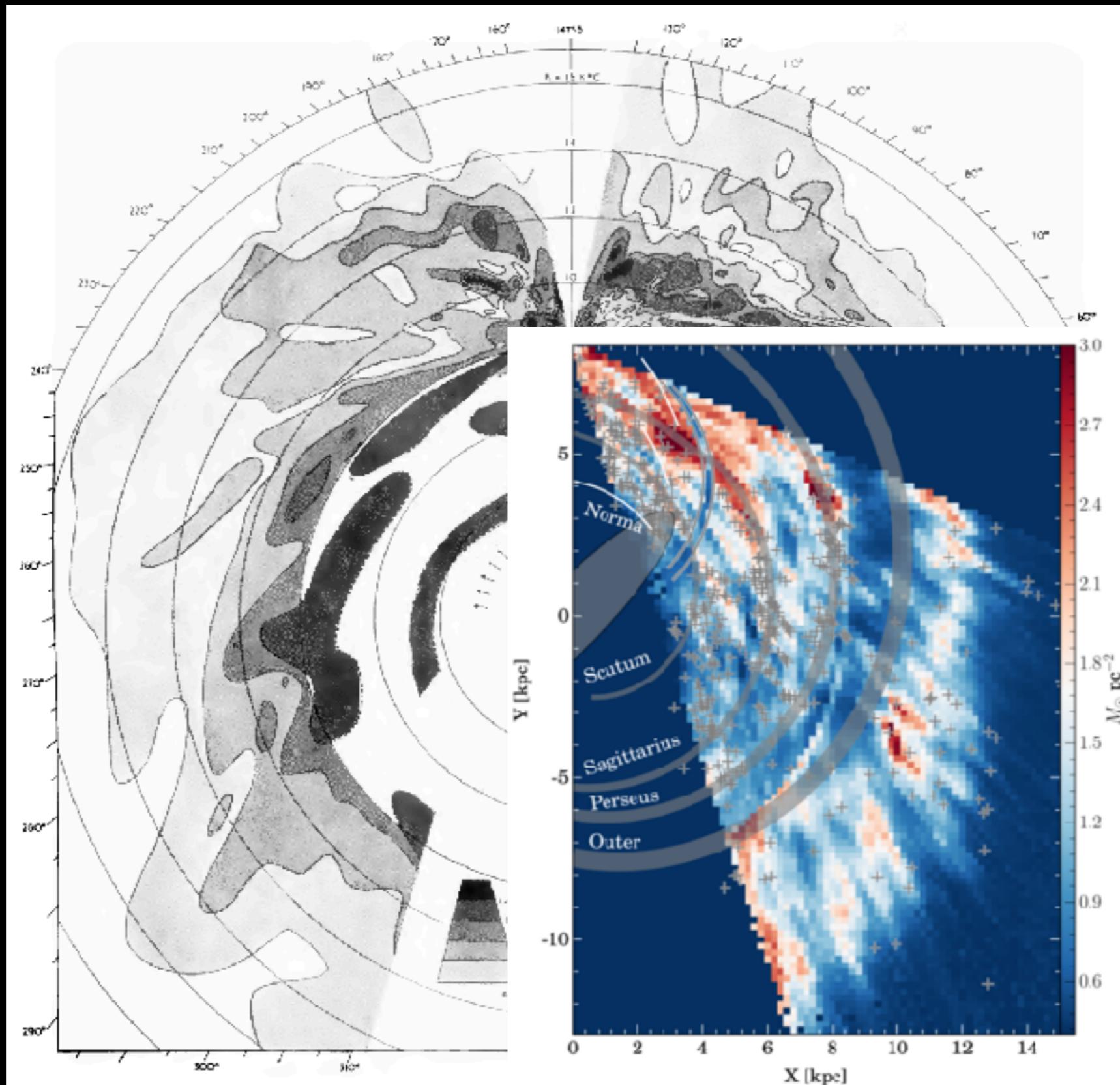
Atomic hydrogen emission toward the Milky Way

Wang, Y., Beuther, H. et al (including JDS). A&A (2020)



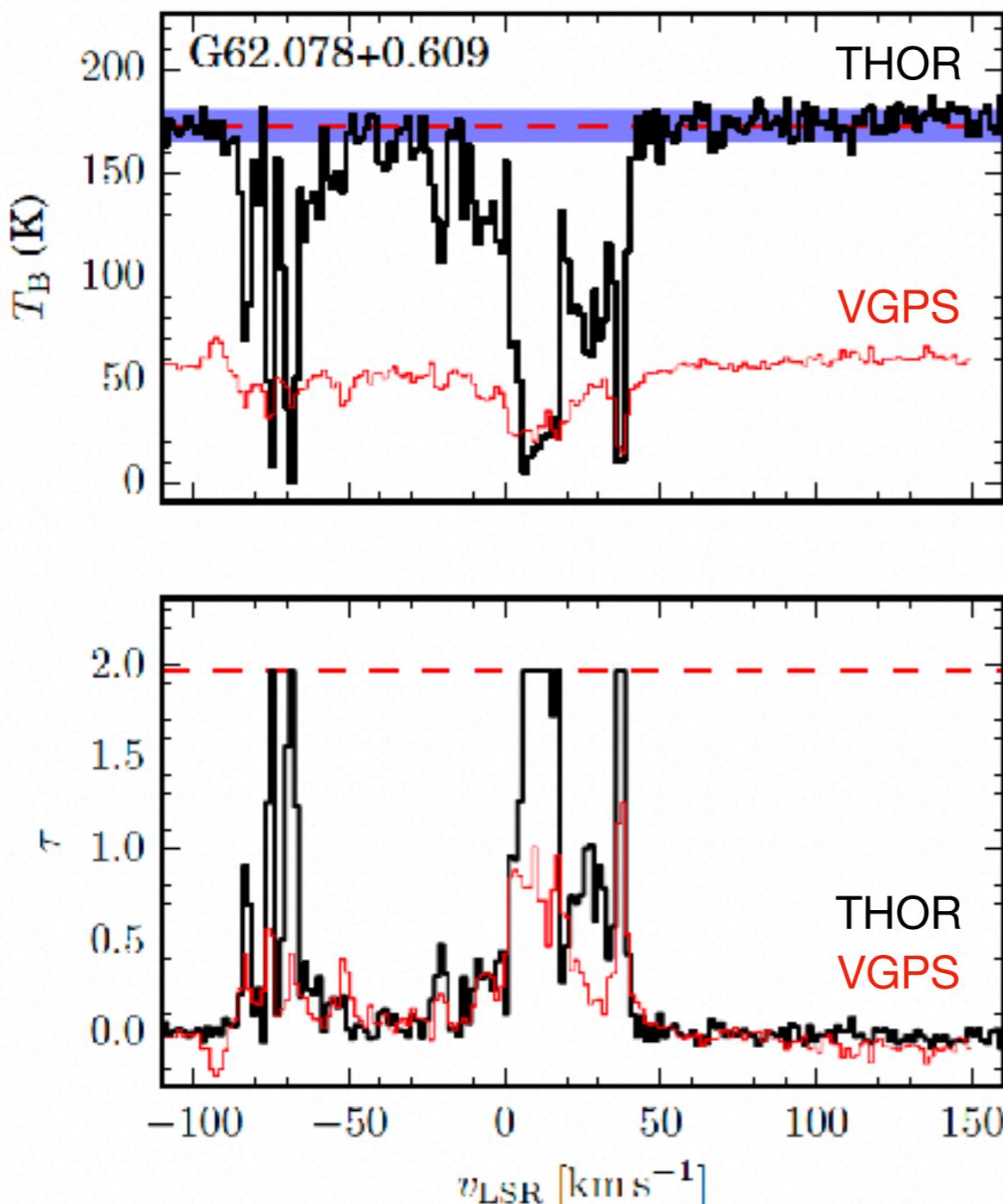
Atomic hydrogen emission toward the Milky Way

Wang, Y., Beuther, H. et al (including JDS). A&A (2020)

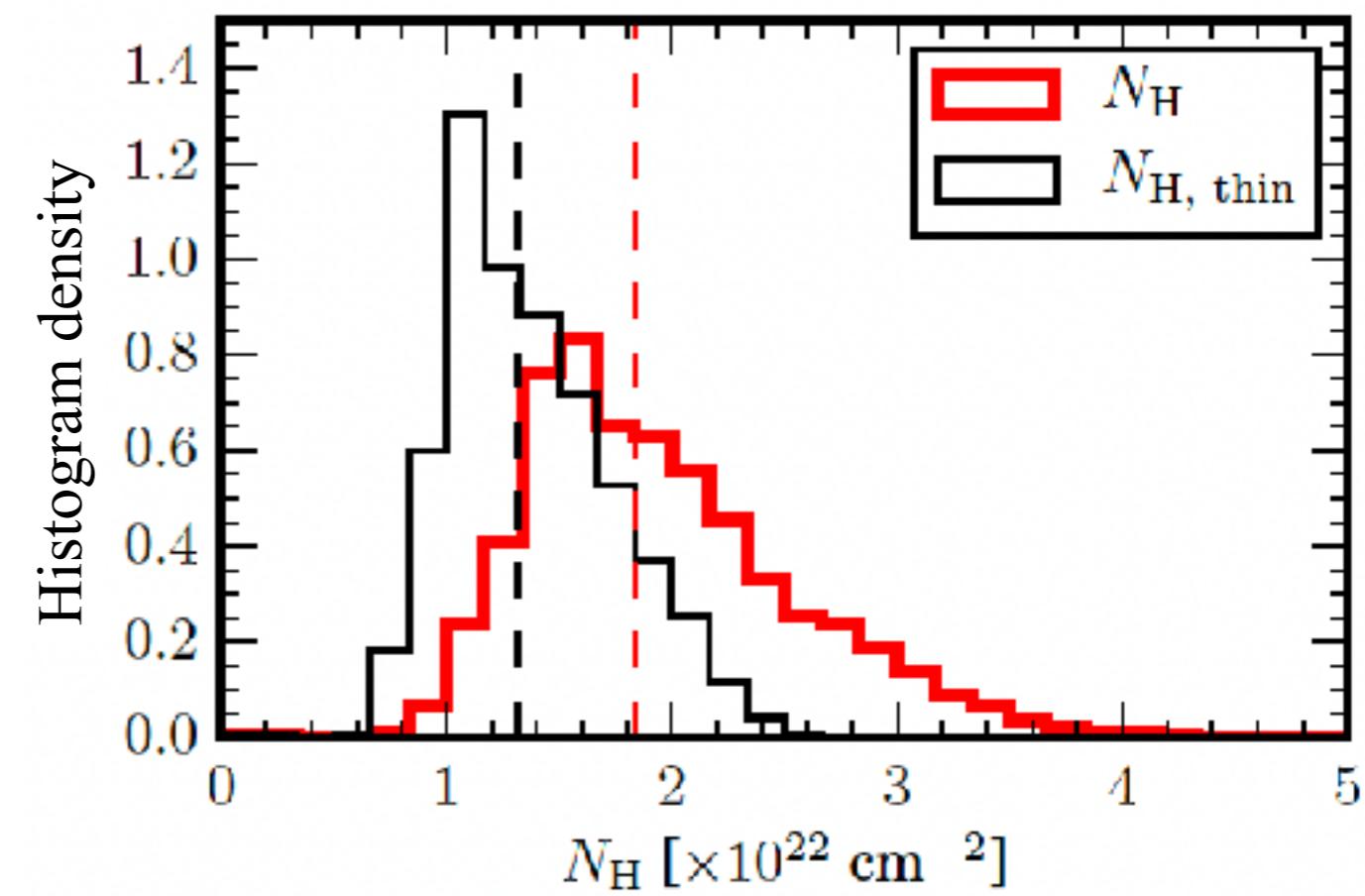


Mass of Galactic hydrogen

Wang, Y., Beuther, H. et al (including JDS). A&A (2020)

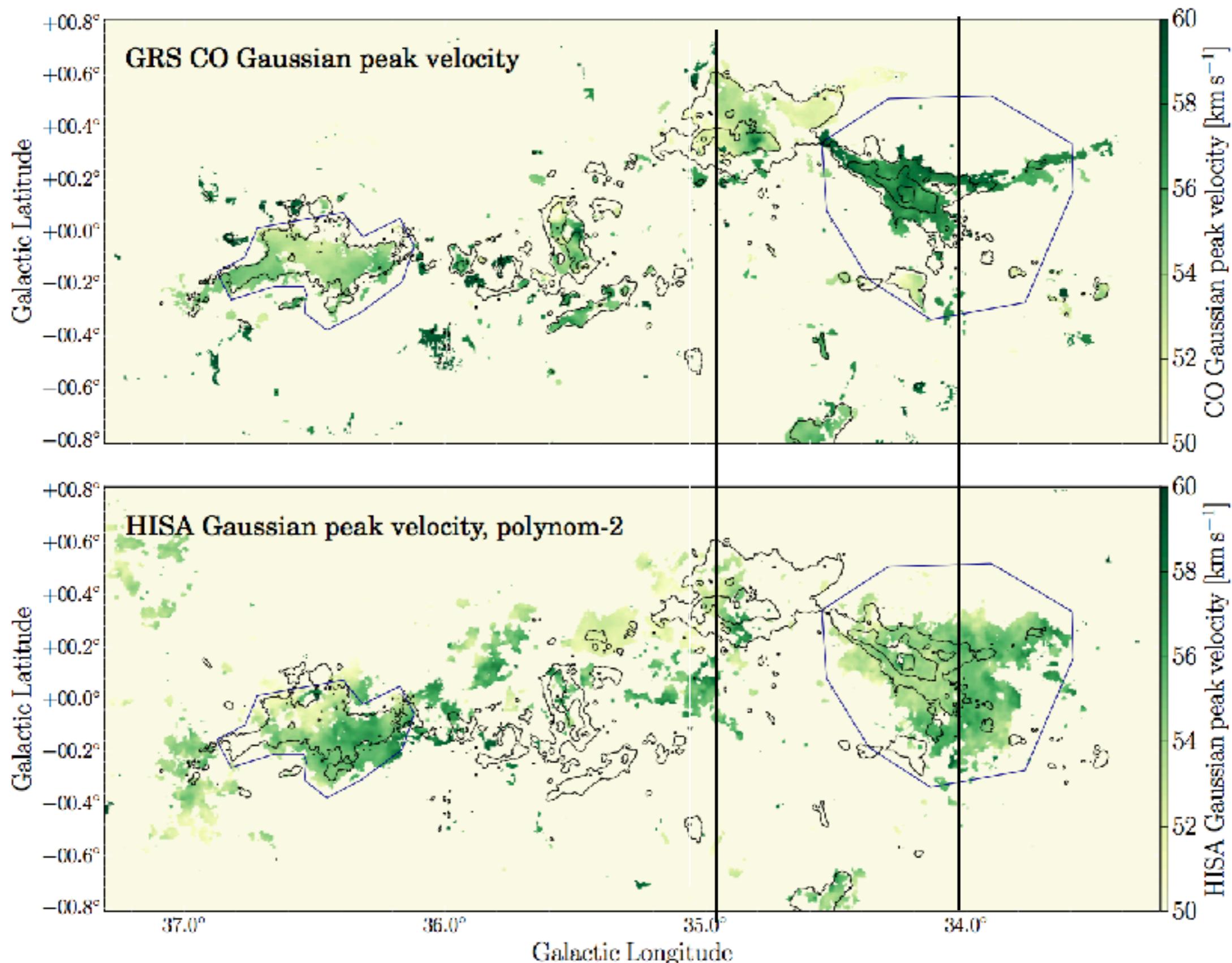


$$M_{\text{HI}} \approx 9.4 \times 10^9 M_{\odot}$$



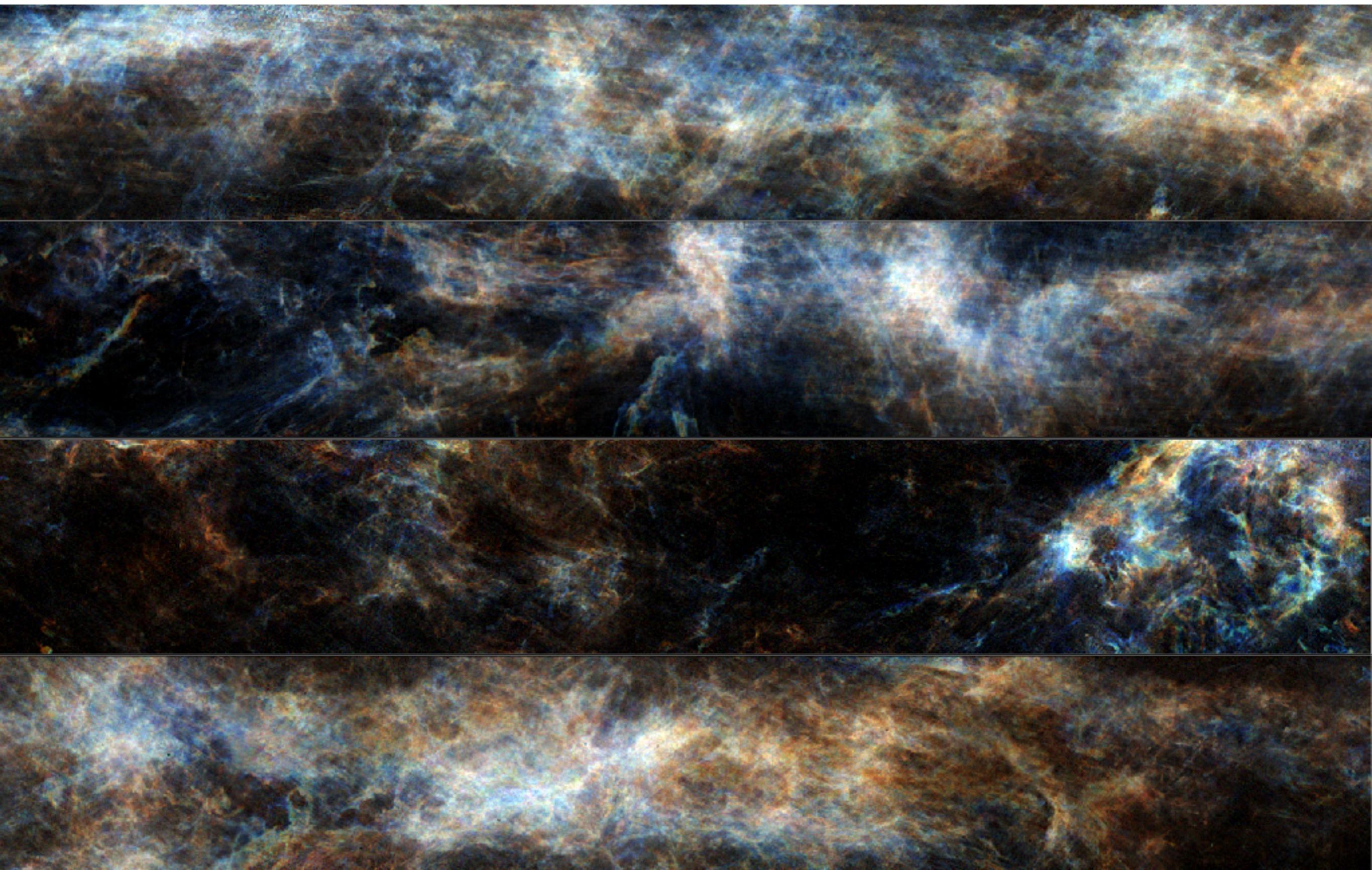
HISA and ^{13}CO

Wang, Y., Beuther, H. et al (including JDS). A&A (2020)



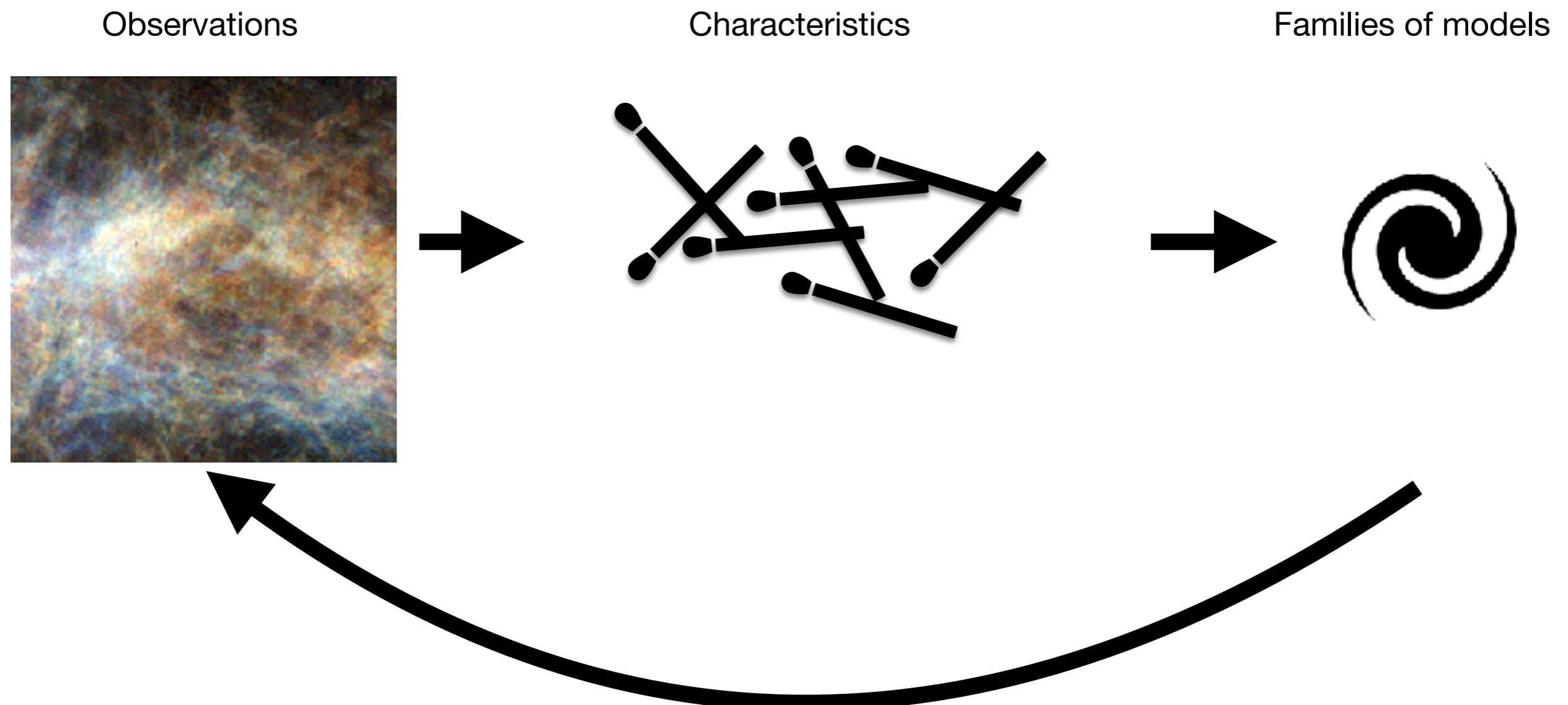
Atomic hydrogen clouds

J.D. Soler; THOR collaboration



Data-driven analysis

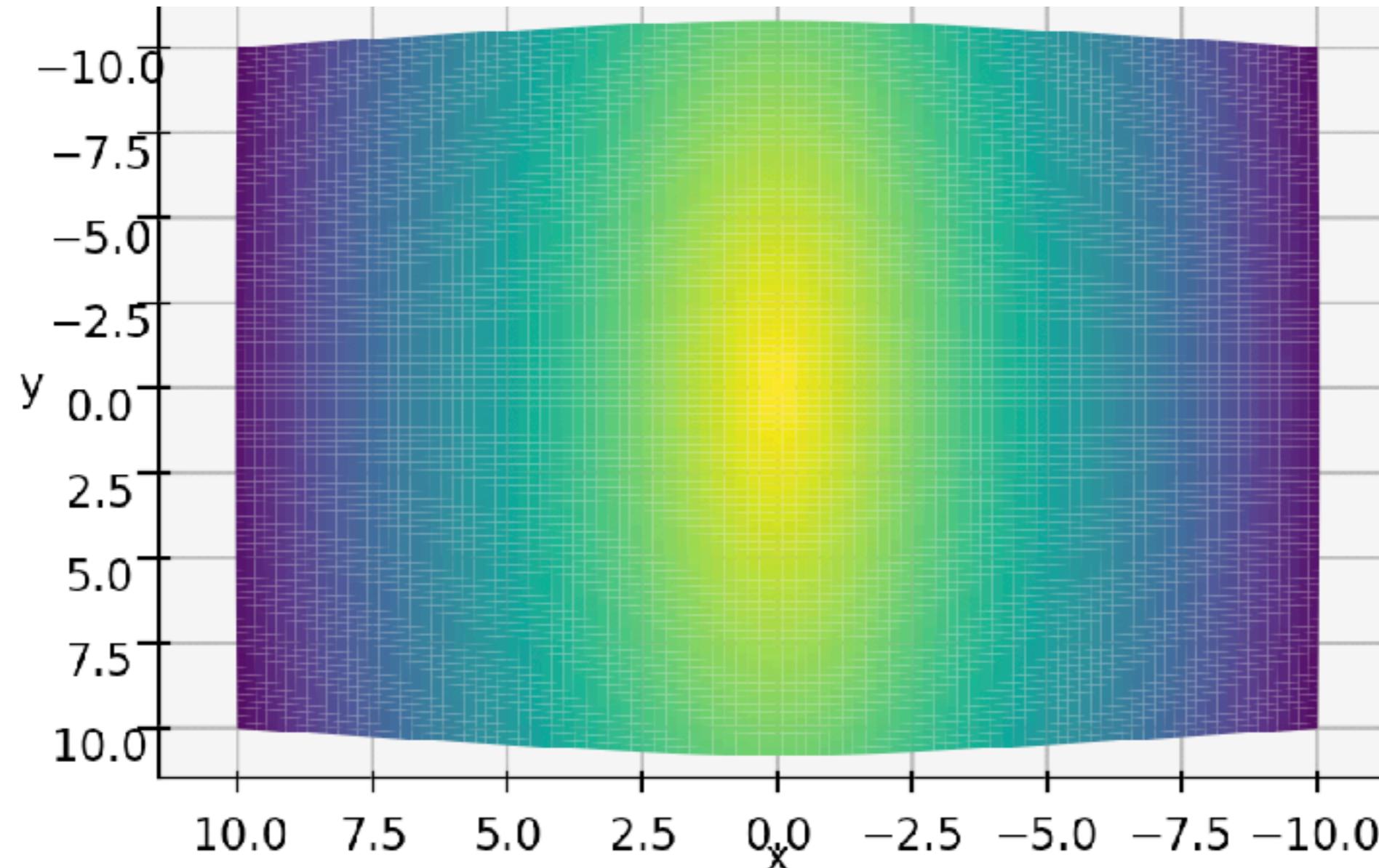
Soler, J.D. et al. A&A (2020)



Machine vision: Hessian matrix method

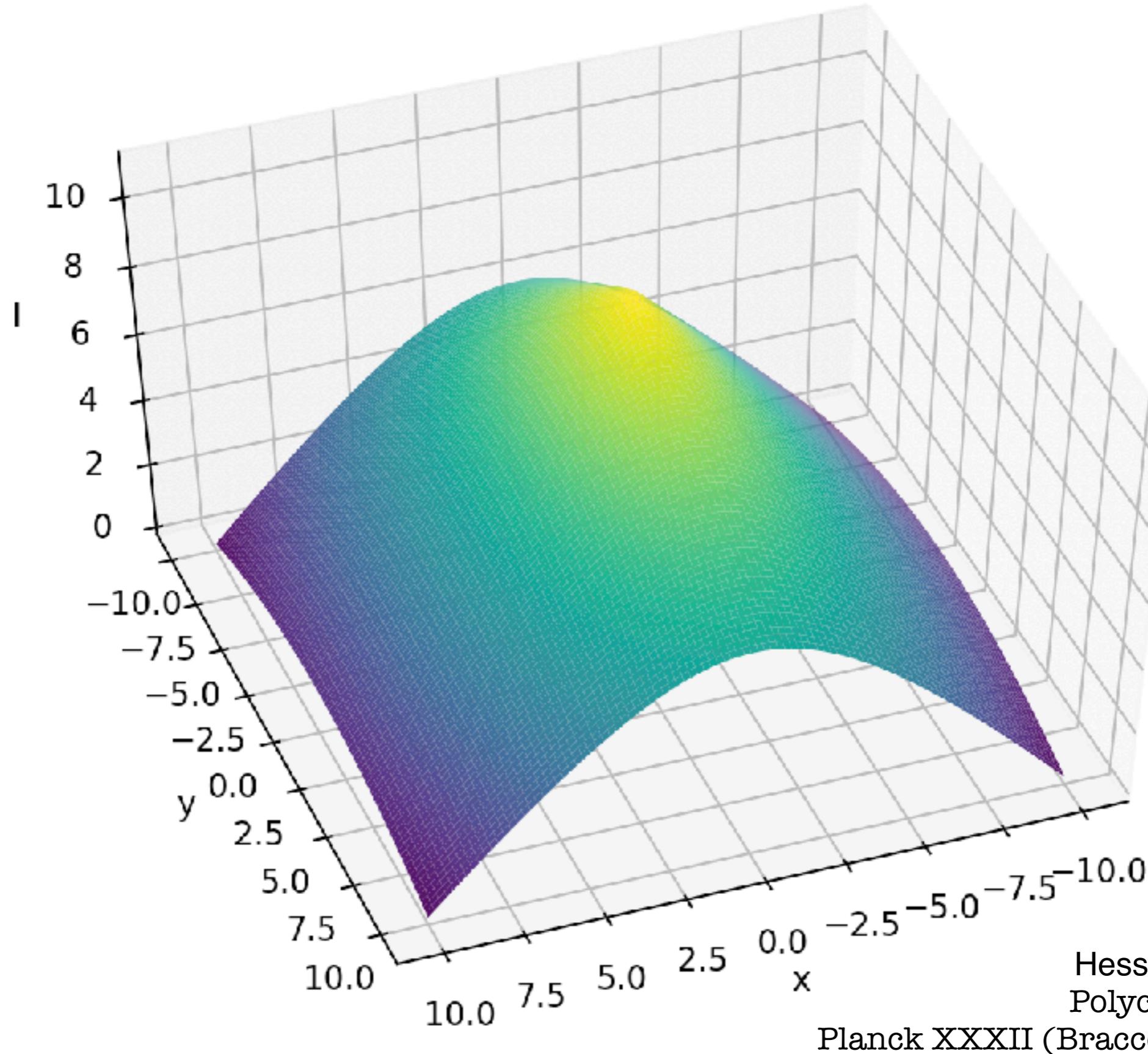
Soler, J.D. et al. A&A. 2020

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



Machine vision: Hessian matrix method

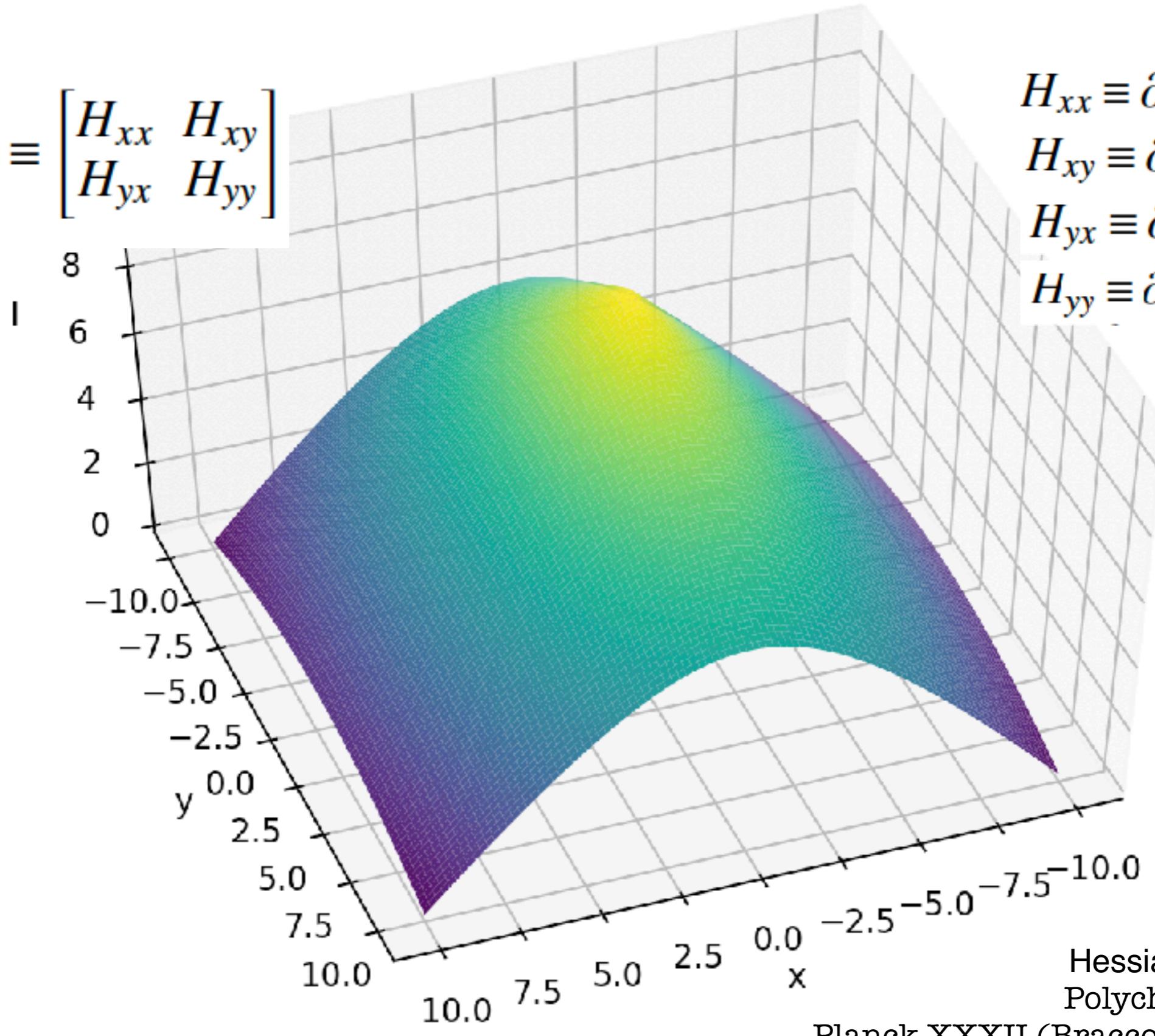
Soler, J.D. et al. A&A. 2020



Machine vision: Hessian matrix method

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

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



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

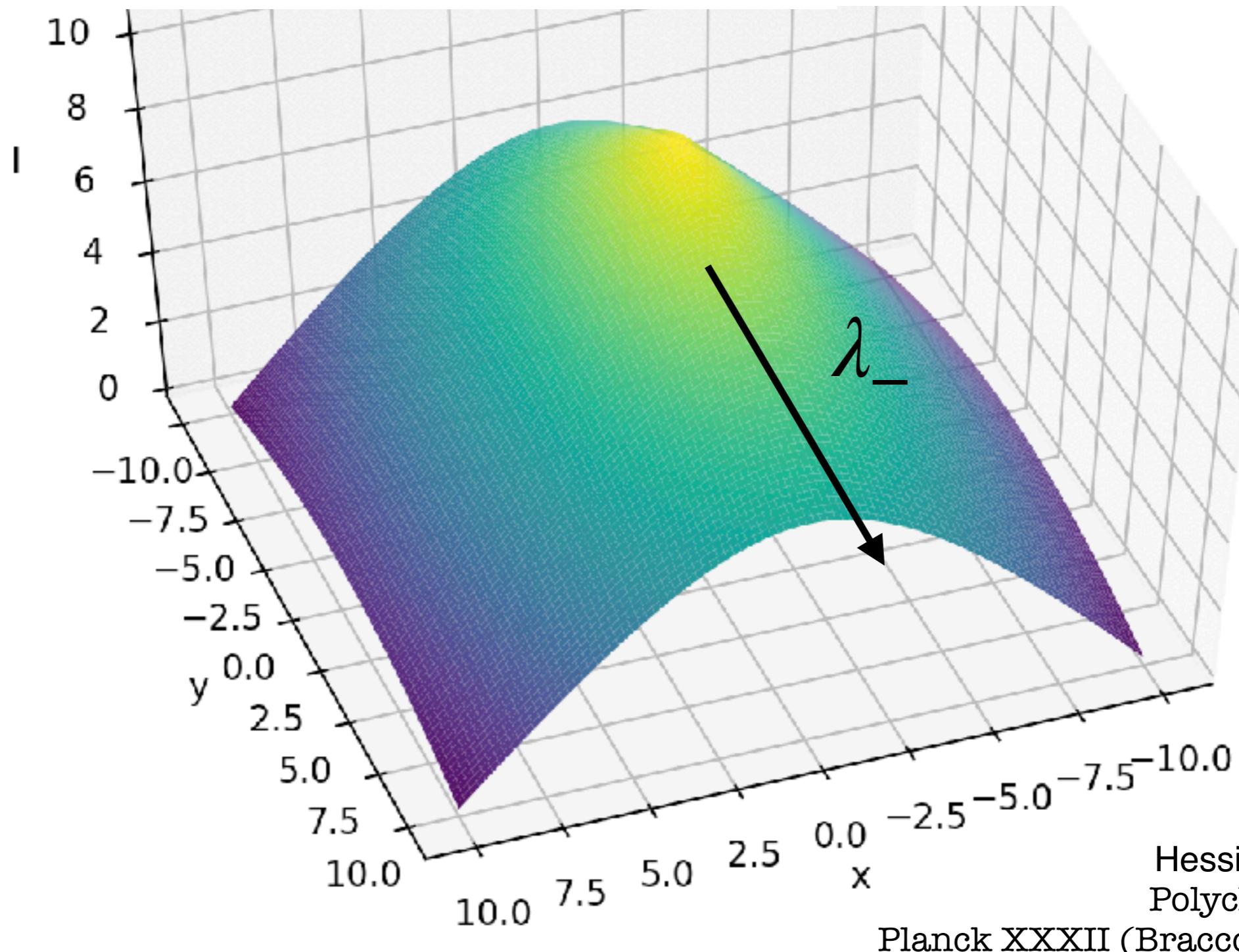
Hessian matrix method
Polychroni et al. 2013
Planck XXXII (Bracco, A. et al.), 2016

Machine vision: Hessian matrix method

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

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

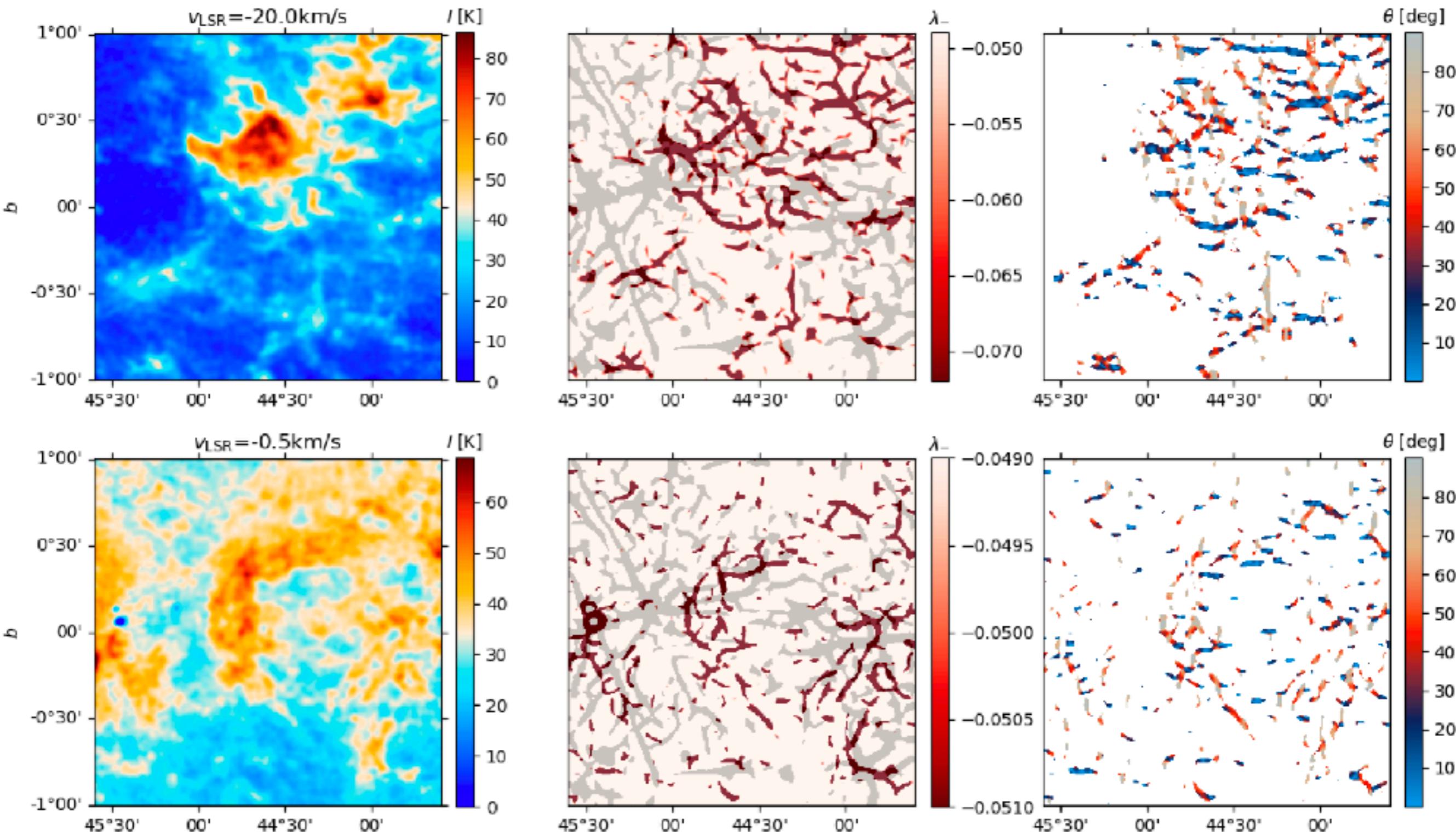
$$\theta = \frac{1}{2} \tan^{-1} \frac{H_{xy} - H_{yx}}{H_{xx} - H_{yy}}$$



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

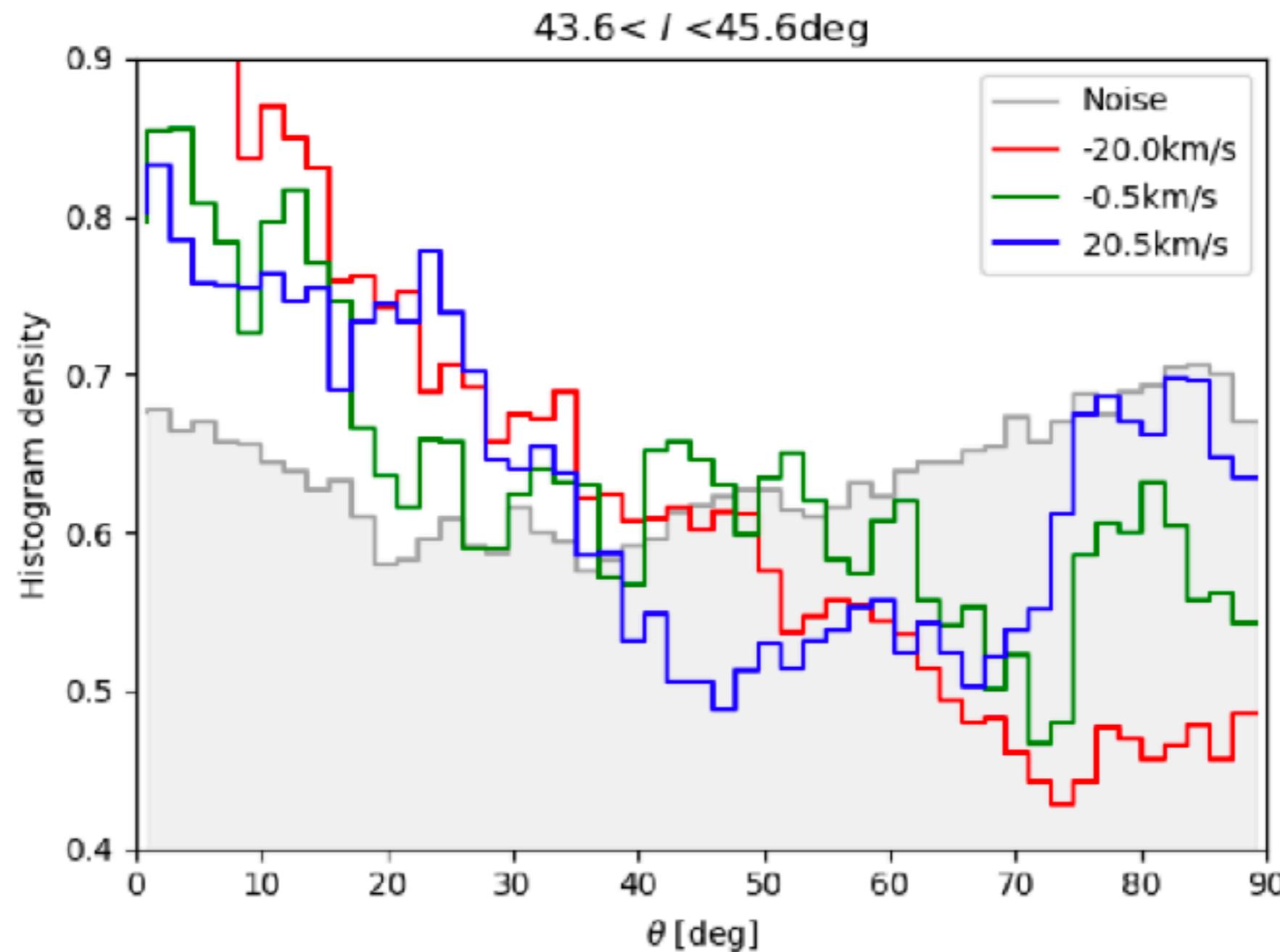
HI filaments

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



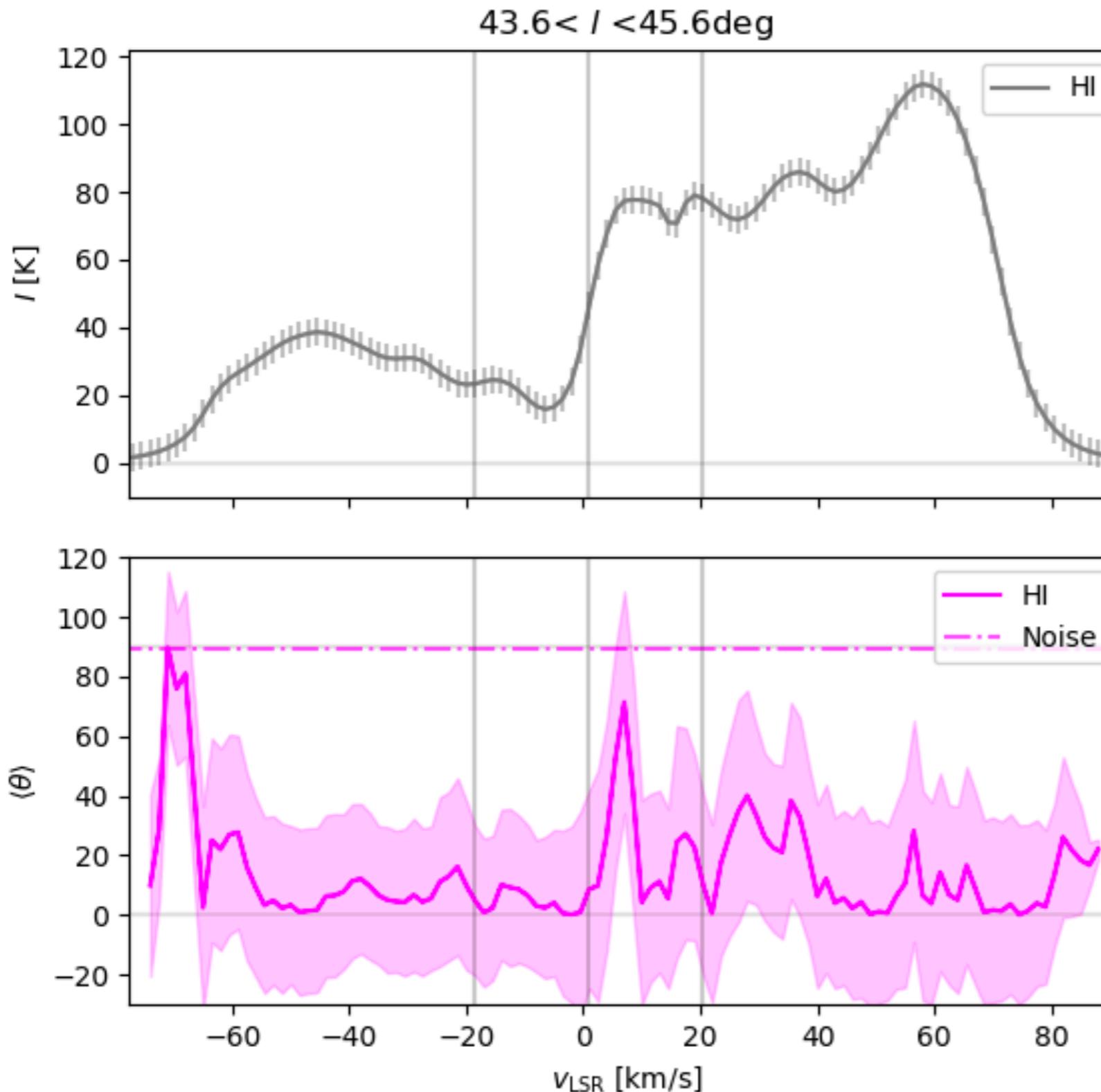
Histograms of HI filament orientation

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



HI filament orientation

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



HI filament orientation: random walk interpretation

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

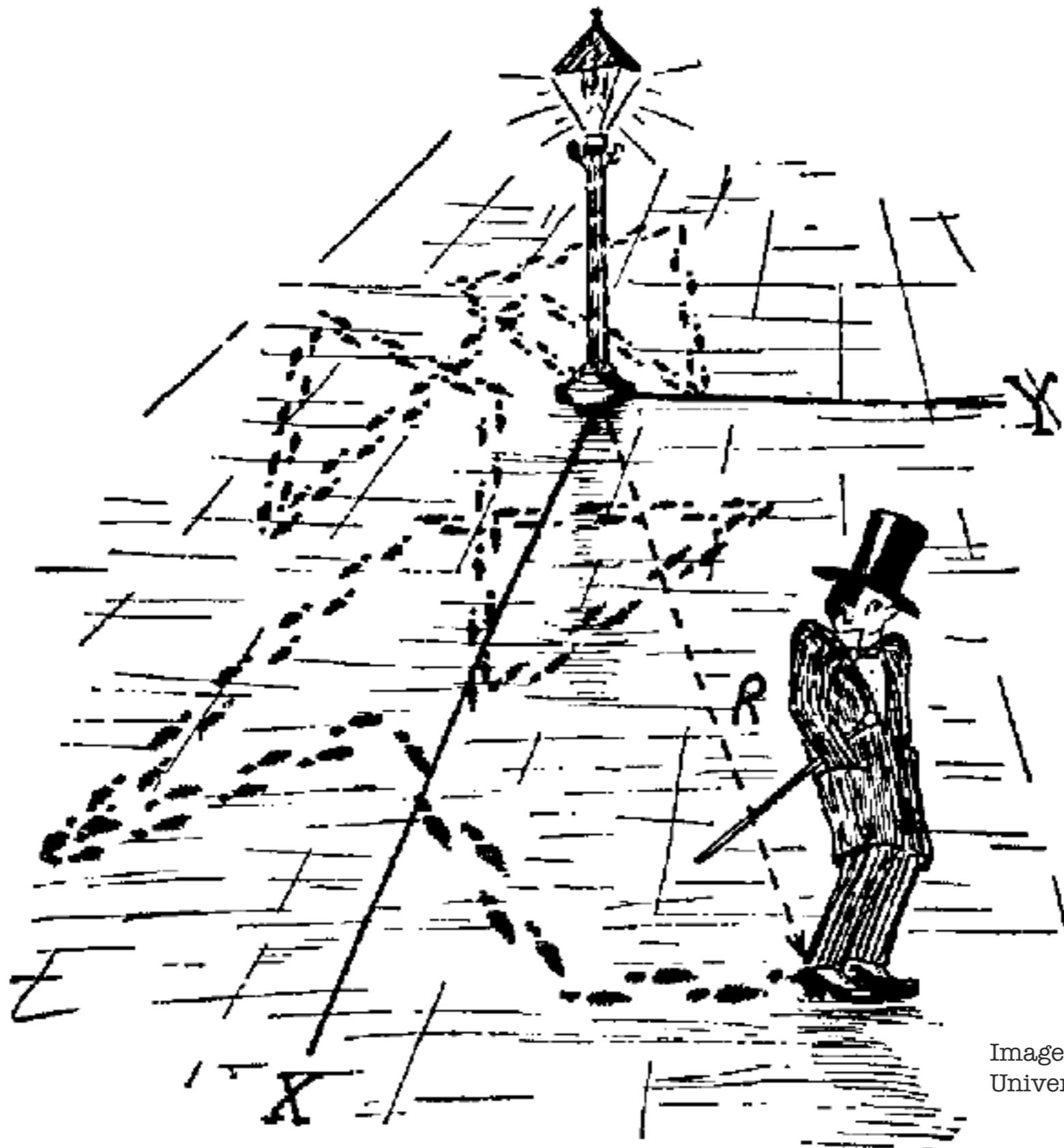
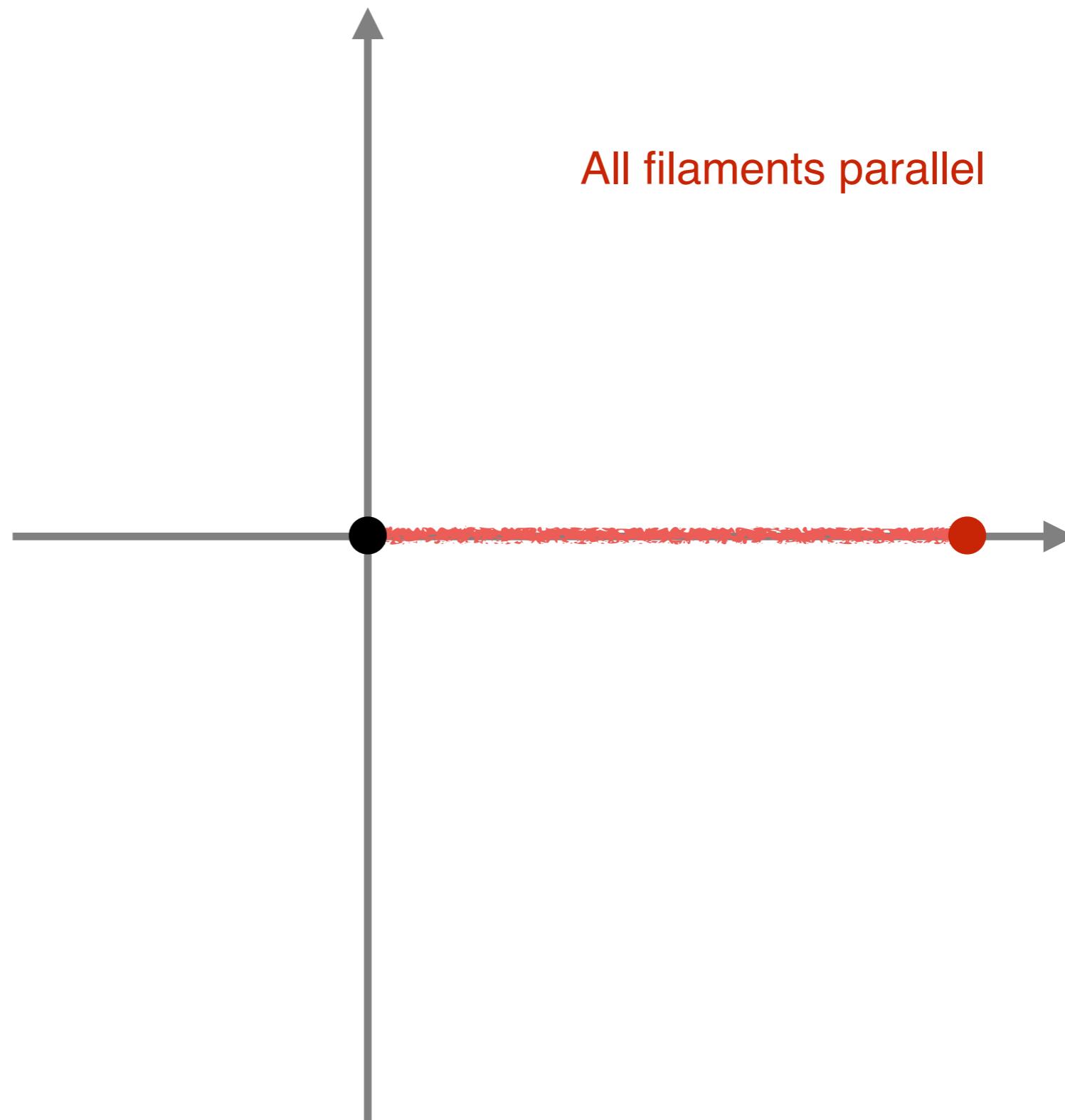


Image: Advanced Design Studies
University of Tokyo

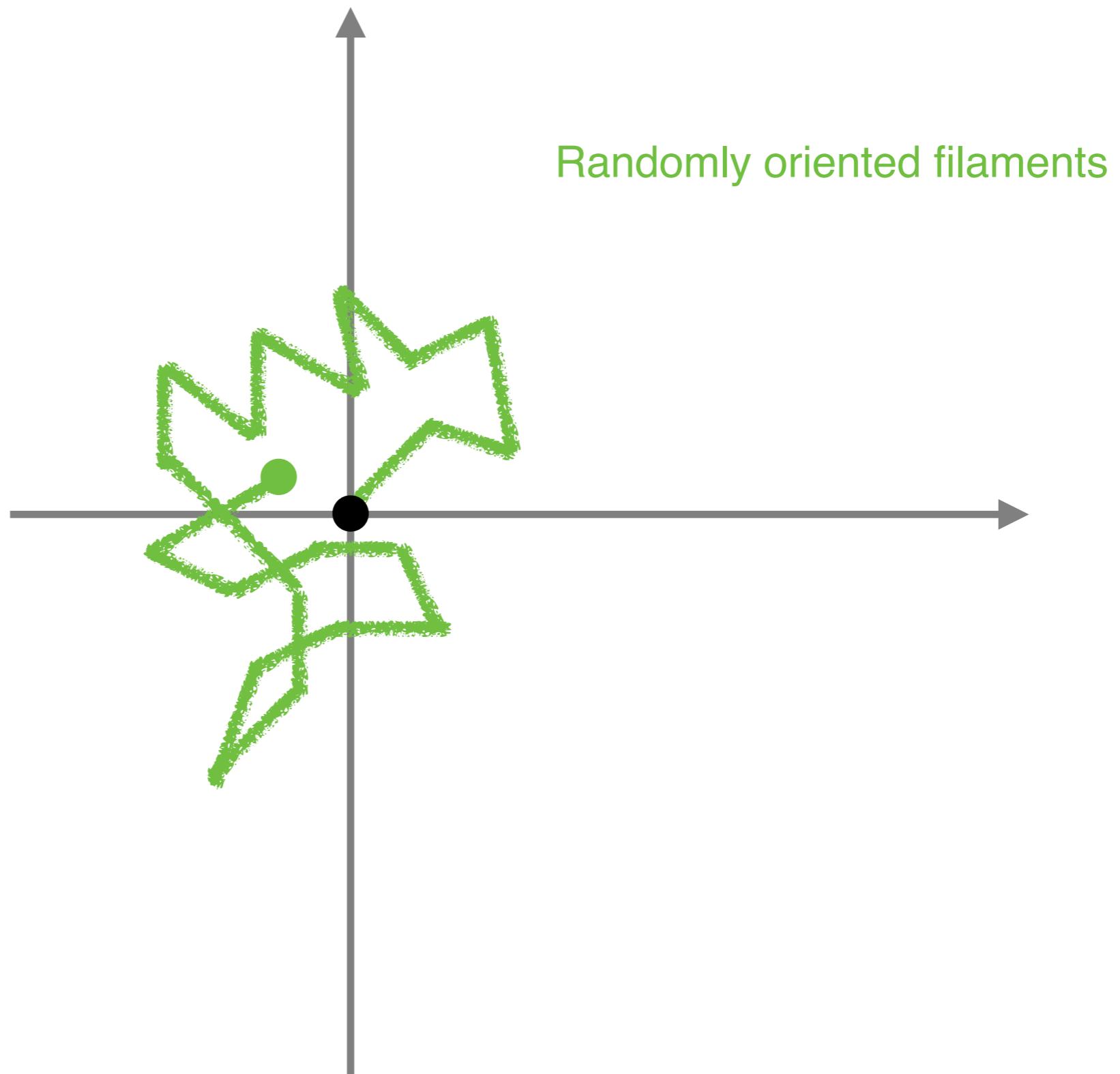
HI filament orientation: random walk interpretation

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



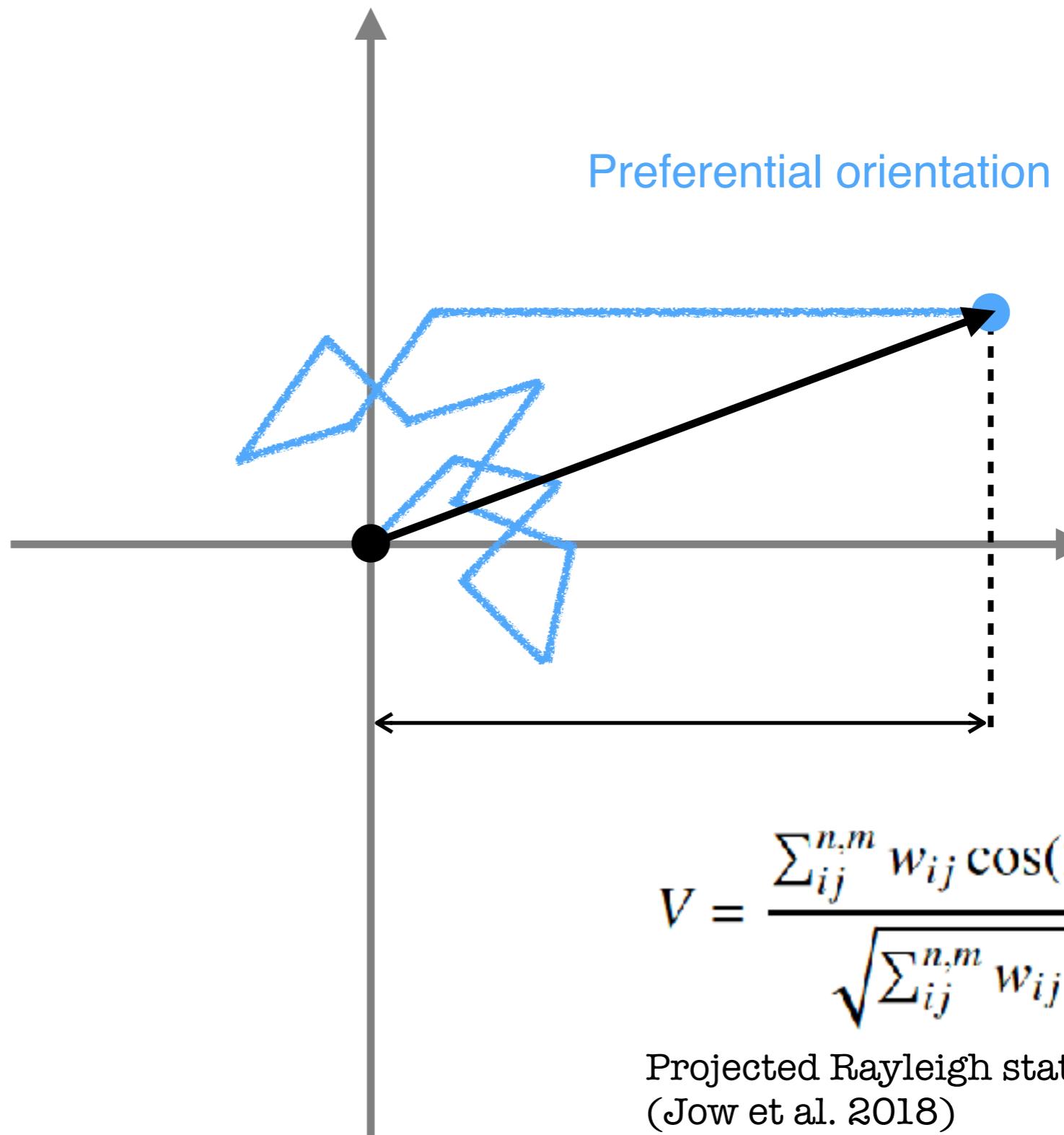
HI filament orientation: random walk interpretation

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



HI filament orientation: random walk interpretation

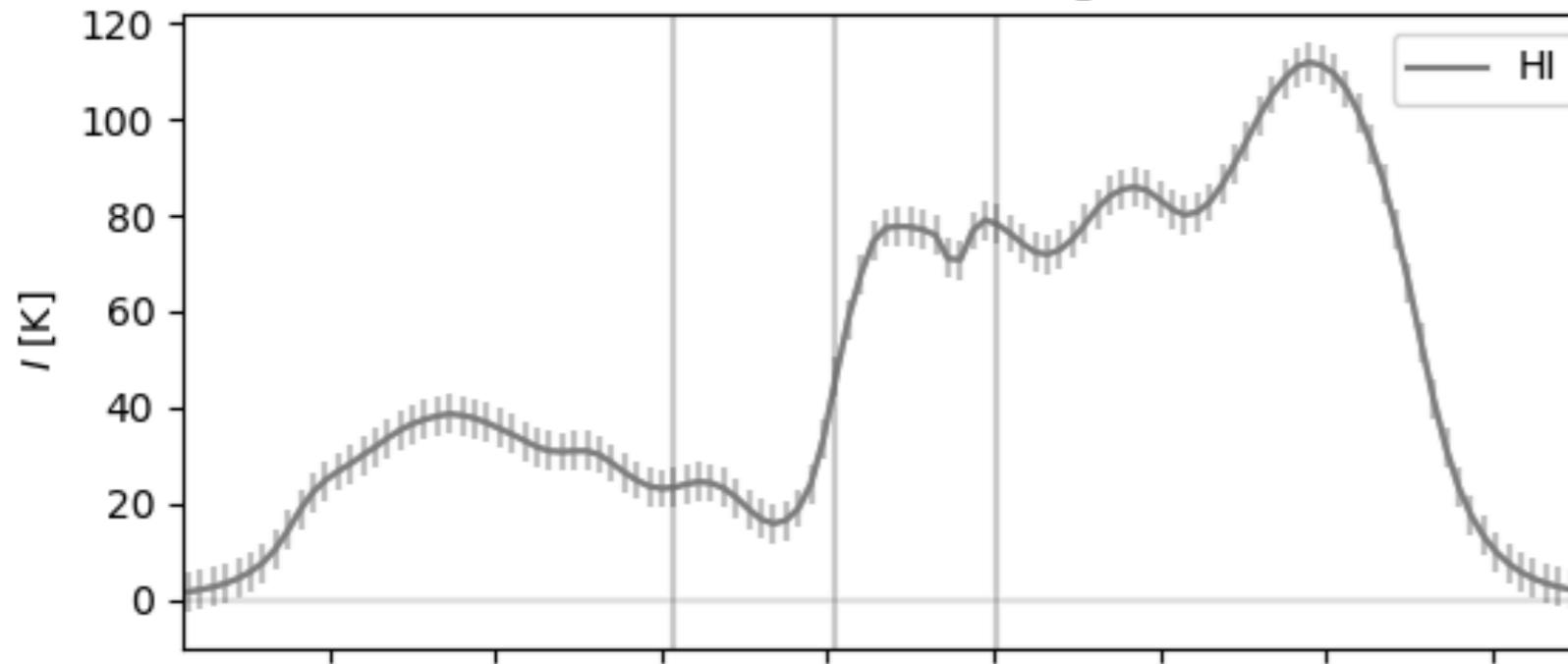
Soler, J.D. et al. A&A. 2020



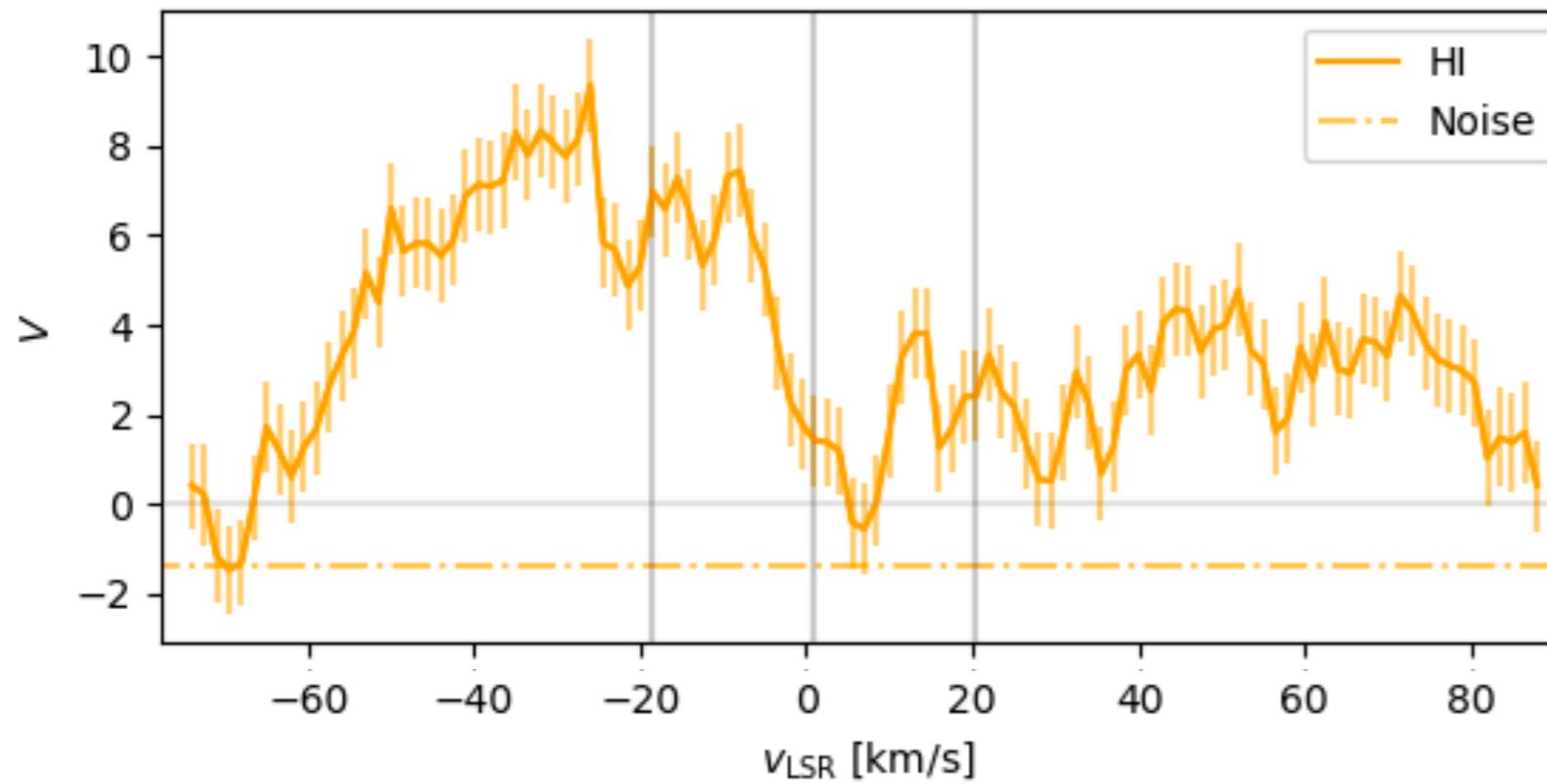
HI filament orientation

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

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



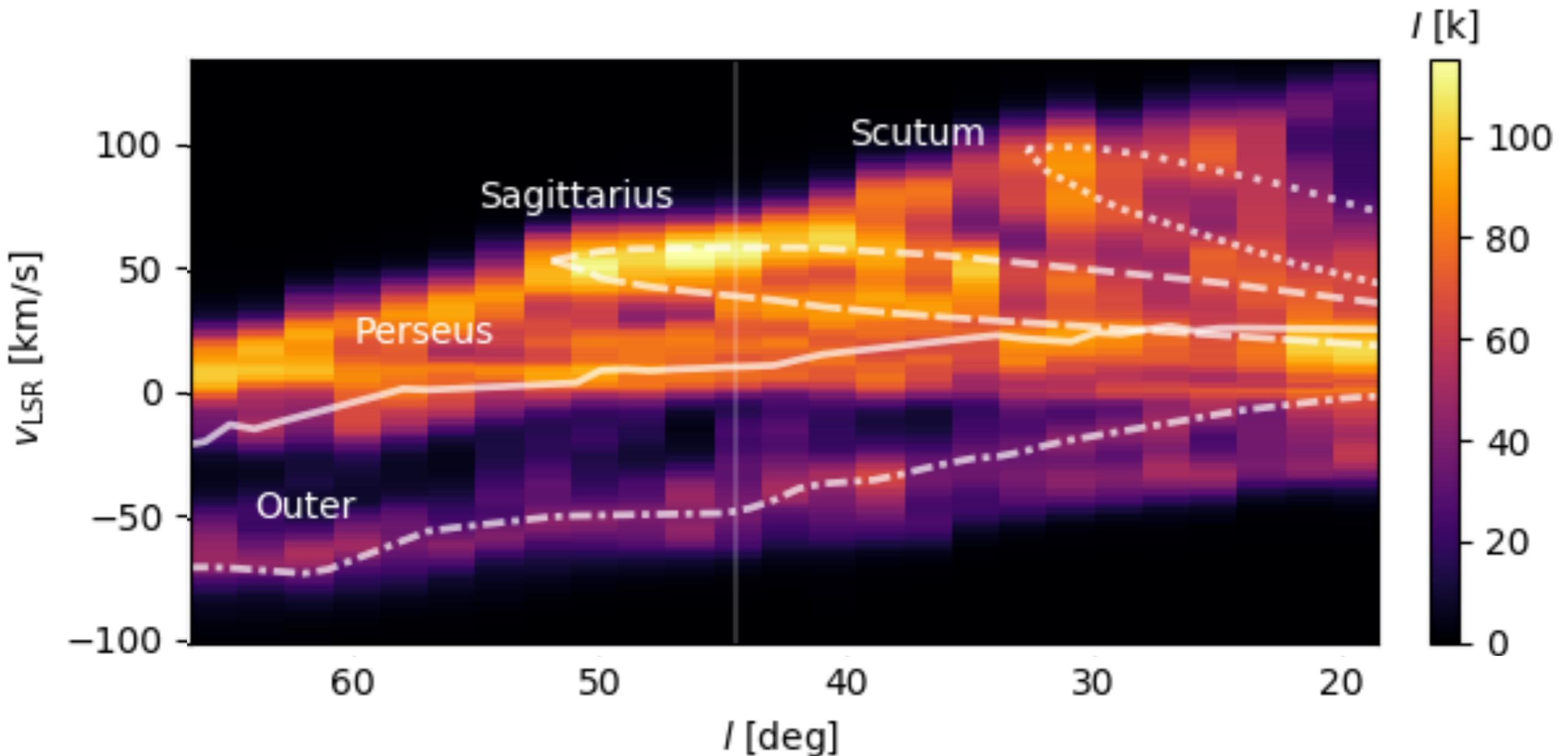
Projected Rayleigh statistic
(Jow et al. 2018)



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

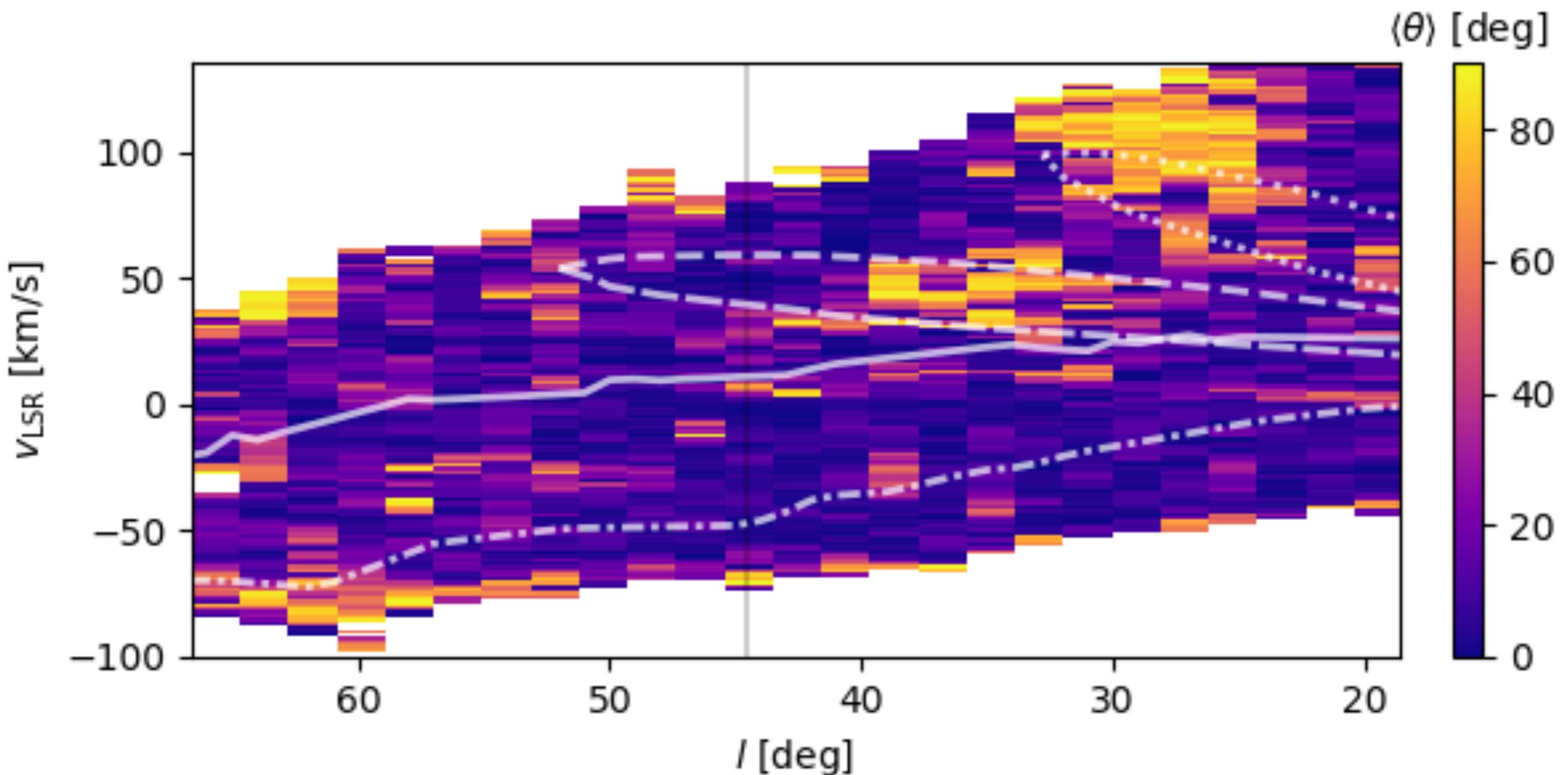
HI emission

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



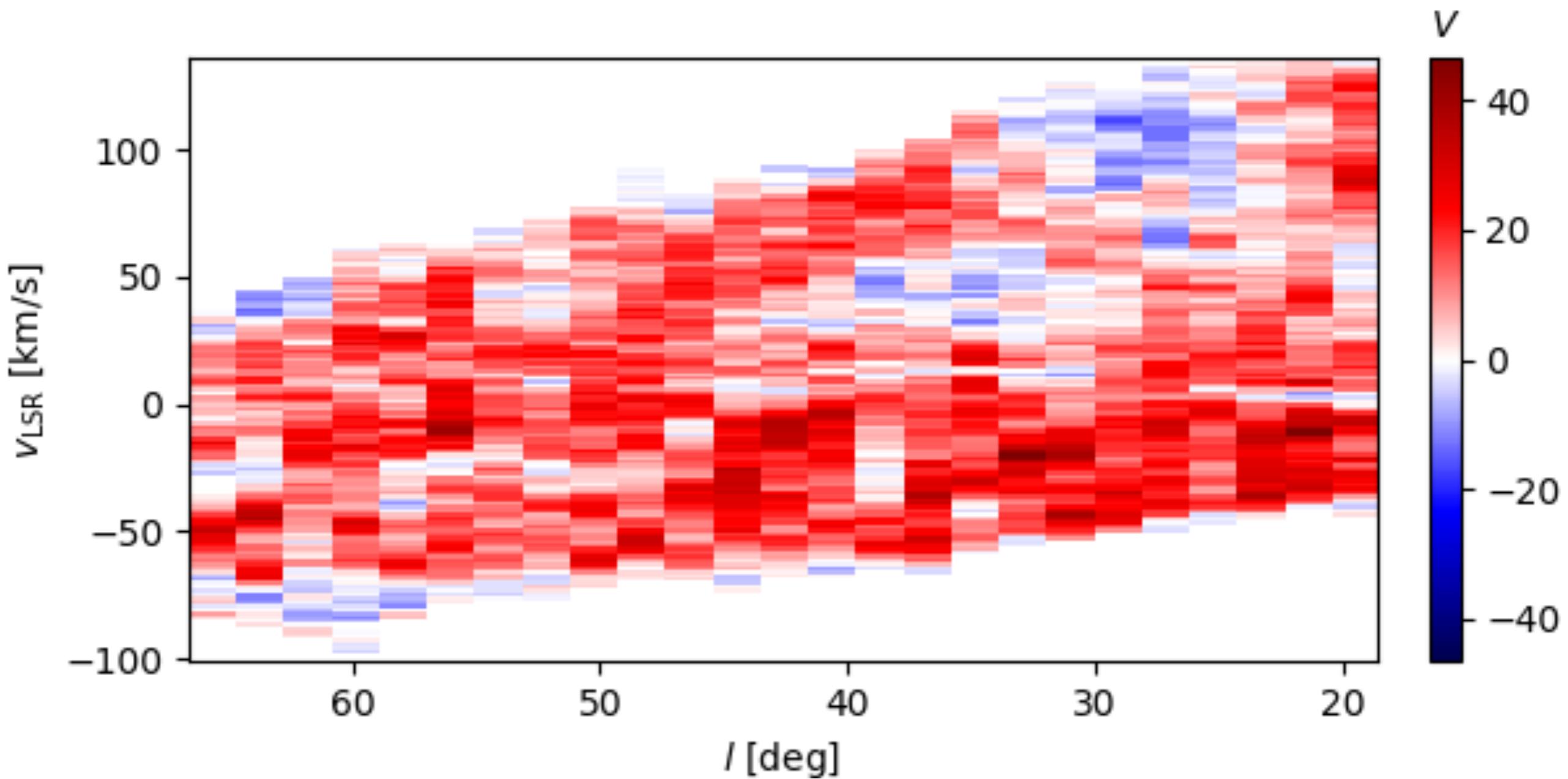
HI filament orientation

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



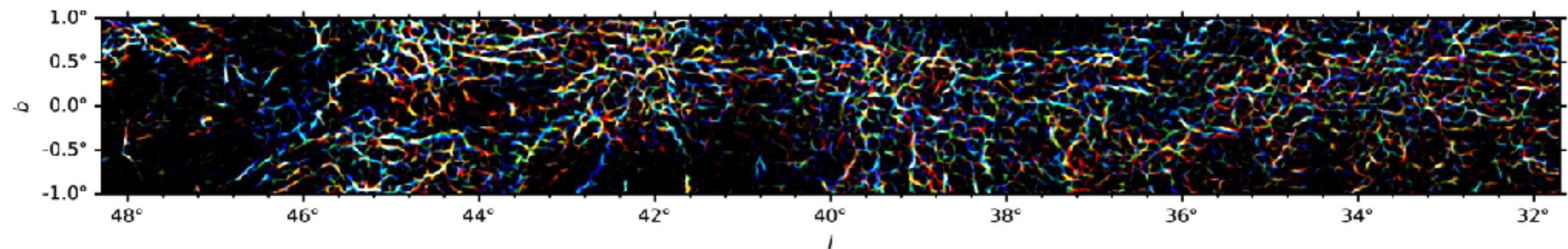
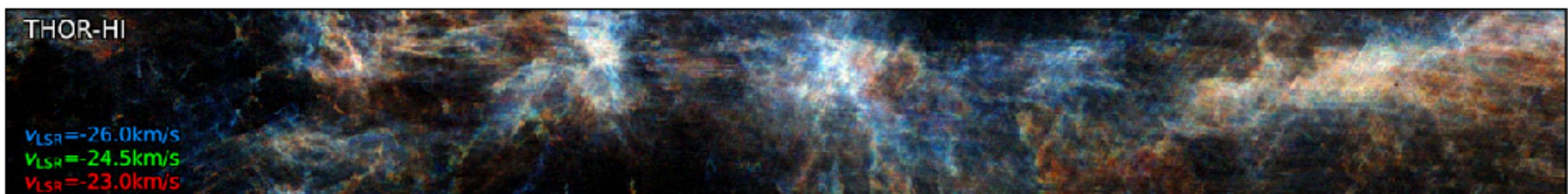
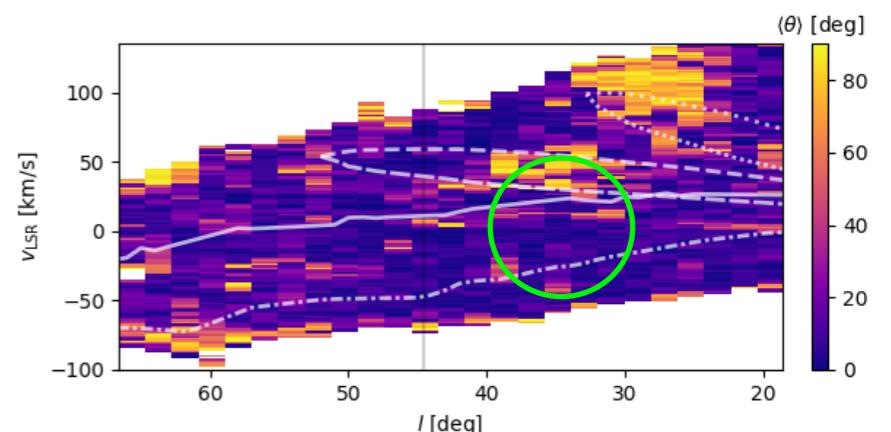
HI filament orientation

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



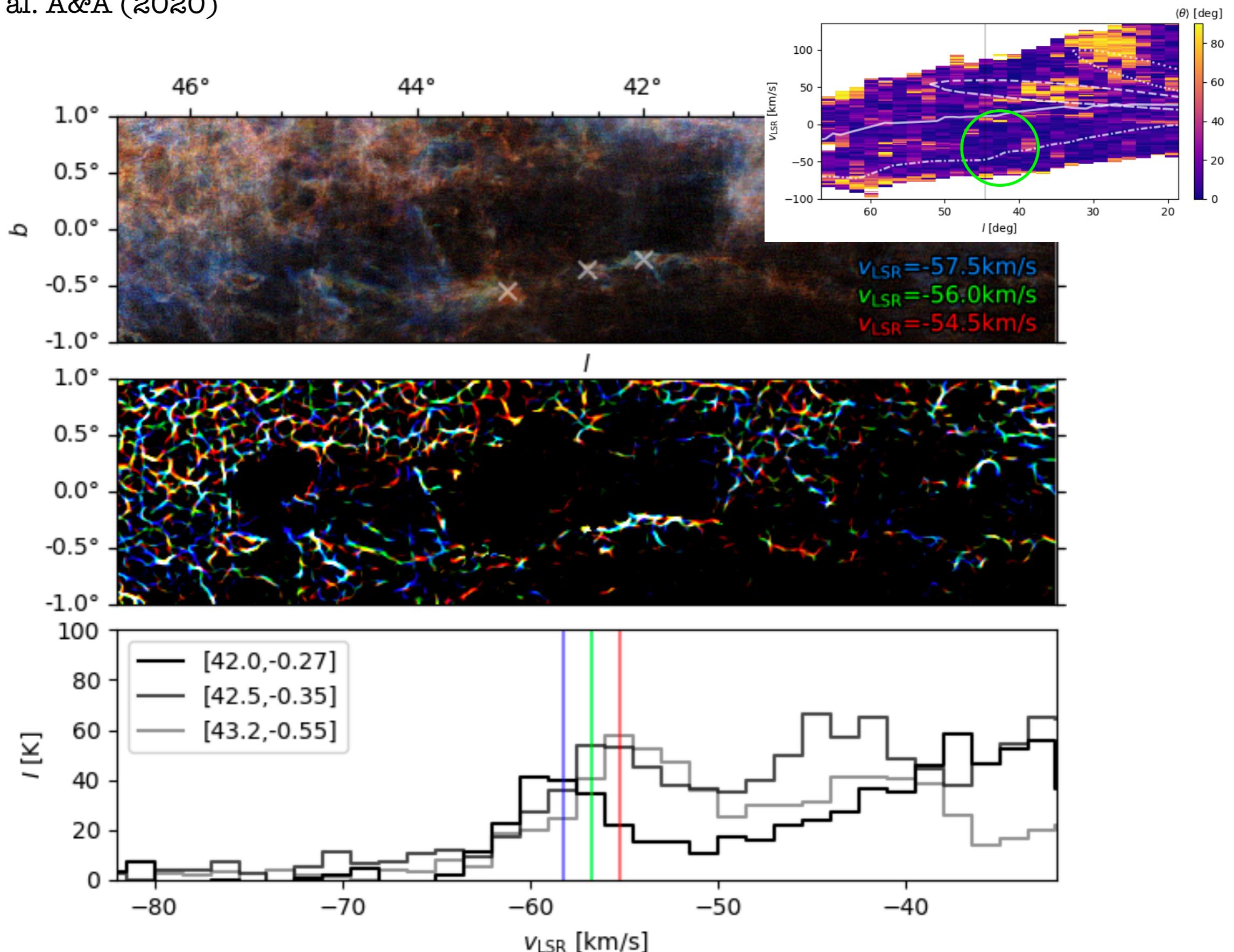
HI filaments (THOR)

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



The Magdalena filament

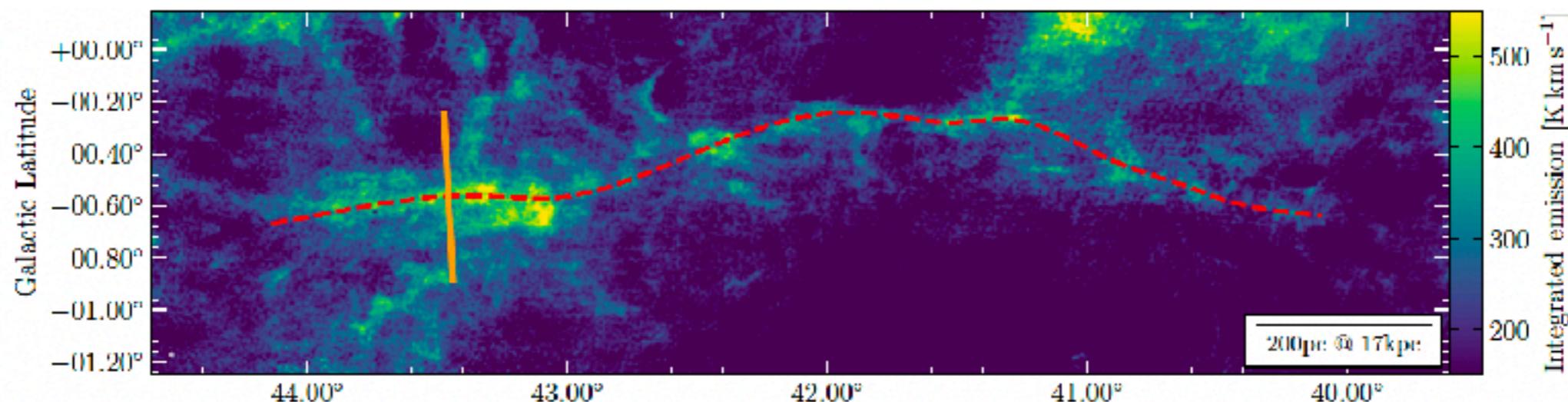
Soler, J.D. et al. A&A (2020)



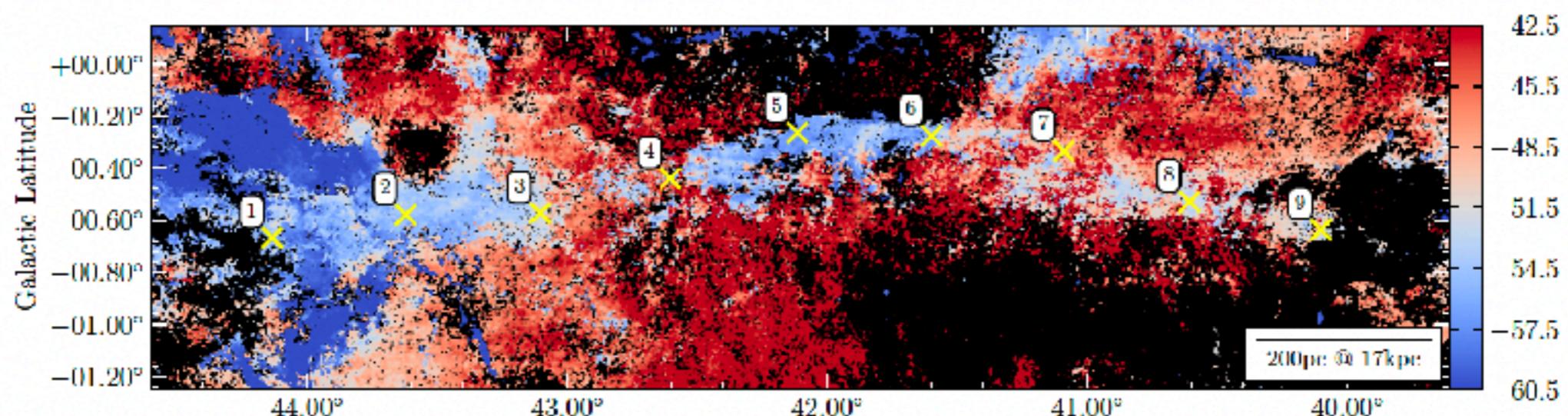
The Magdalena filament

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

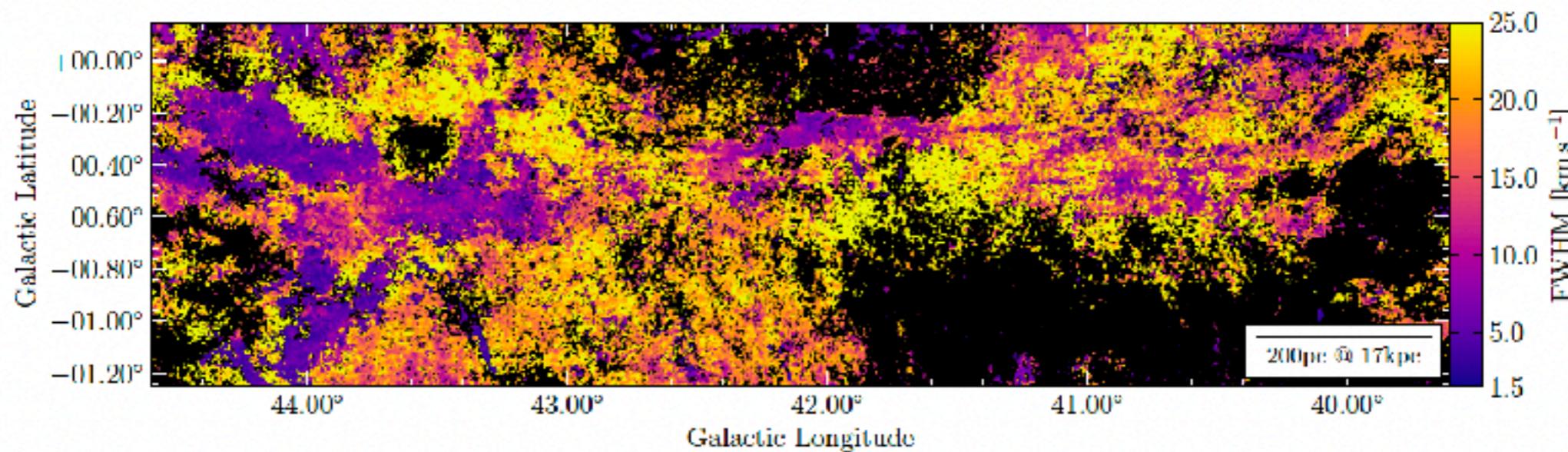
N_{H}



$\langle v \rangle$



σ_v



The Magdalena (Maggie) filament

Syed, J., JDS, et al. A&A 2022

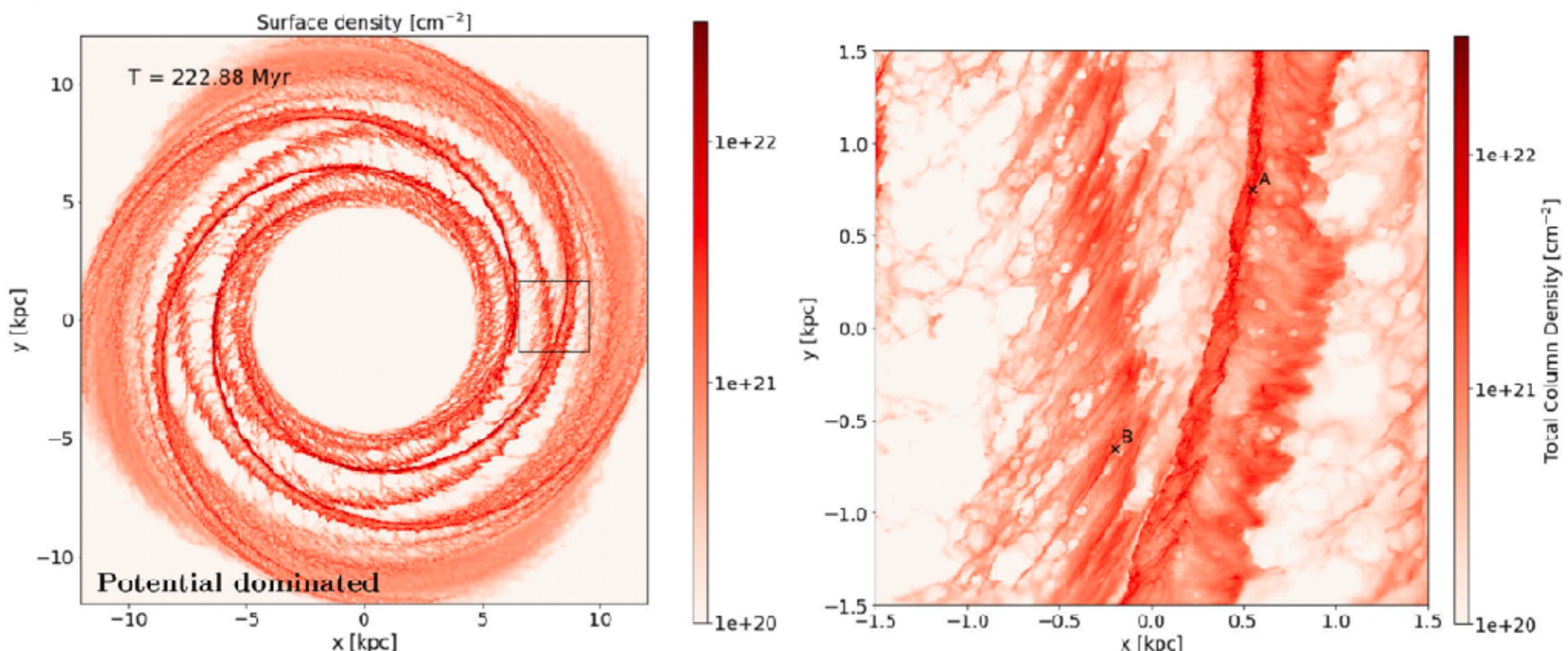
The “Maggie” filament: Physical properties of a giant atomic cloud

J. Syed + Team



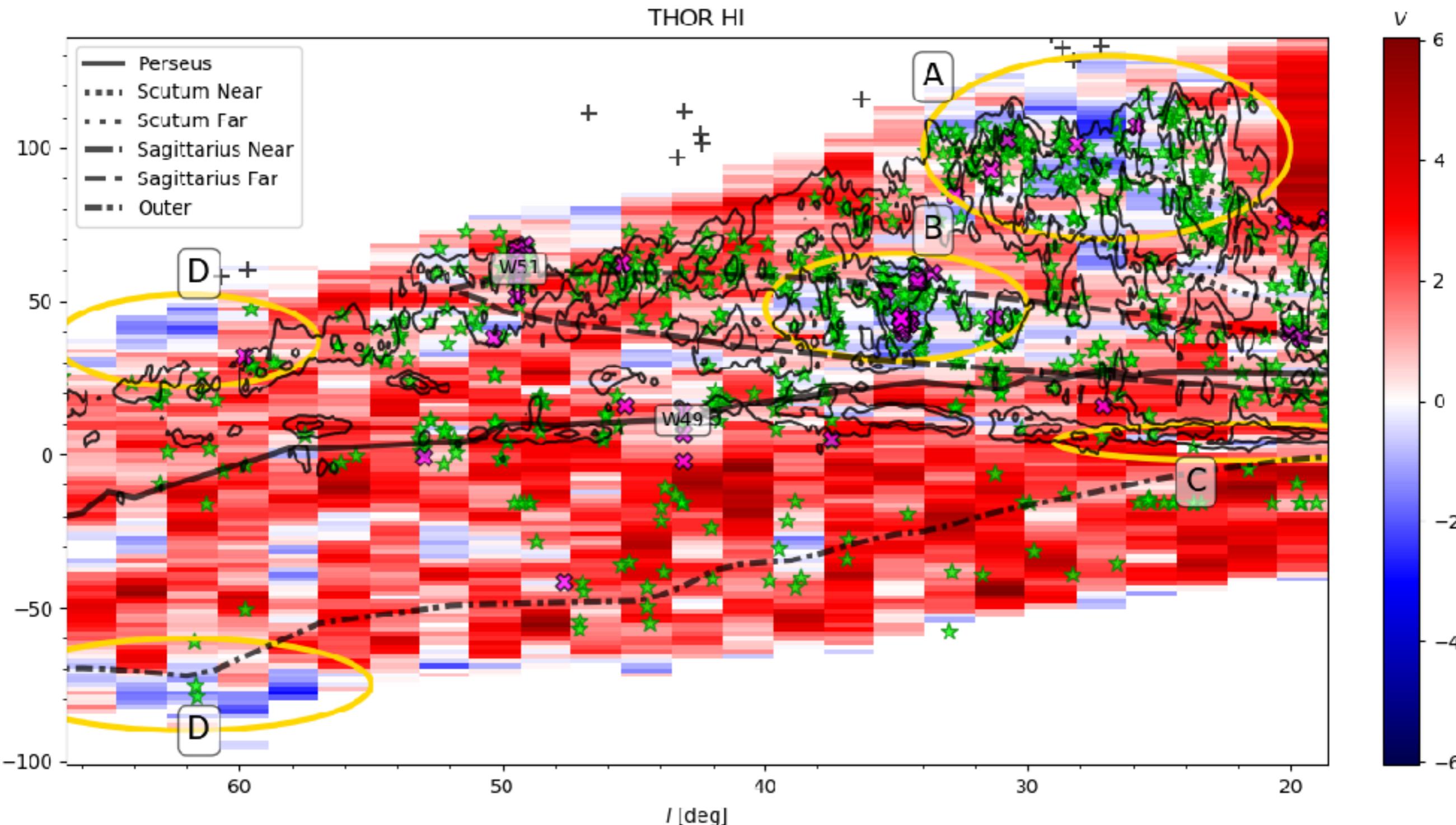
HI filament orientation

Smith, R.. et al. MNRAS. 2020



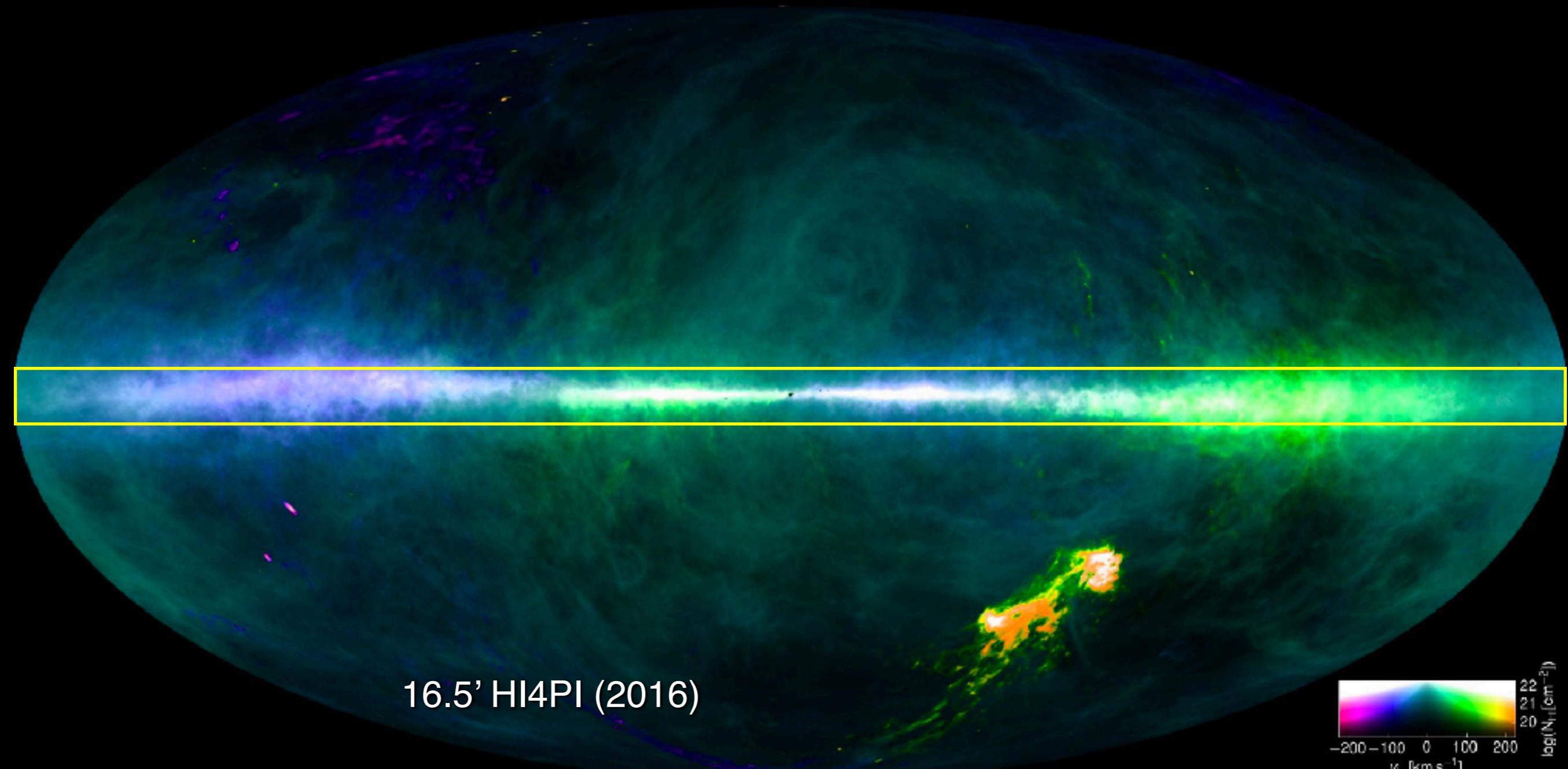
HI filament orientation

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



Atomic hydrogen emission

HI4PI Collaboration. A&A (2016)



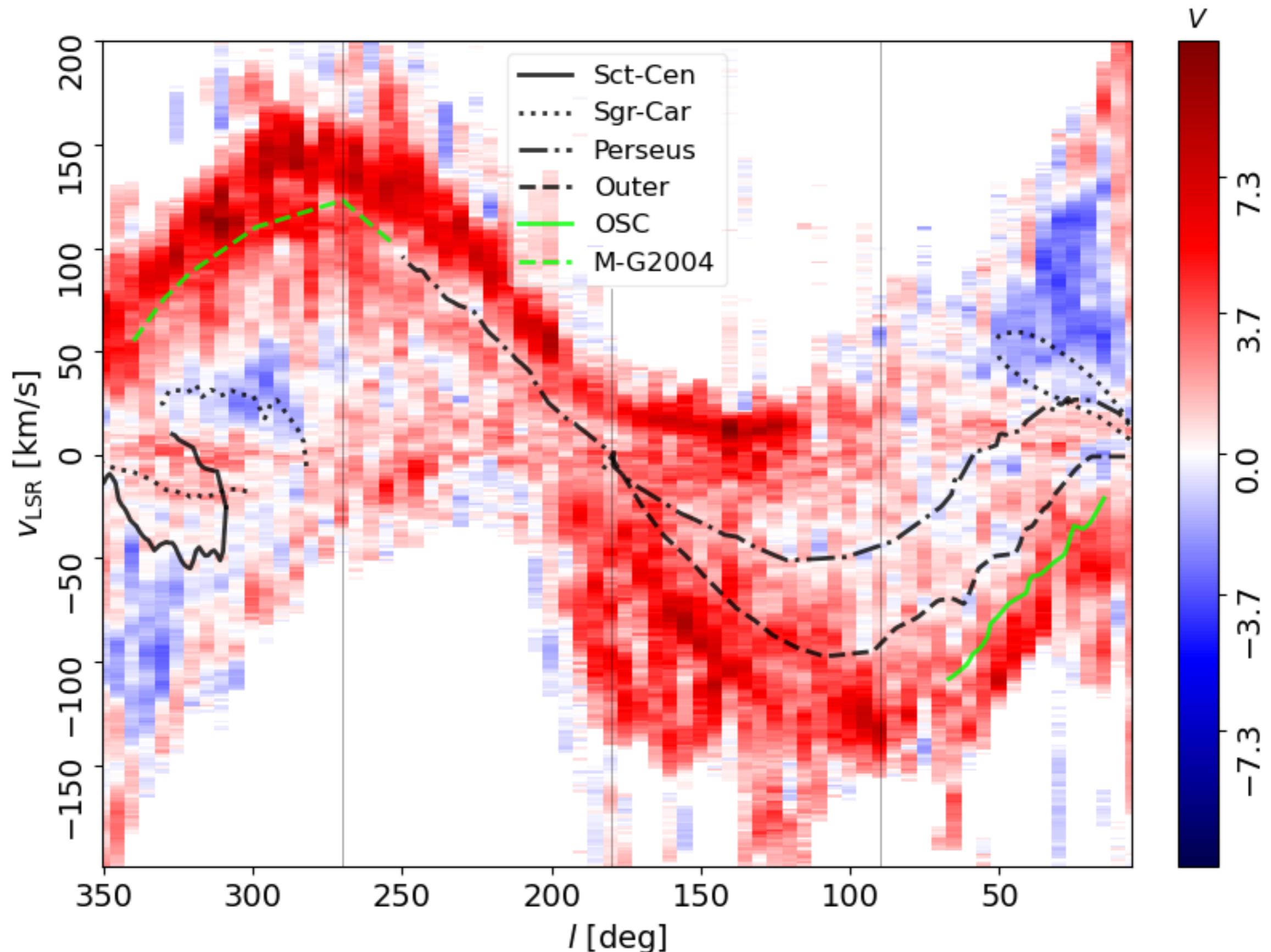
Benjamin Winkel & HI4PI Collaboration

Atomic hydrogen emission

HI4PI survey

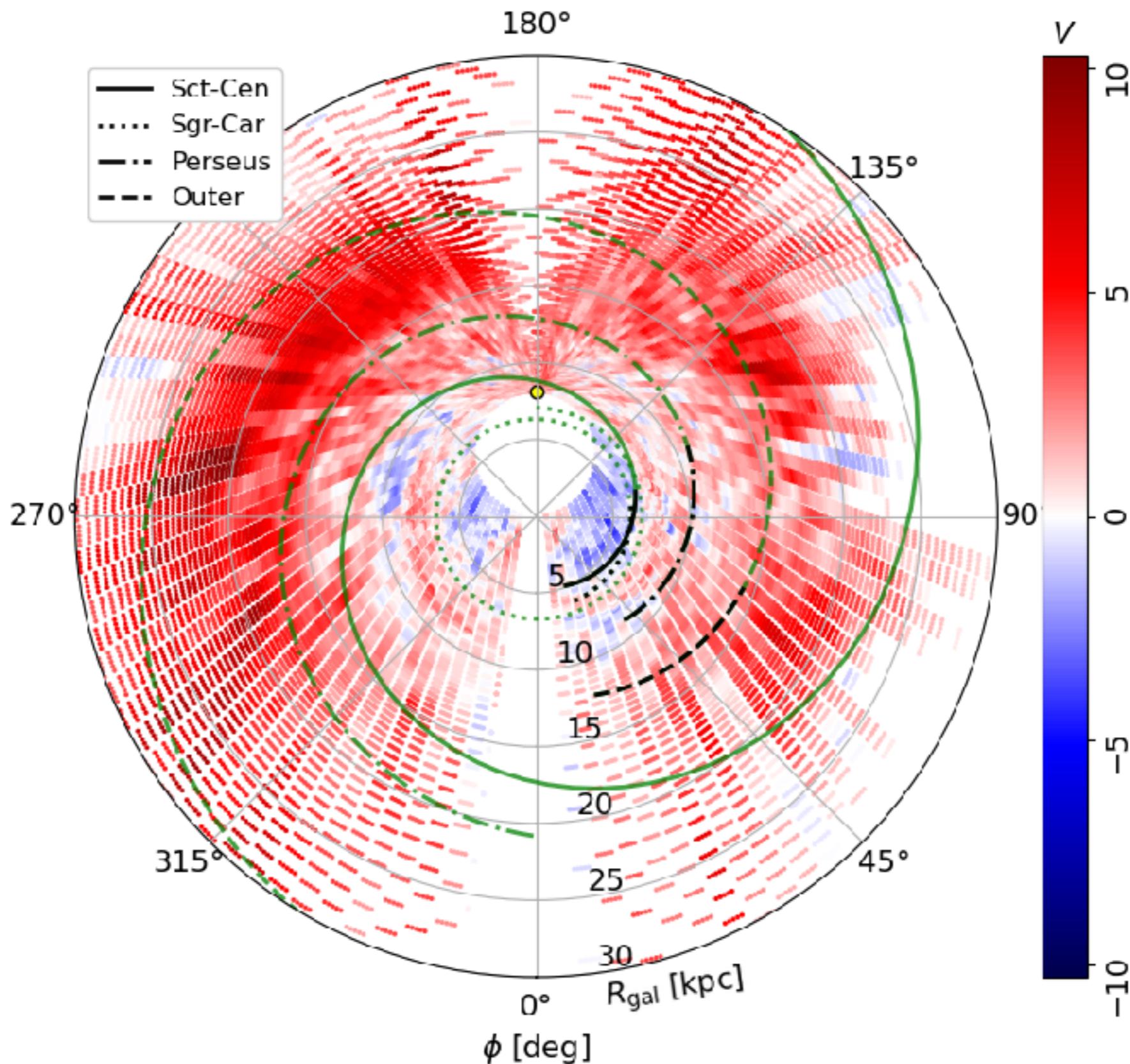
Orientation of atomic filaments

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



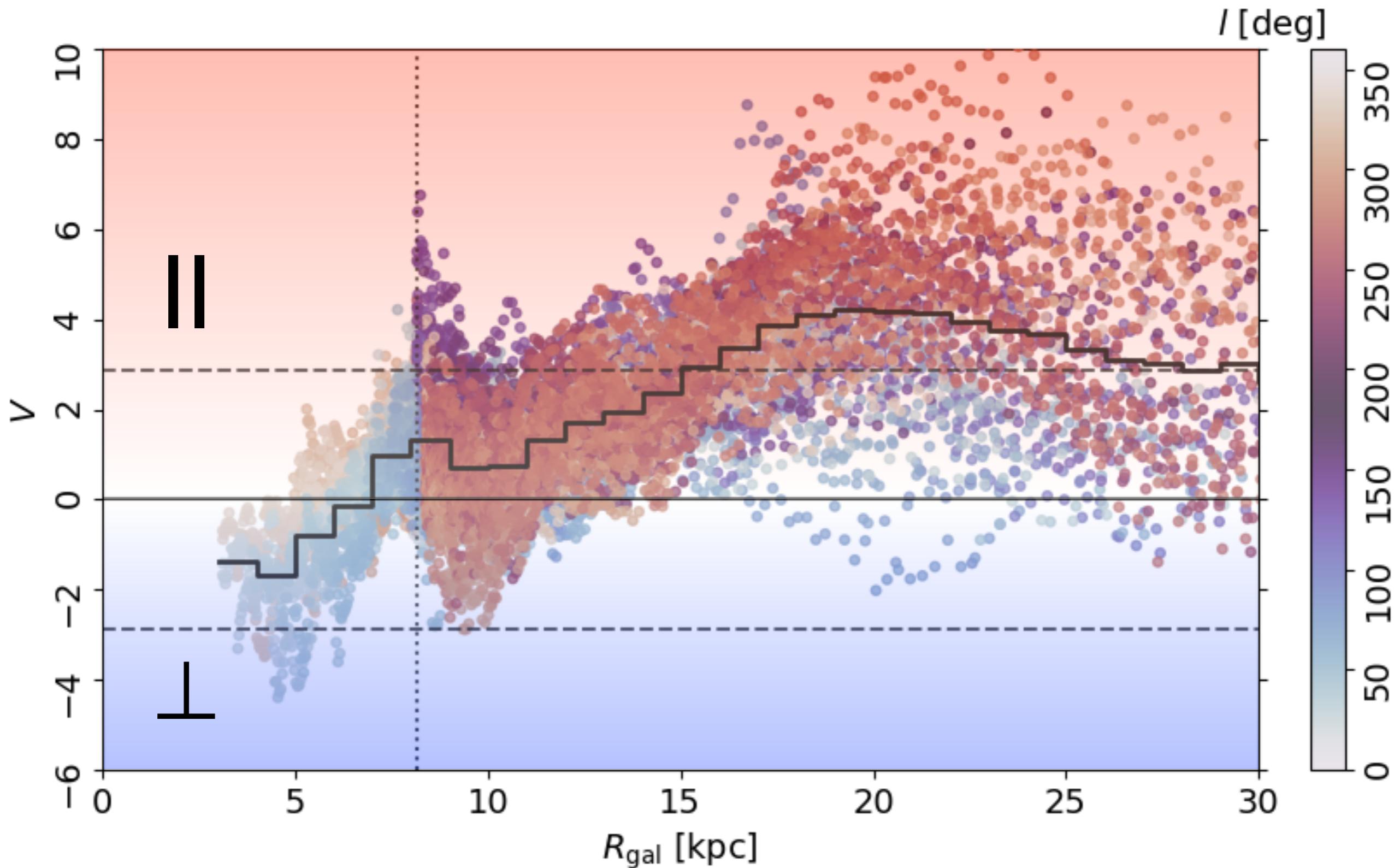
Orientation of atomic filaments

Soler, J.D. et al. 2022



Atomic filament orientation

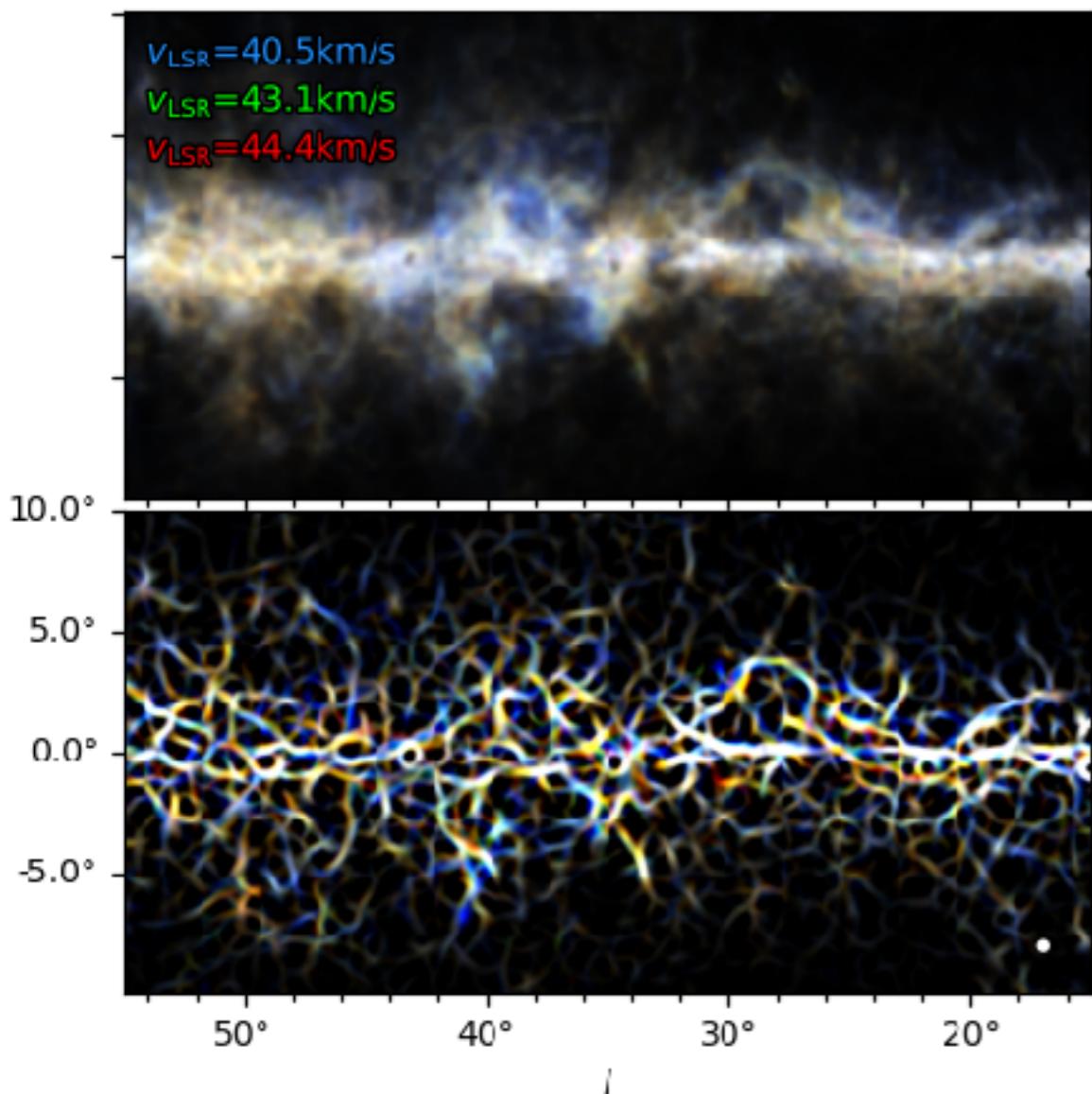
Soler, J.D. et al. 2022.



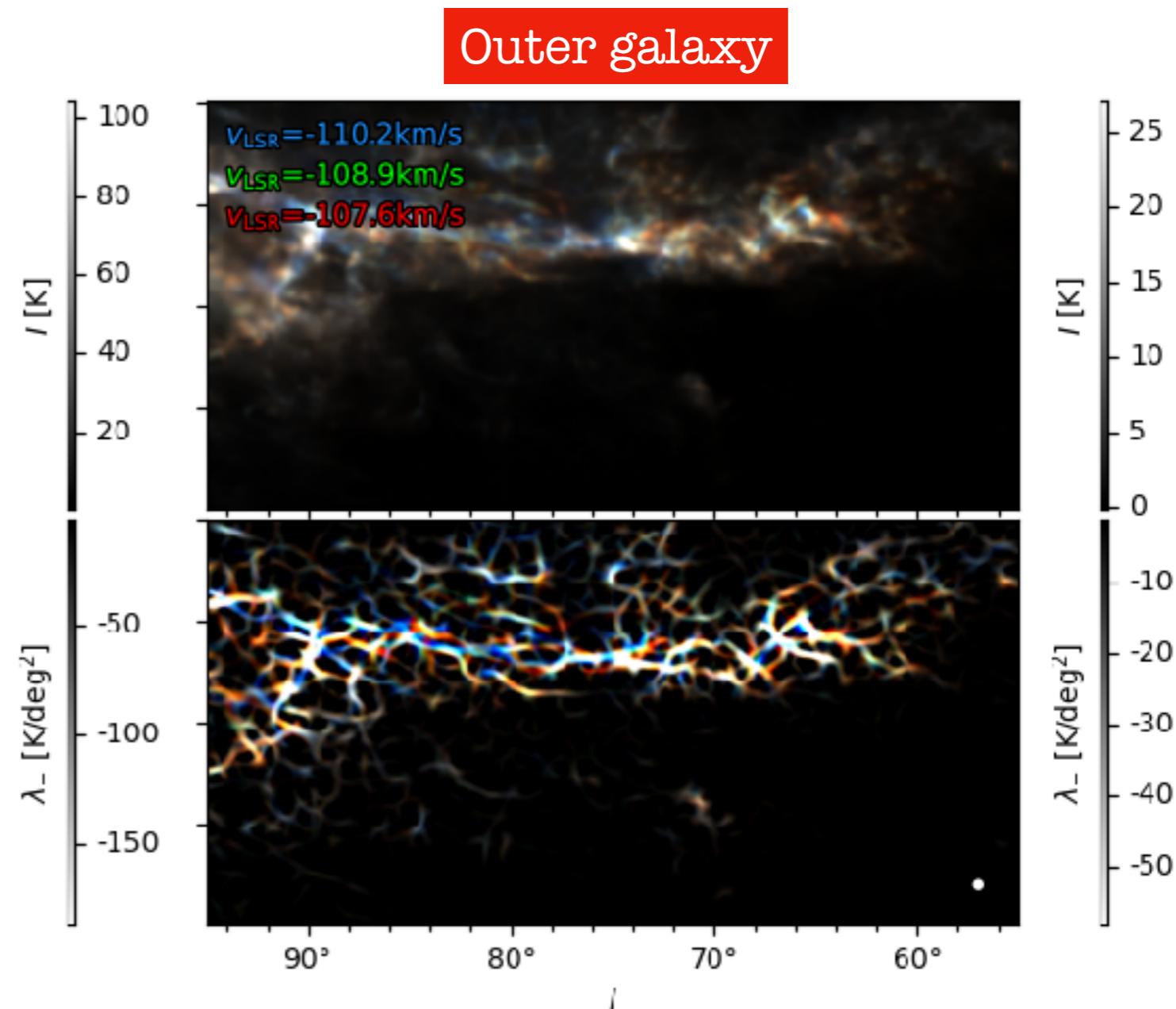
Atomic filament orientation

Soler, J.D. et al. 2022.

Inner galaxy

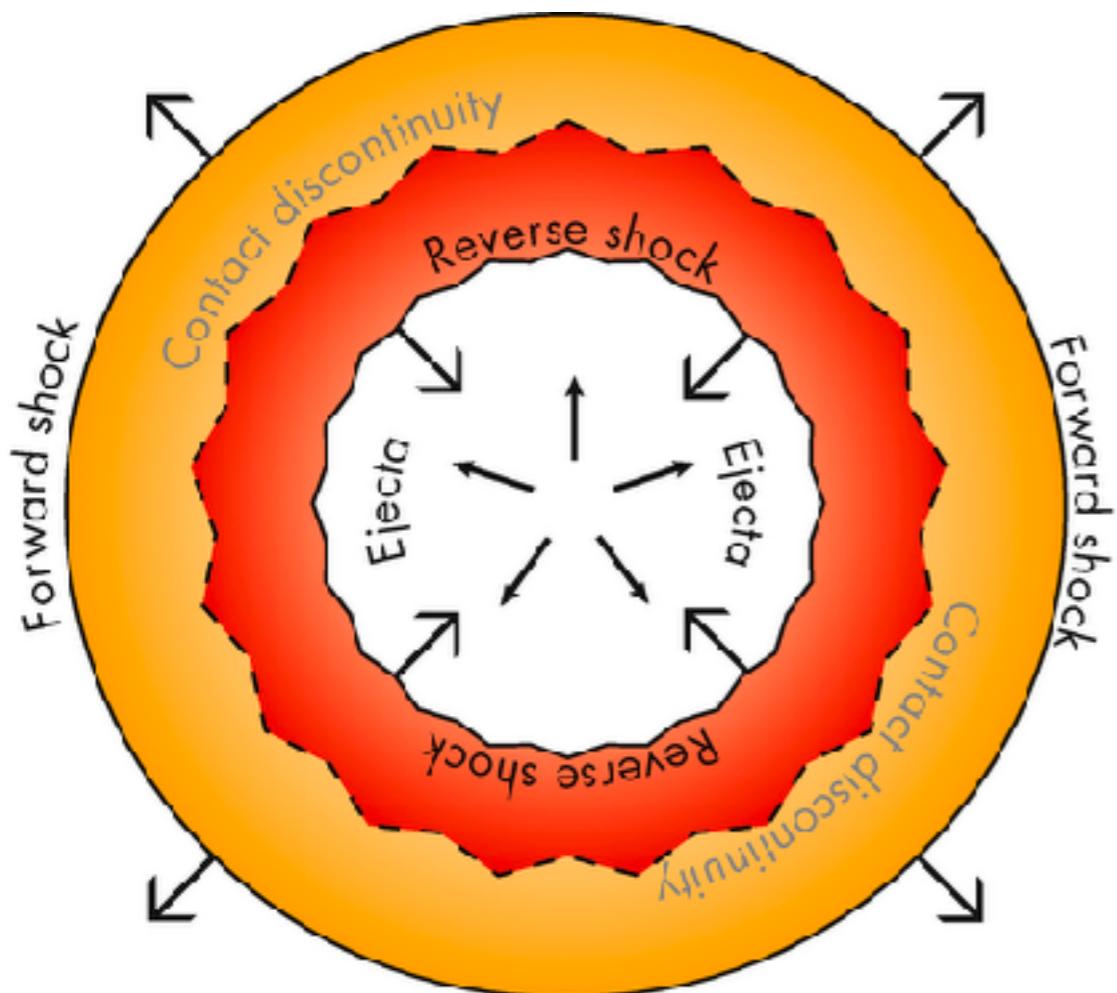


Outer galaxy

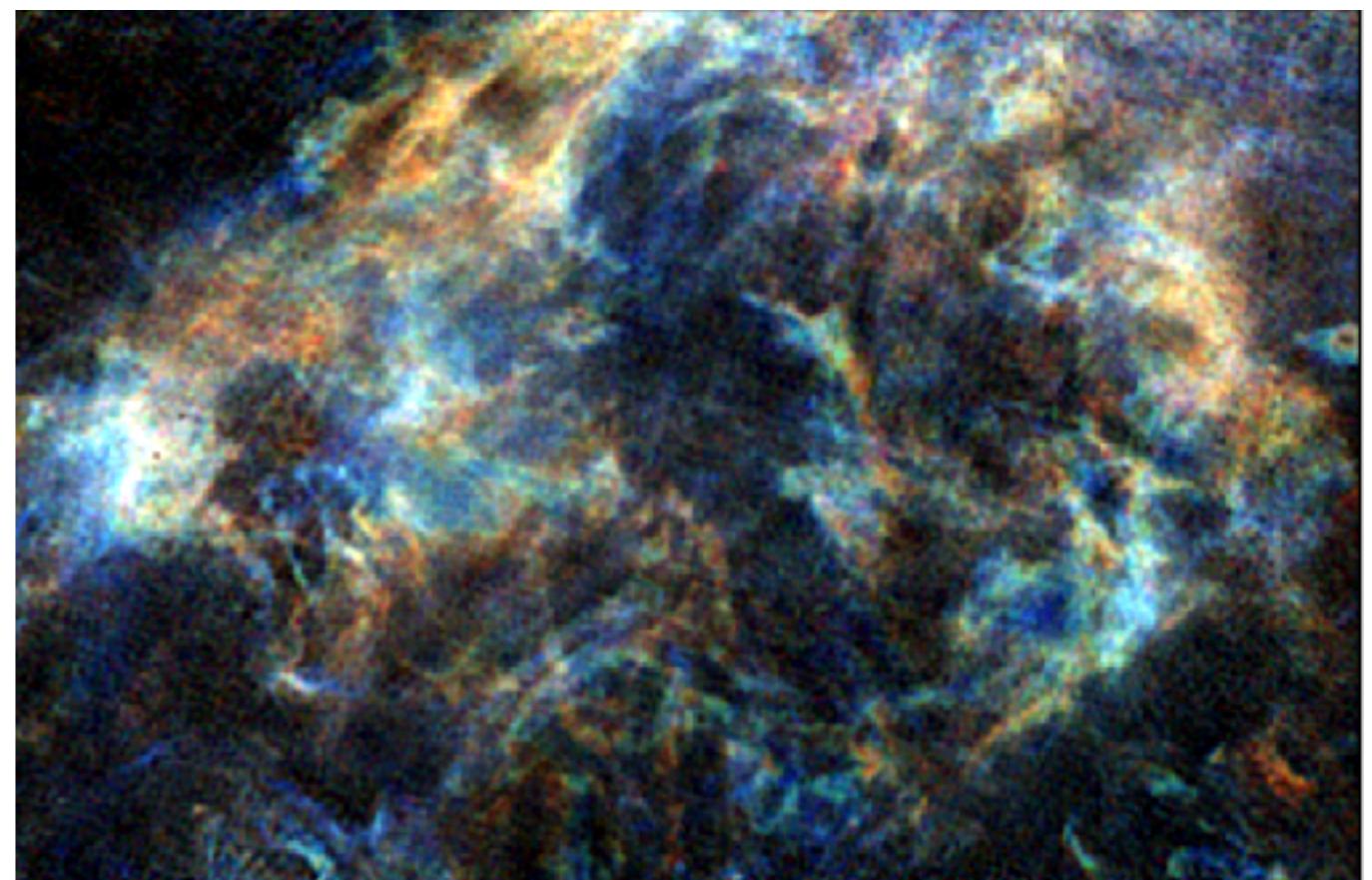


Atomic shells pushed by supernovae

Supernova Remnant Evolution. Vink, 2020.

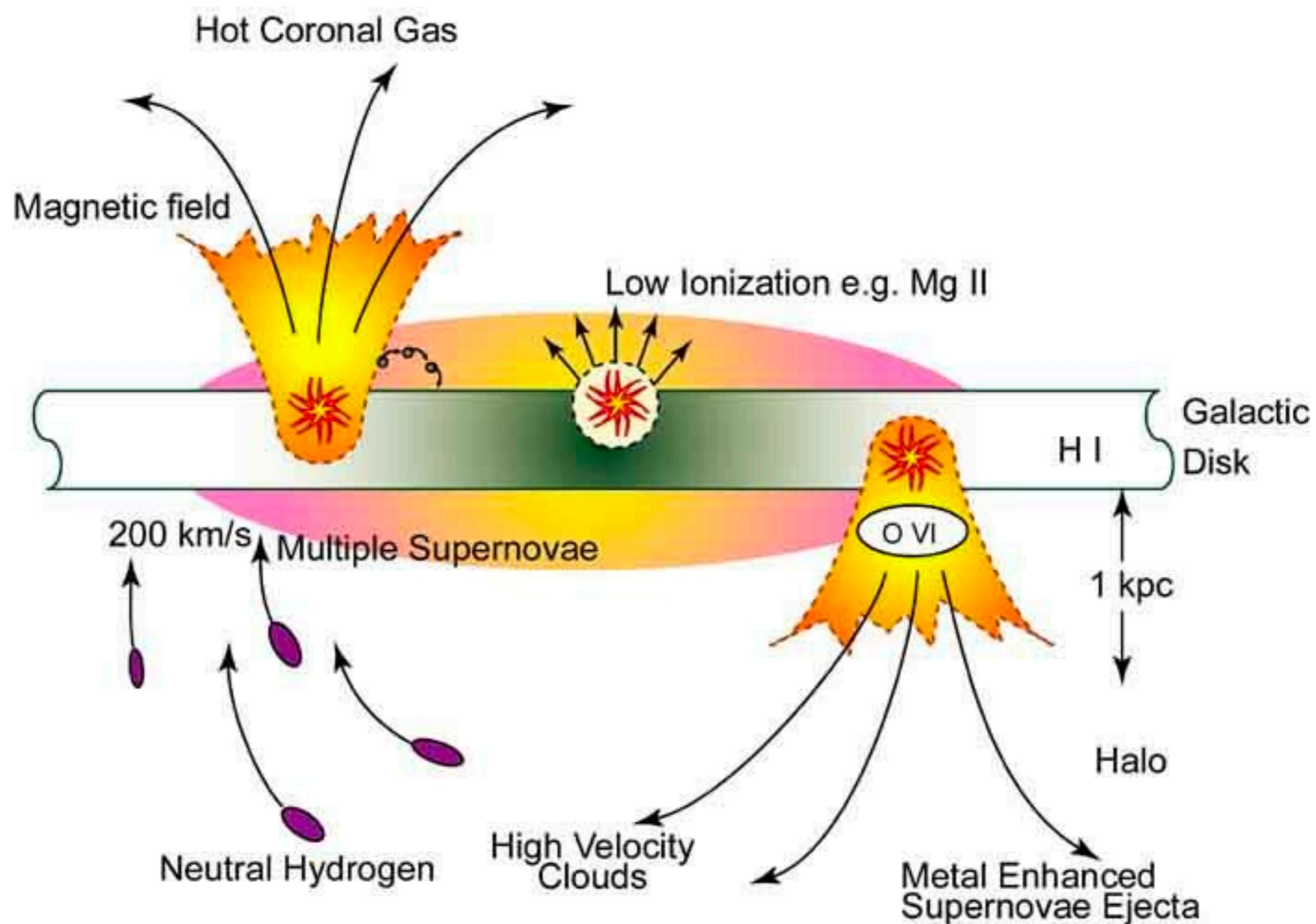


HI shell in THOR



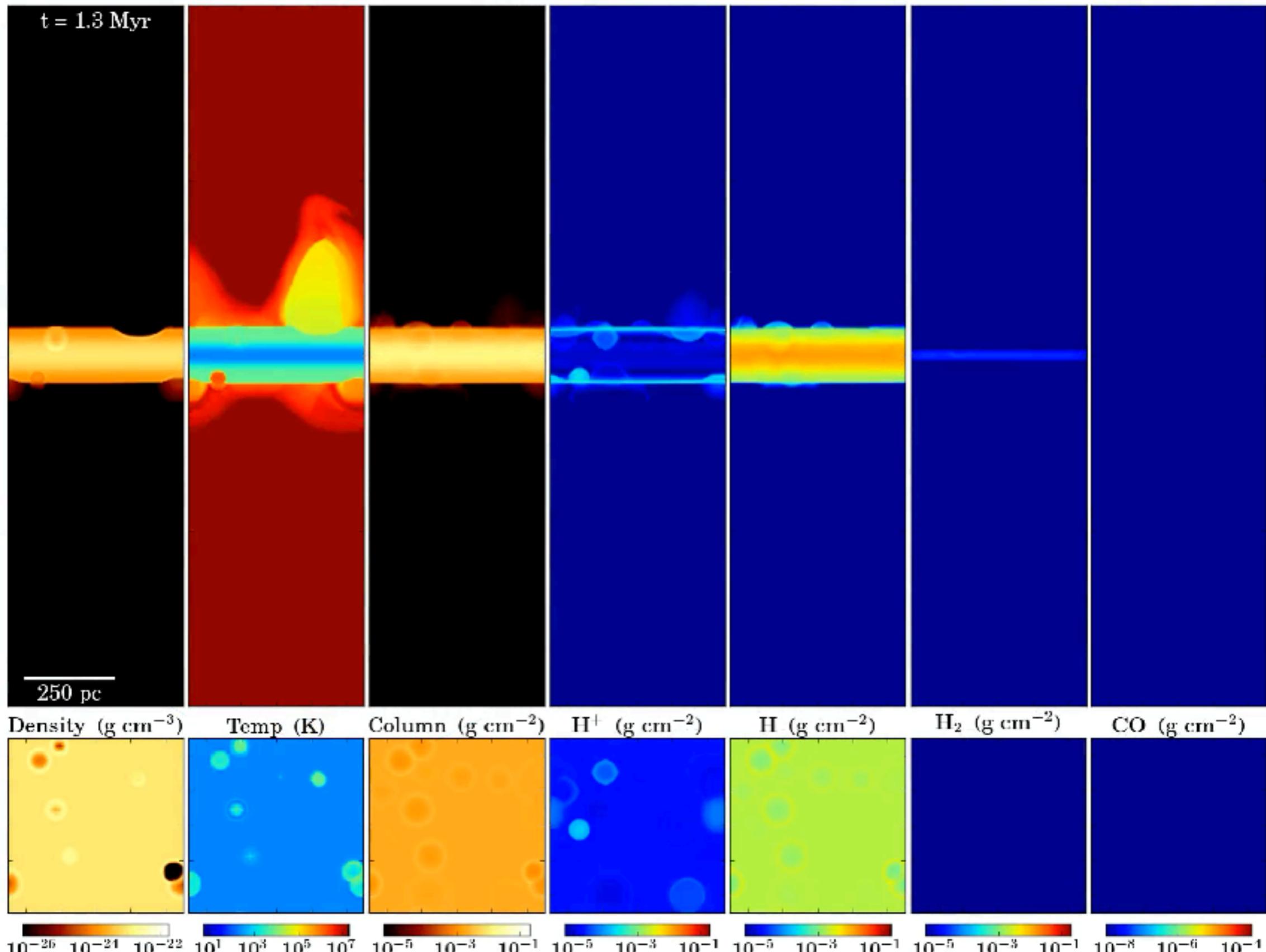
Atomic worms and chimneys

Heiles, 1994

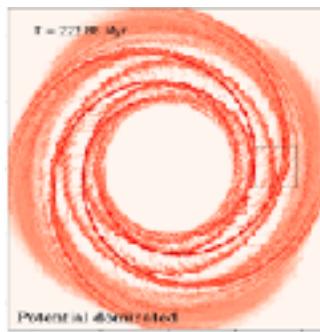


Atomic filament orientation and HI bubbles

Girichidis et al. MNRAS 2021. SILCC: Simulating the LifeCycle of molecular Clouds

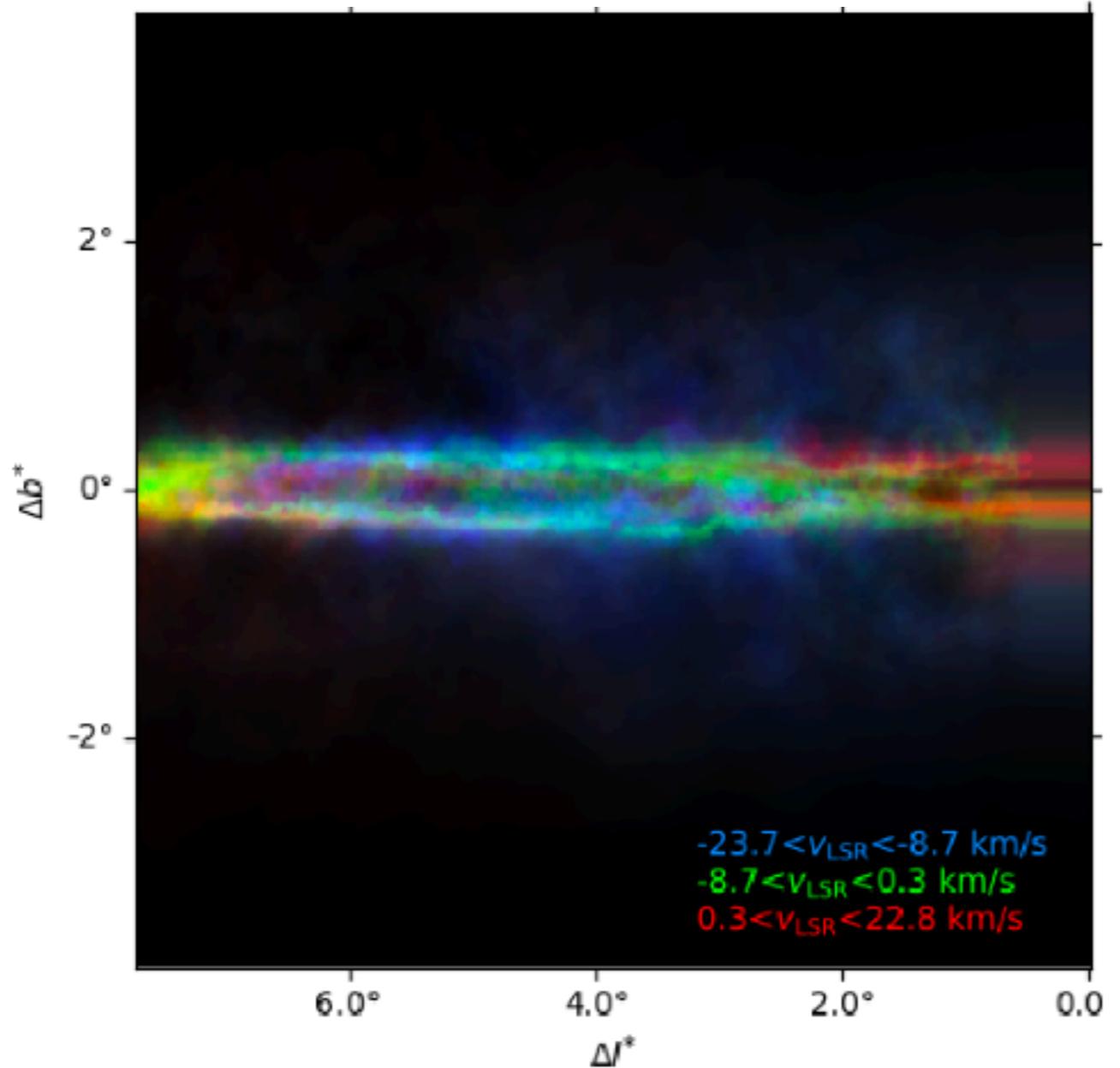


HI filaments - MHD simulations

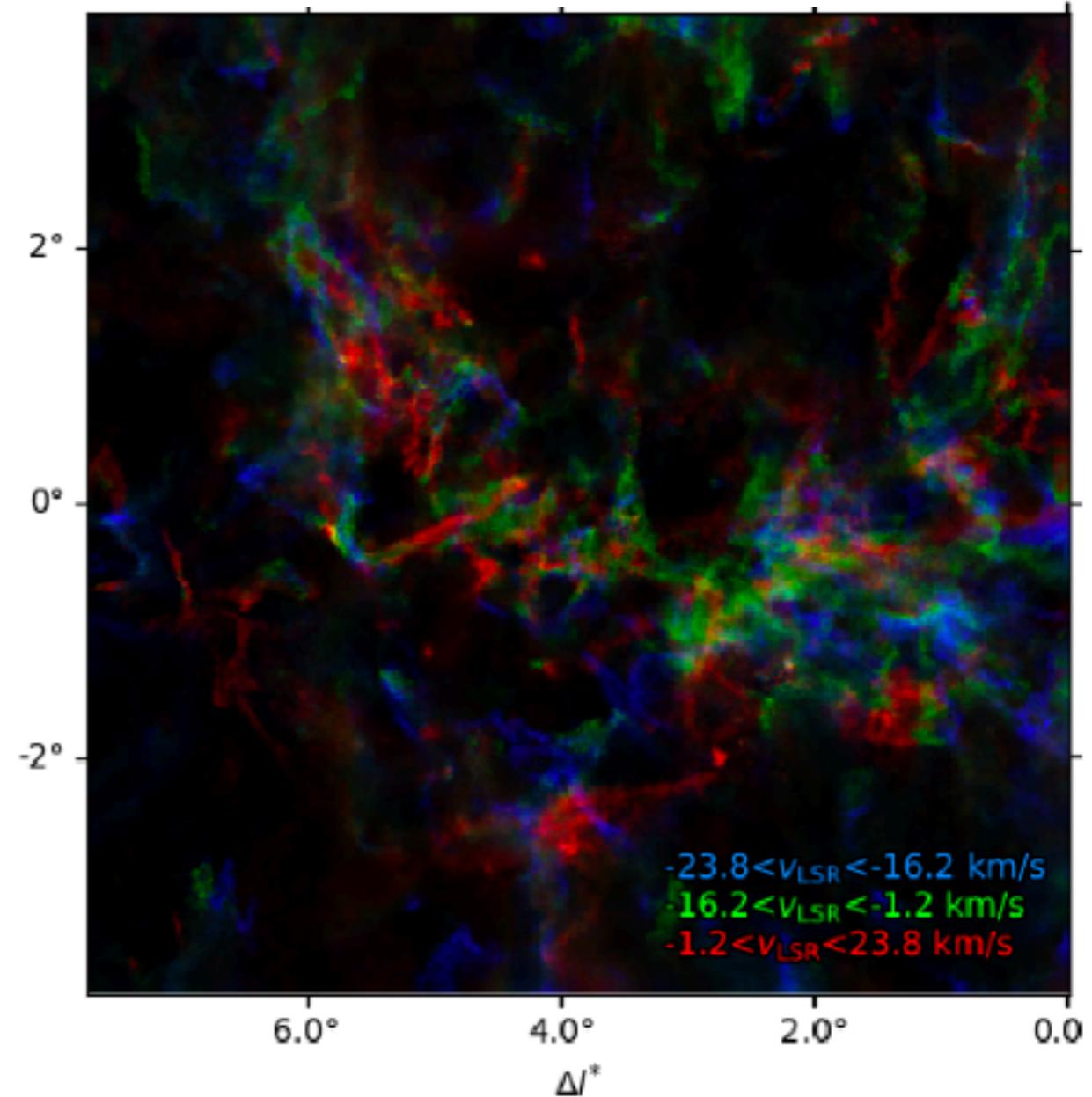


CloudFactory simulations (Smith et al. A&A 2020)
Soler, J.D. et al. A&A 2020

Potential-dominated



Feedback-dominated

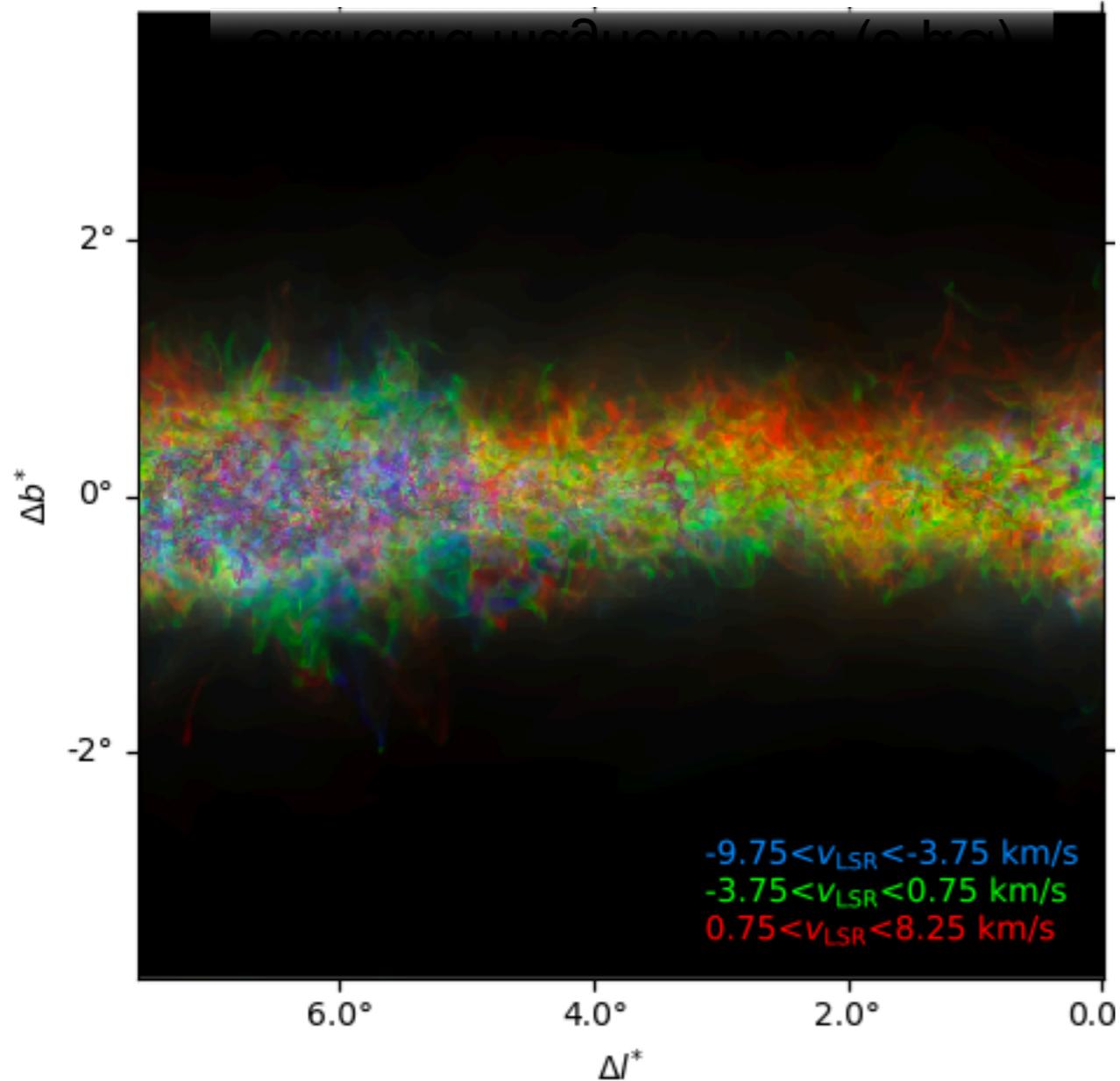


HI filaments - MHD simulations

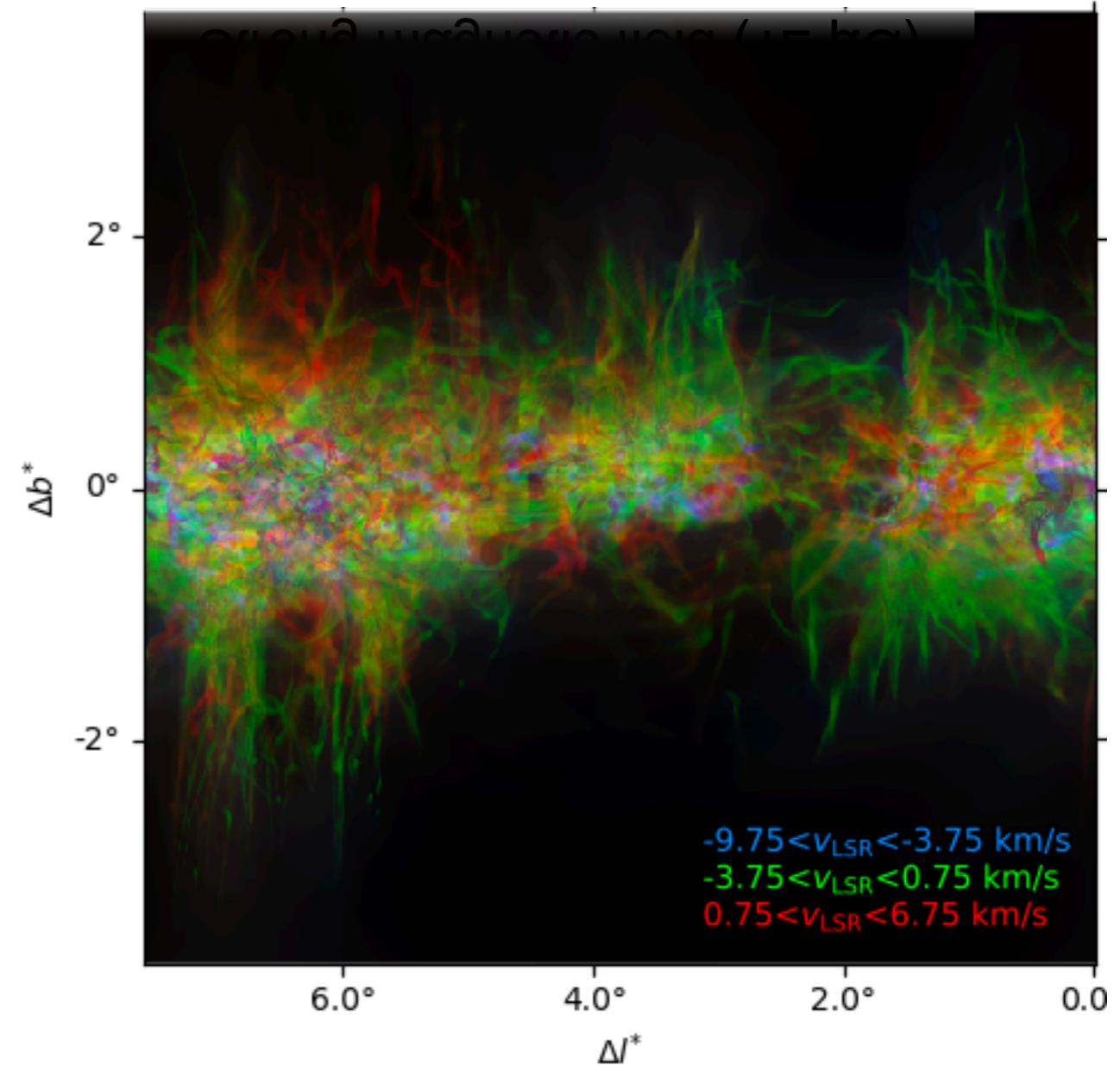
FRIGG simulations (Hennebelle et al. A&A 2018)

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

Standard magnetic field (3 μG)

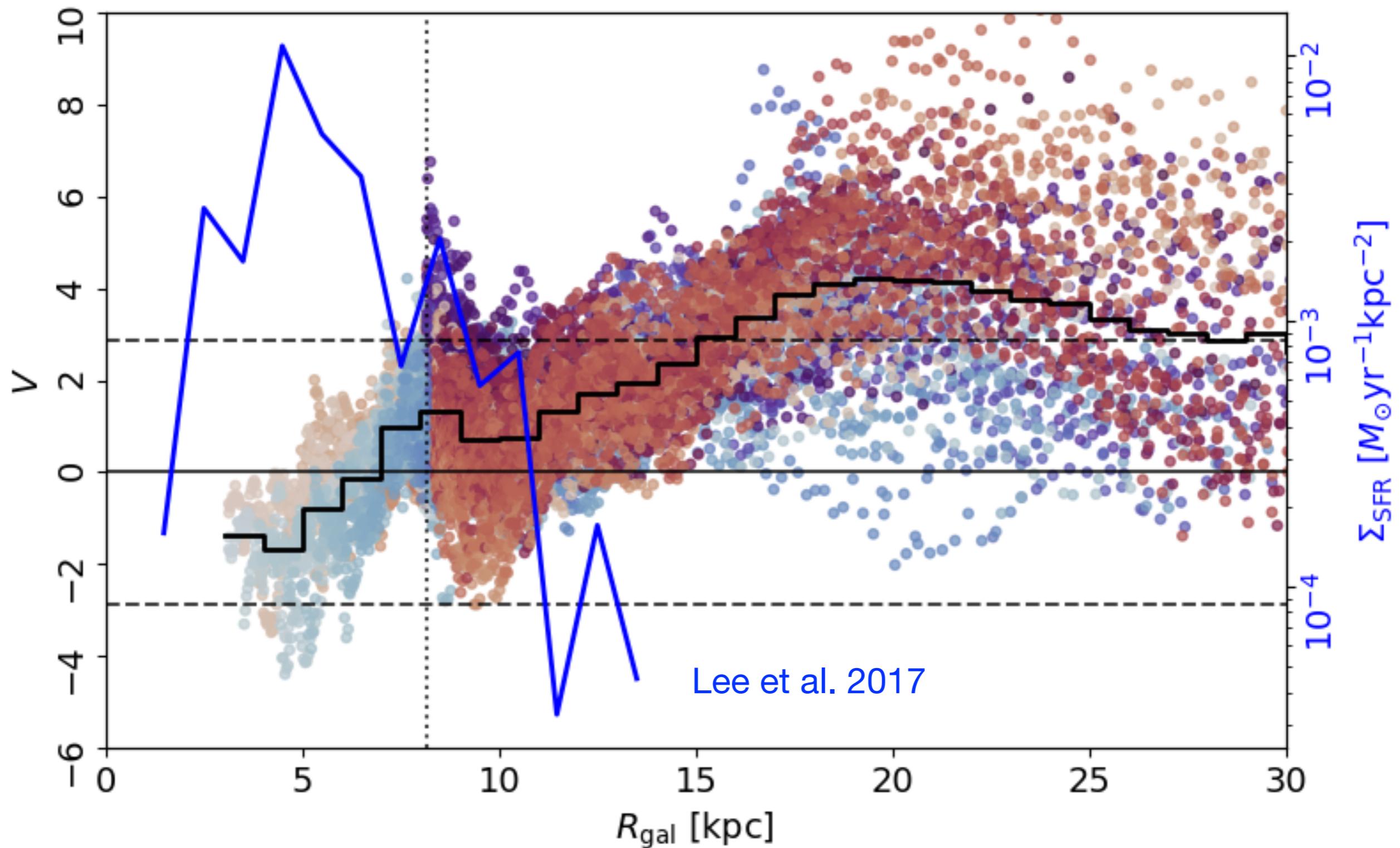


Strong magnetic field (12 μG)



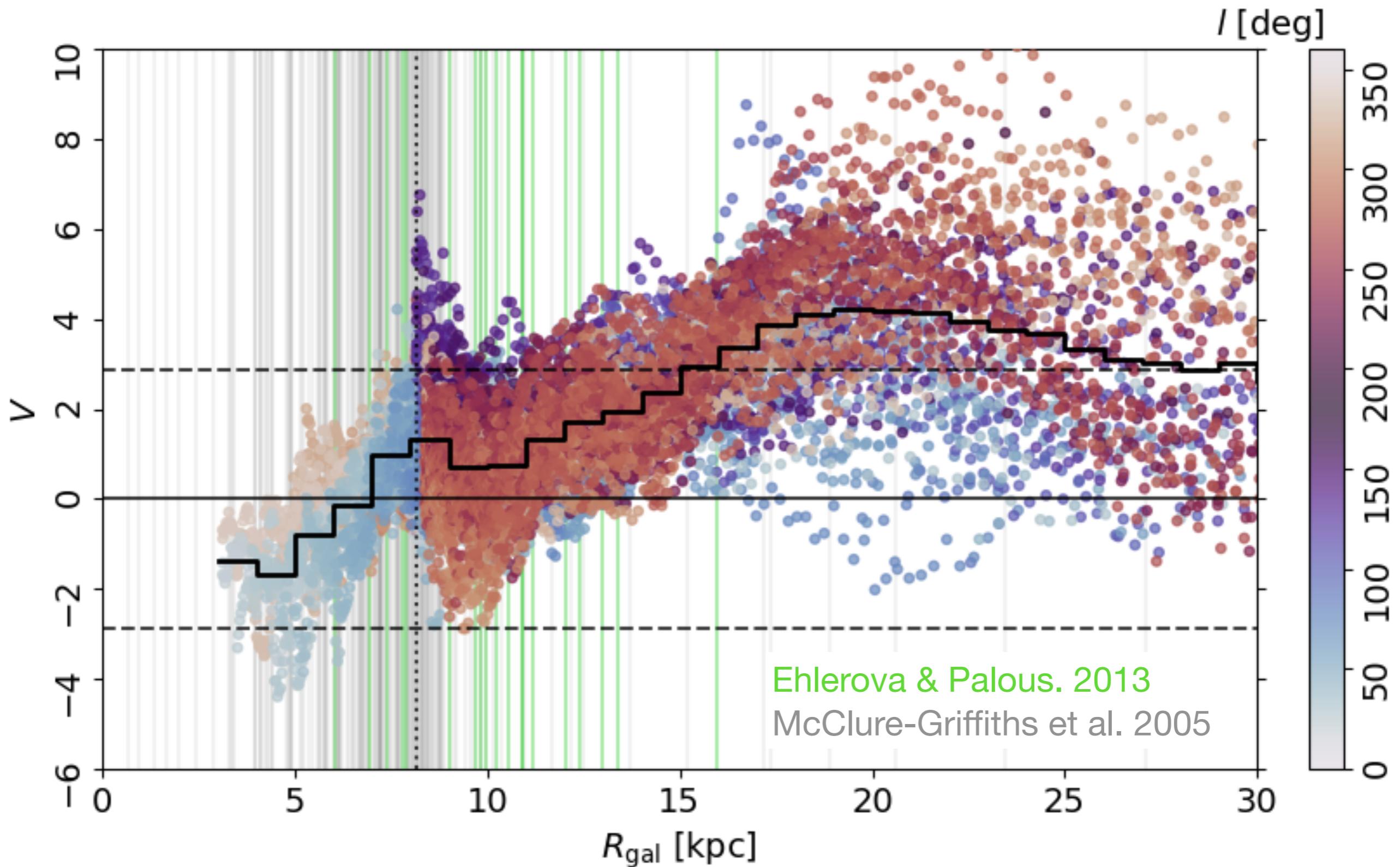
Atomic filament orientation and star formation

Soler, J.D. et al. 2022.



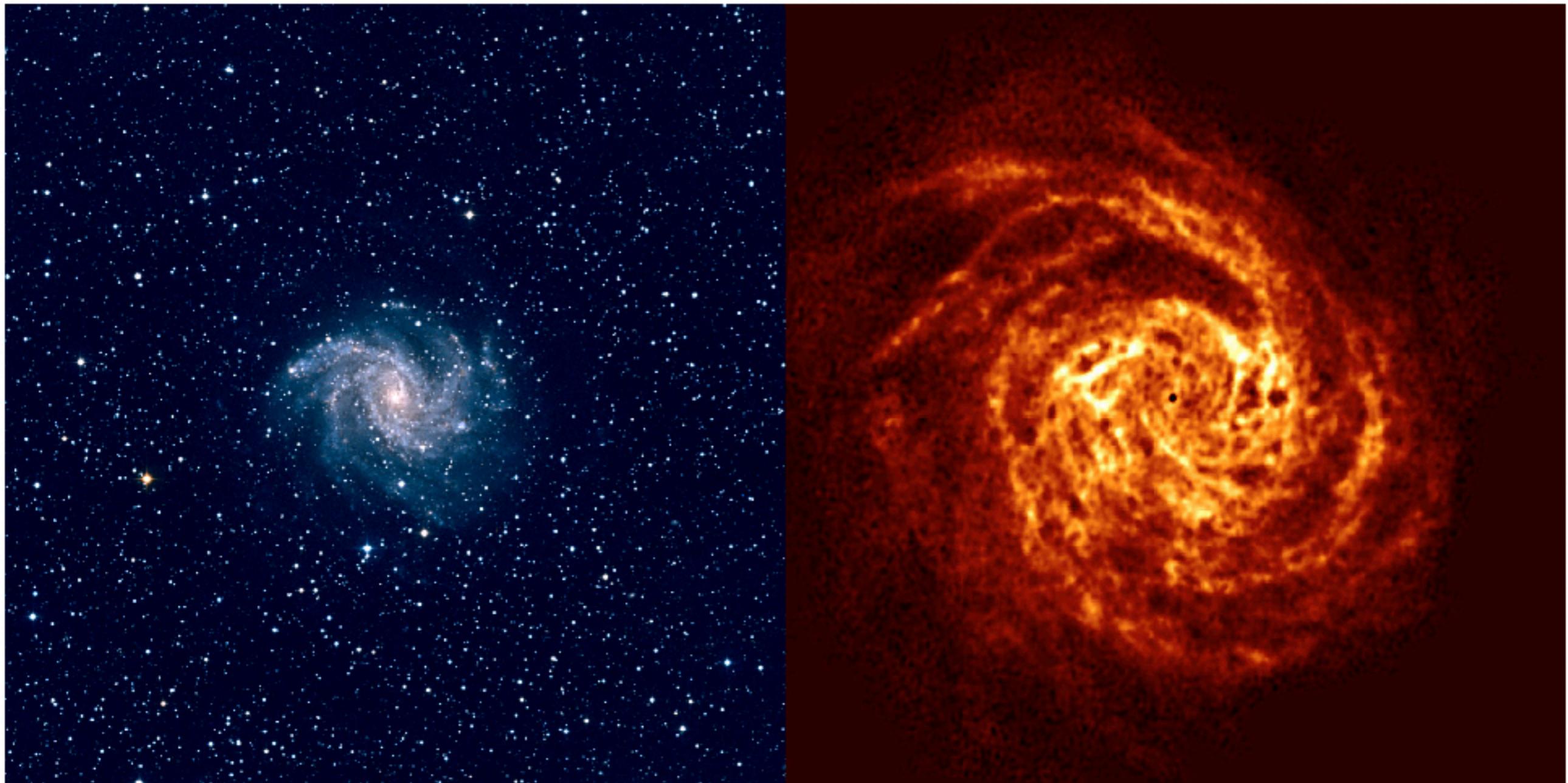
Atomic filament orientation and HI bubbles

Soler, J.D. et al. 2022.



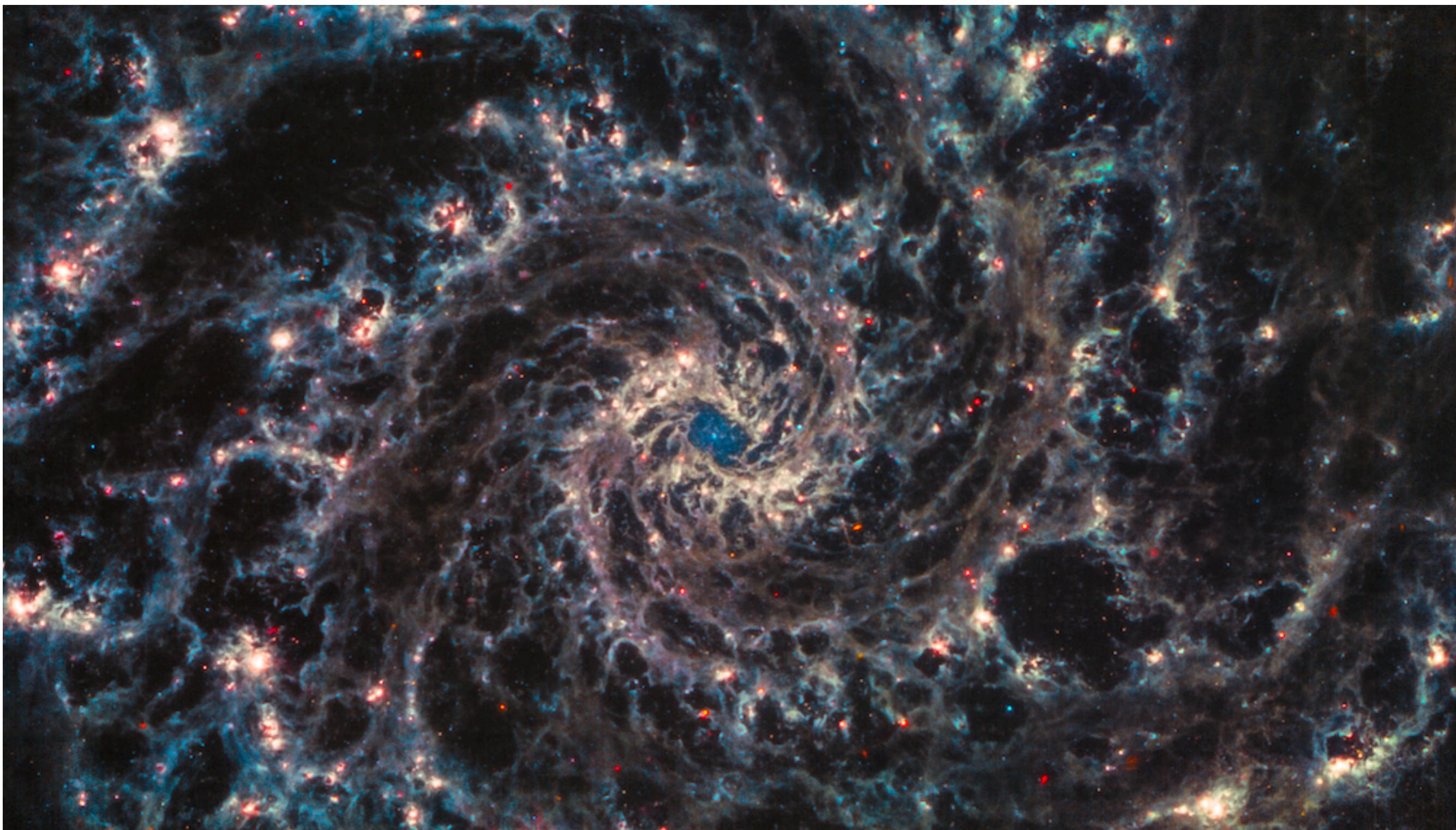
HI holes in the spiral galaxy NGC6946

Boomsma et al. A&A 2008



Holes and filaments in NGC628

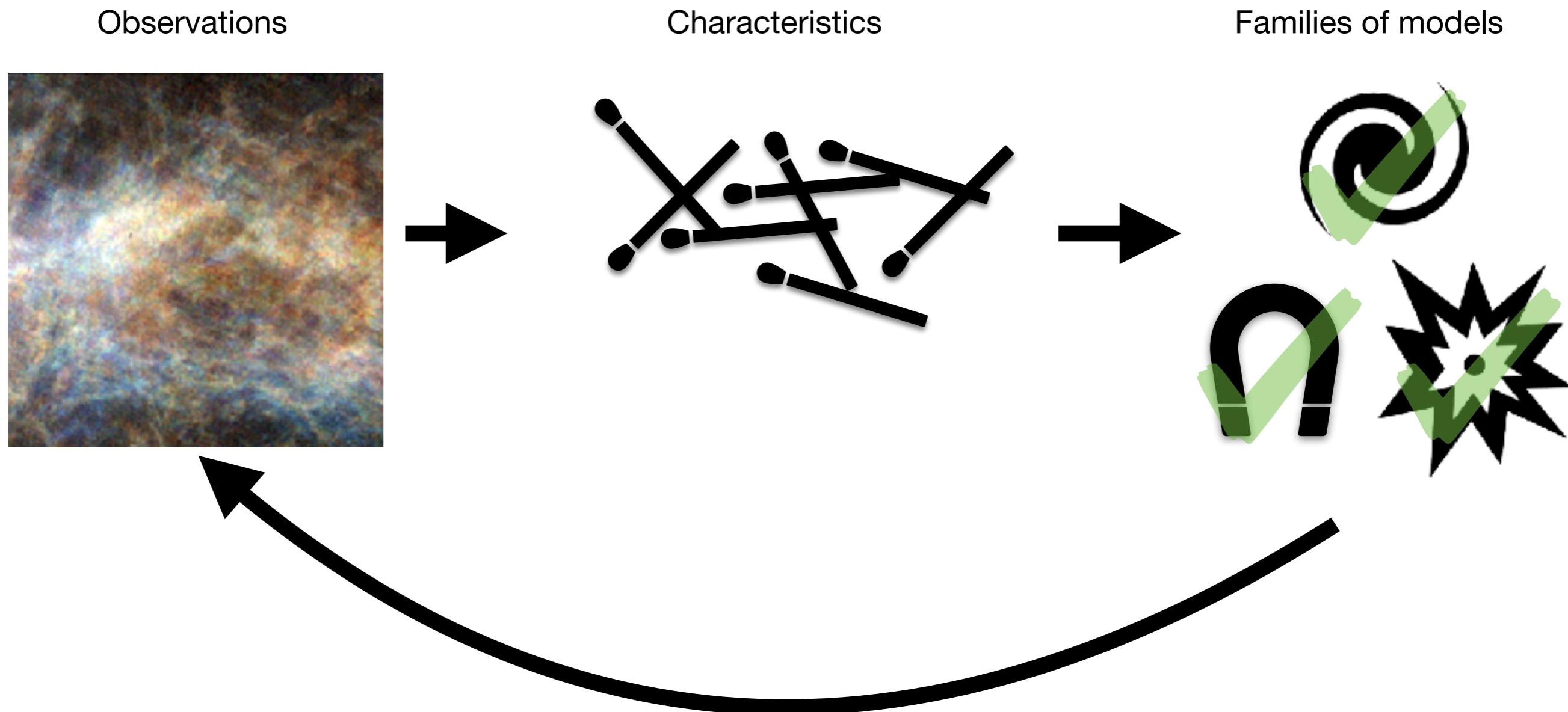
JWST/NASA/ESA/CSA/Judy Schmid



Data-driven analysis

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

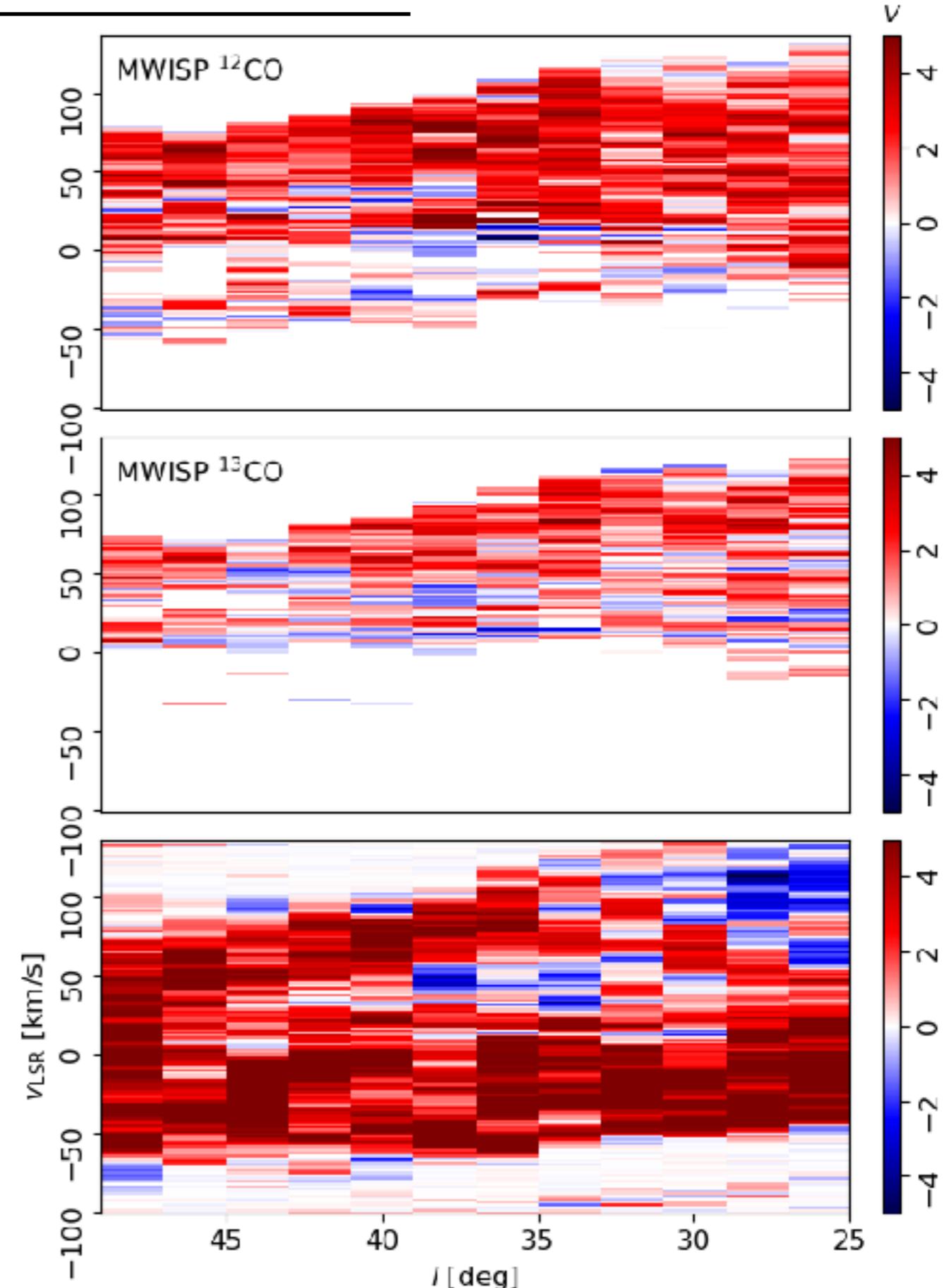
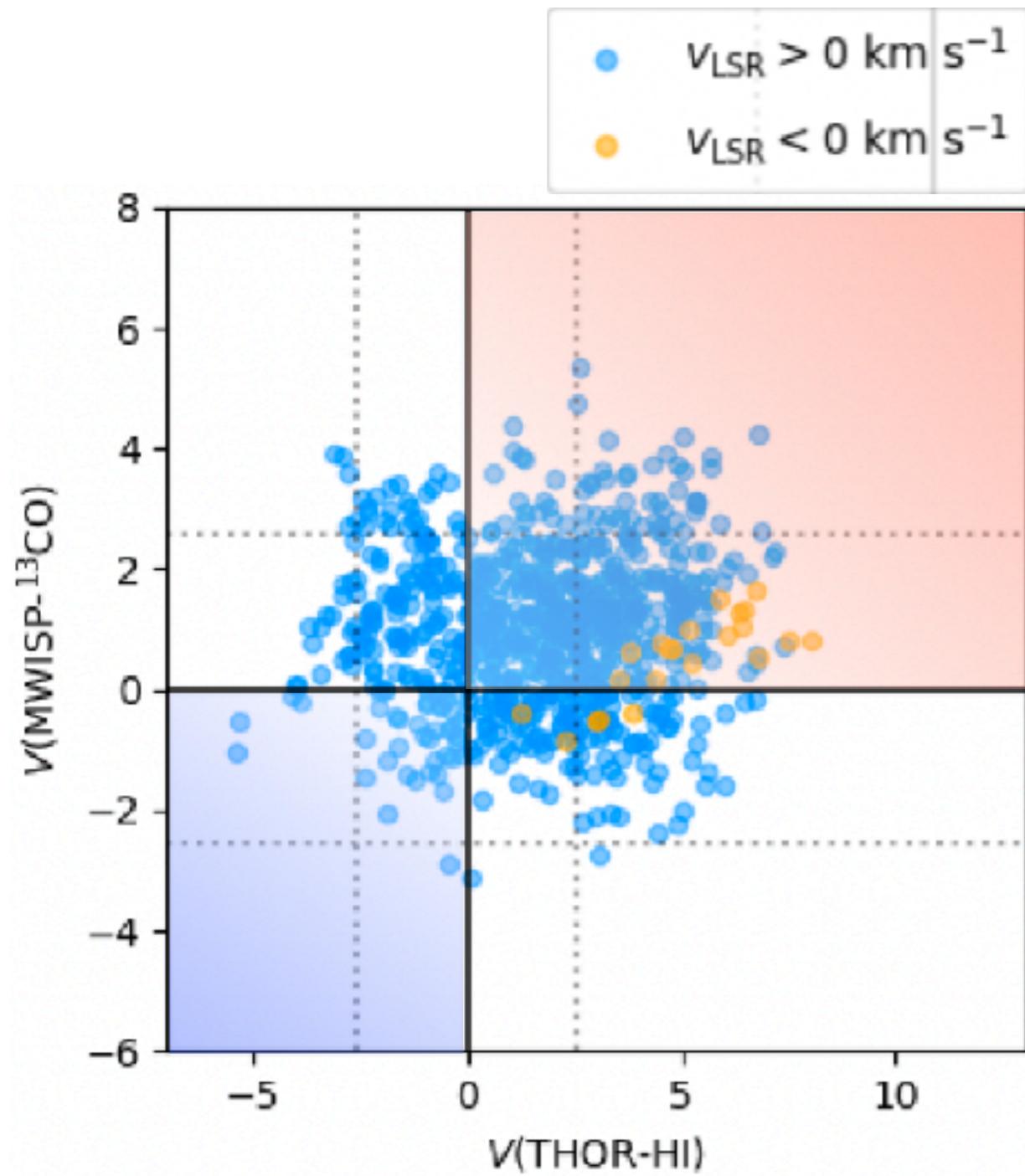
Soler, J.D., et al. 2022. A&A



CO filament orientation

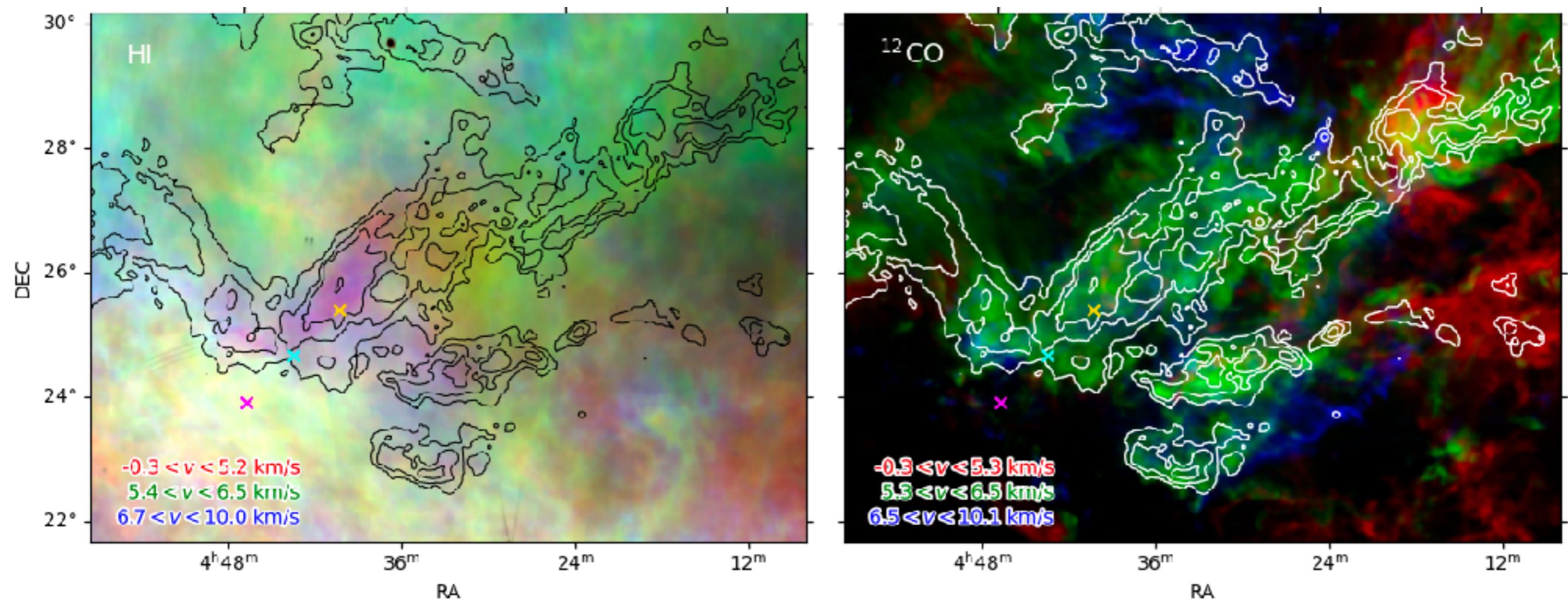
MWISP CO survey. Sun et al. (2018)

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



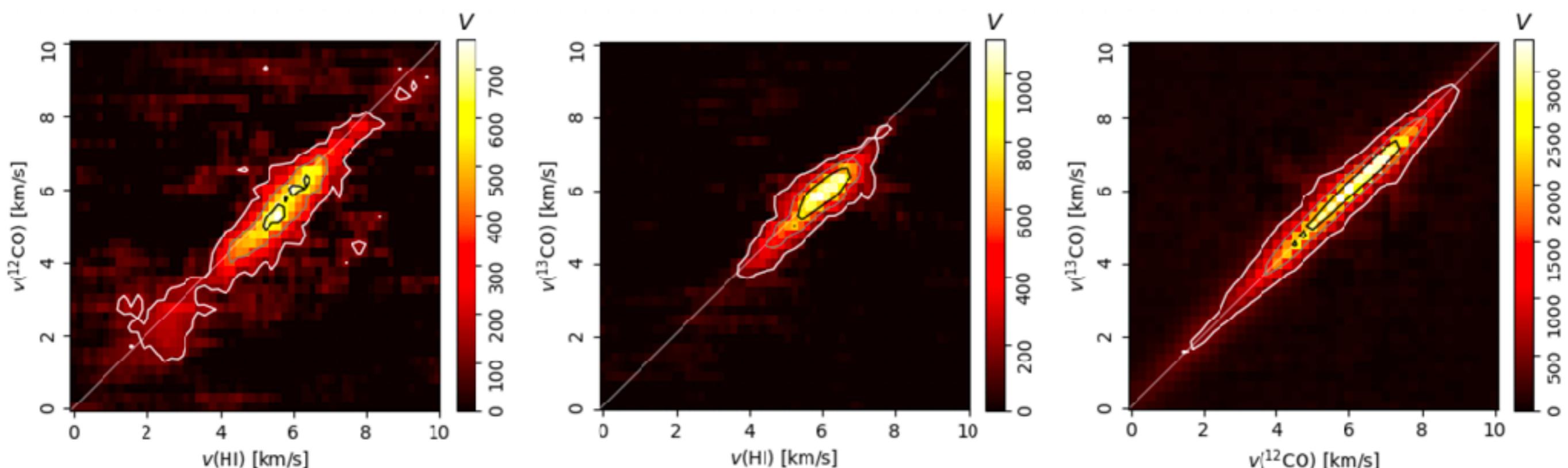
The atomic hydrogen in and around MCs

Soler, J.D. et al. In prep.



The atomic hydrogen in and around MCs

Soler, J.D. et al. In prep.



The Galactic dynamics revealed by HI and CO emission



We found that the **HI filament orientation** changes from mostly perpendicular 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 **HI filament orientation** is **not inherited** by the **CO filaments**, which may indicate the effect of stellar feedback and magnetic fields (not just gravity) shaping MCs.

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

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

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

juandiegosolerp@gmail.com

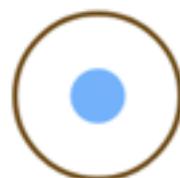
Extra slides

What is next?



Understanding our Galactic ecosystem : from the disk of the Milky Way to the formation sites of stars and planets

Based on a unique combination of theoretical modeling and multi-wavelengths observations, three fundamental issues :



PLANETS

How do planet-forming disks relate to the Galactic environment?



STARS

What processes regulate the birth of stars?



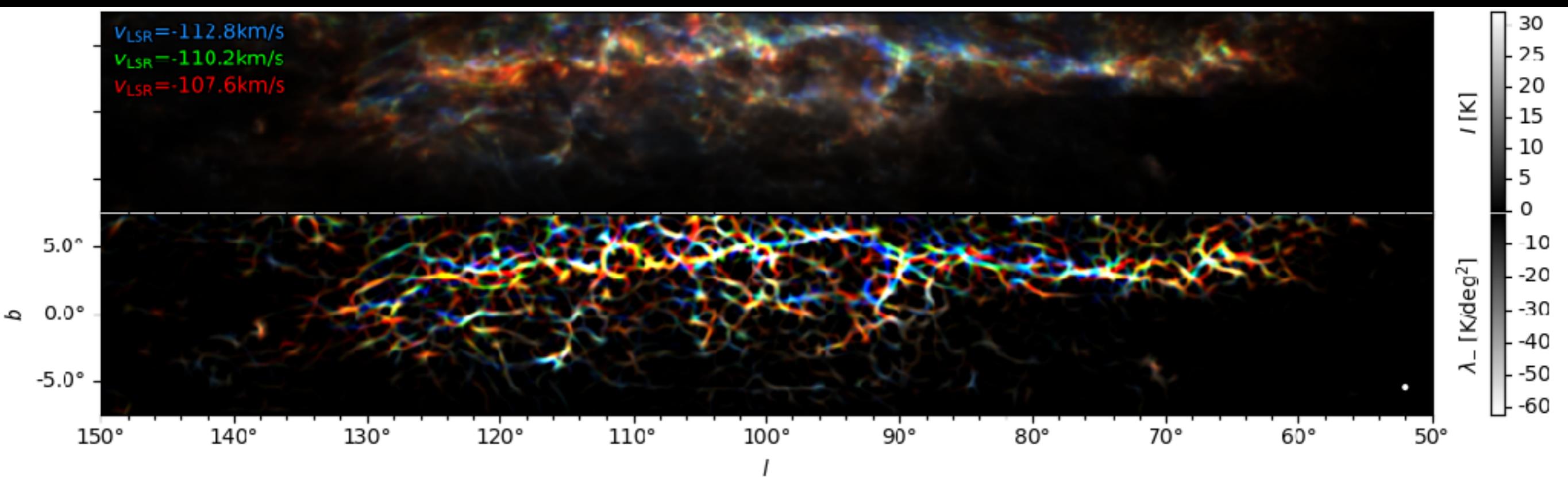
GALAXY

Can we understand galaxy-scale star formation?



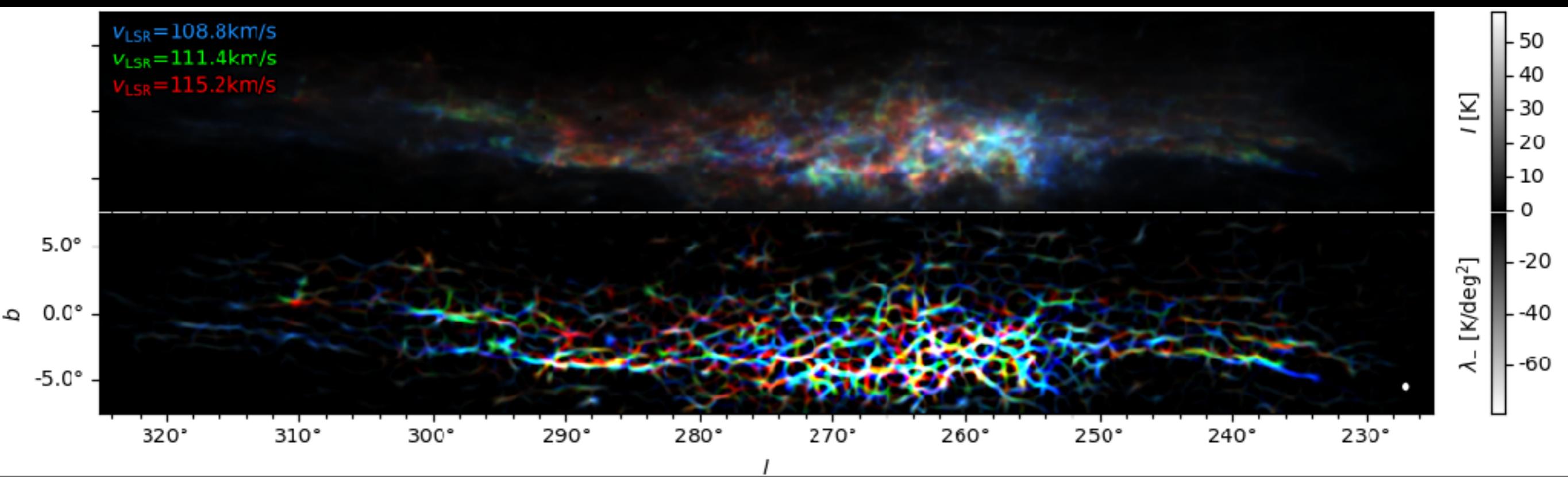
Atomic hydrogen emission

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



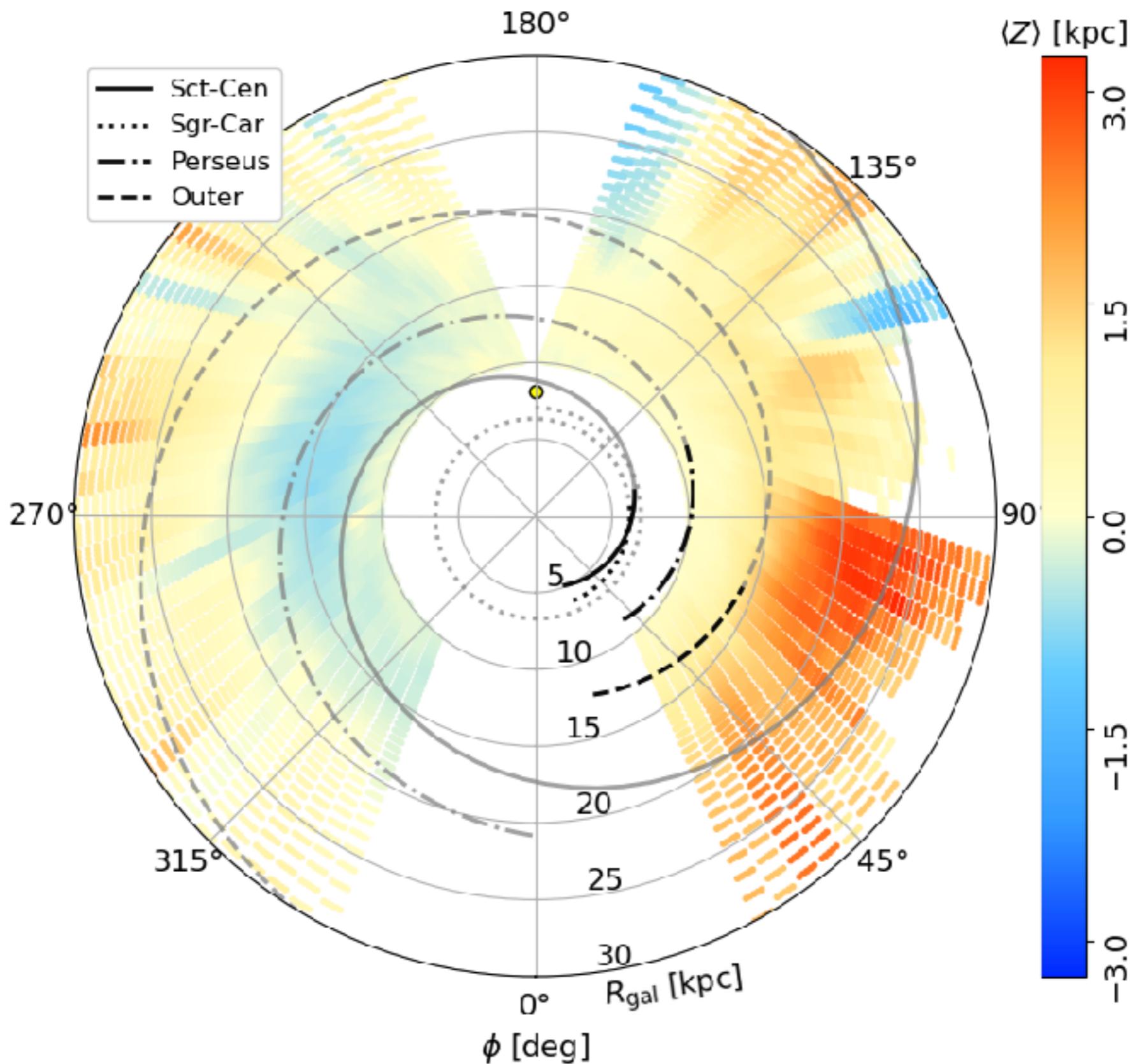
Atomic hydrogen emission

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



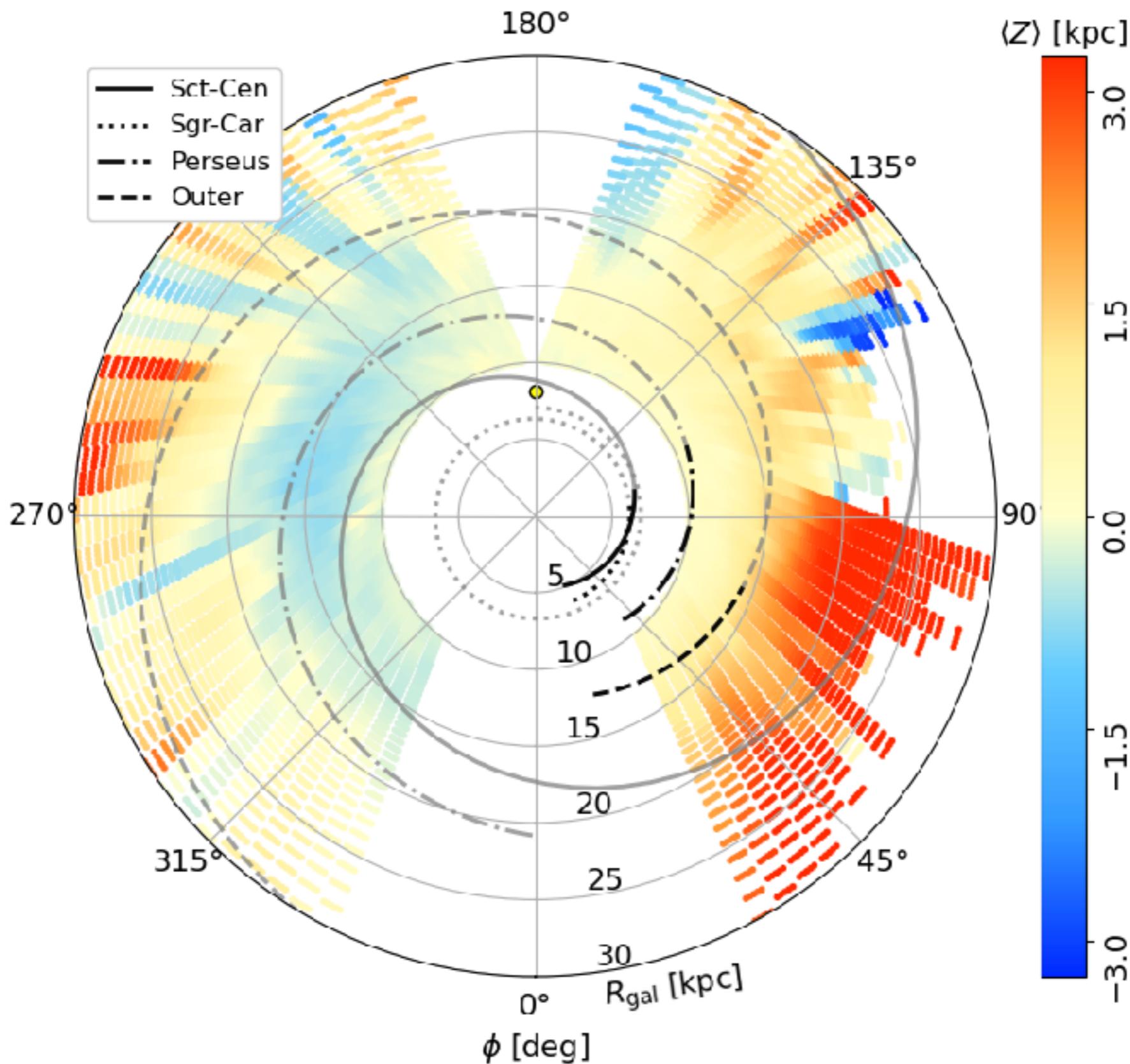
Orientation of atomic filaments

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



Orientation of atomic filaments

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



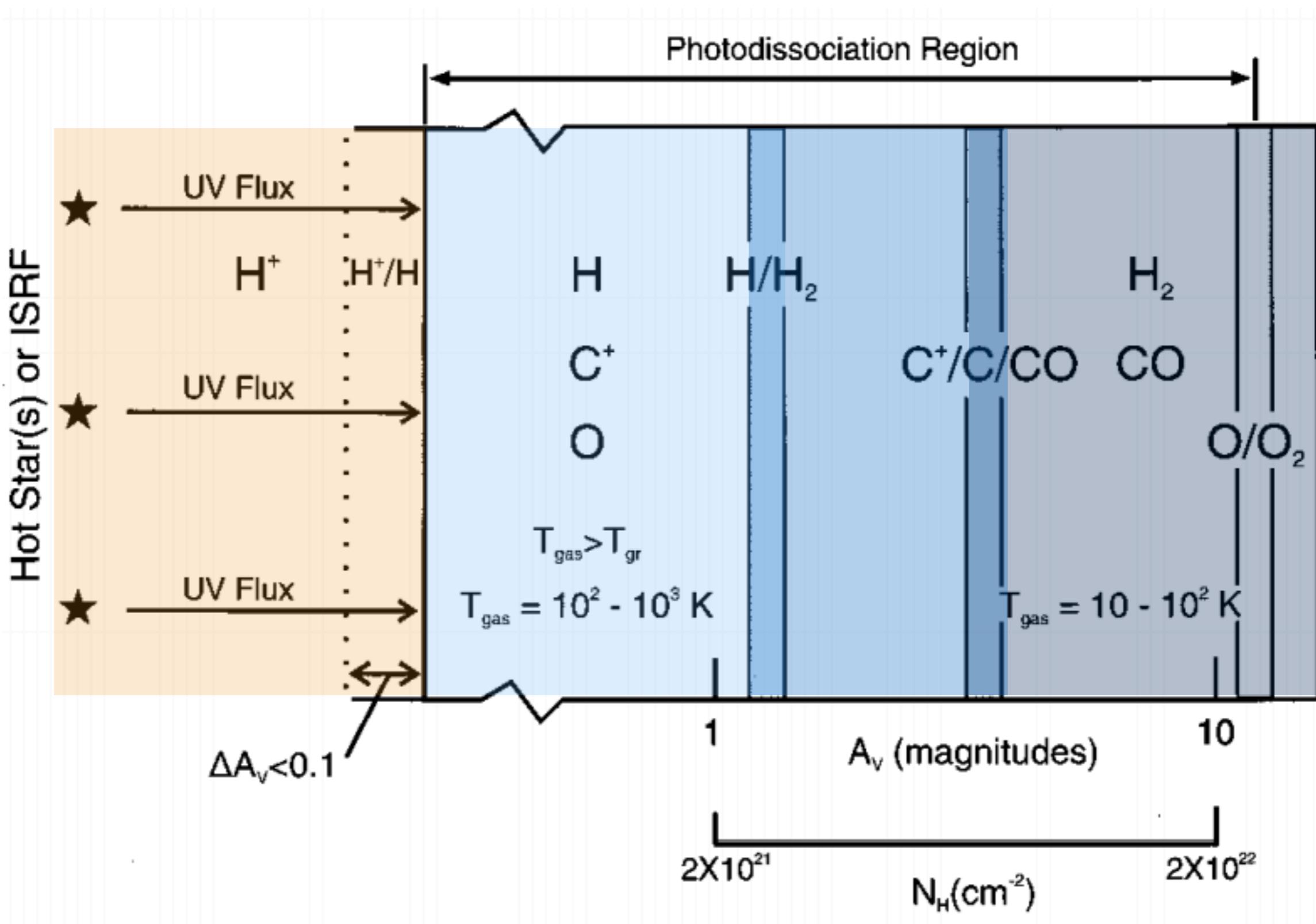


SQUARE KILOMETRE ARRAY NEWSLETTER



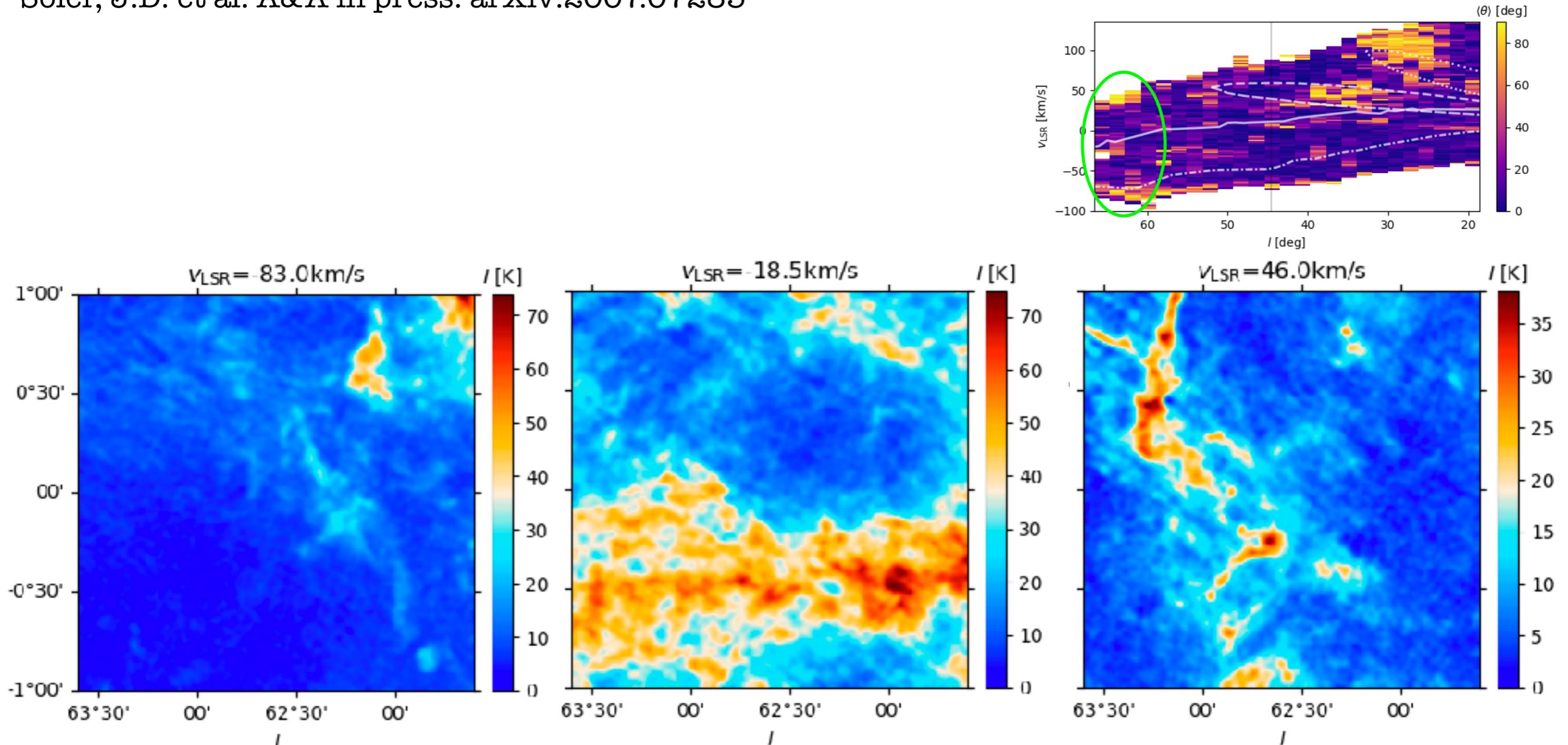
Structure of photodissociation regions

Hollenbach, D.J., & Tielens, A.G.G.M. Reviews of Modern Physics (1999)



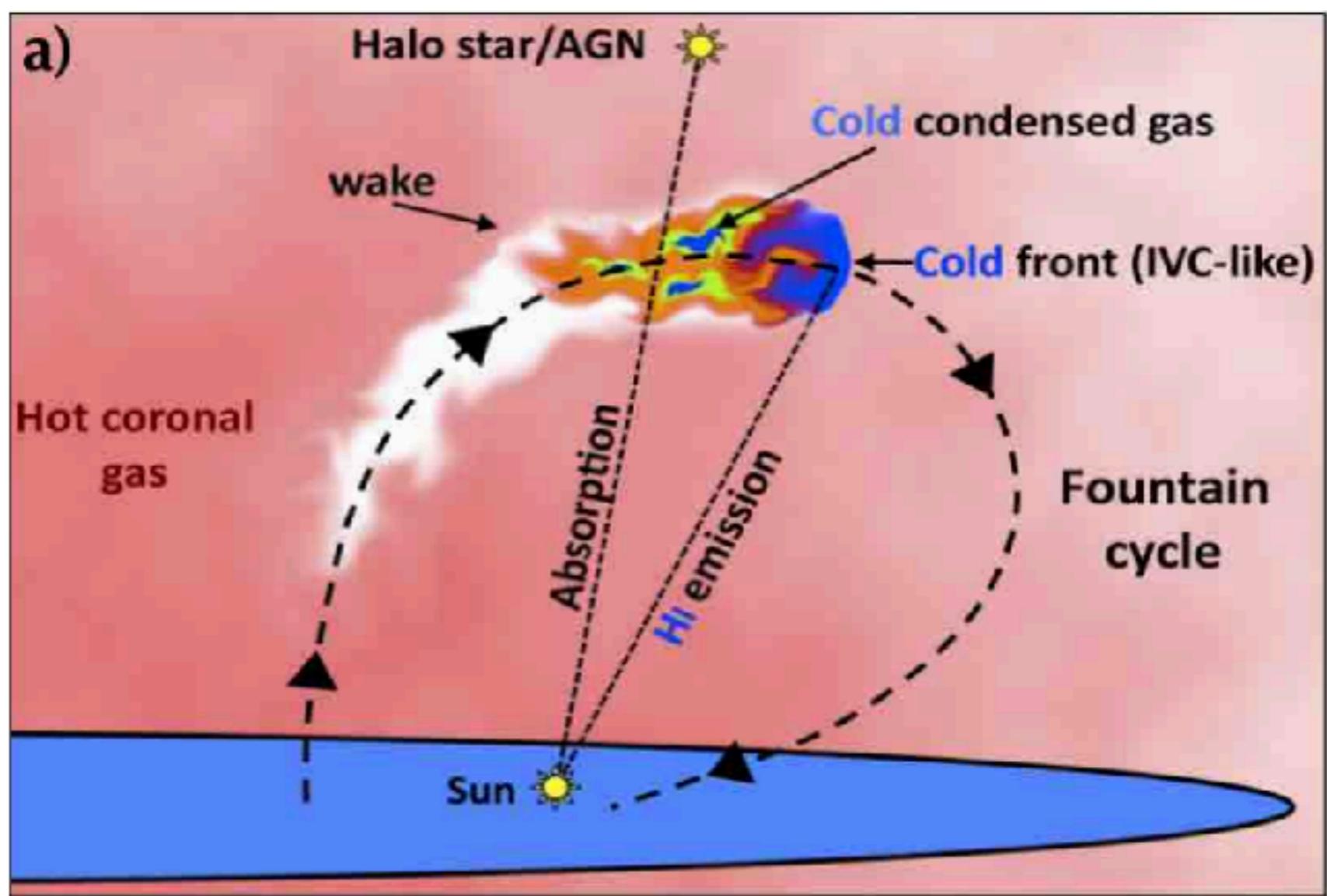
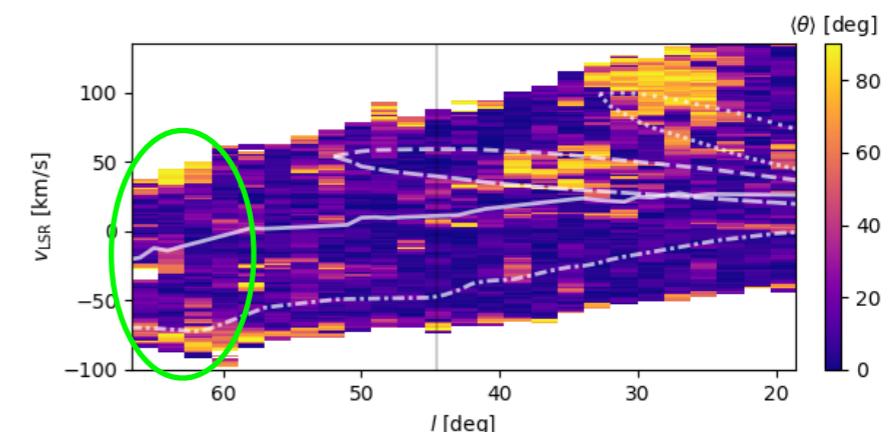
HI filaments - terminal velocities

Soler, J.D. et al. A&A in press. arXiv:2007.07285



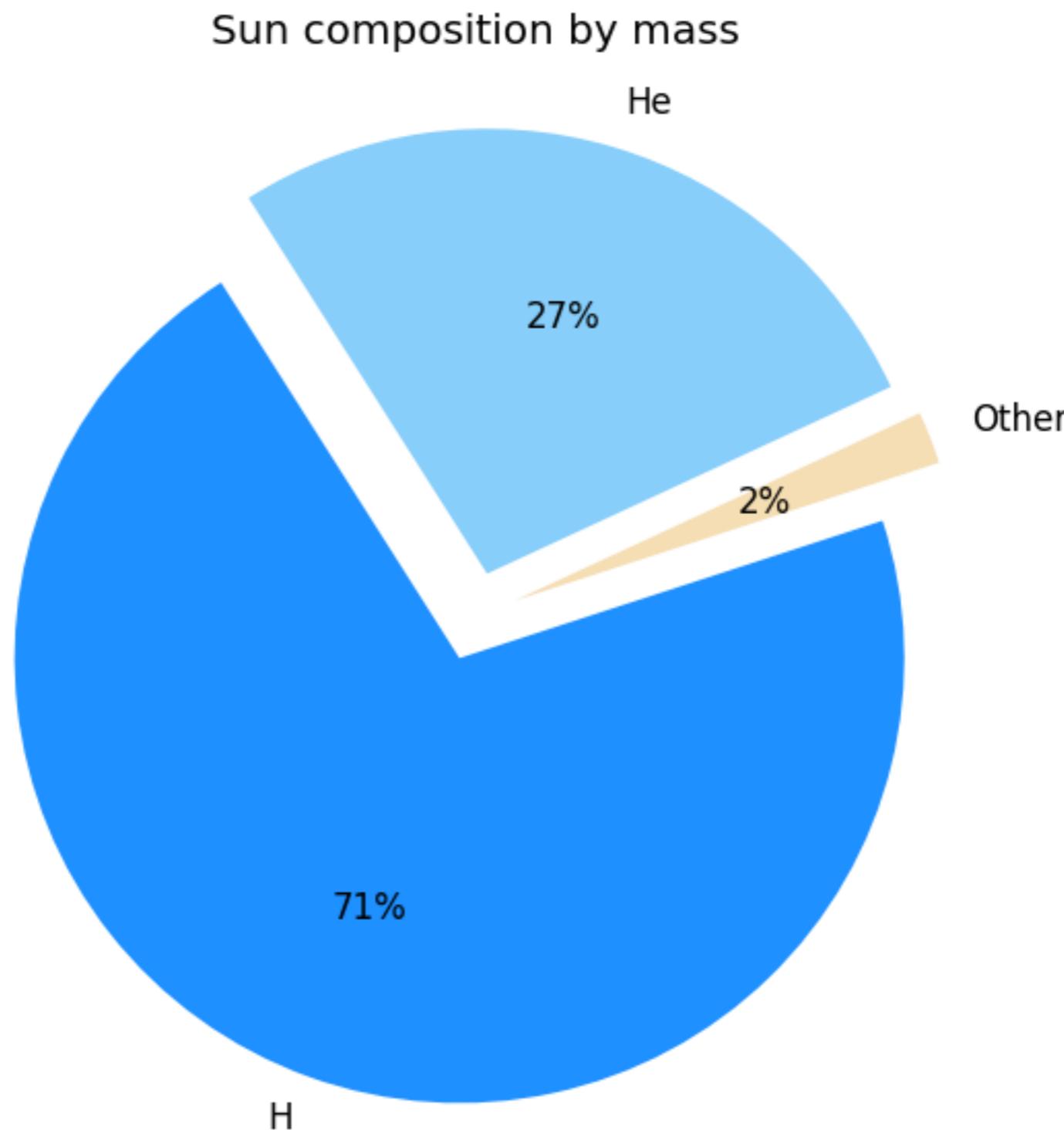
Extraplanar gas

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



The composition of the Sun

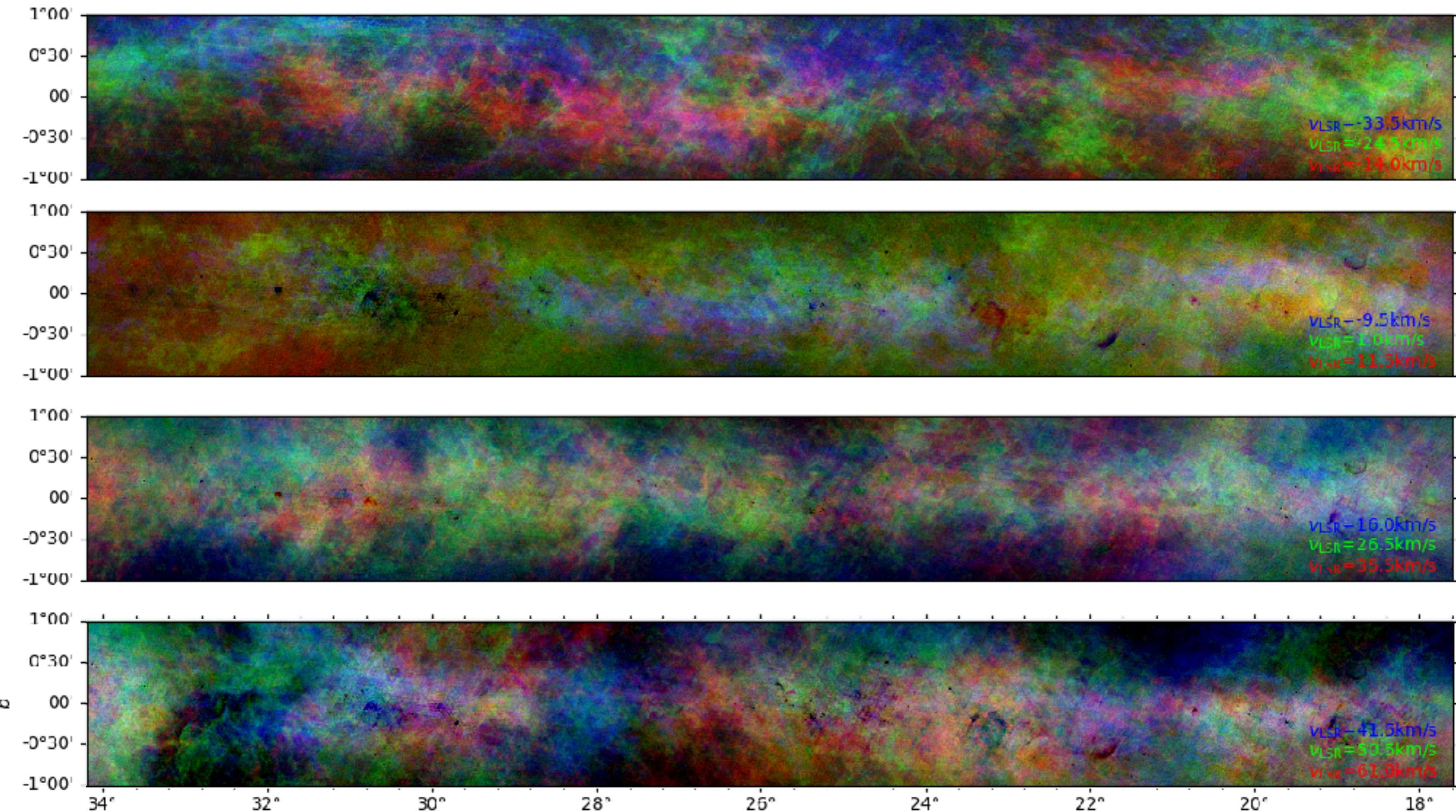
M. Asplund, A. Amarsi, and N. Grevesse 2021, A&A, 653, A141



Hessian matrix method

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

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Hessian matrix method

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

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