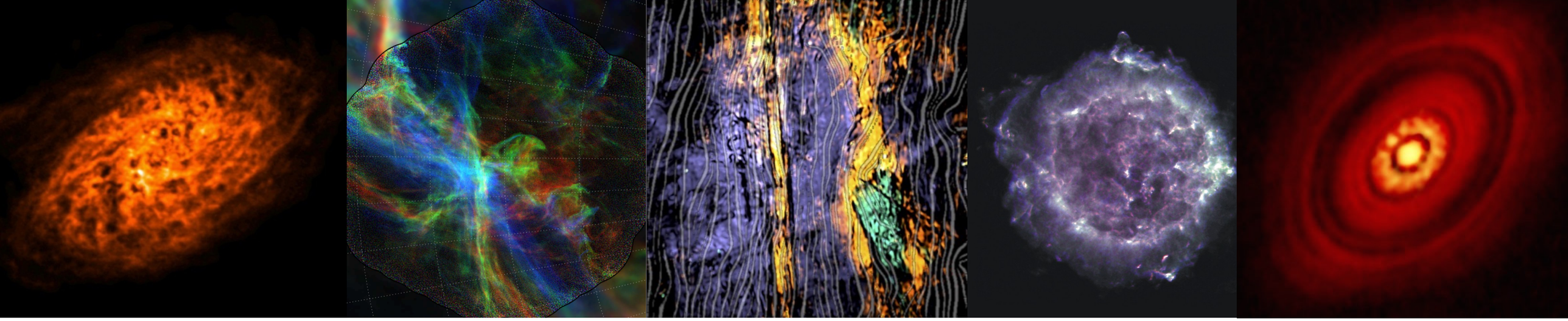
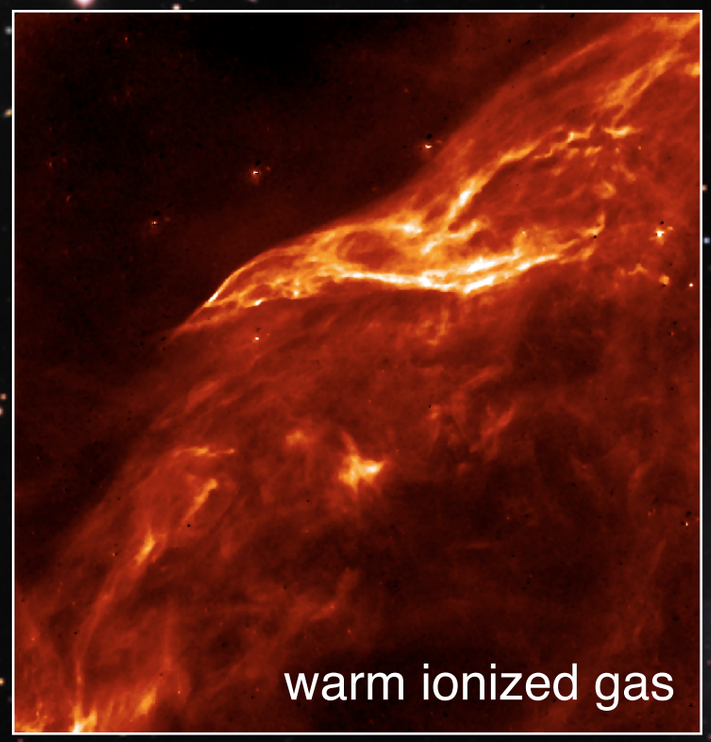
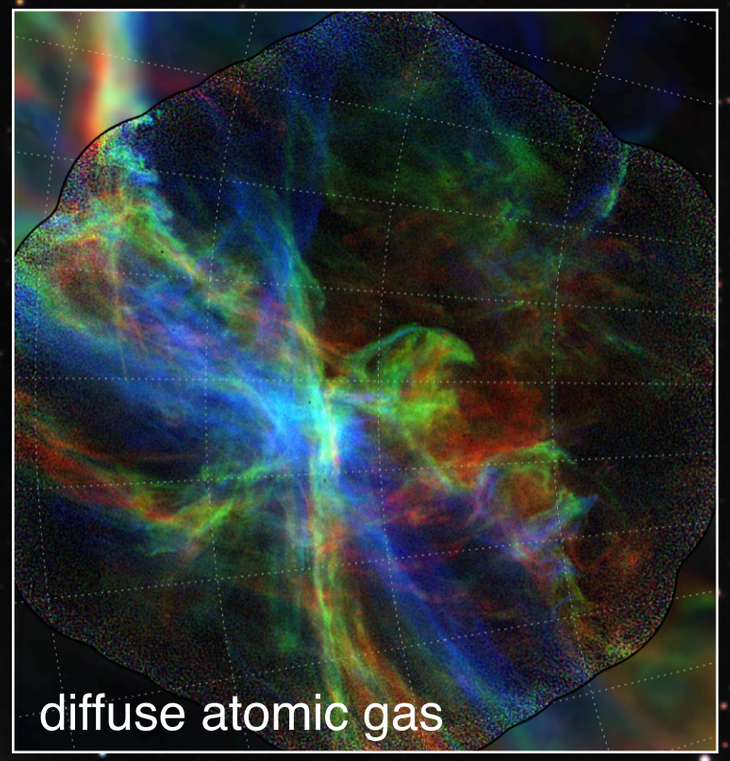


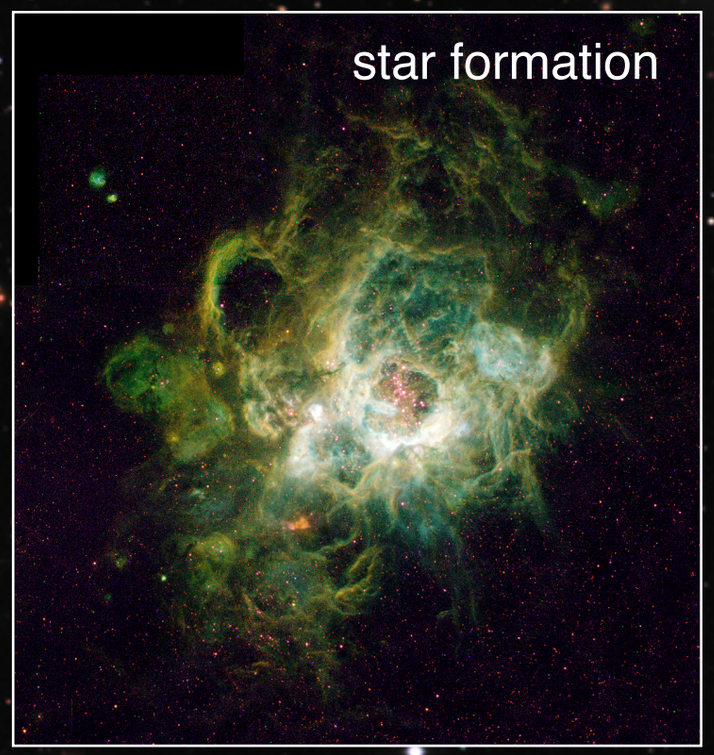
La physique du milieu interstellaire avec SKA

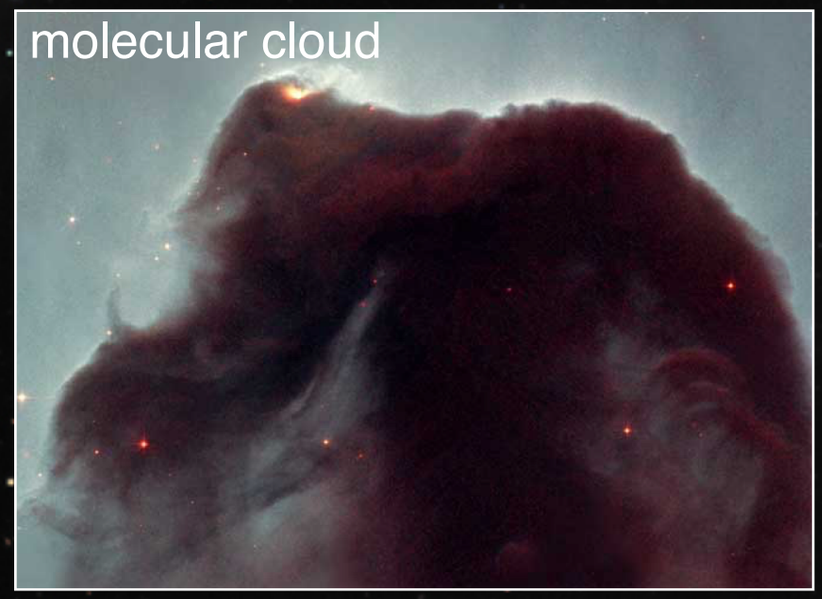
Marc-Antoine Miville-Deschênes
DAp/AIM, CEA-Saclay
directeur de l'Action Spécifique SKA-LOFAR

the interstellar medium in galaxies

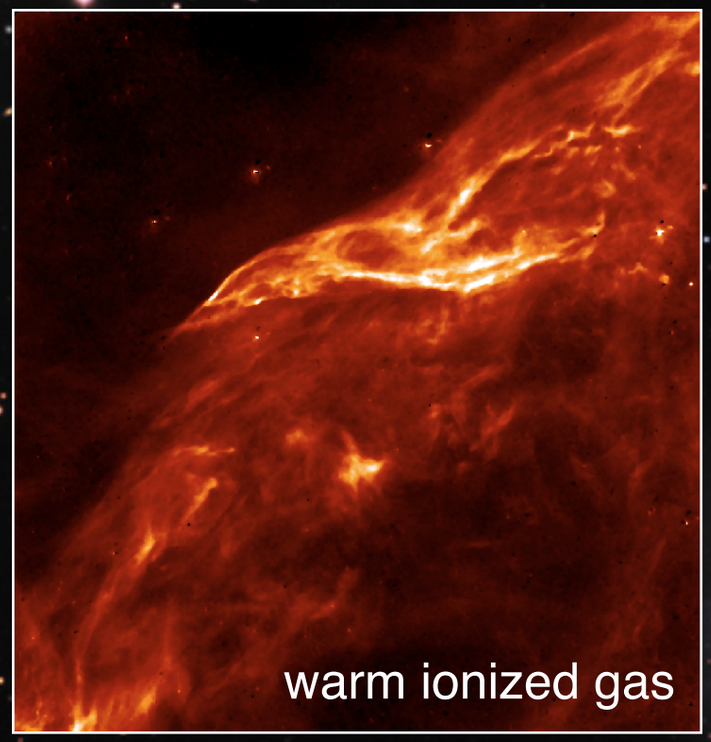


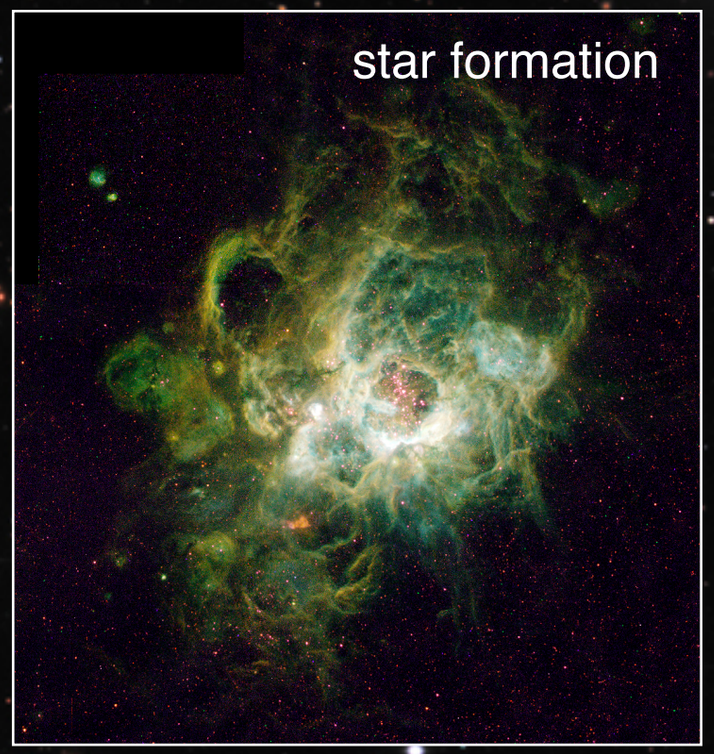






the interstellar medium in galaxies





- Scientific goal
  - Cycle of star formation in galaxies
  - Growth of solids in space
  - Evolution of molecular complexity

- Processes
  - Hydrodynamics
  - Magnetic field
  - Gravity
  - Heating and cooling
  - Stellar feedback
  - Chemistry
  - Cosmic rays
  - Dust

- Tools
  - Multi-wavelength observations
  - Numerical simulations
  - Models
  - Laboratory experiments
  - Data science

Why is SKA unique for ISM studies ?

Why is SKA unique for ISM studies ?

- **Frequency coverage** : a wealth of diagnostics
  - 21cm, OH, RRLs (H, He, C), free-free, synchrotron, dust continuum, anomalous microwave emission, molecular lines (COMs)
  - Innovative magnetic field diagnostics: Zeeman, Faraday tomography
  - Hyperspectral data over large areas
- **Angular resolution**
  - Small-scale structures : disks, filaments, shocks, dissipation
  - Astrophysics of galaxies like for the Milky Way
  - Distance determination (parallax) and proper motion in dense regions
- **Mapping speed** : multi-scale physics, connection with the environments
- **Sensitivity** : Galactic halo, external galaxies, small-scale features, HI absorption, pulsars, faint line emission…

21 cm - GALFA, Arecibo. credit Joshua Peek

- In the Solar neighborhood, molecular gas is only 14% of the gas and only 4% of the baryons
- The diffuse gas (the HI, the WIM) is the matrix out of which stars form

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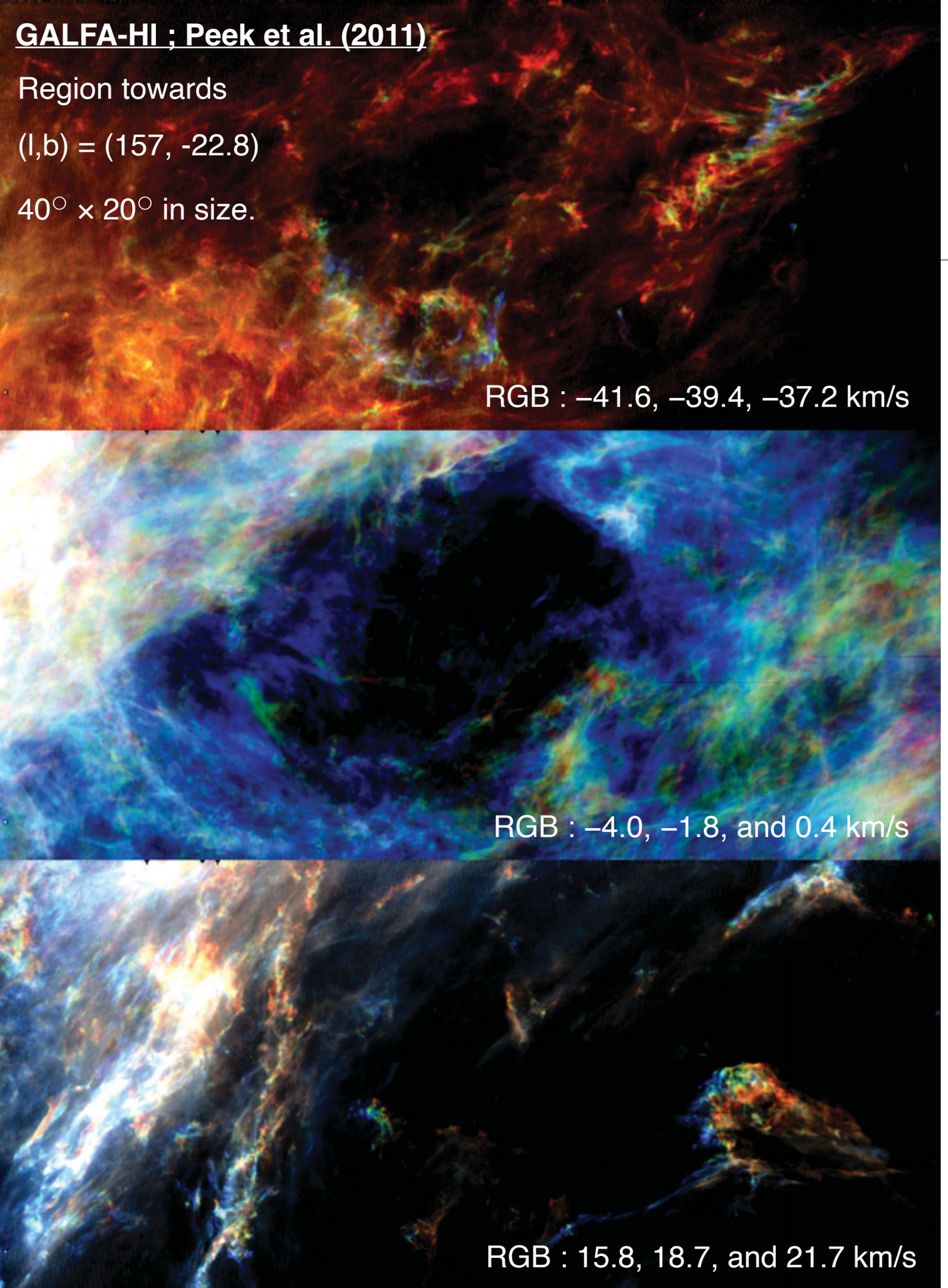
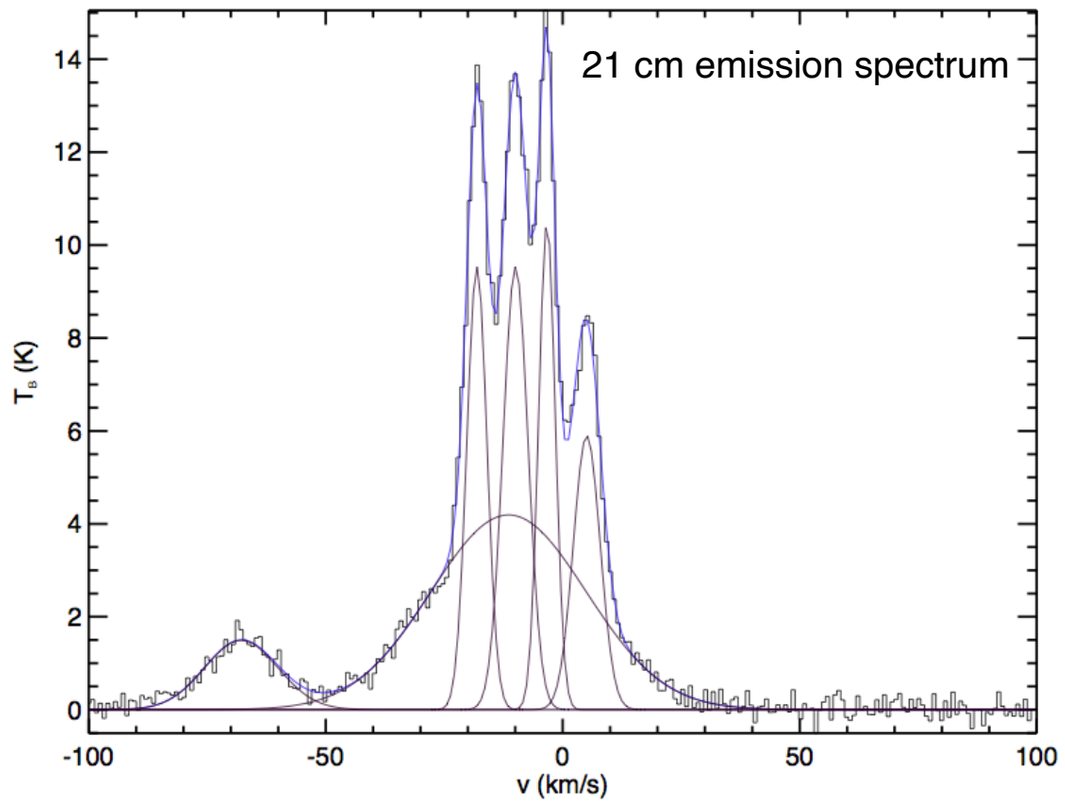


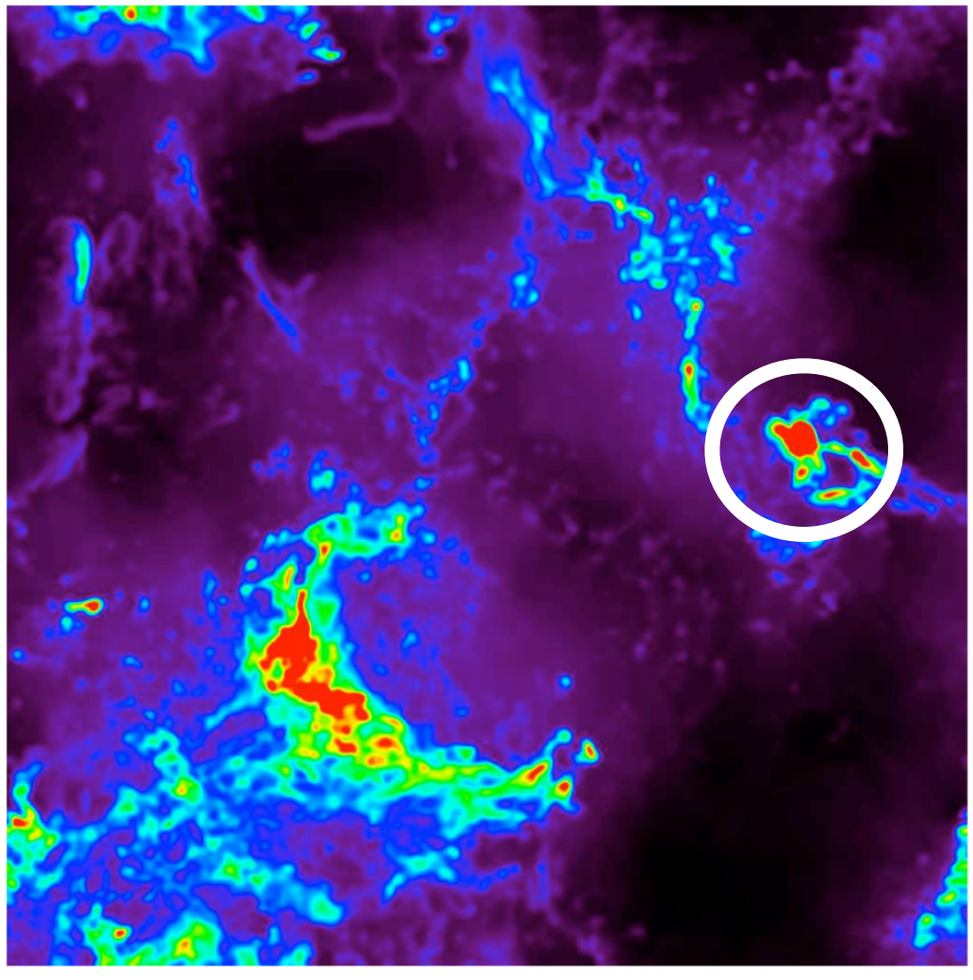
phase transition in the diffuse ISM

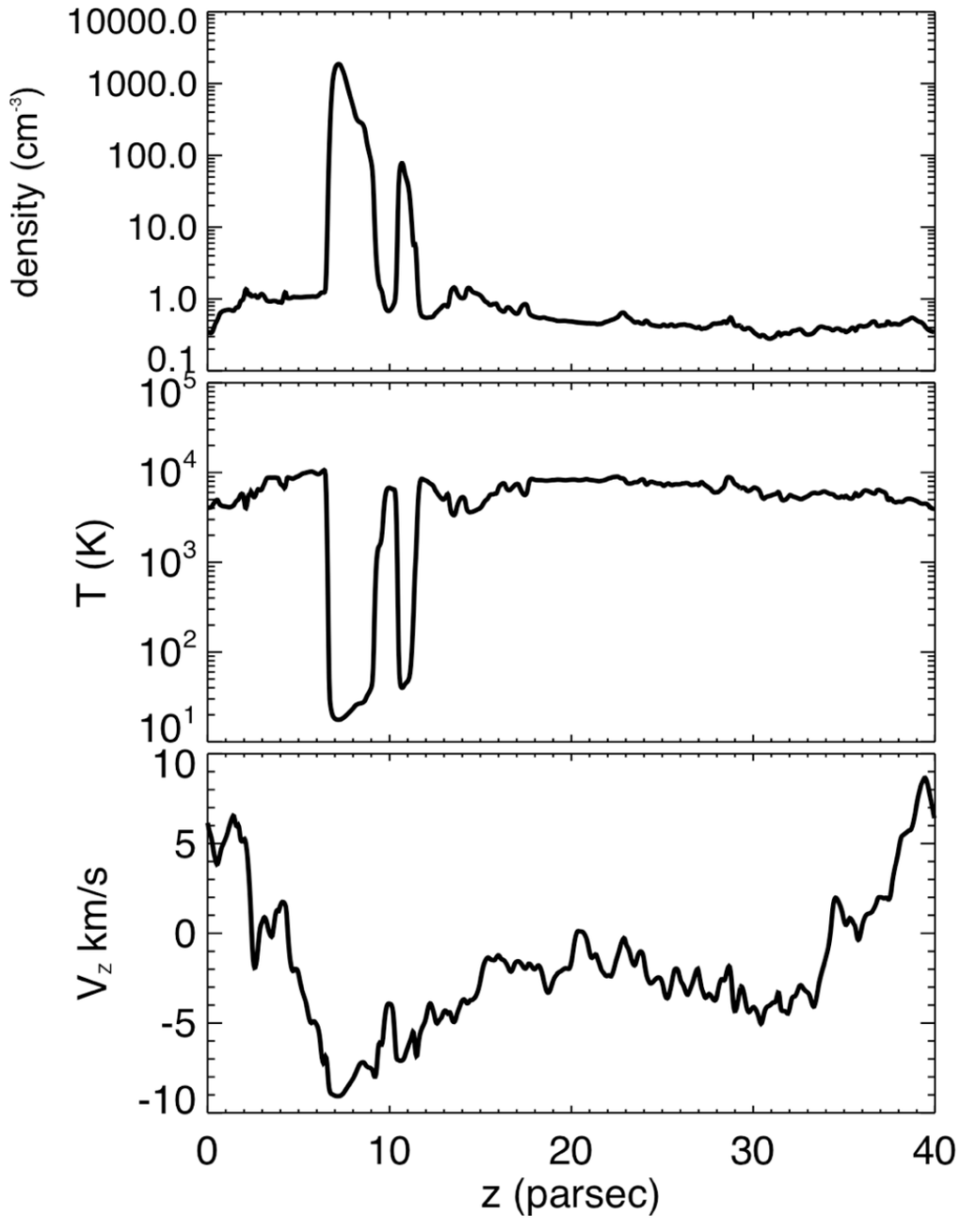


The cold gas (50-100K) is clumpy, filamentary with narrow 21 cm lines.

The warm gas (6000K) with broad lines is volume filling

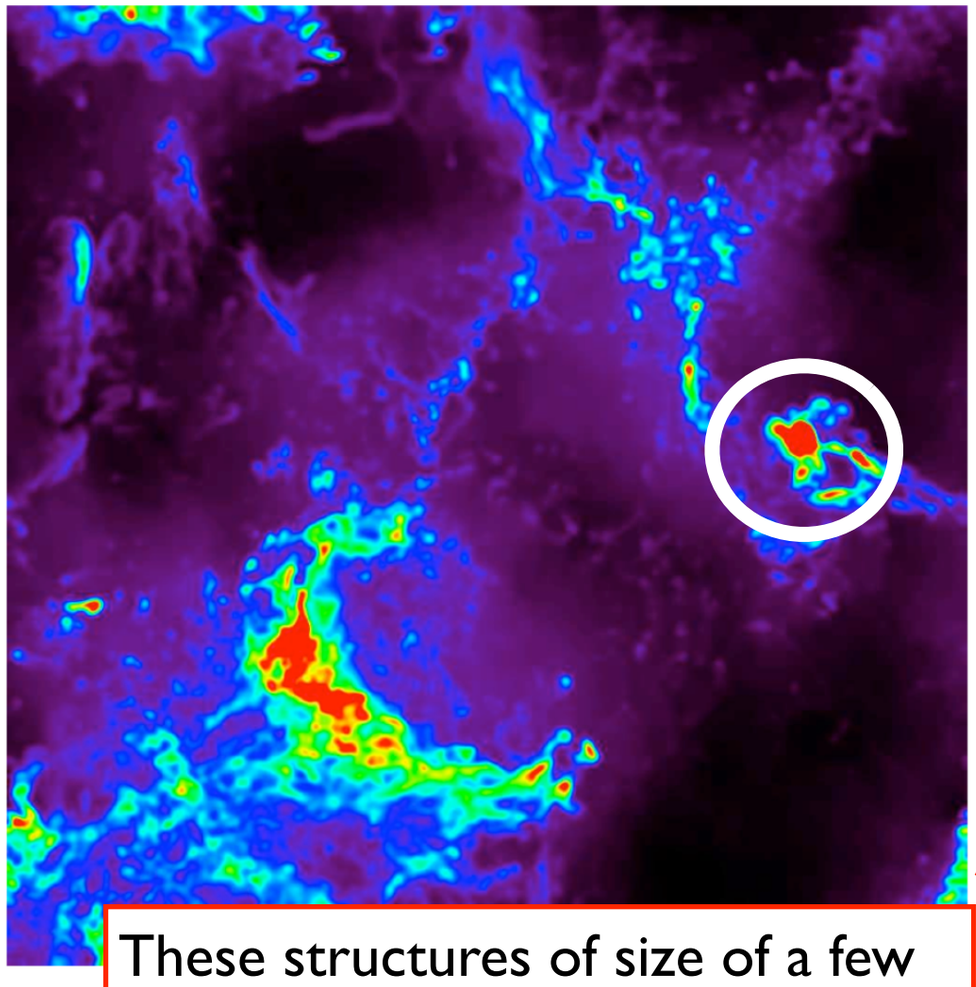
What is on the line of sight of an HI cloud ?

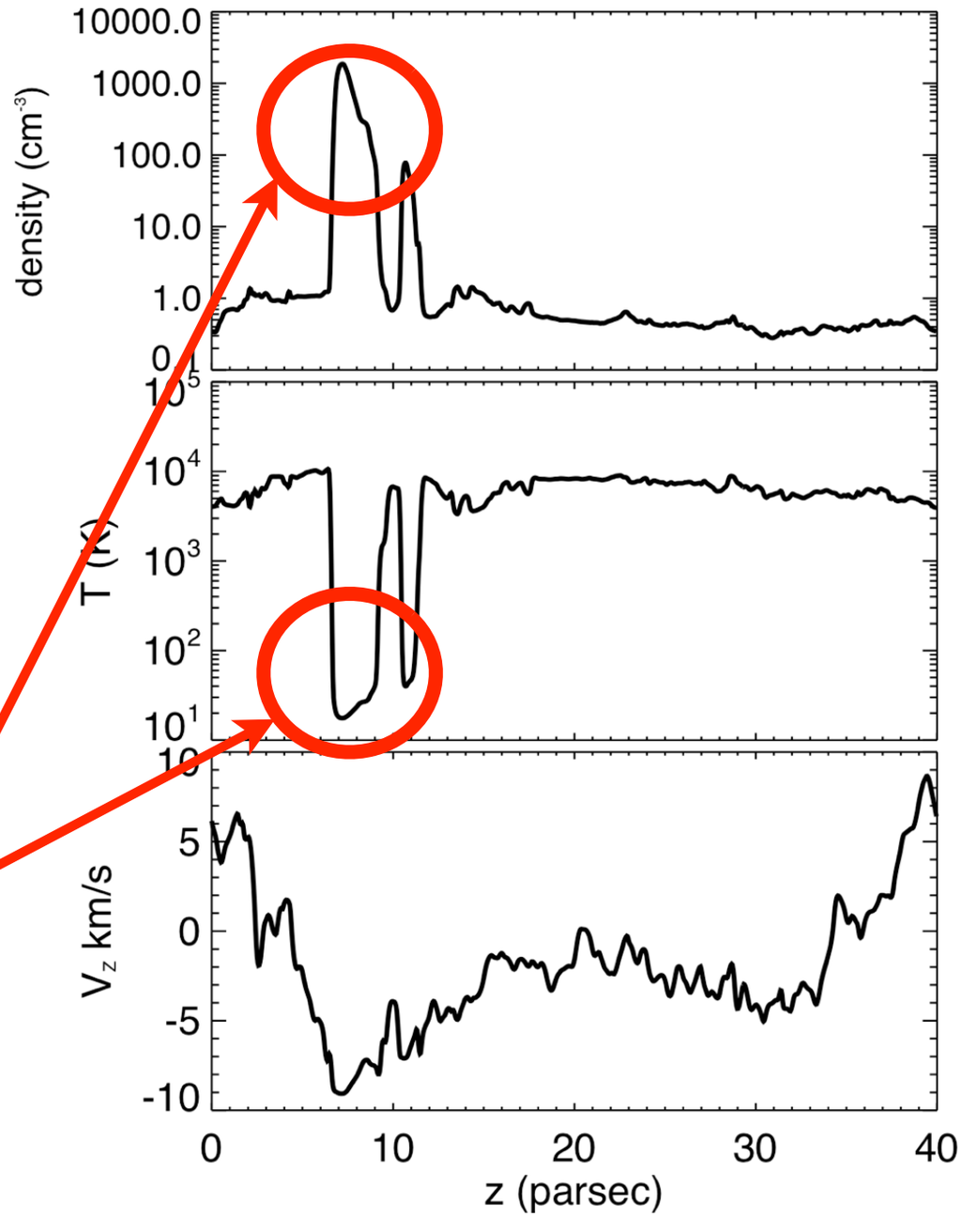




Saury et al. 2014

What is on the line of sight of an HI cloud ?

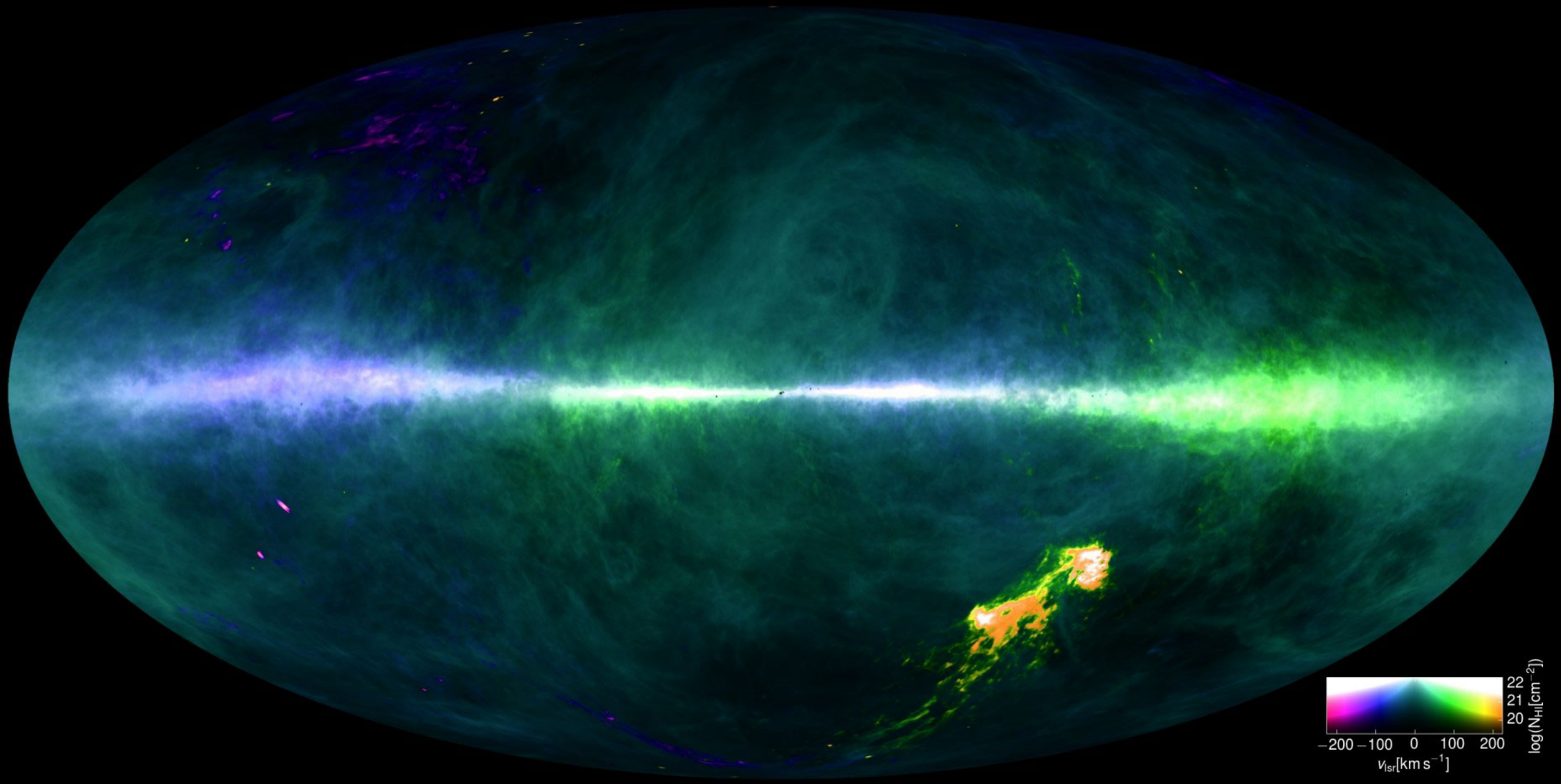




These structures of size of a few 0.1 pc, of density 10^3 cm^{-3} and of temperature 10-20 K are similar to non self-gravitating structures observed in HI

Saury et al. 2014

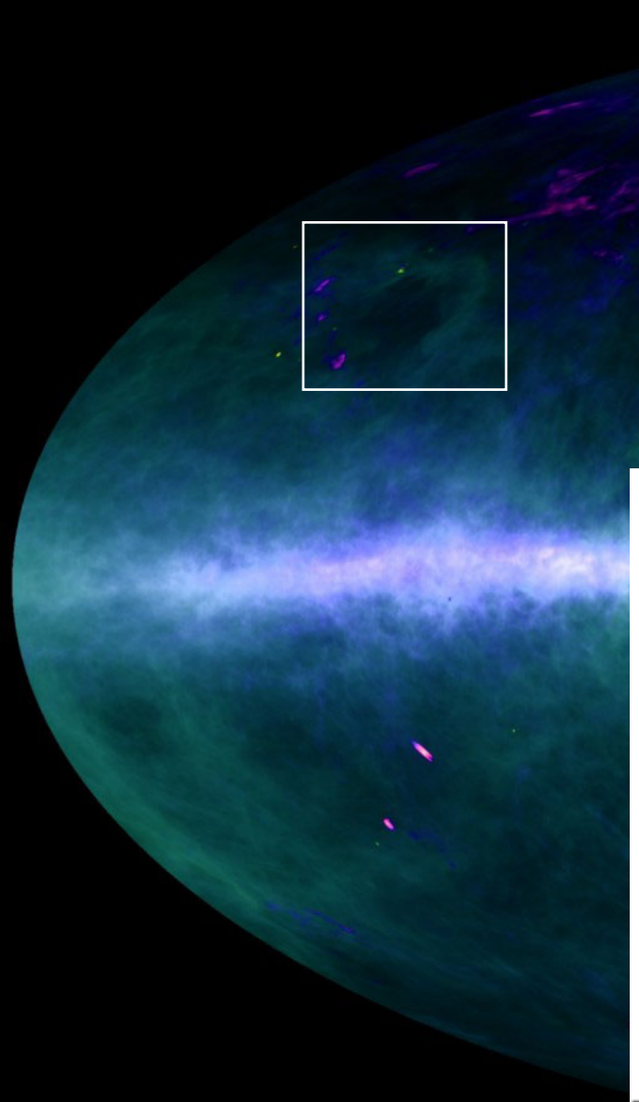
Th HI - HI4PI survey - integrated 21 cm line emission

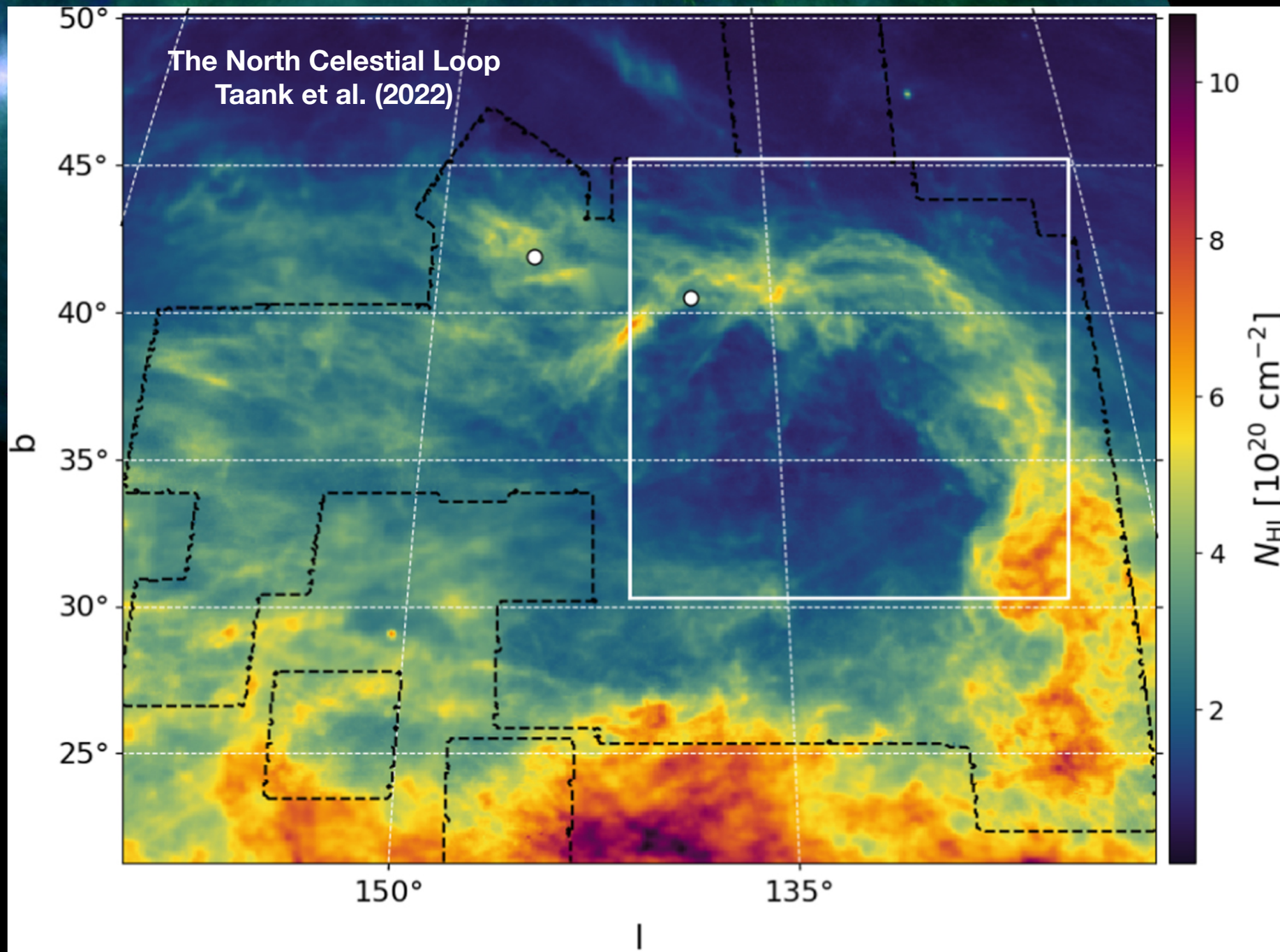


Benjamin Winkel & HI4PI Collaboration

How to separate phase information from the blended 21 cm data ?

Th HI - HI4PI survey - integrated 21 cm line emission





How to separate phase information from the blended 21 cm data ?

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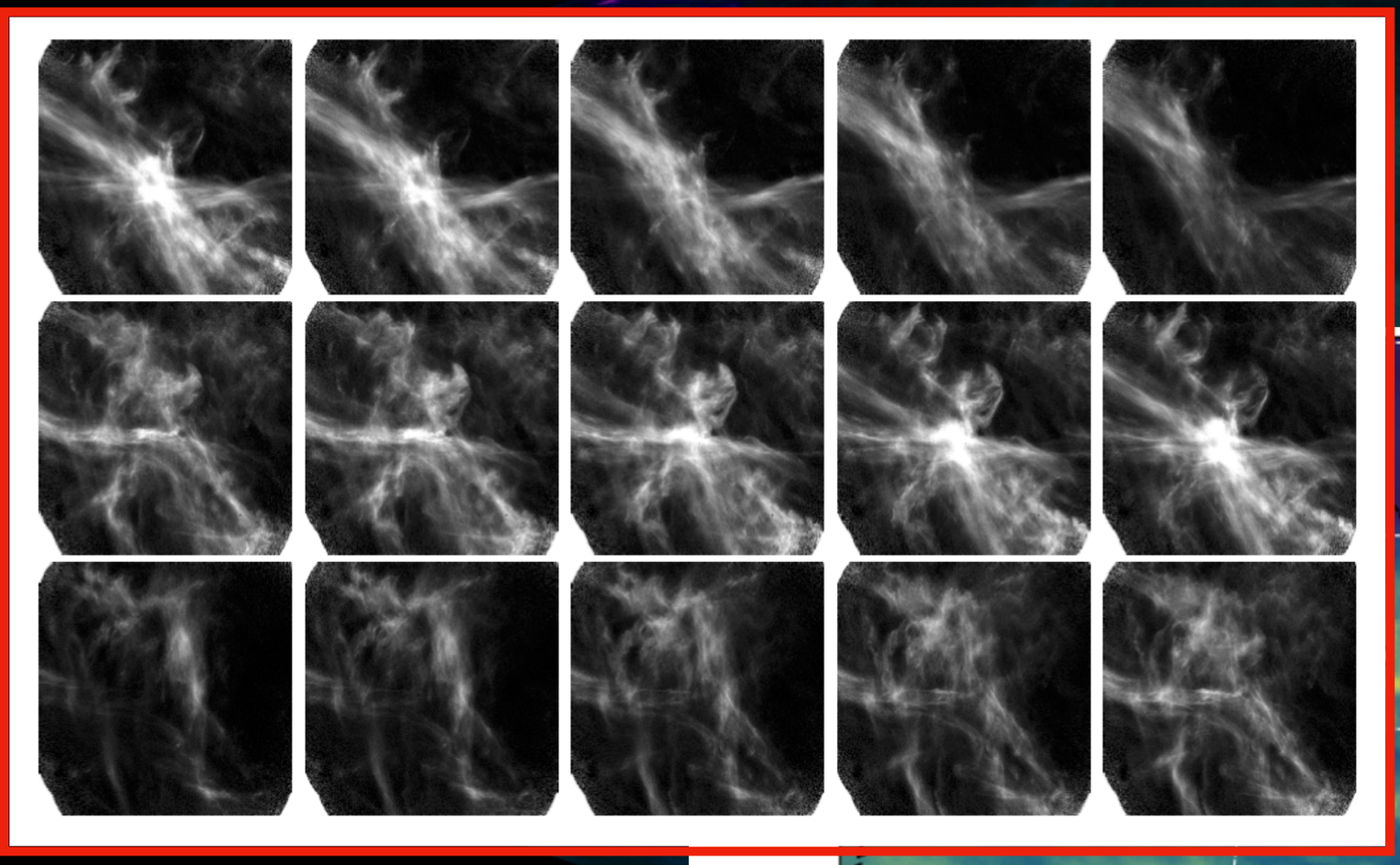
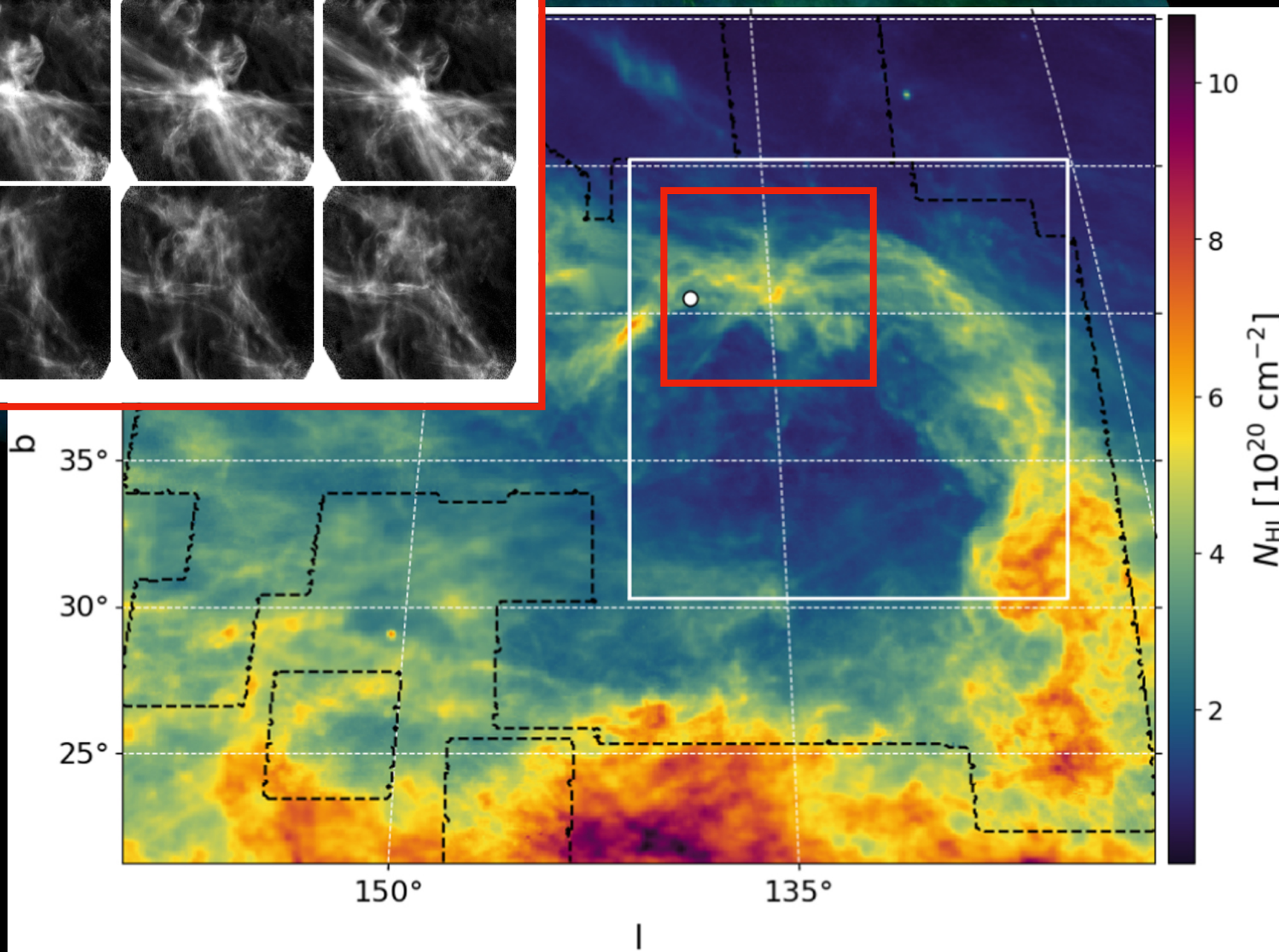


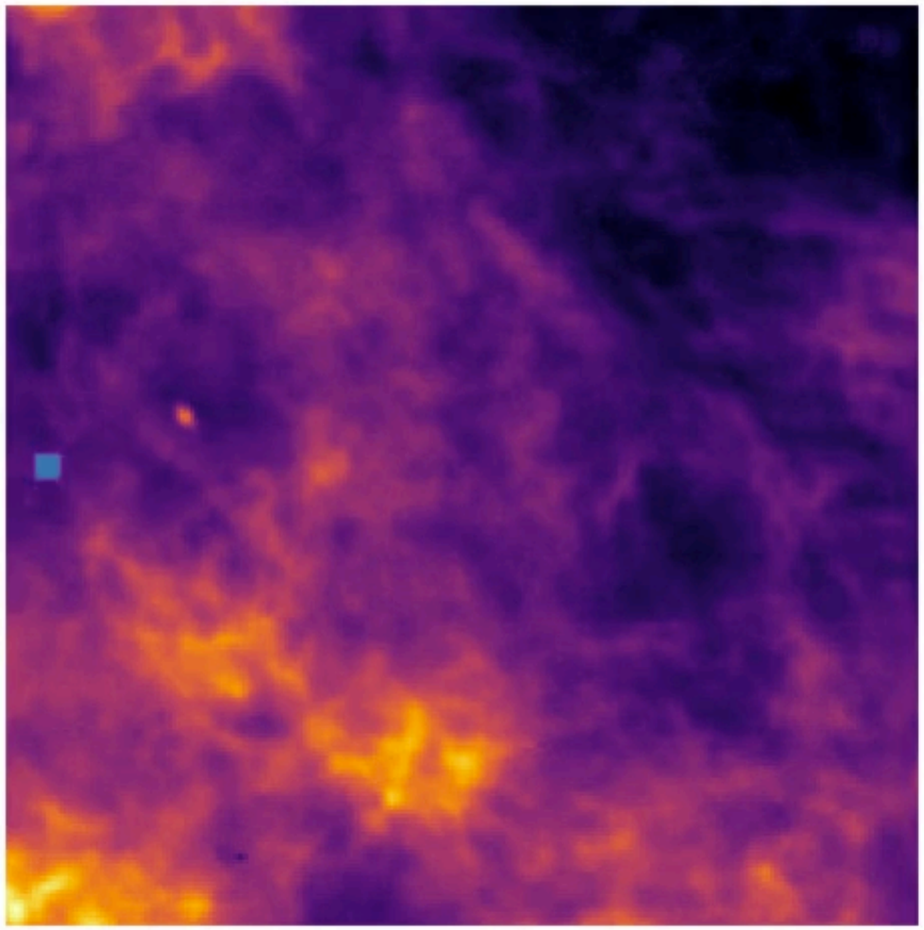
Blagrave et al. (2017)

How to separate phase information from the blended 21 cm data ?

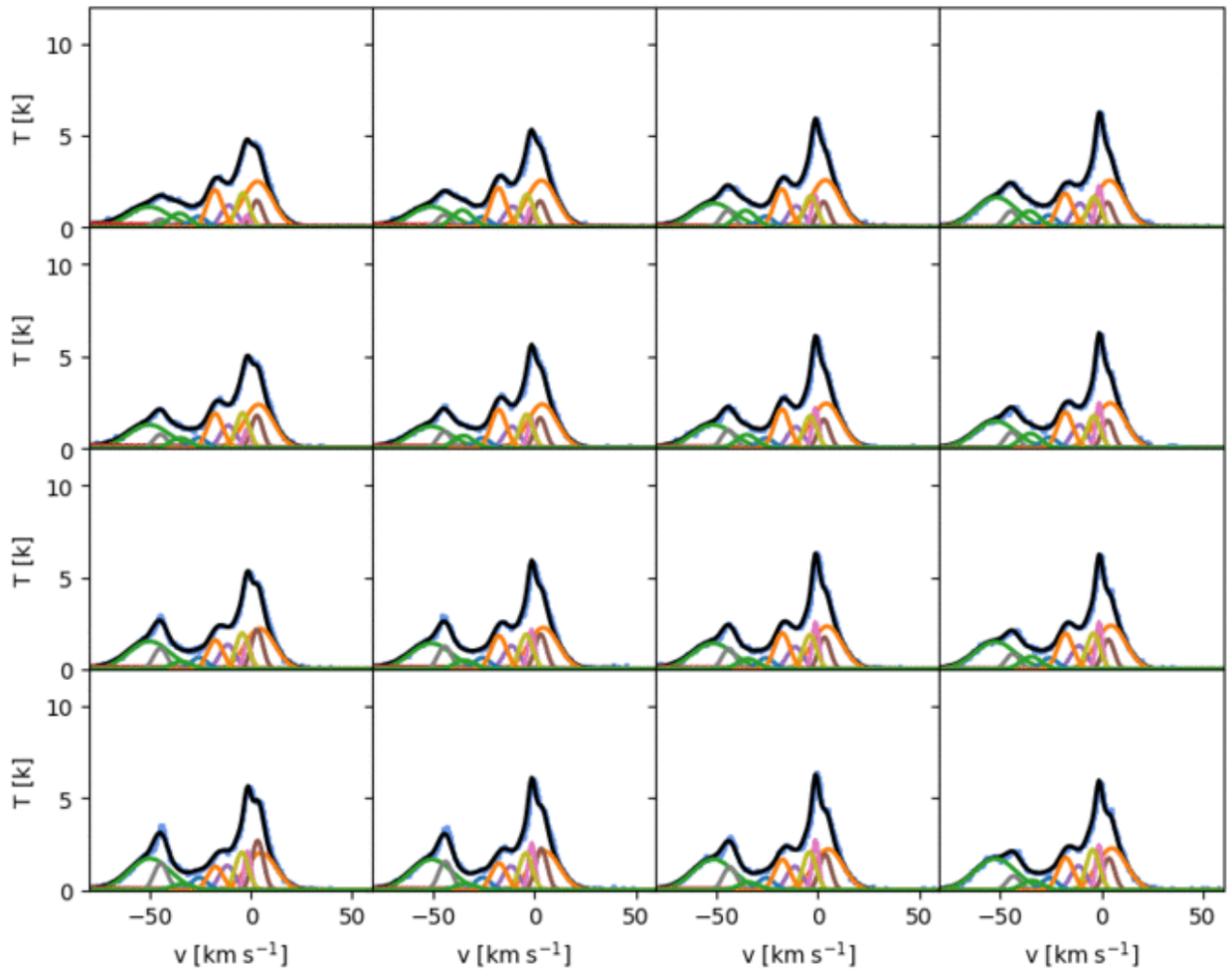


Application on 21 cm observations of the North Ecliptic Pole field

Integrated emission of TB[x, y, v]



TB[v] for 16 adjacent lines of sight

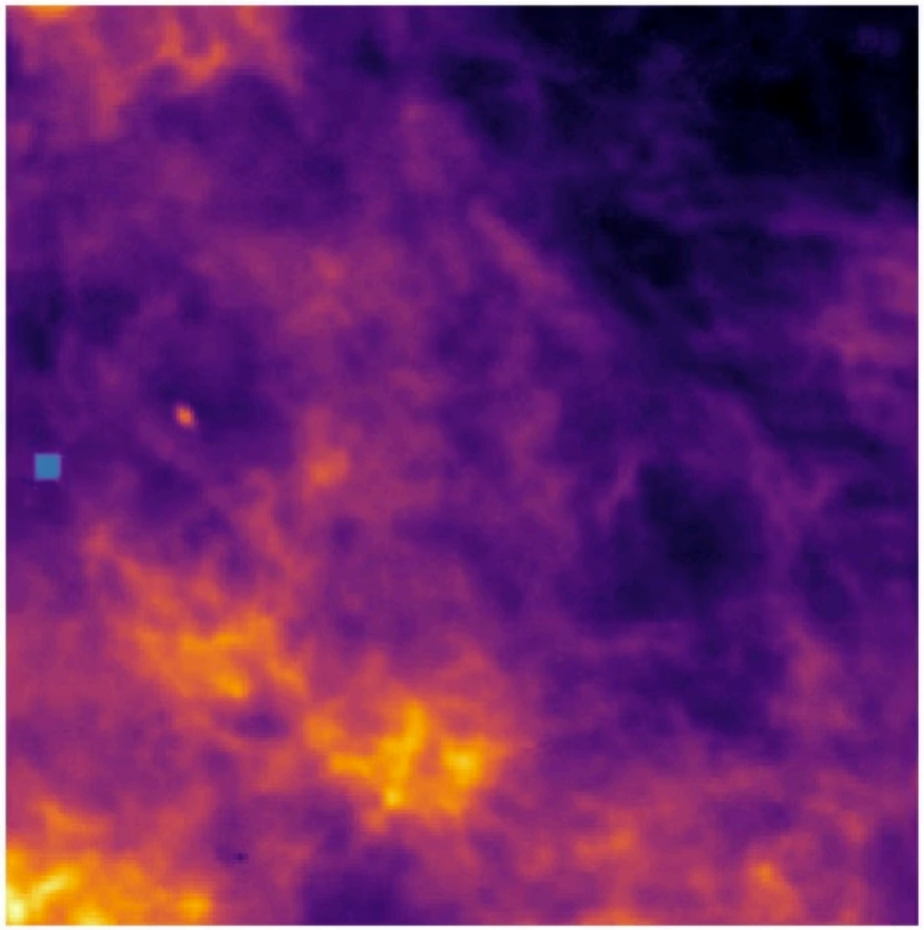


ROHSA : decomposition of emission on a Gaussian basis

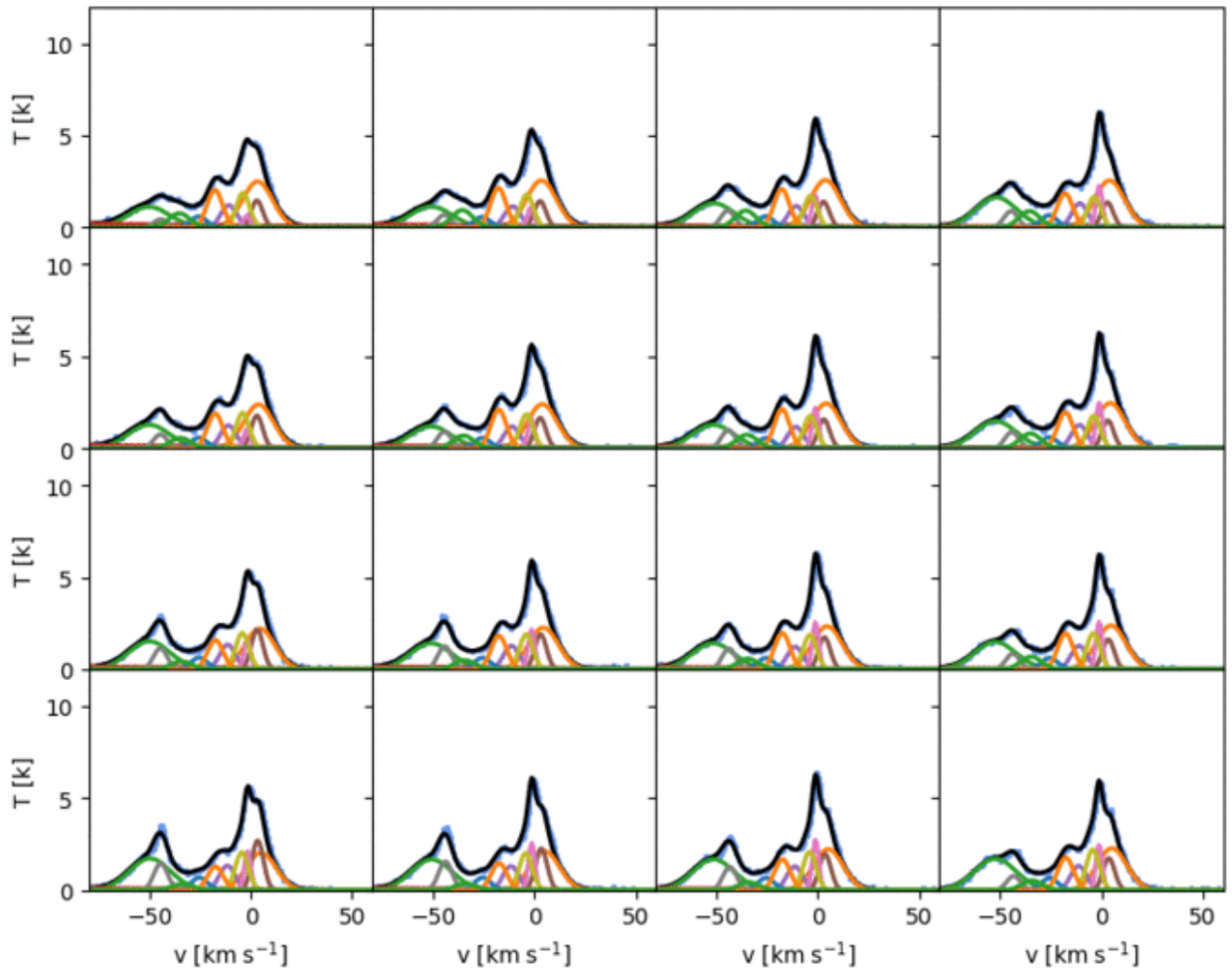
Marchal et al. (2019)

Application on 21 cm observations of the North Ecliptic Pole field

Integrated emission of TB[x, y, v]



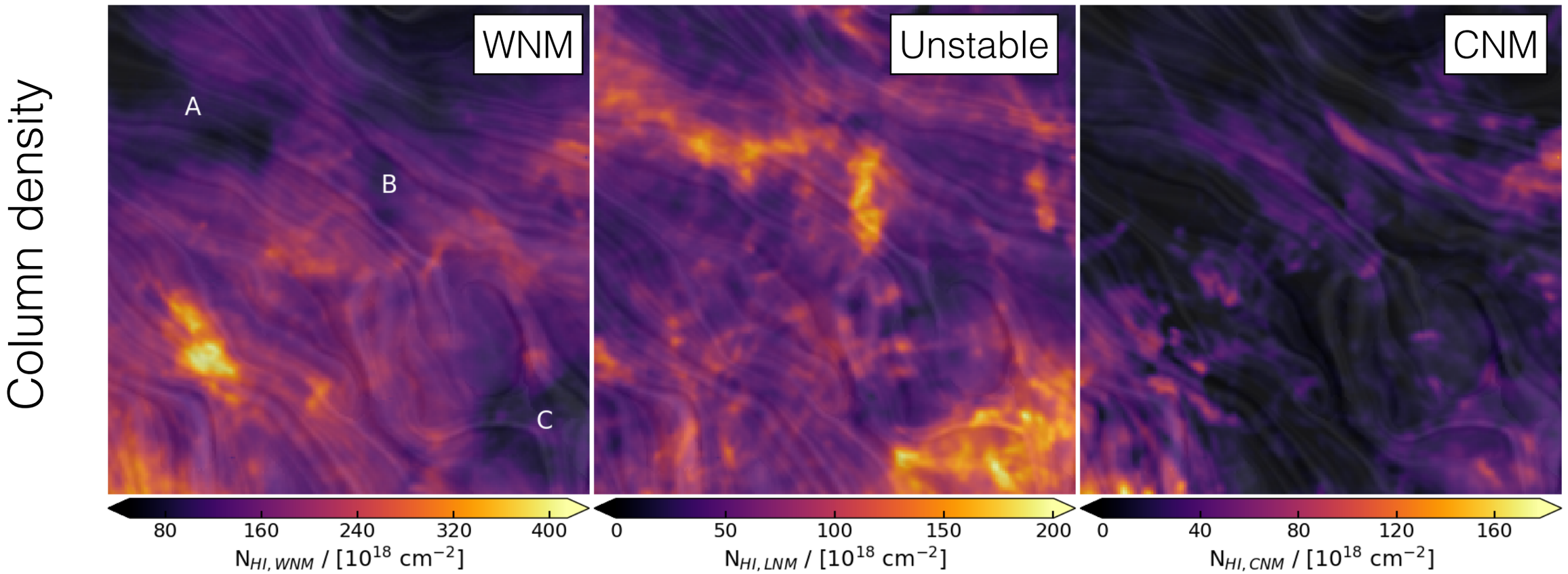
TB[v] for 16 adjacent lines of sight



ROHSA : decomposition of emission on a Gaussian basis

Marchal et al. (2019)

Phase separation using 21 cm emission data and ROHSA



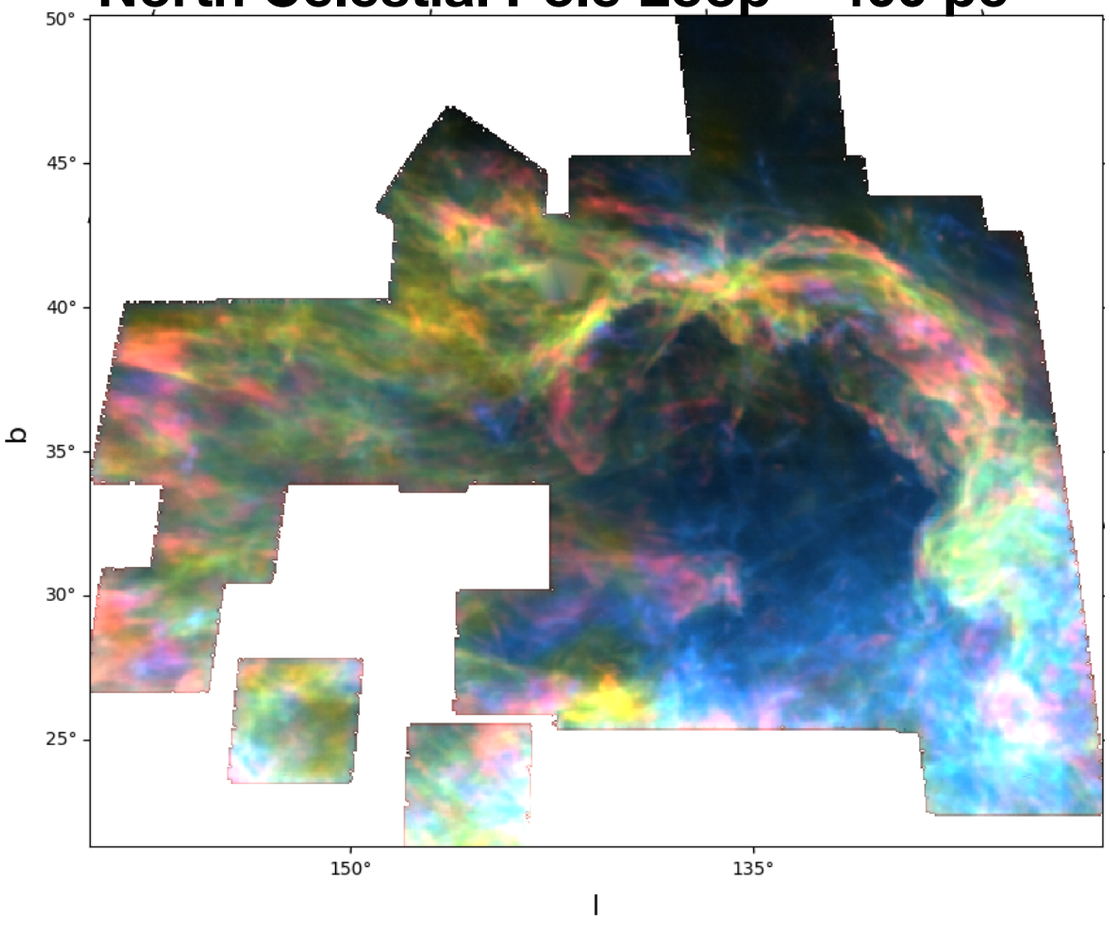
- **Warm Neutral Medium** ~ 64%
  - first map of the WNM velocity field
  - compatible with trans-sonic turbulence
- **Thermally unstable gas** ~ 28%
- **Cold Neutral Medium** ~ 8%
  - structures are a few 1019 cm-2
  - typical size : a fraction of pc
  - volume filling factor of 1%

North Ecliptic Pole region
12x12 degrees; 21 cm (GBT data)

Marchal + (2019)
Marchal & Miville-Deschênes (2021)

Large variability of the CNM fraction as a function of environment

North Celestial Pole Loop ~ 400 pc

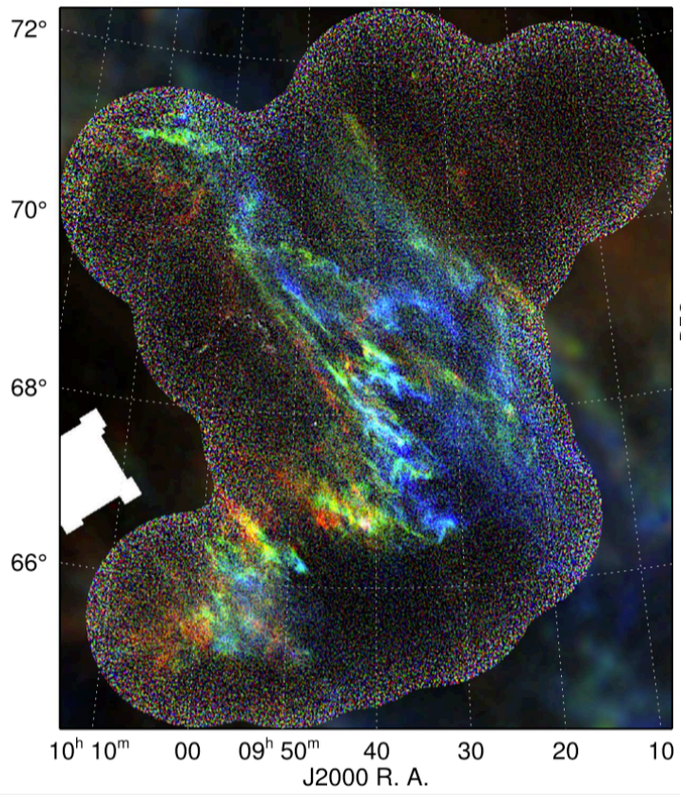


GBT data - CNM 30%, up to 70%

Taank et al. 2022

Marchal & Martin 2022

IV Arch - IVC ~ 2-3 kpc

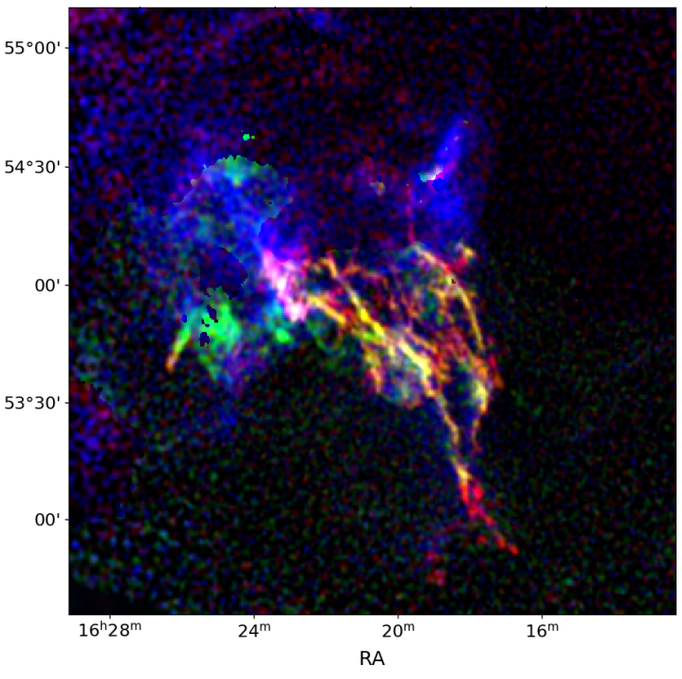


ROHSA-GPU

DHIGLS data - CNM ~ 20%

Besson et al, in prep

Complex C - HVC ~ 10 kpc



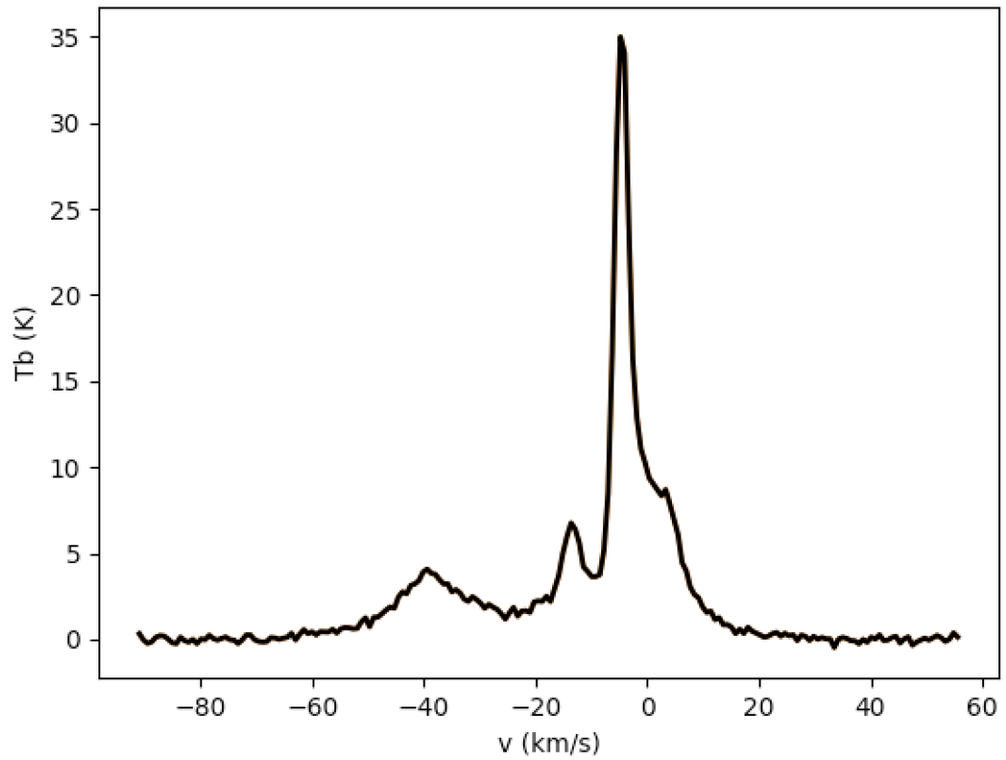
DHIGLS data - CNM ~ 7%

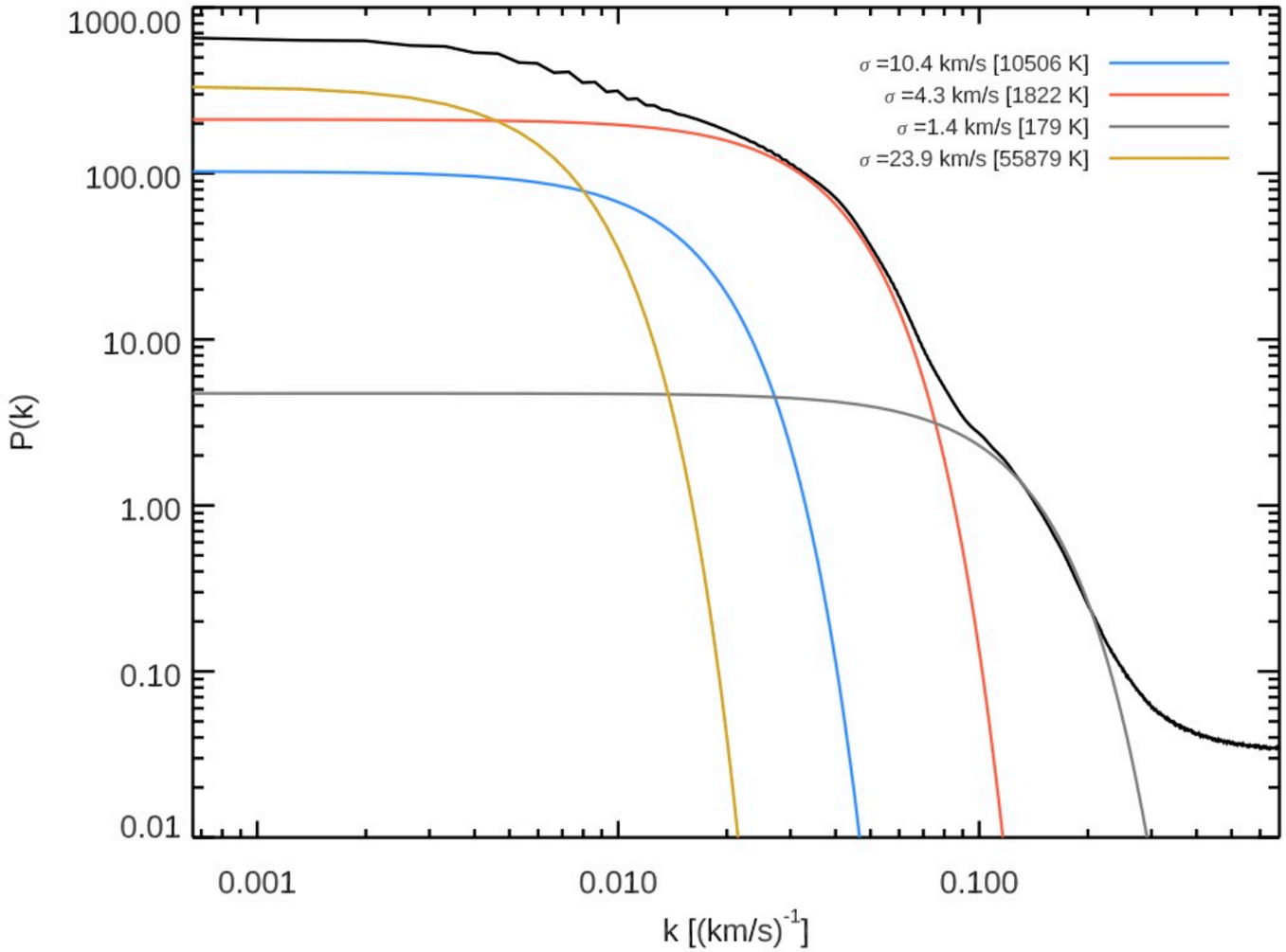
Marchal, et al 2021

Is there a faster way of doing this ?

spectral analysis of 21 cm emission

A 21 cm spectrum of the diffuse ISM

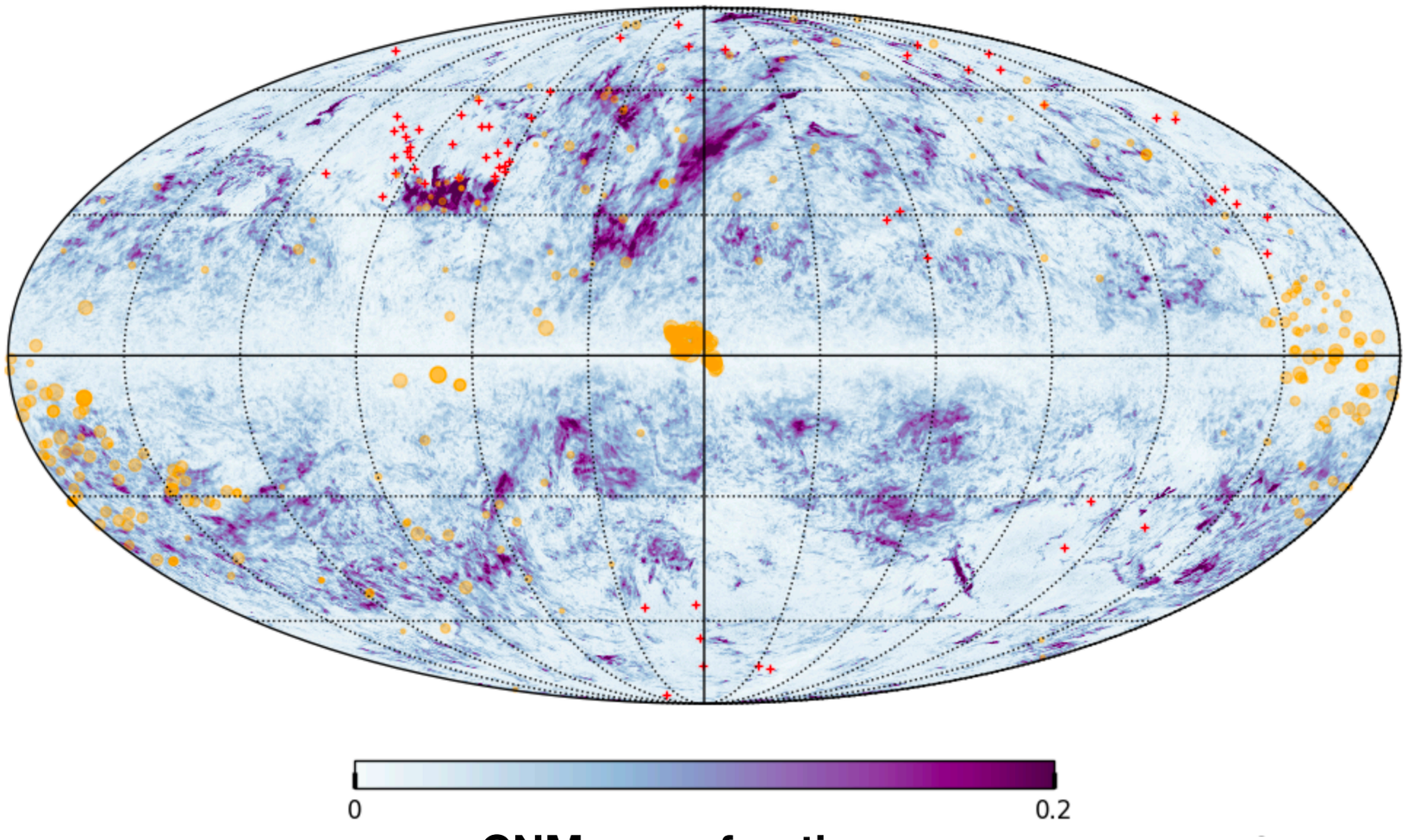




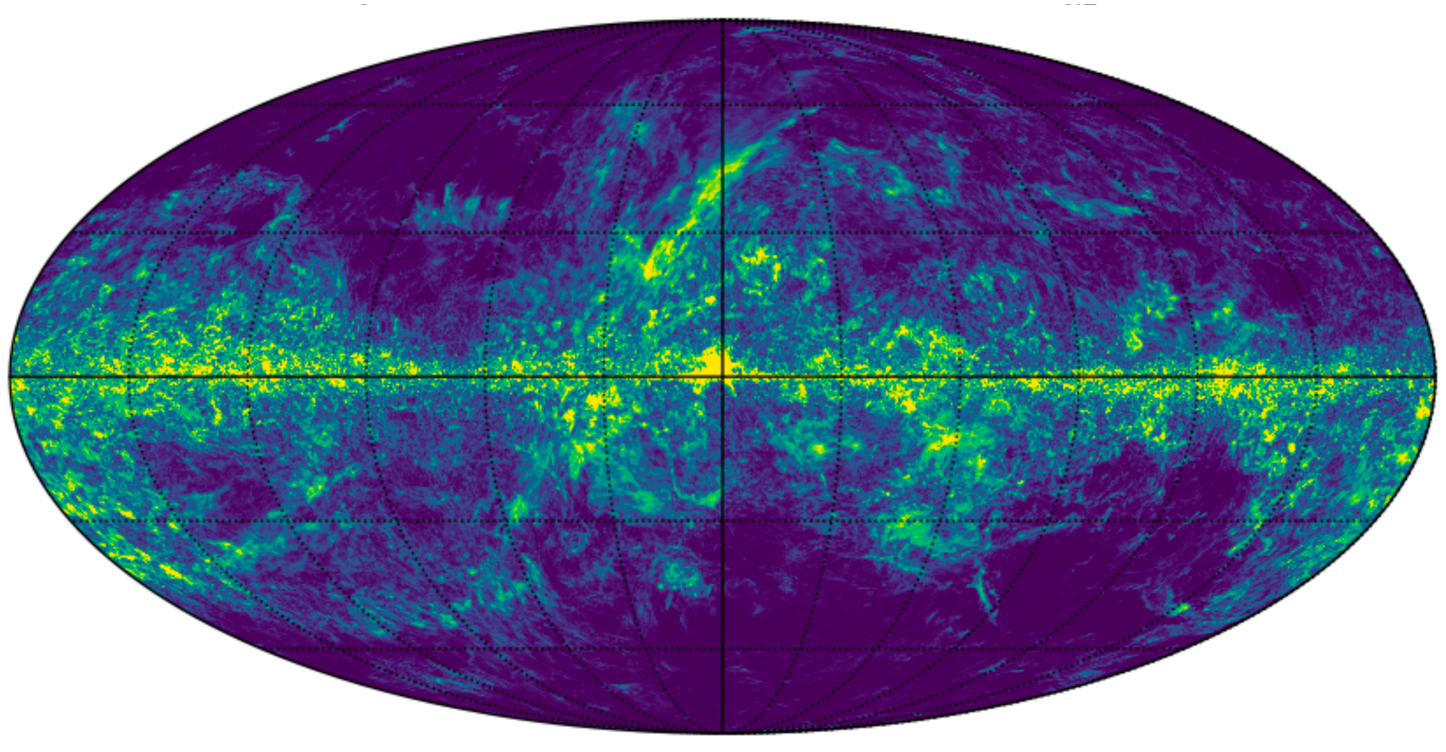
Average Pk_1D of a 512x512 cube in Taurus (GALFA data)

Marchal et al. (submitted)

Application on full sky HI4PI survey - 21 cm



CNM mass fraction



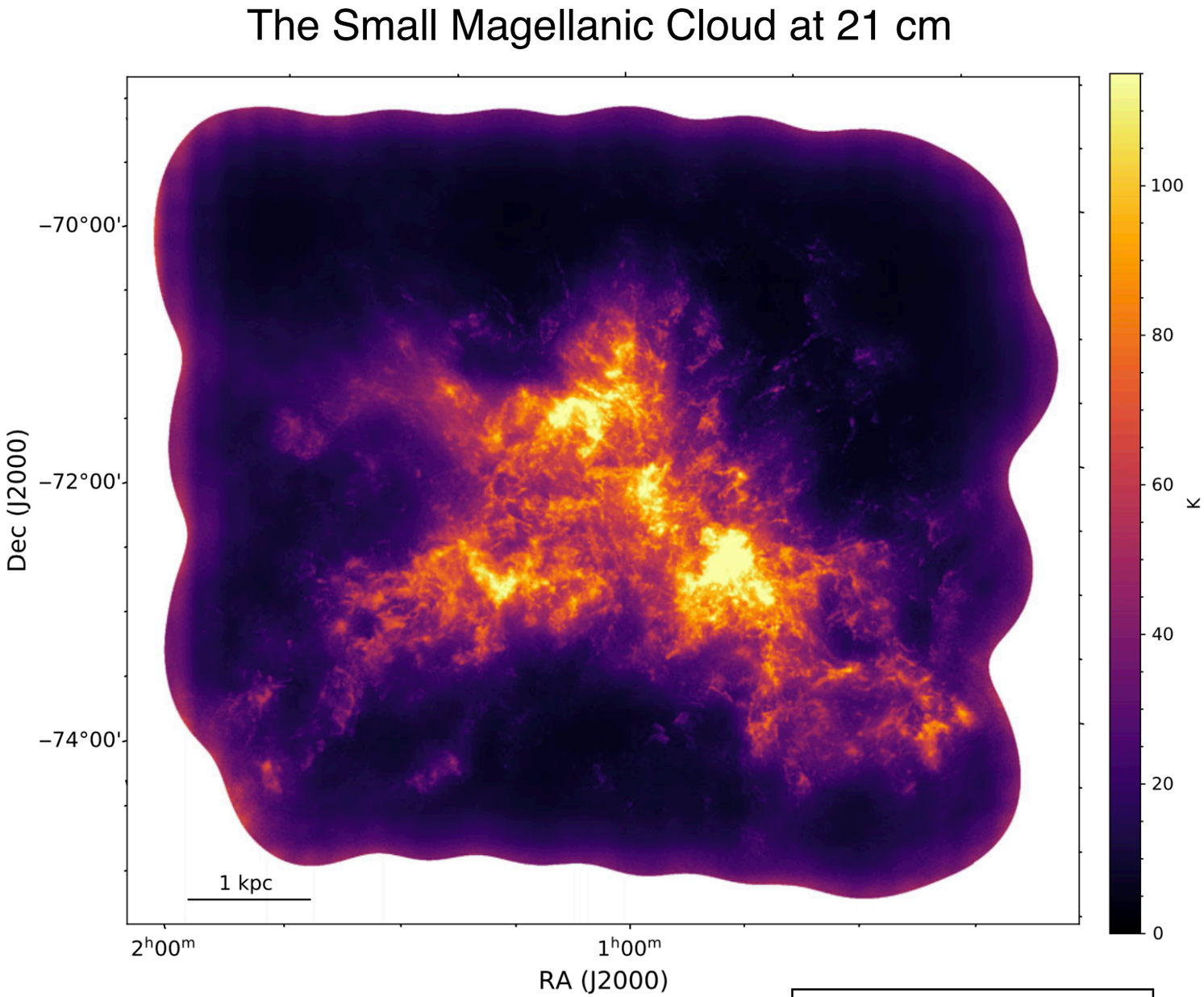
CNM column density [1E19 cm-2]

Marchal et al. (submitted)

GASKAP : the Galactic ASKAP

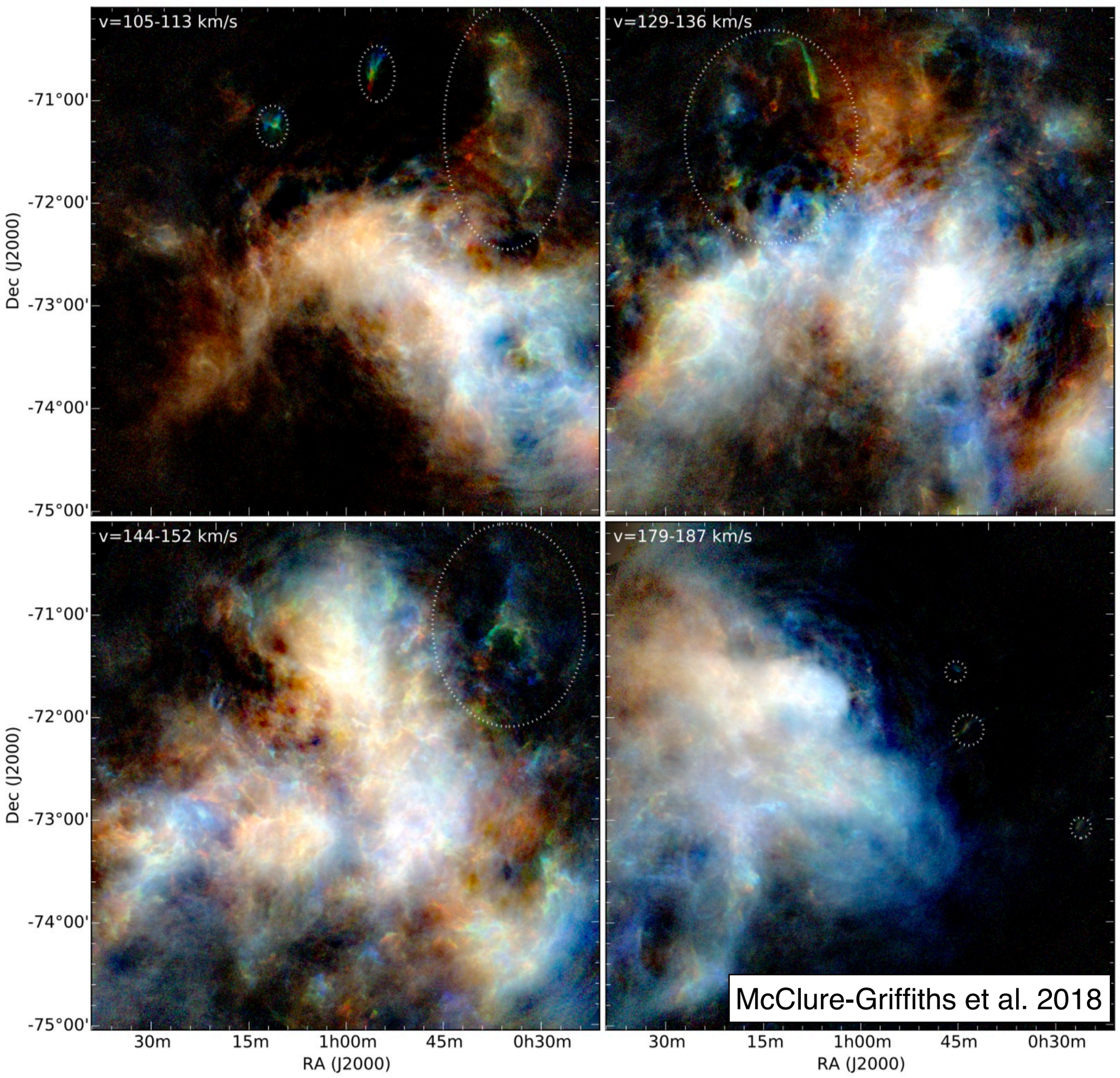
ASKAP

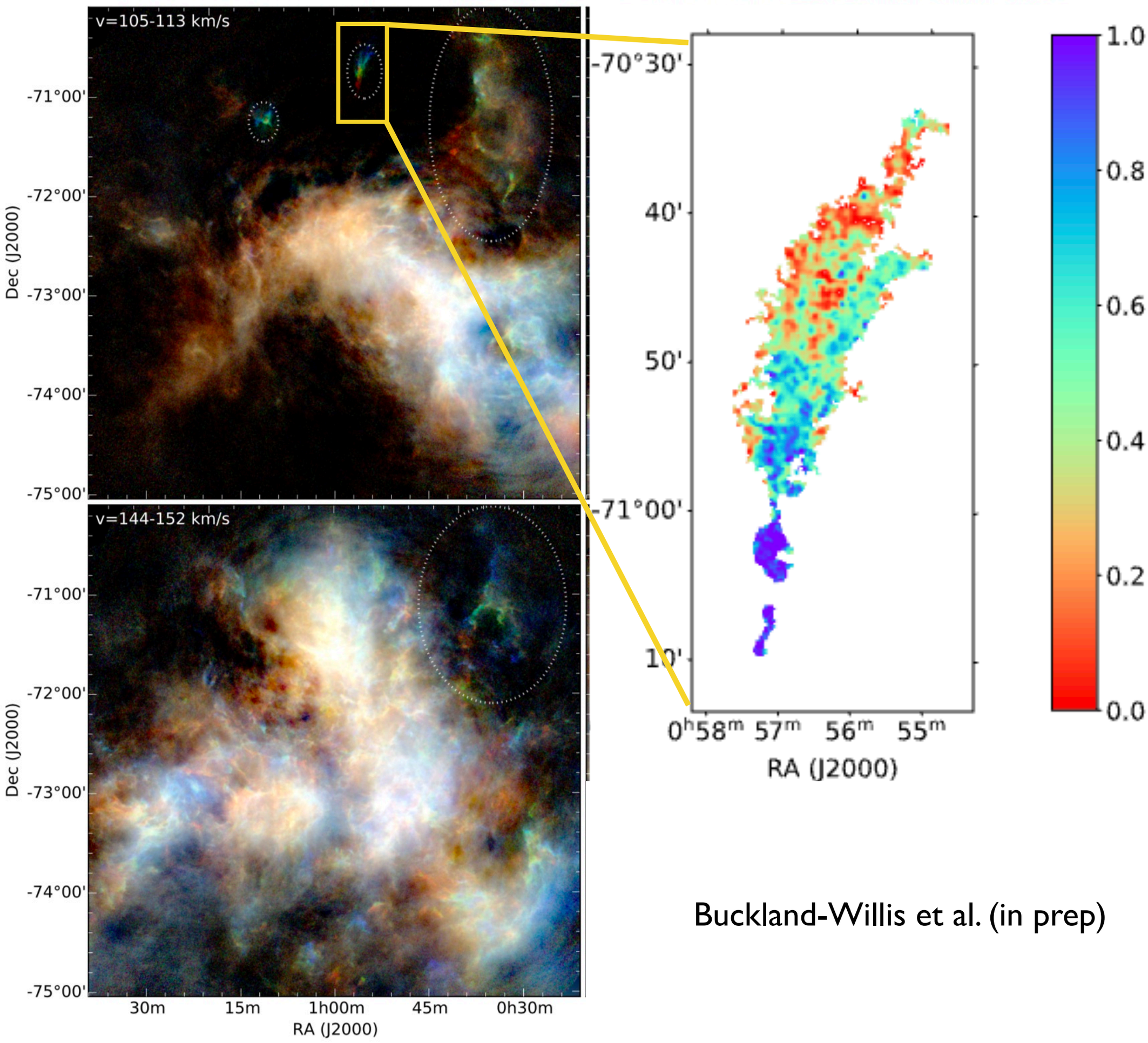
- 36 antenas of 12m with Phased Array
- field of view : 30 square degree
- resolution : 20 arcsec at 21 cm
- velocity resolution : 0.2 km/s



Pingel et al. 2022

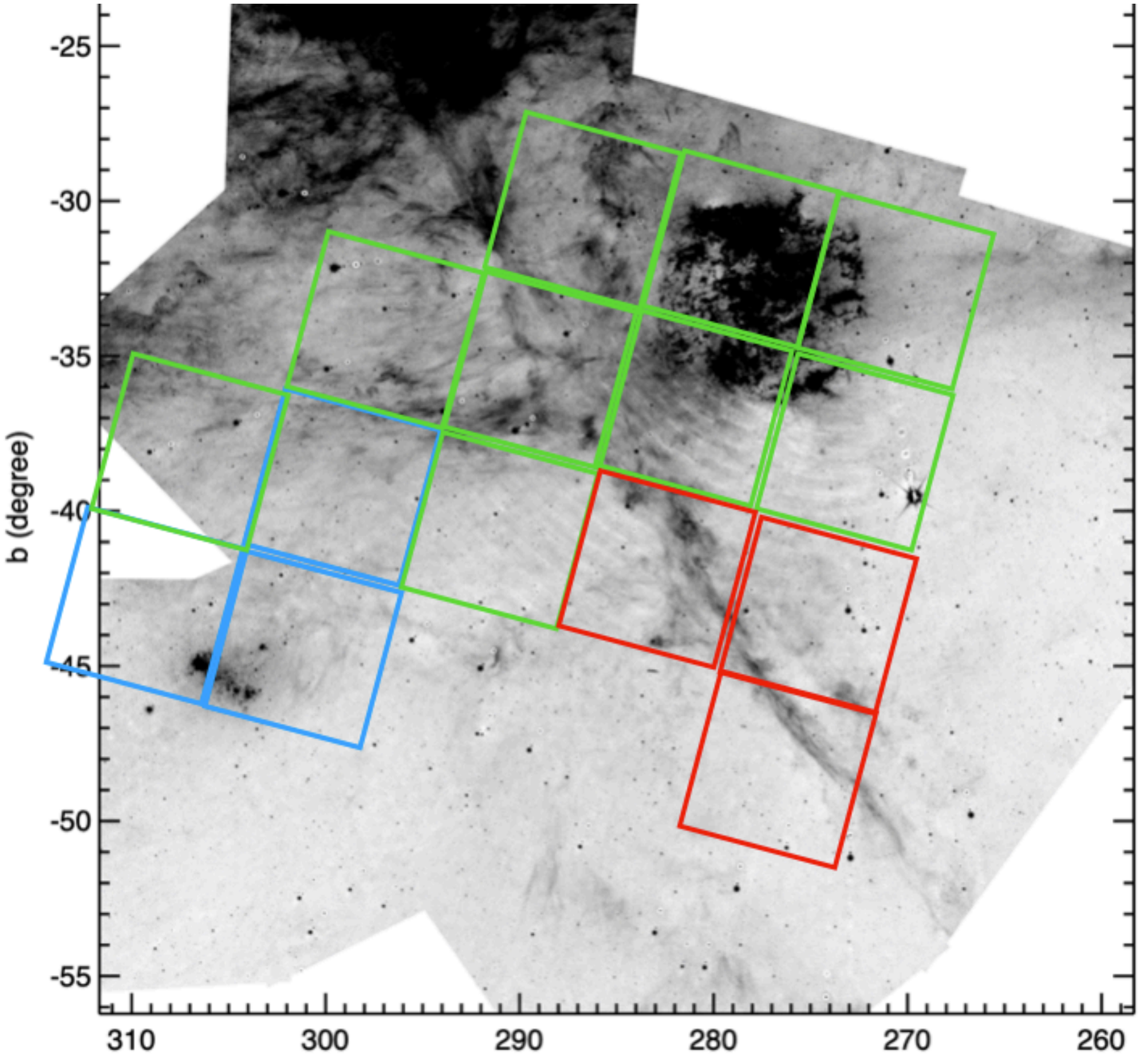
M-A Miville-Deschênes and Frances Buckland-Willis : members of the GASKAP collaboration

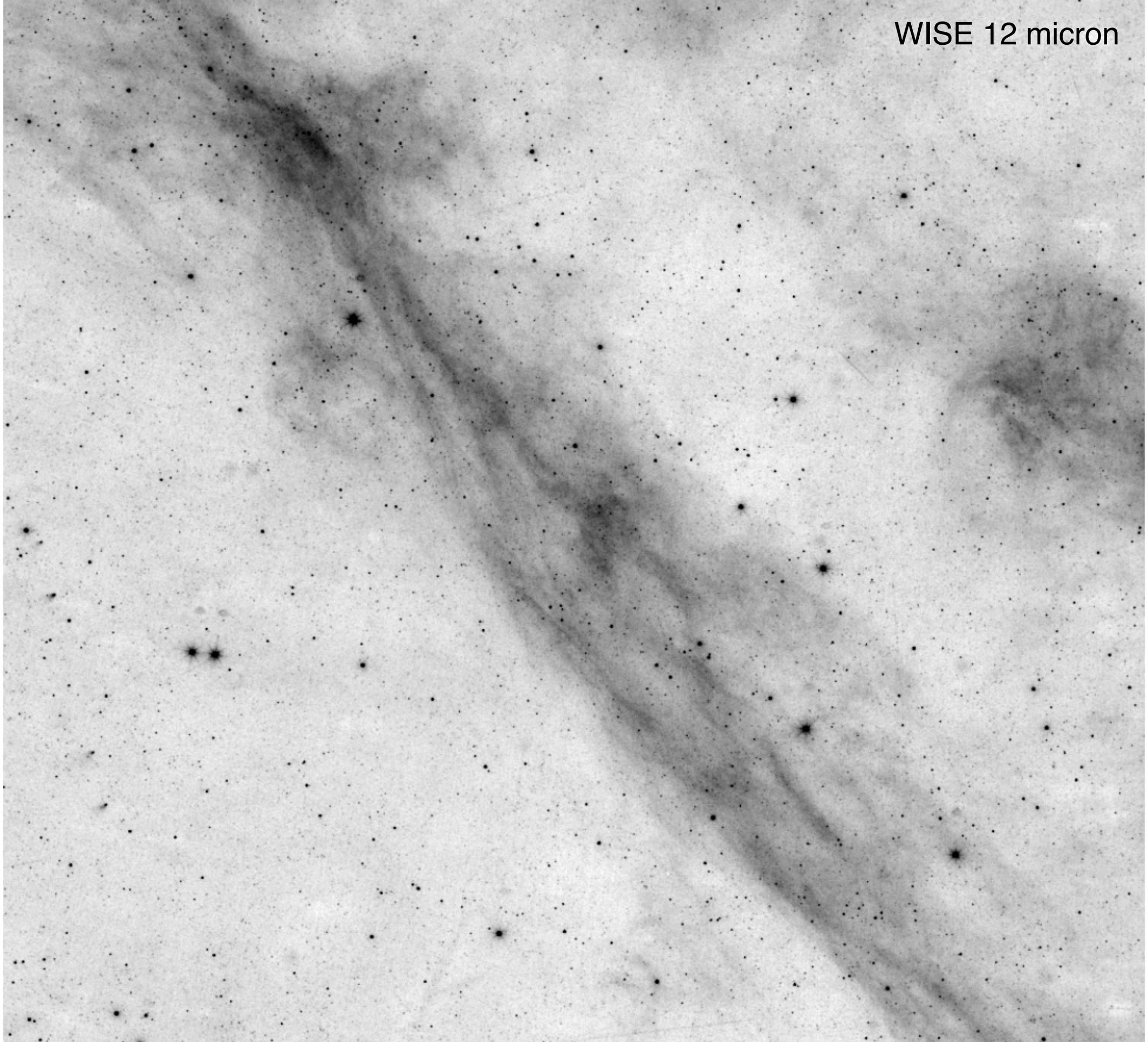

v=105-113 km/s
v=129-136 km/s
v=144-152 km/s
v=179-187 km/s
-71°00'
-72°00'
-73°00'
-74°00'
-75°00'
Dec (J2000)
30m
15m
1h00m
45m
0h30m
RA (J2000)
McClure-Griffiths et al. 2018



Buckland-Willis et al. (in prep)

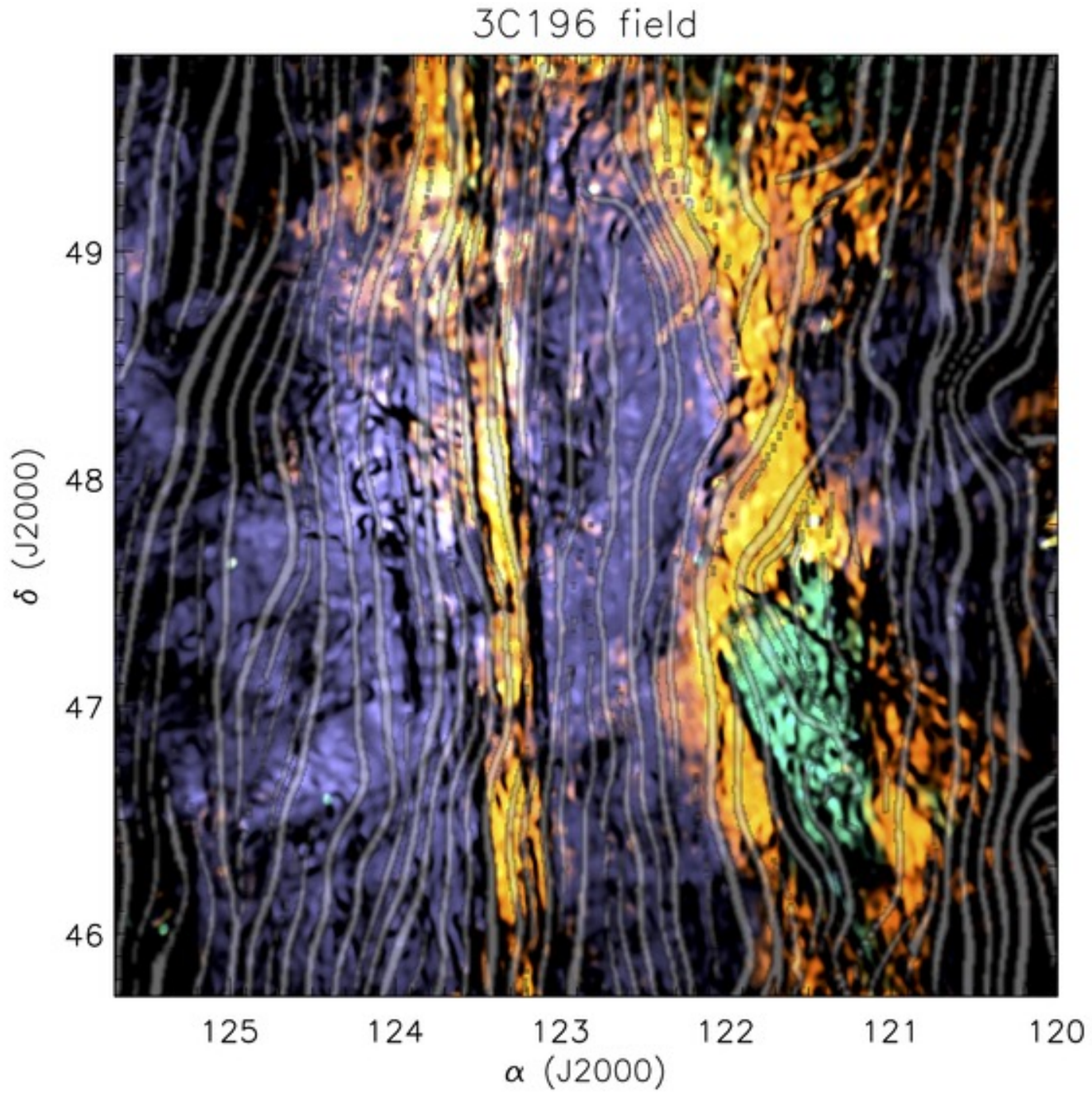
next with GASKAP




WISE 12 micron

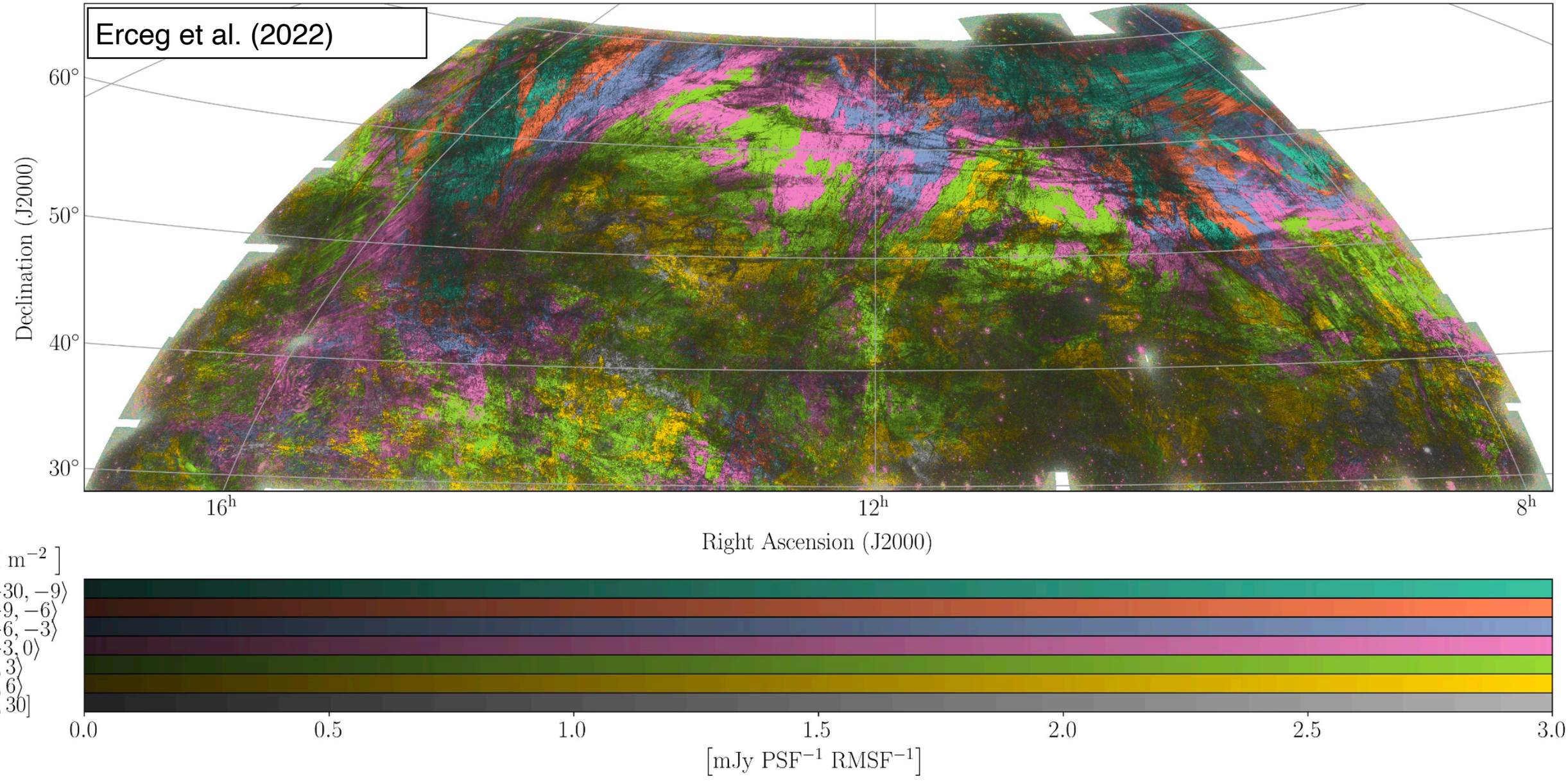
The discovery of low-frequency polarized signal of the diffuse ISM

- **Surprising result on the structure of the Galactic magnetic field from LOFAR data**
- Spatial correlation of magnetic field structures seen in Faraday depth (ionized gas) and dust polarization (neutral gas) in a diffuse region at high Galactic latitude

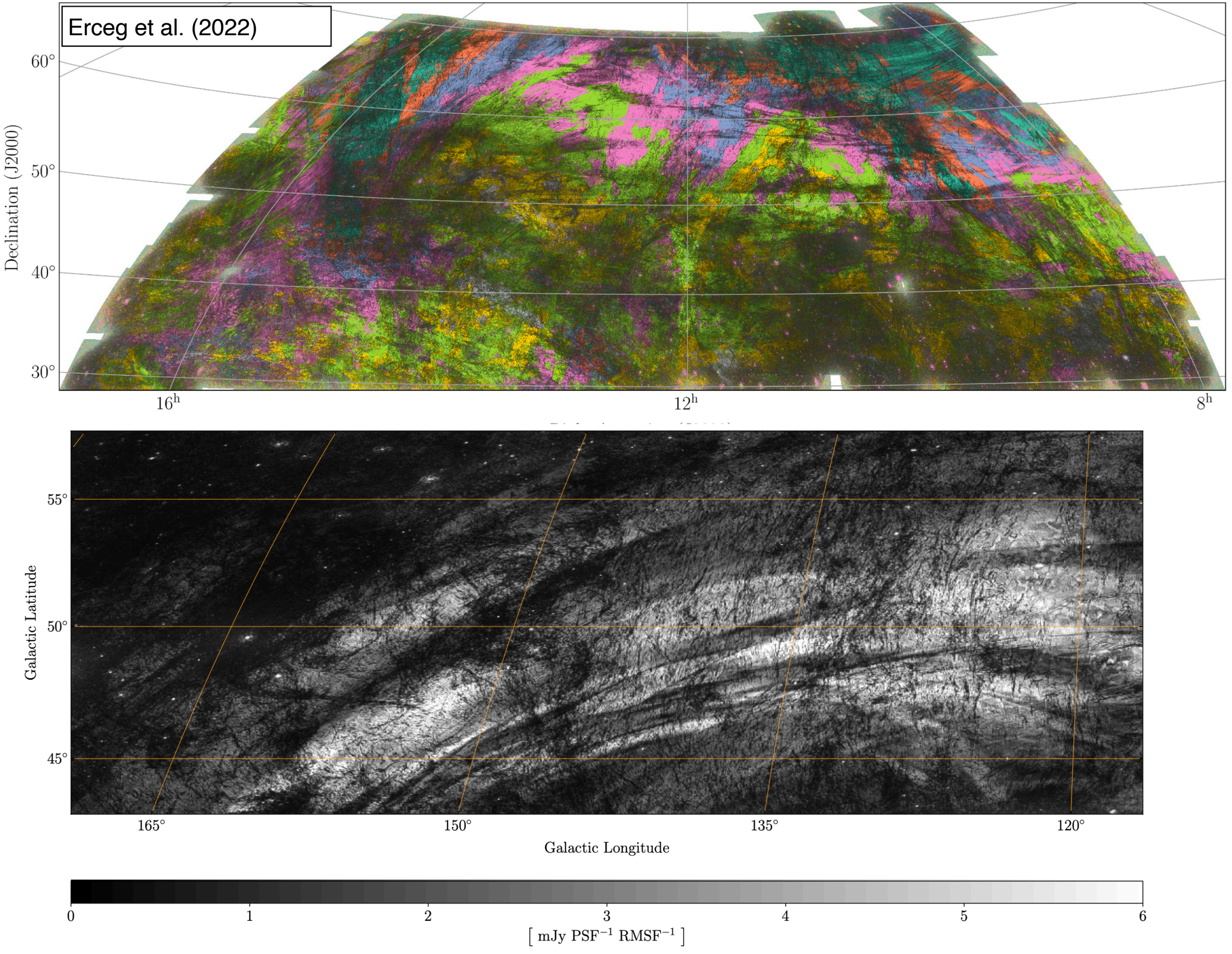


Bracco et al. (2020),
Jelic et al. (2015),
Zaroubi et al. (2015)

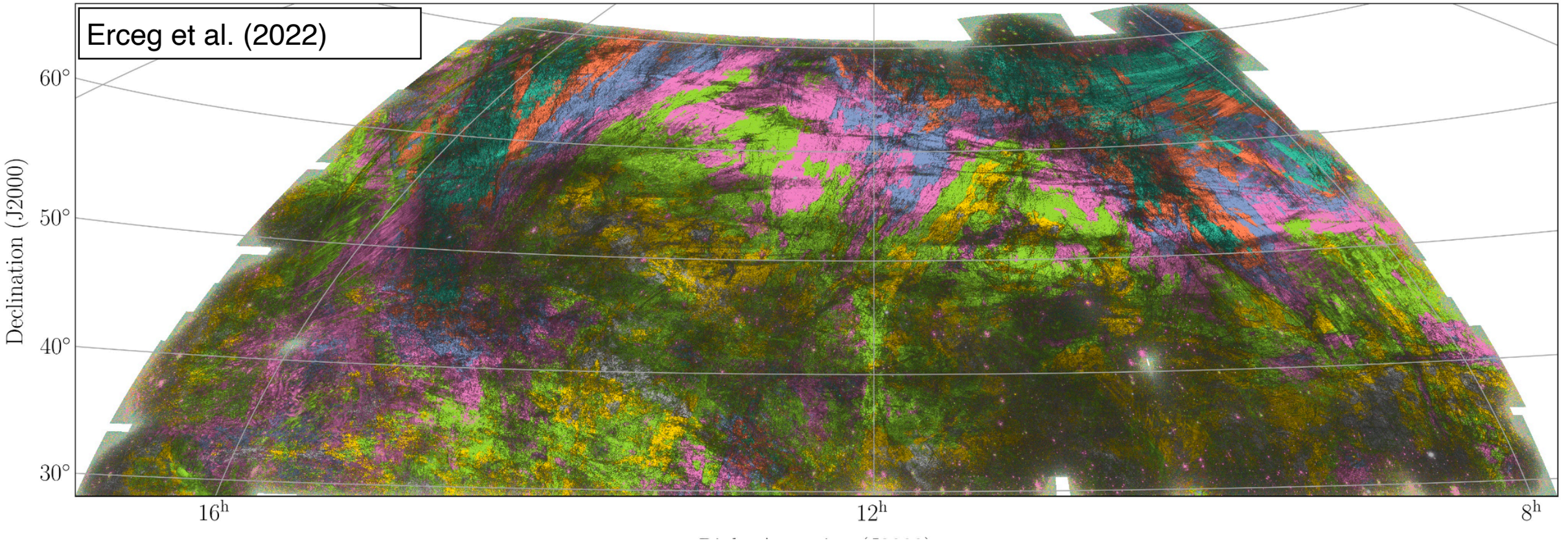
Erceg et al. (2022)



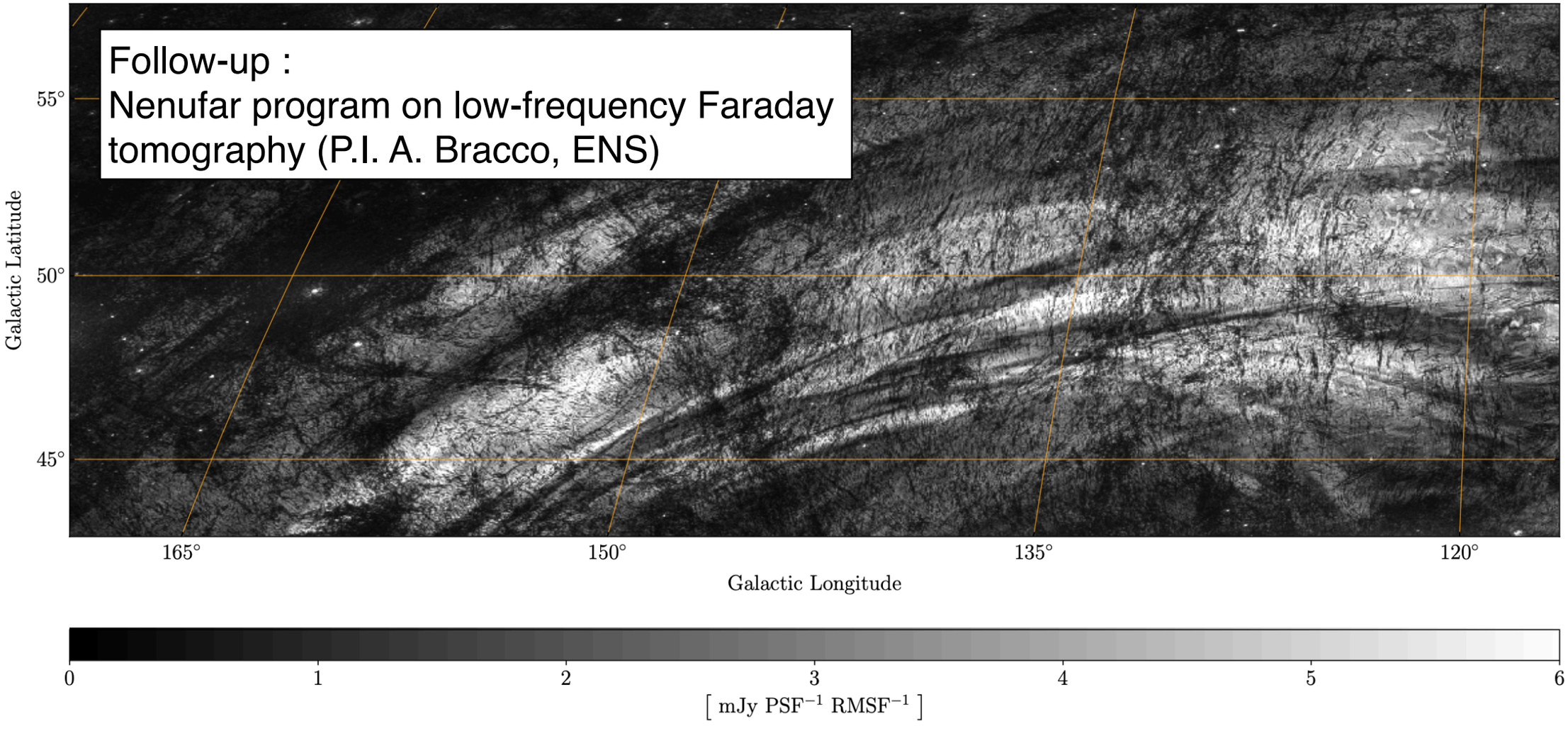
Erceg et al. (2022)



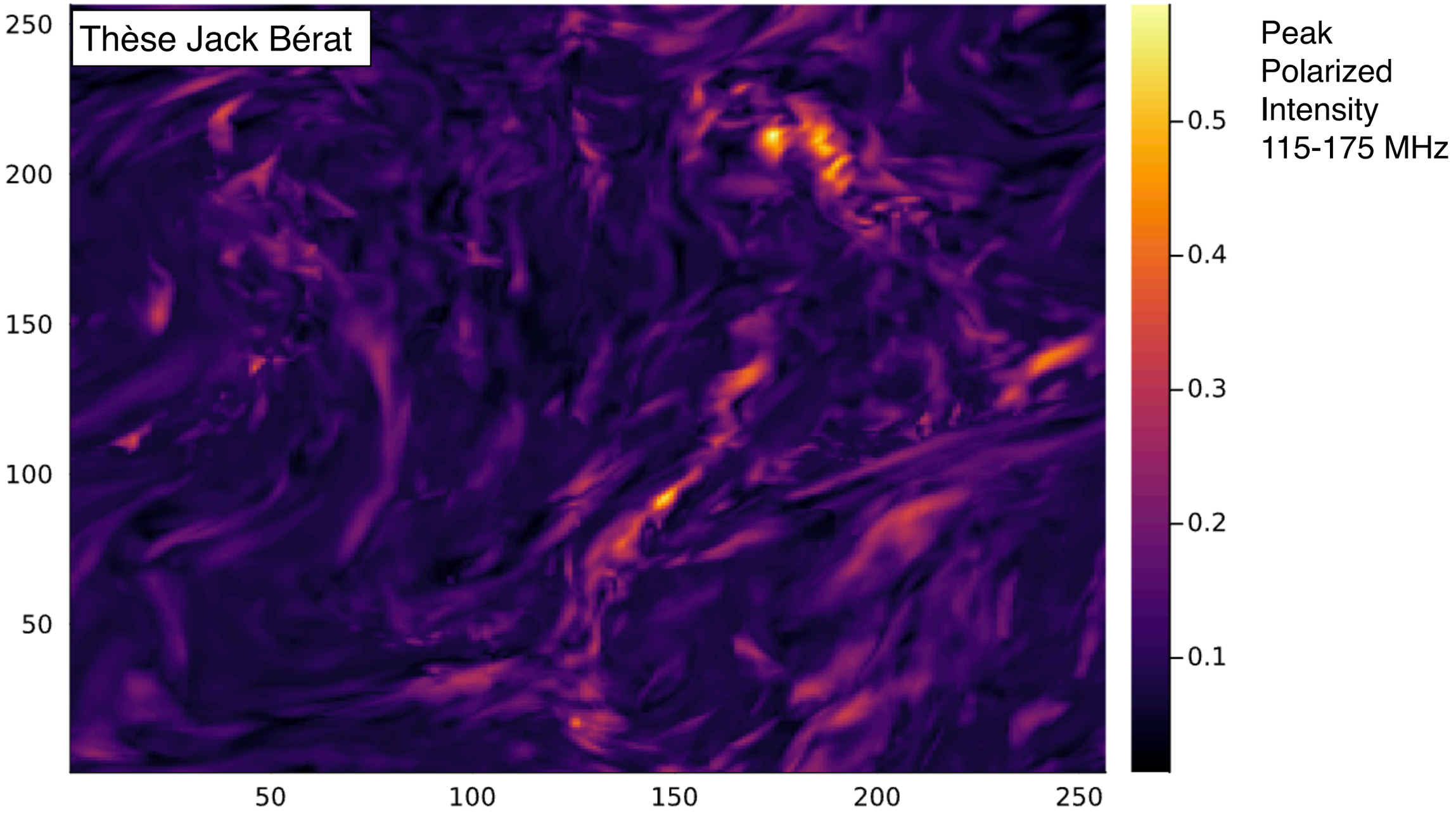
Erceg et al. (2022)



Follow-up :
Nenufar program on low-frequency Faraday tomography (P.I. A. Bracco, ENS)



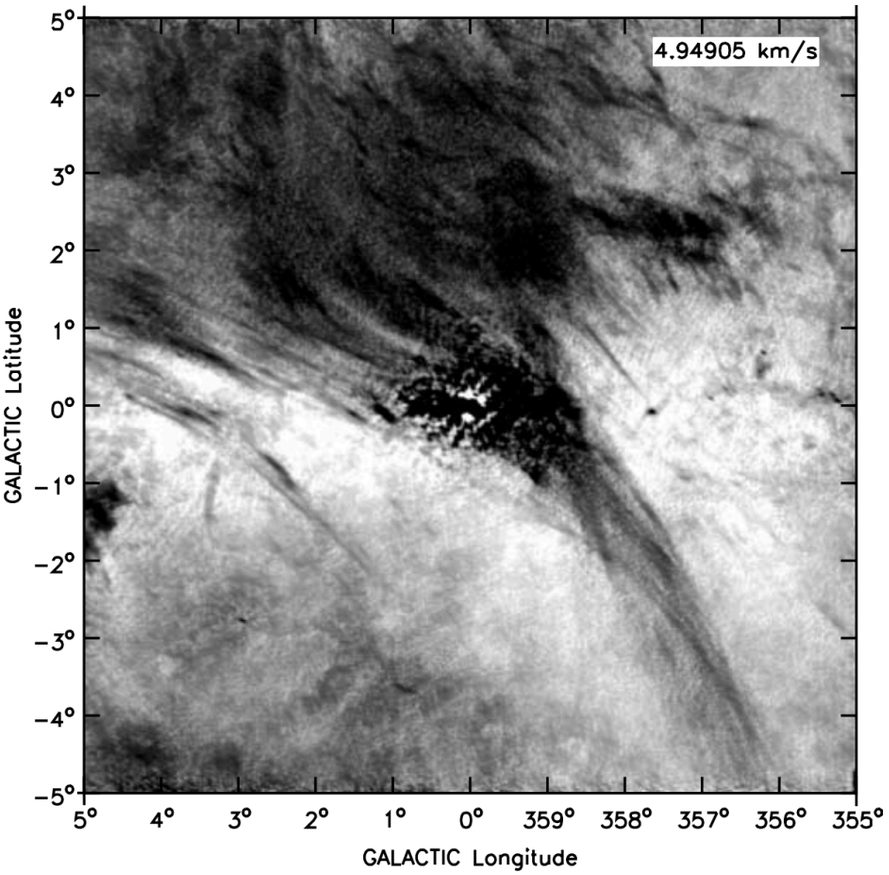
Observations synthétiques synchrotron Faraday



Simulations RAMSES : L=50 pc, <n>=1cm-3, <B>=7.6 microG,
Mach = subsonic (WNM) / transonic (CNM)

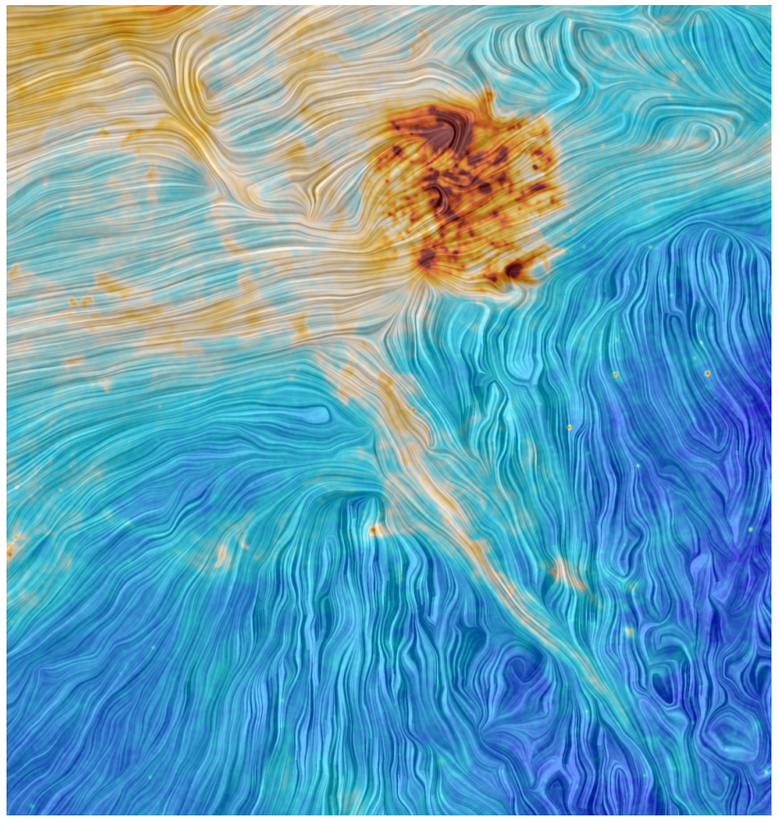
The diffuse ISM puzzle : filamentarity, B-aligned, and Faraday signal of CNM structures

21 cm HI emission



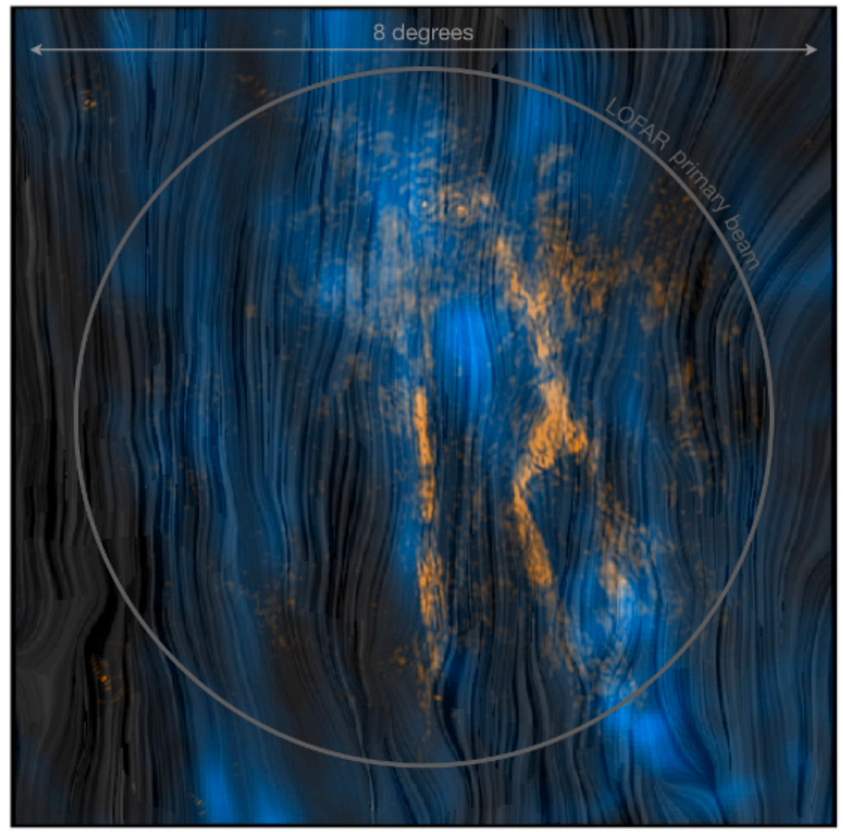
McClure-Griffiths et al. (2006)

dust polarization



Planck collaboration

synchrotron - Faraday tomography



Bracco et al. 2020

SKA Key Program combining SKA-mid and SKA-low so study the multi-phase, magneto ionic condensation process

Strong expertise in France (CEA, ENS, OP) : ISM science, radio-data, analysis techniques, numerical simulations, modelling