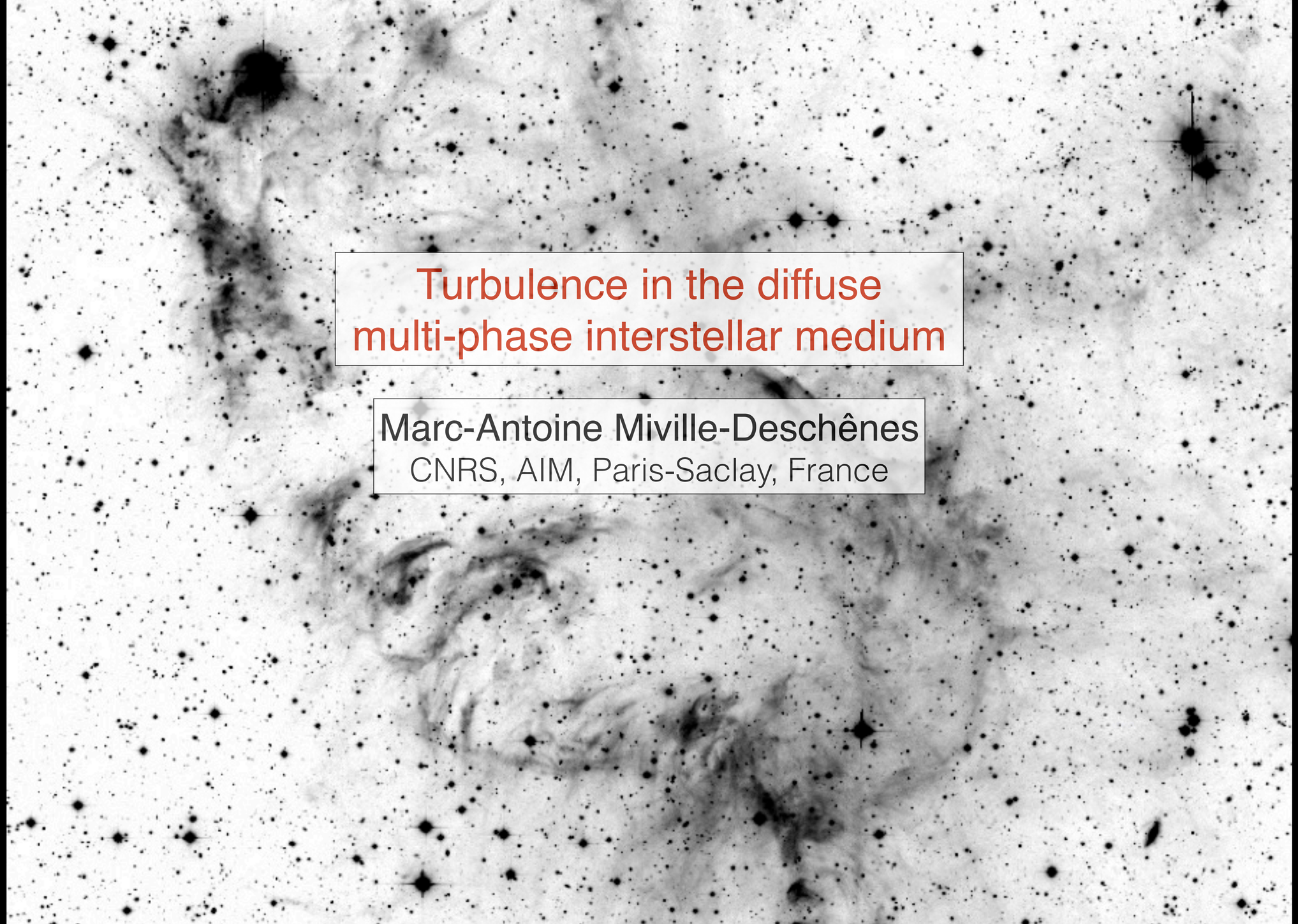
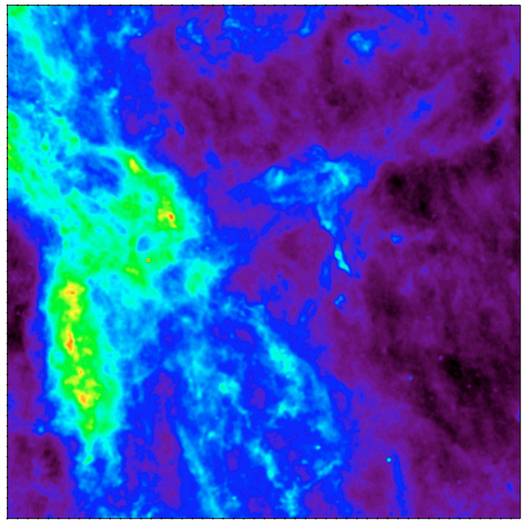


Turbulence in the diffuse multi-phase interstellar medium

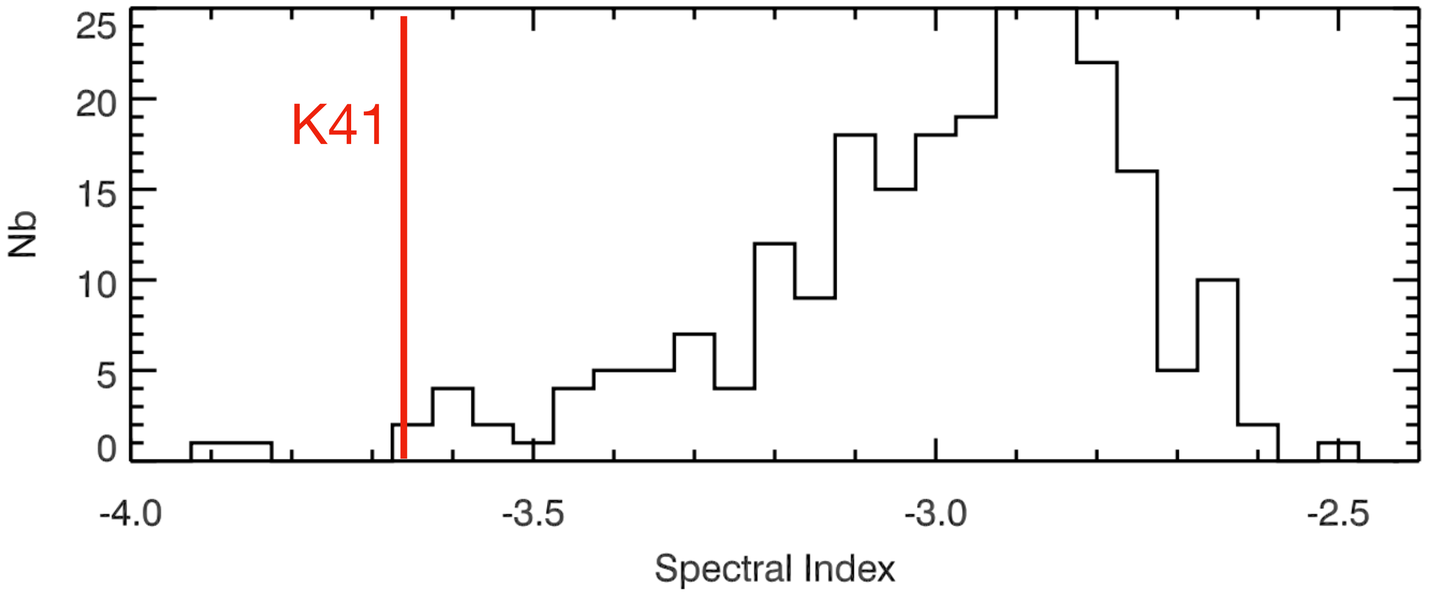
Marc-Antoine Miville-Deschênes
CNRS, AIM, Paris-Saclay, France

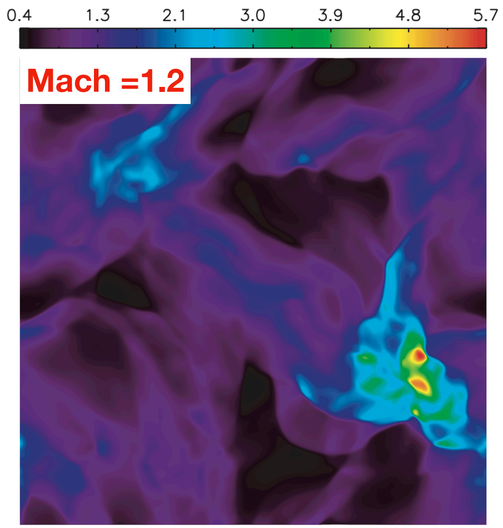
A few words on ISM statistics

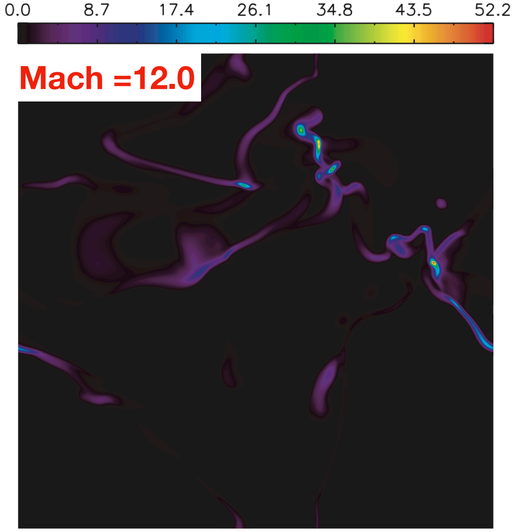
ISM power spectrum slope flatter than K41

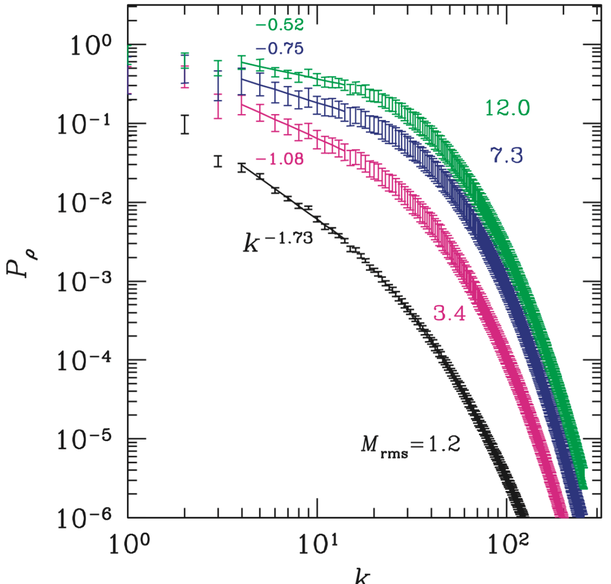


Miville-Deschênes et al. (2007)







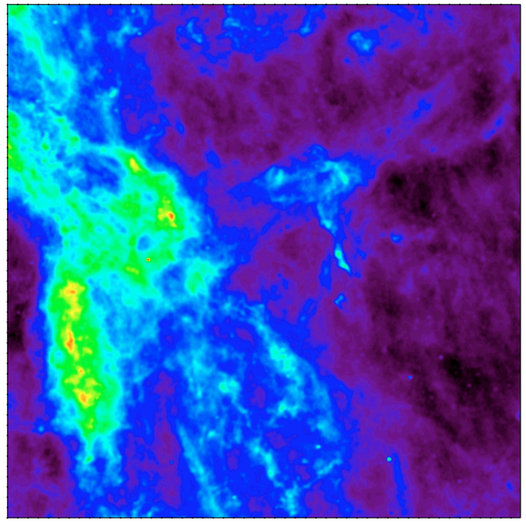


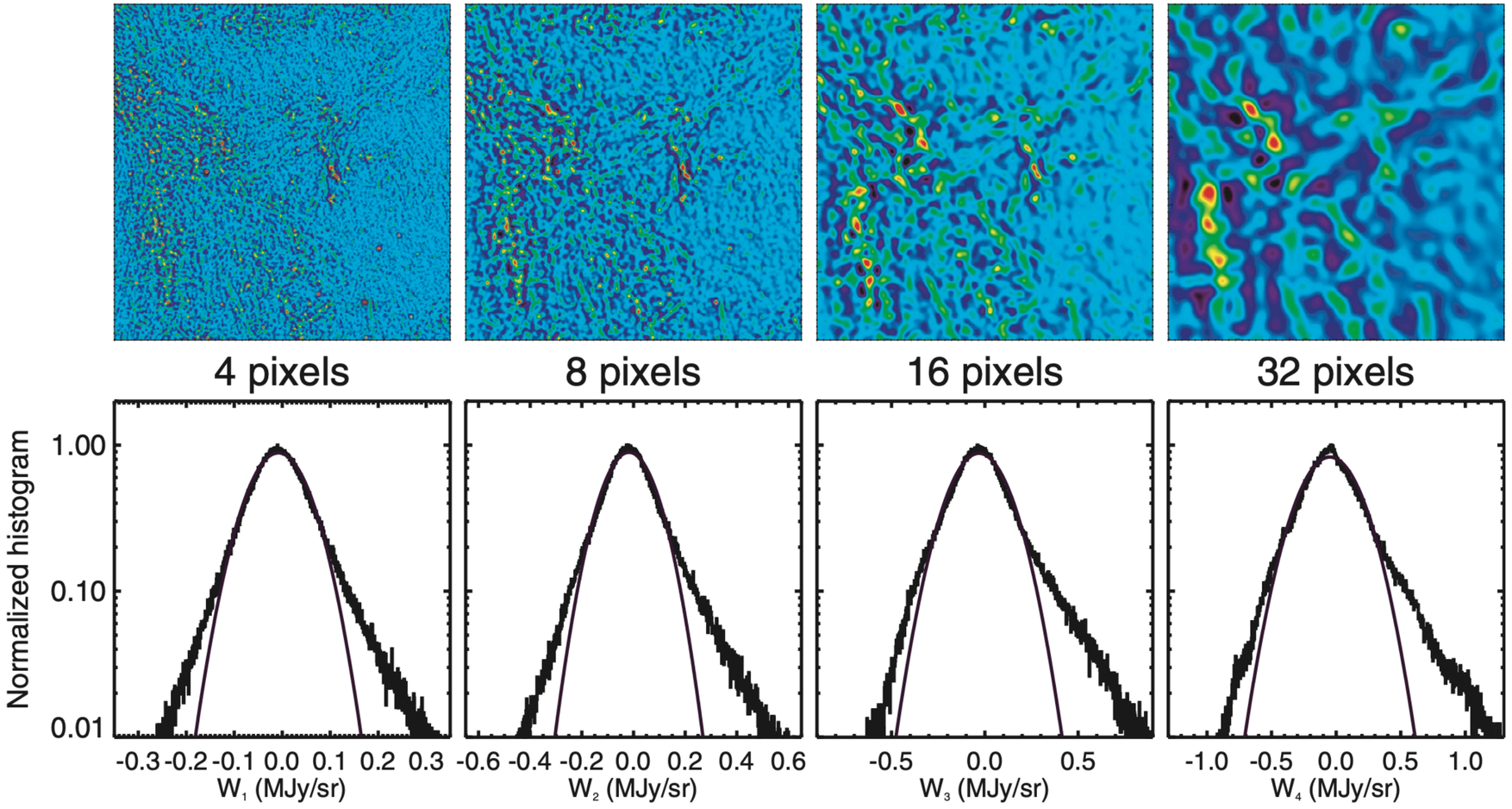
Density P(k) of compressible turbulence

Slope flattens with increasing Mach number

Kim & Ryu (2005)

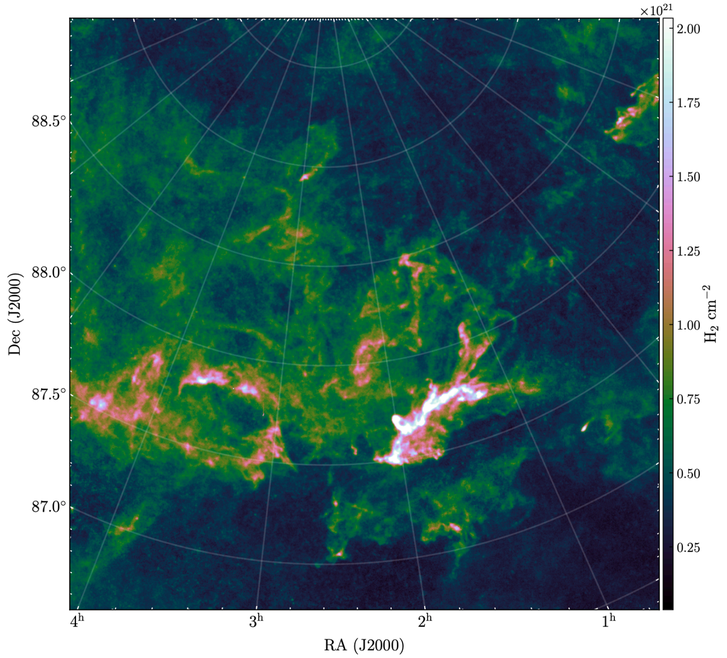
Non-stationarity of the interstellar density distribution





Miville-Deschênes et al. (2007)

Polaris Flare - Herschel 250 micron



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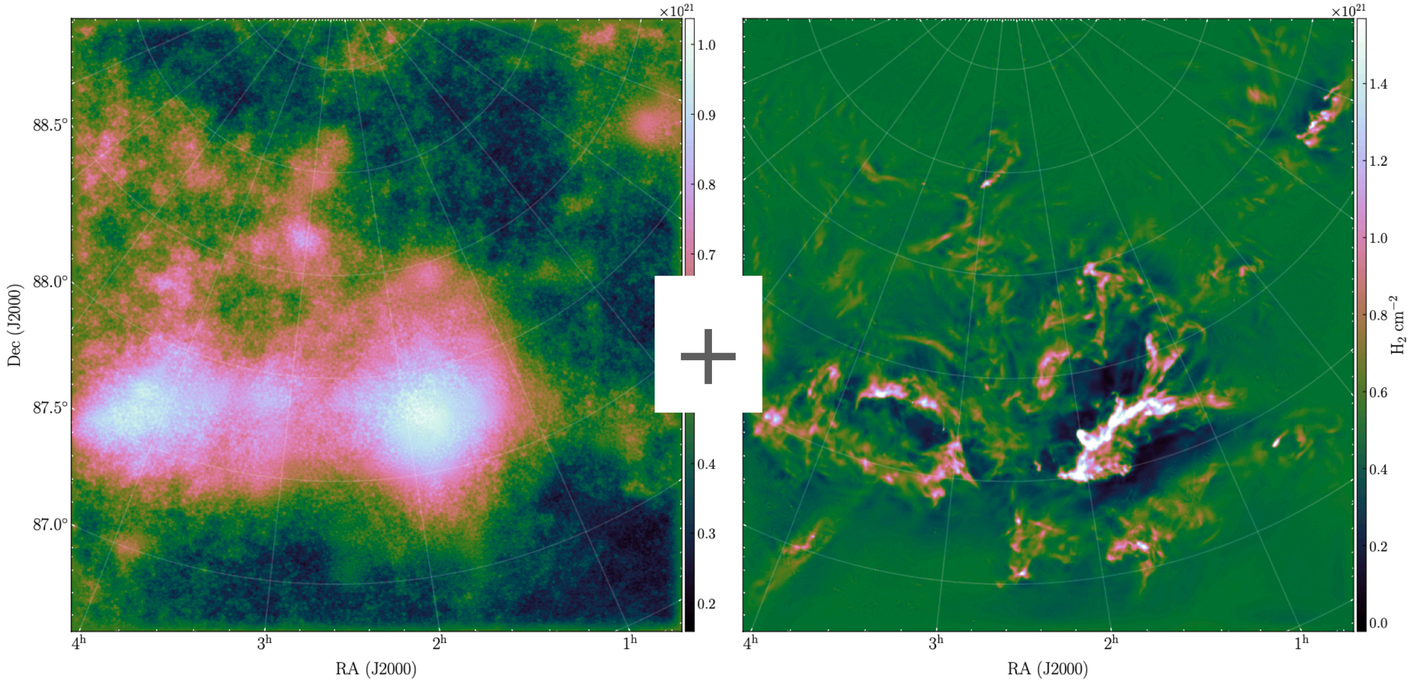
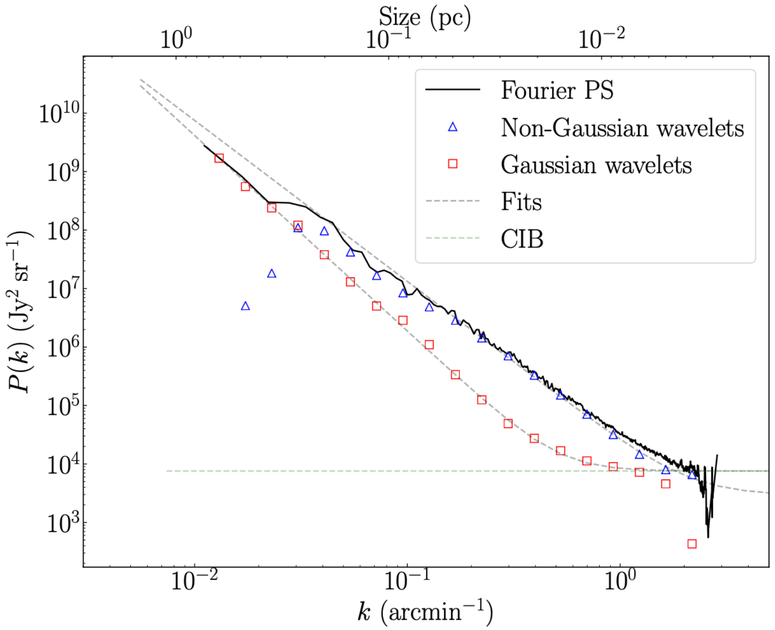




P(k) exponents

Original image : -2.58
Stationary (Gaussian) : -3.34
Non-stationary (Coherent) : -2.75

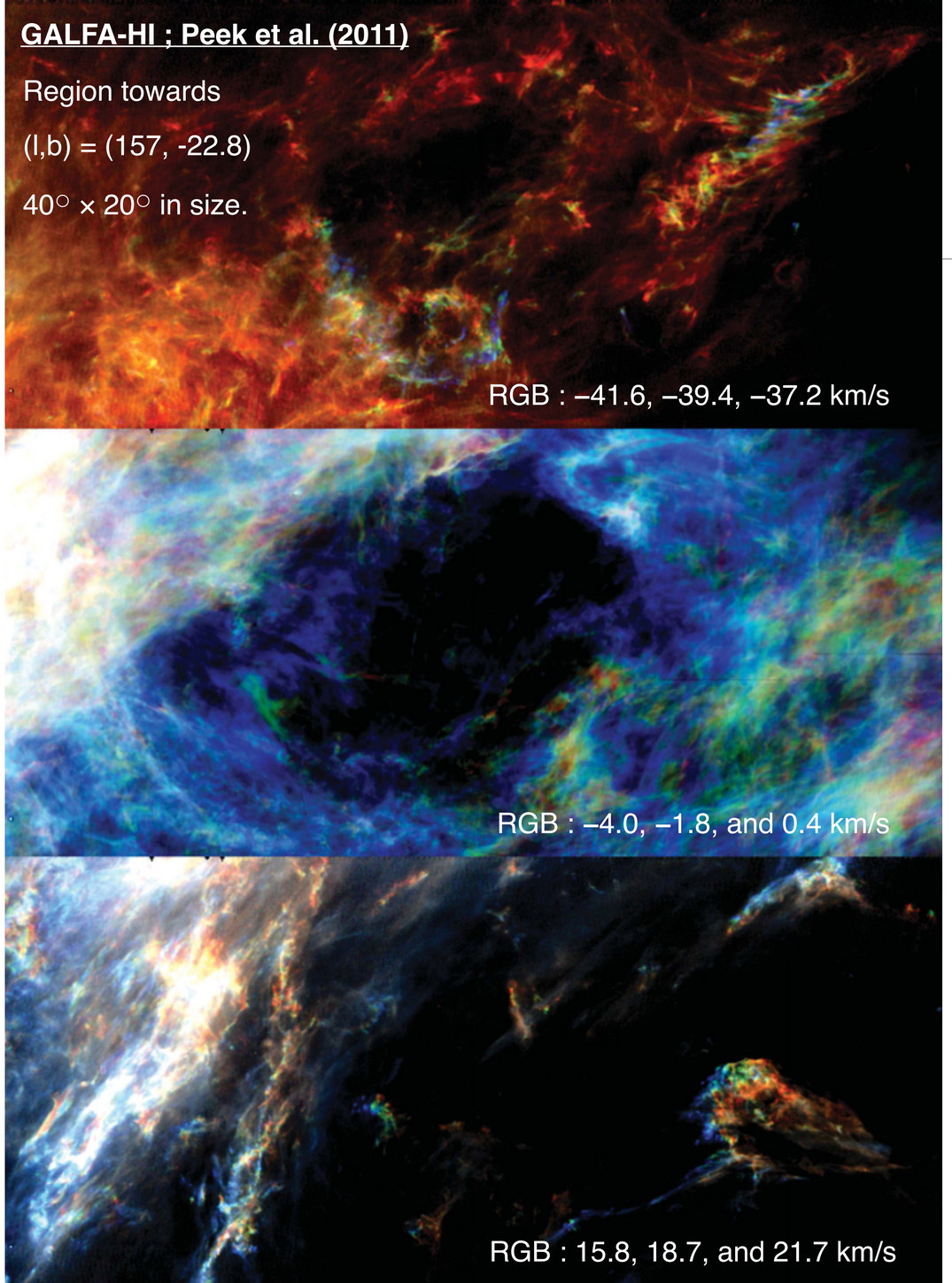
Robitaille et al. (2019)

Nature of the non-stationarity ?

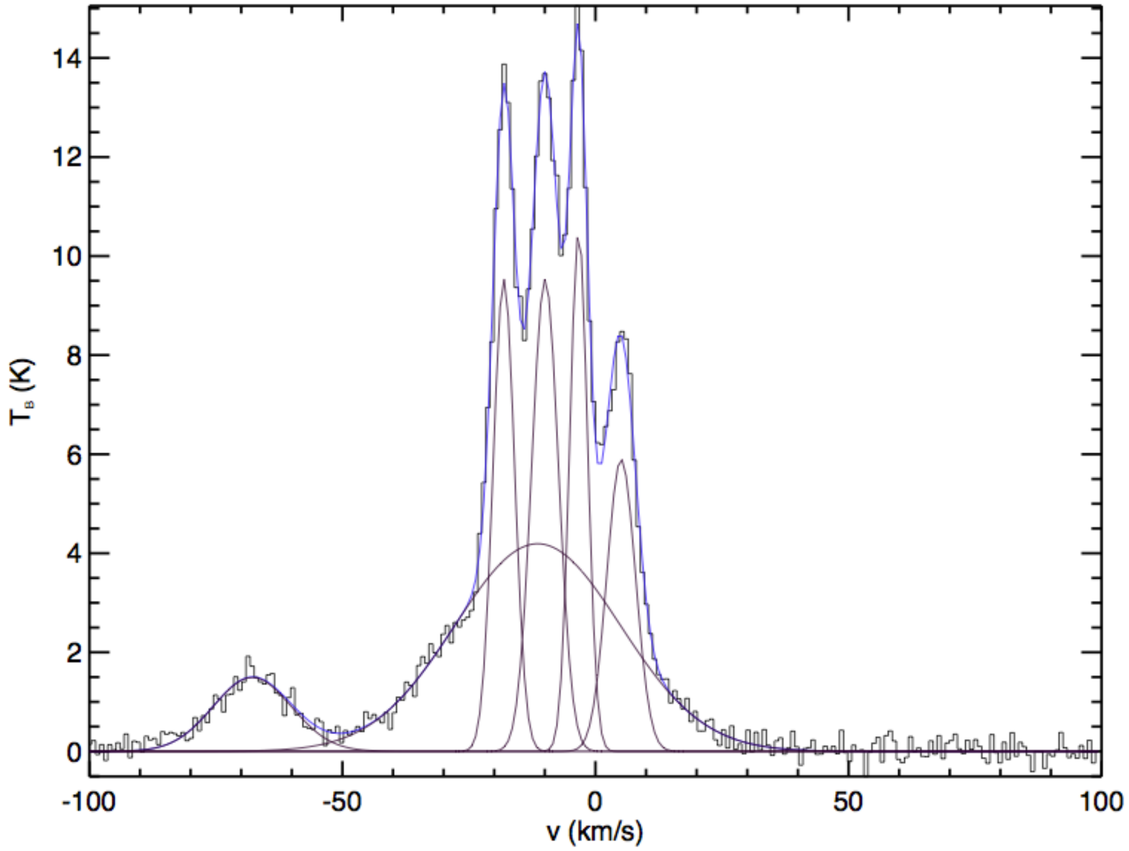
- Turbulence intermittency
- High Mach number
- HI condensation process
- Self-gravity

Interstellar turbulence is multiphase

and it is important for star formation



21 cm data showing a thermally bi-stable ISM

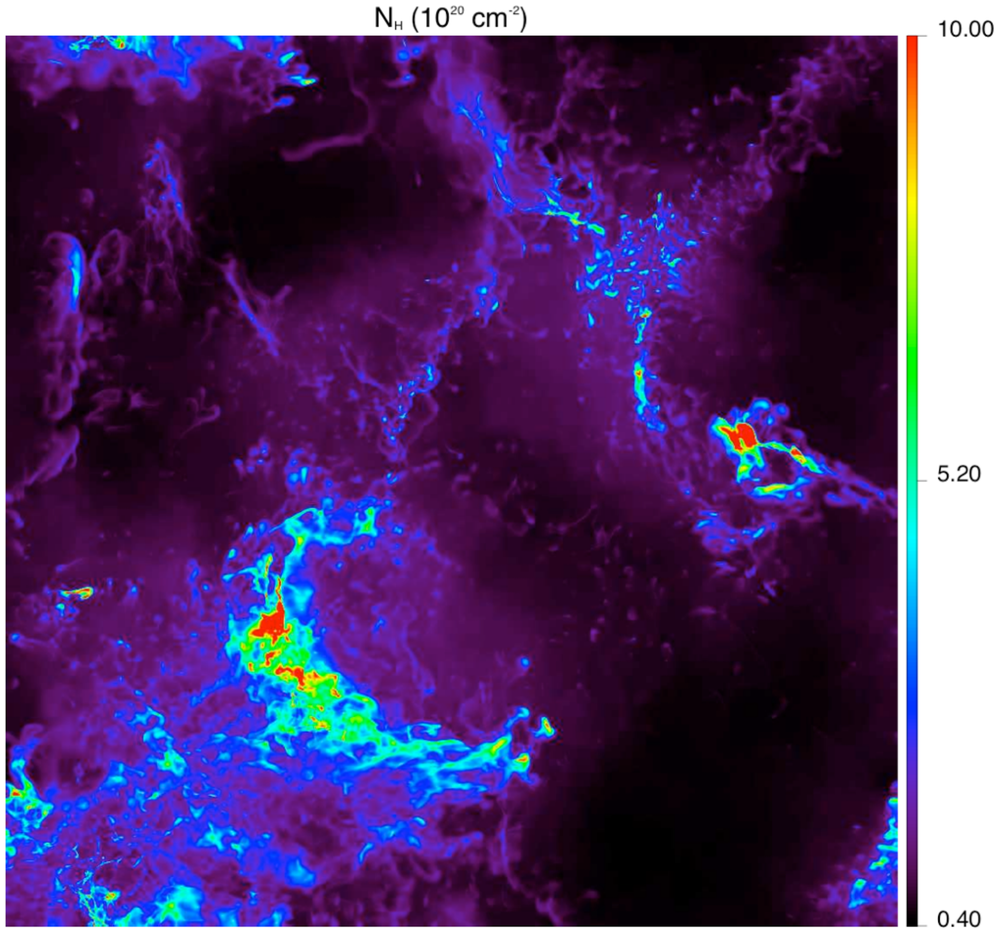


CNM formation
linked to WNM pressure and Mach number

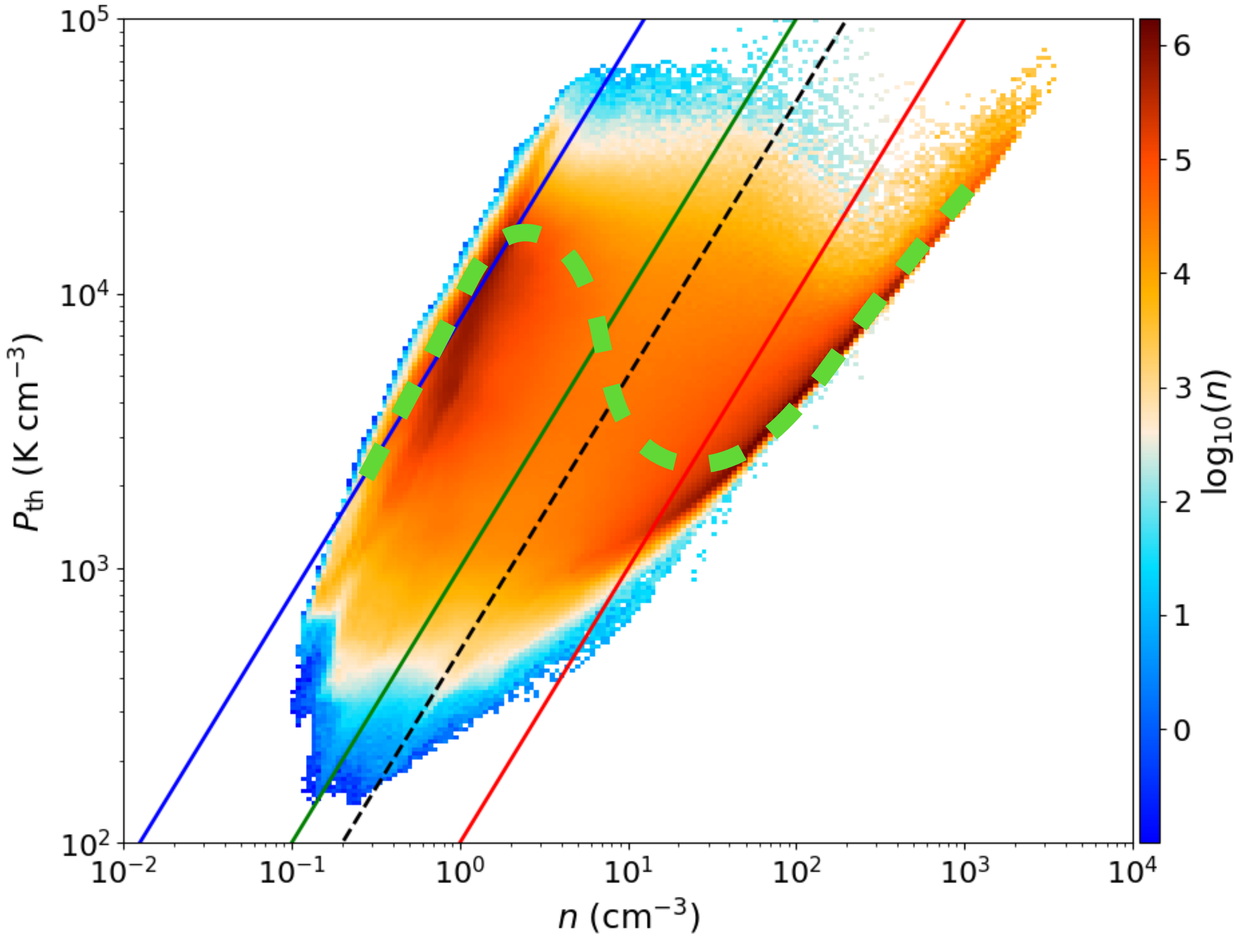
The condensation process is favored in pressurized sub/transonic WNM when cooling time < dynamical time

thermal instability act as a regulation process for star formation

HD simulation of thermally bi-stable turbulence



Saury et al 2014



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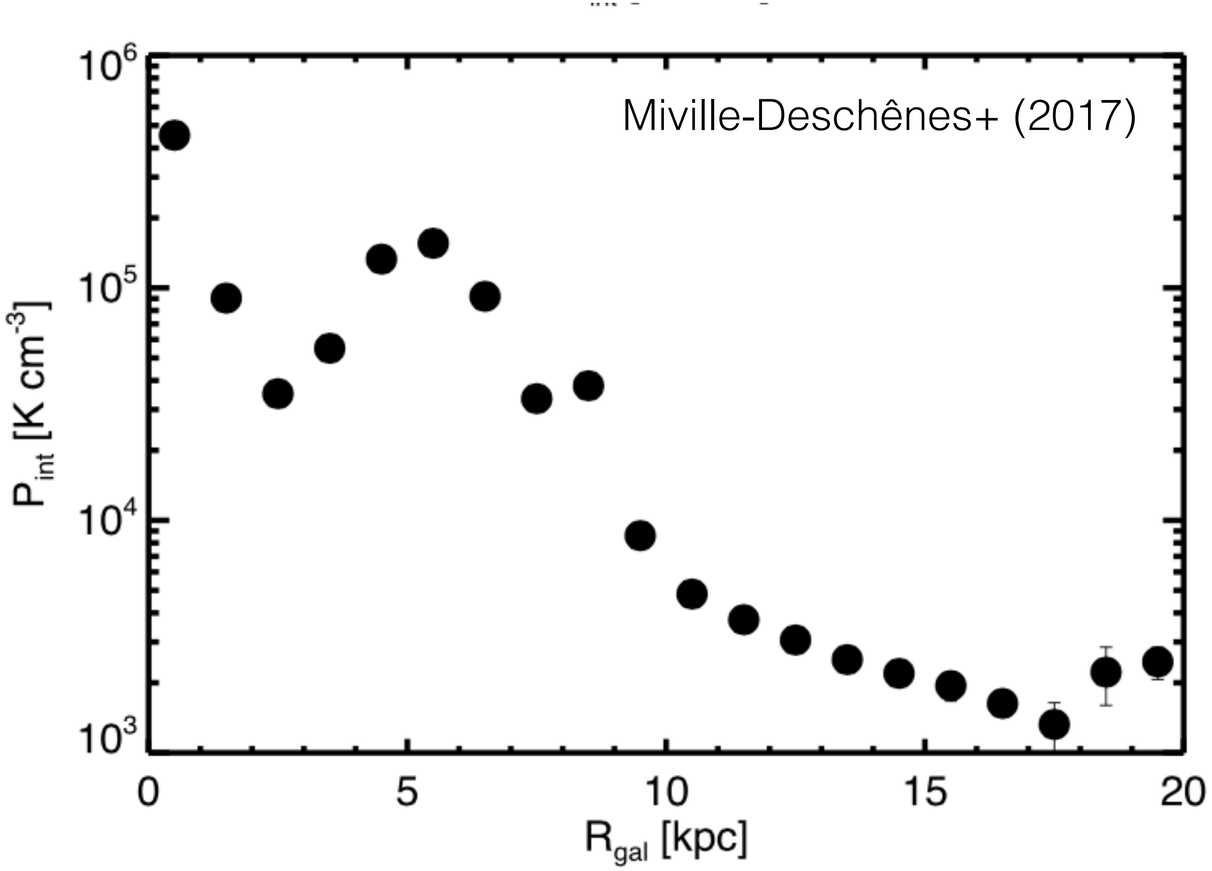
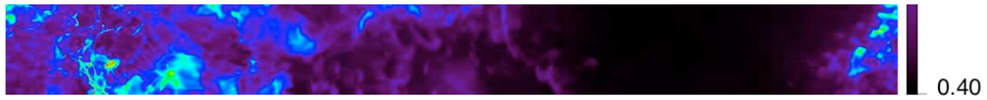
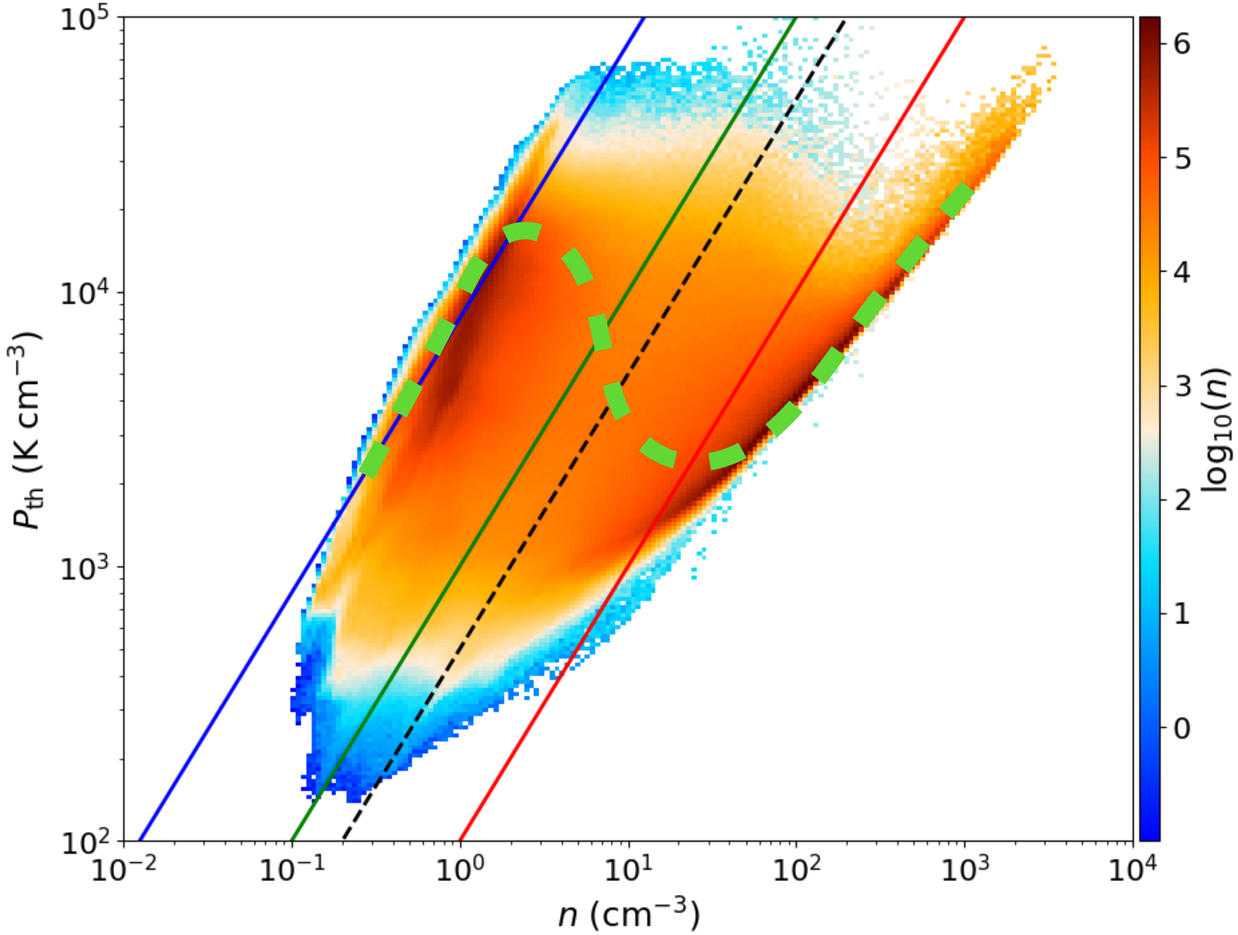




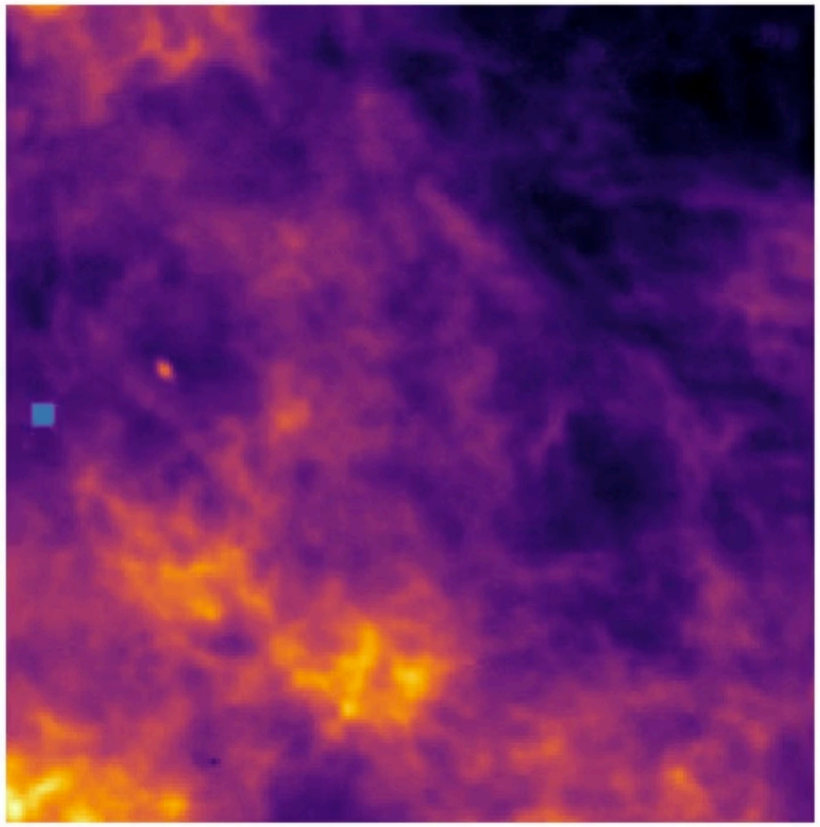
Saury et al 2014



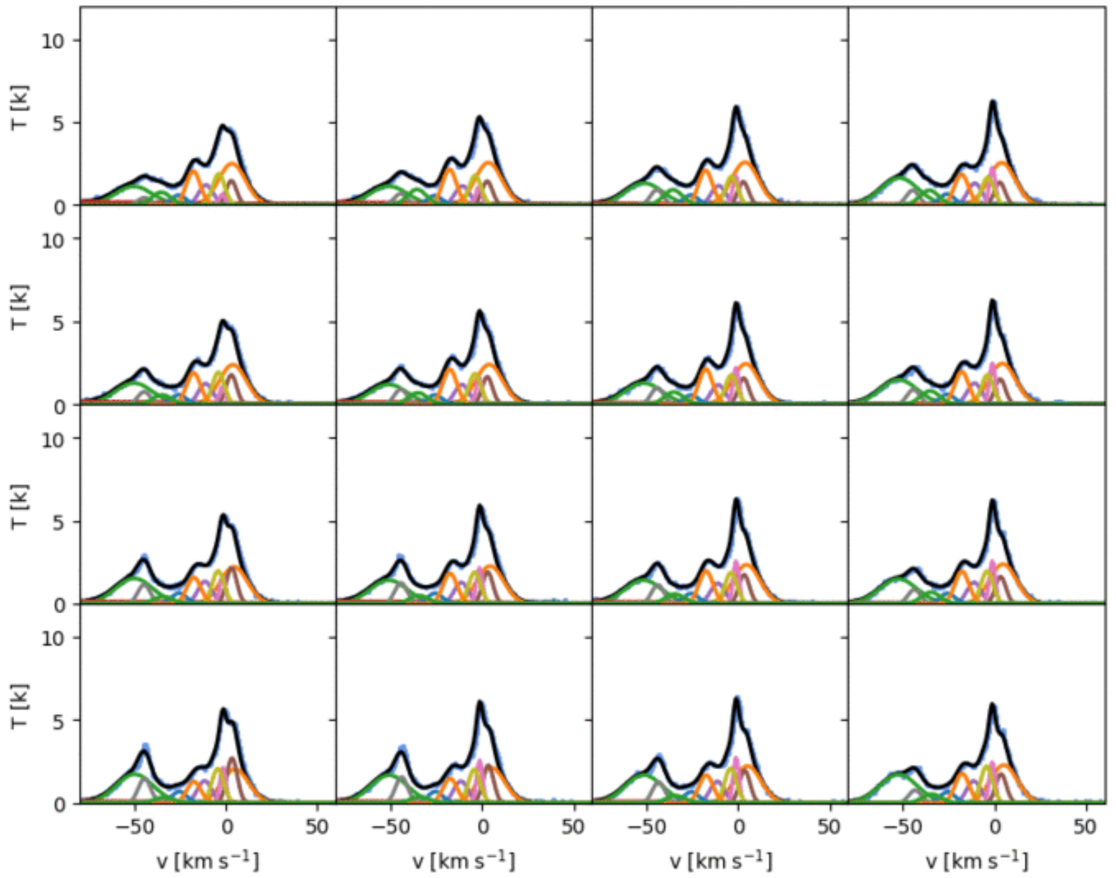
Mapping turbulence with 21 cm data

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

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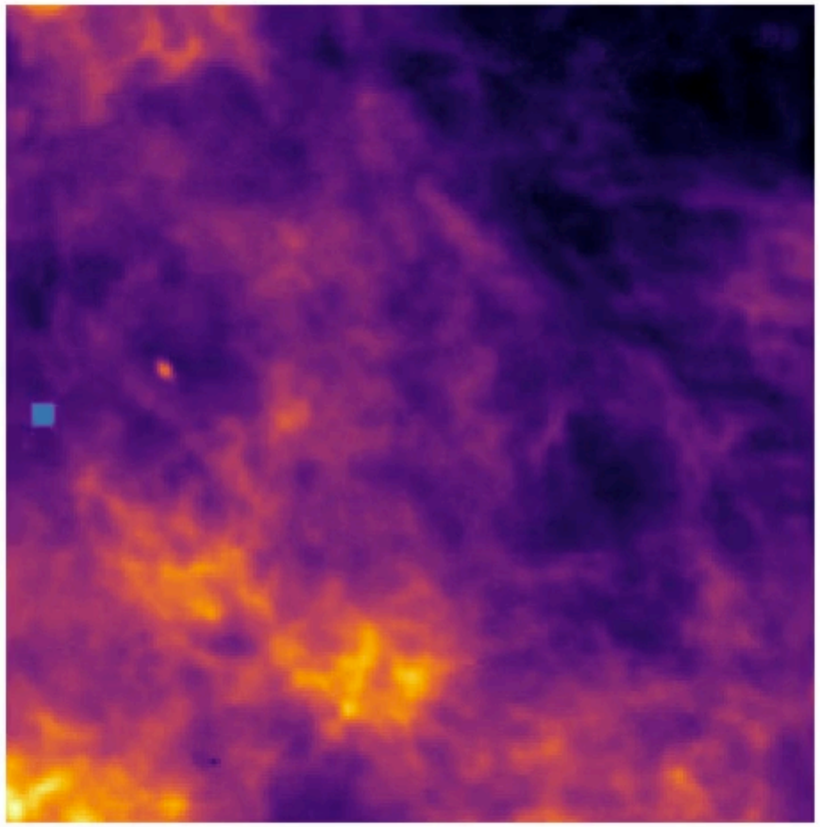

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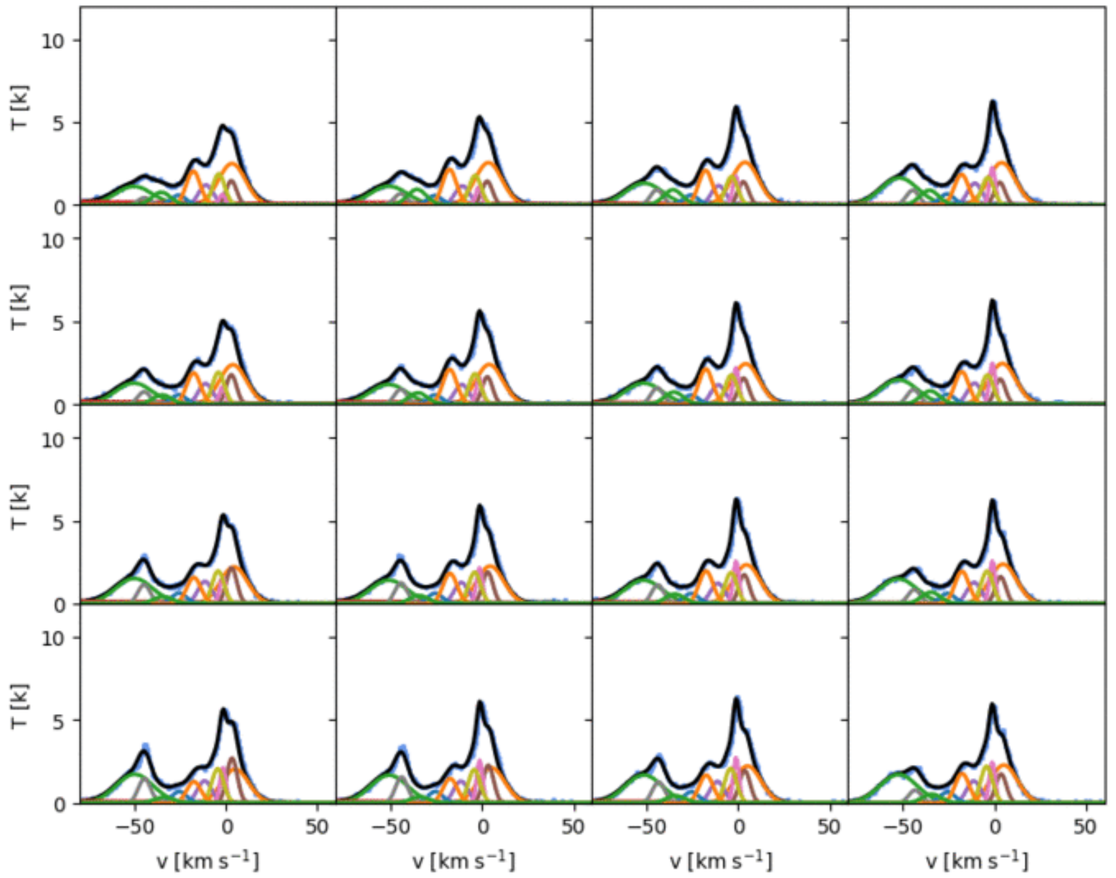
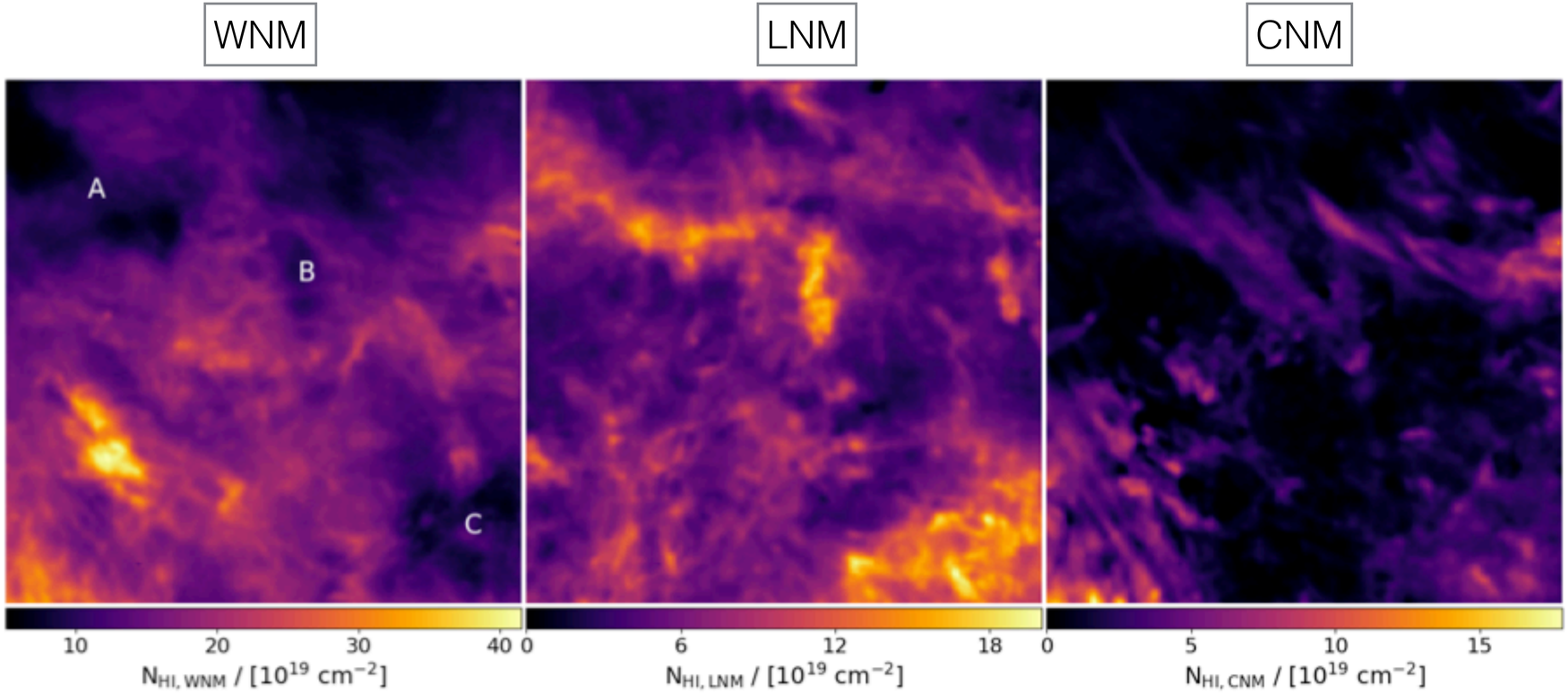


ROHSA : decomposition of emission on a Gaussian basis

Marchal et al. (2019)

Mapping each HI phases in the diffuse ISM



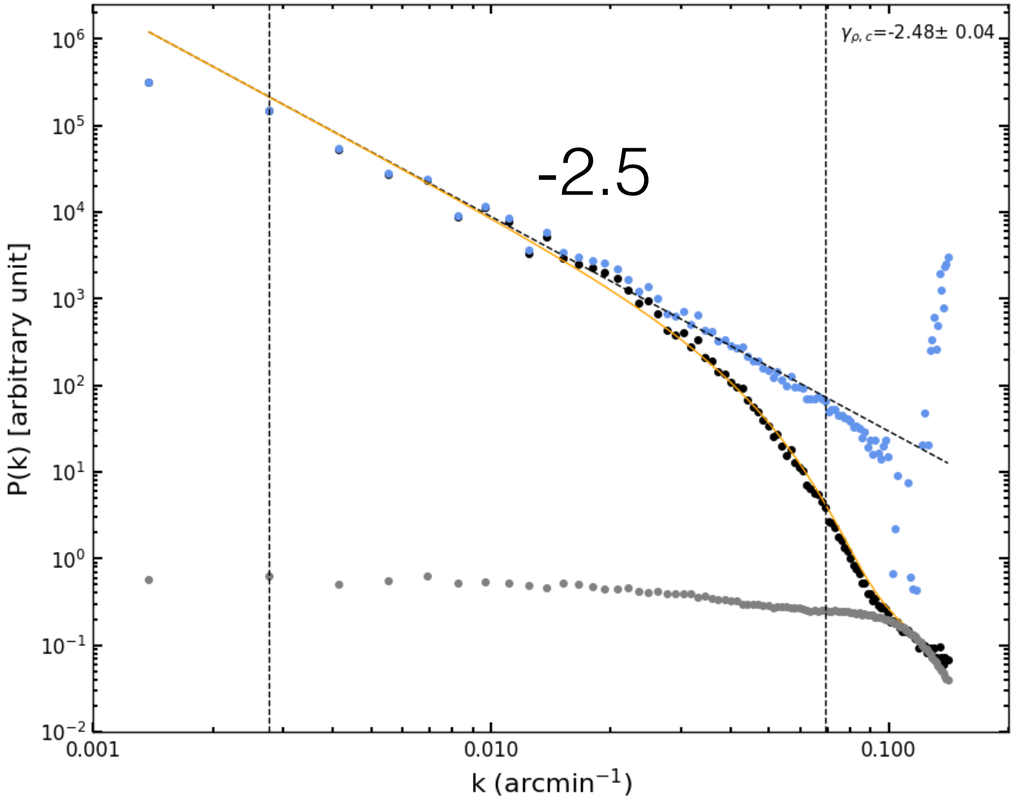
- Separate phases using ROHSA
  - WNM ~ 64%
  - LNM ~ 28%
  - CNM ~ 8%
- Estimate depth and distance of WNM using 3D dust tomography

North Ecliptic Pole
12x12 degrees
21 cm (GBT)

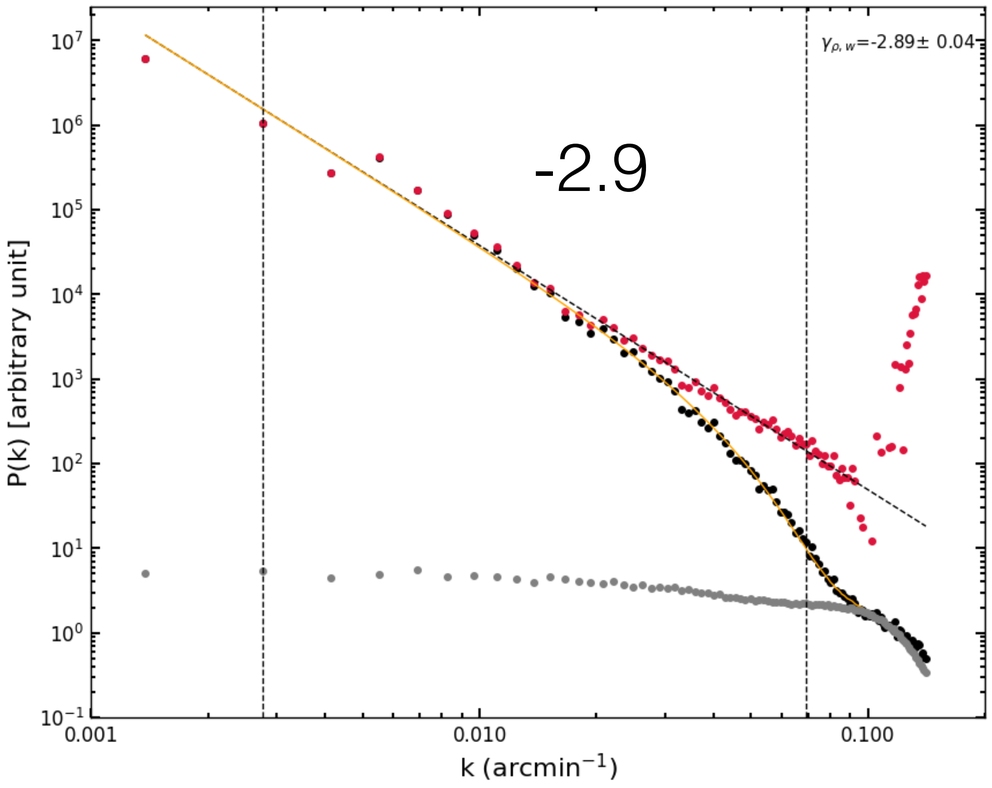
Marchal + (2019), Marchal & Miville-Deschênes (2021)

CNM shows more structure at small scales

N_{HI} CNM

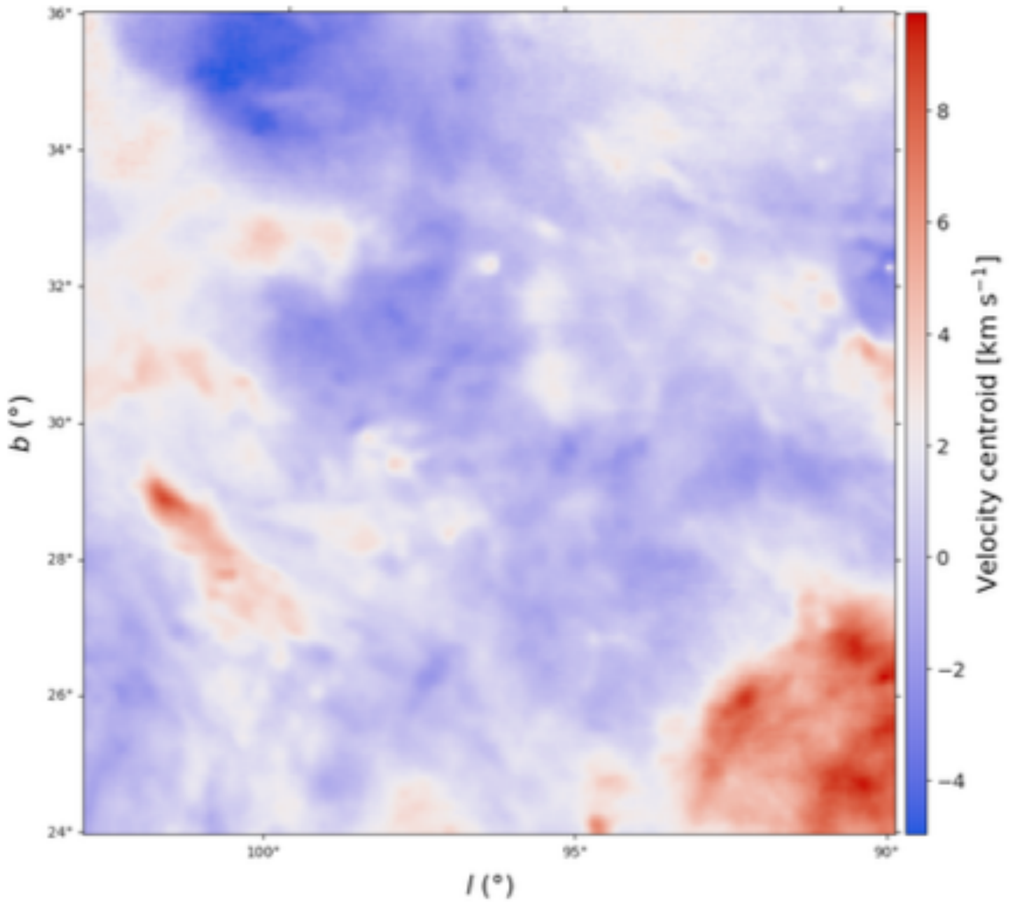


N_{HI} WNM



- Typical N_{HI} CNM ~ a few 10^{19} cm^{-2}
- Scale is a fraction of pc
- Volume filling factor of 1%

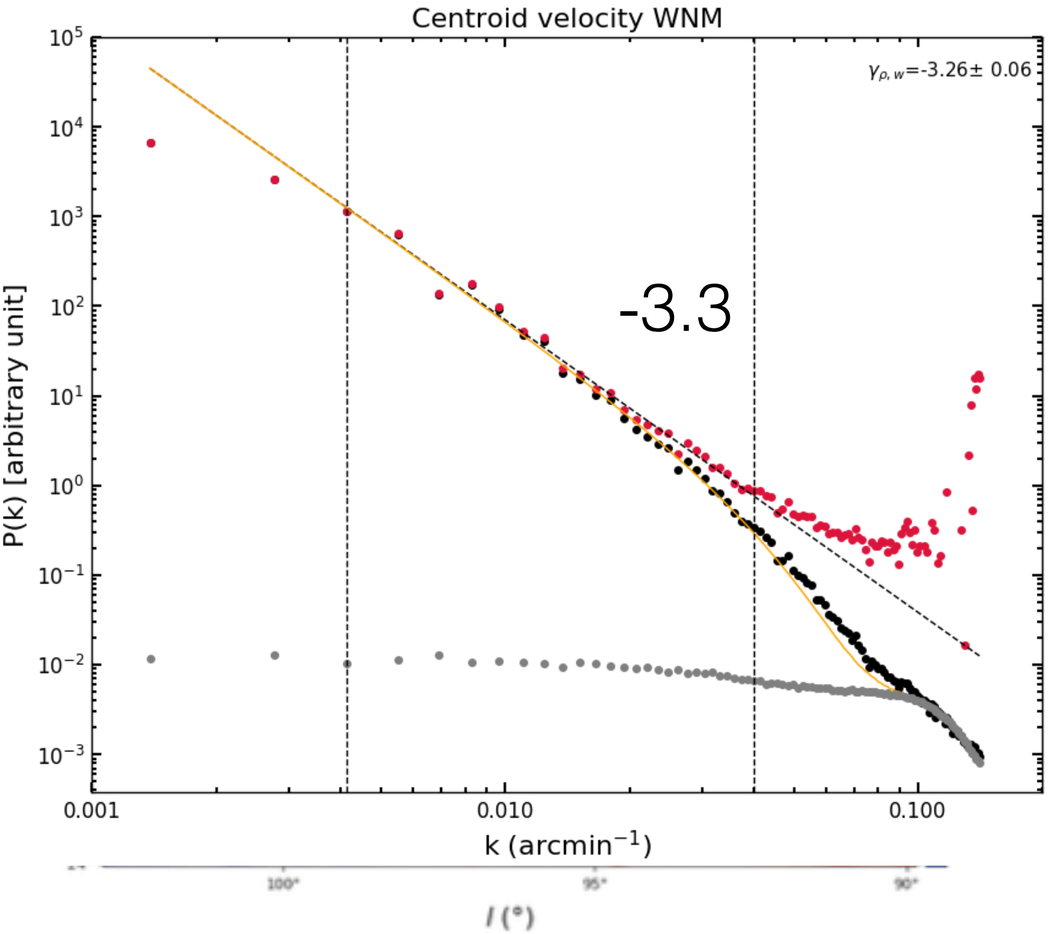
Thermal and turbulent properties of the Warm Neutral Medium in the solar neighborhood



- First map of WNM column density and velocity field
- WNM is ~ 64% of the mass in this field
- Pressure ~ 4400 K cm-3
- Density ~ 0.7 cm-3
- Temperature ~ 6000 K
- Density contrast ~ 0.6
- Mach number ~ 0.9
- Volume filling factor ~ 0.6
- Turbulence velocity dispersion at 1pc is 0.8 km/s, similar to what is observed in denser gas
- Velocity power spectrum compatible with K41

Marchal & Miville-Deschênes (2021)

Thermal and turbulent properties of the Warm Neutral Medium in the solar neighborhood



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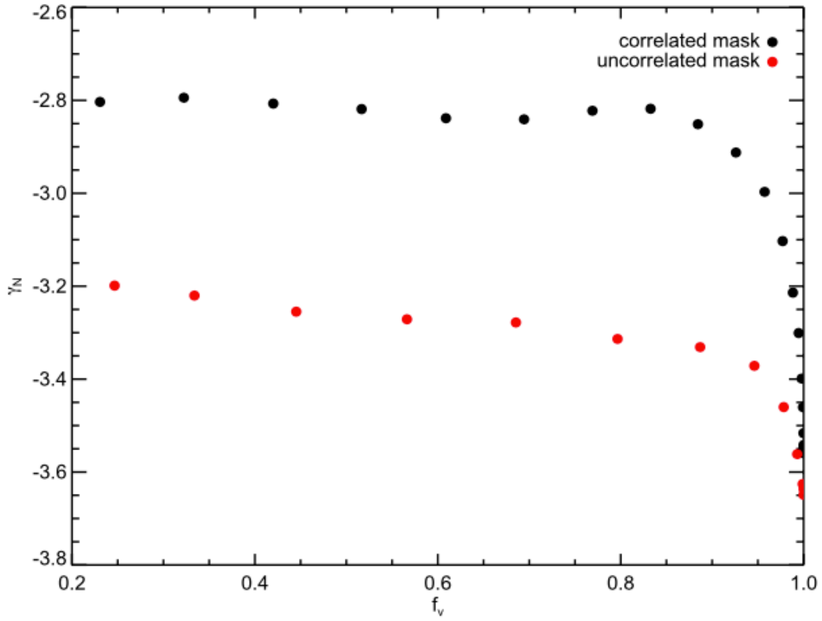
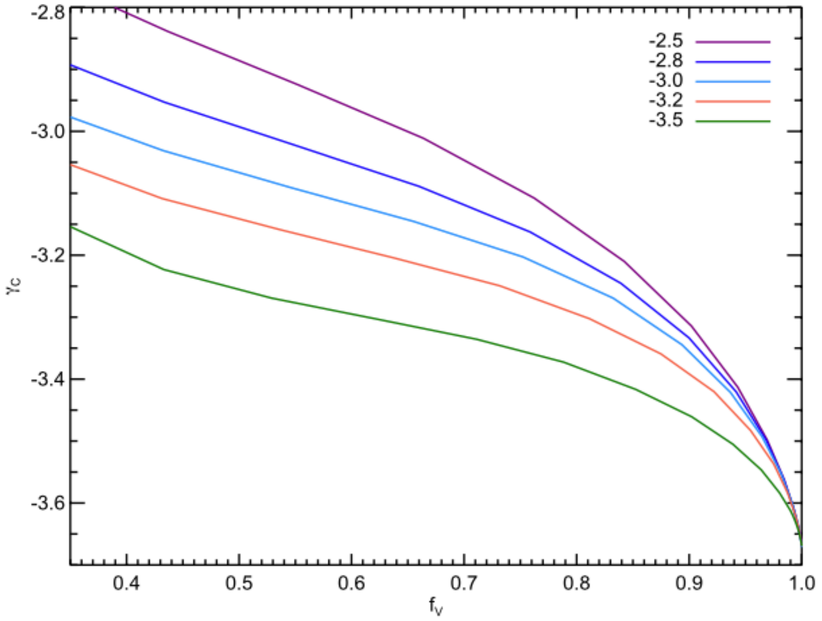
Marchal & Miville-Deschênes (2021)

Effect of filling factor on statistical estimators

column density



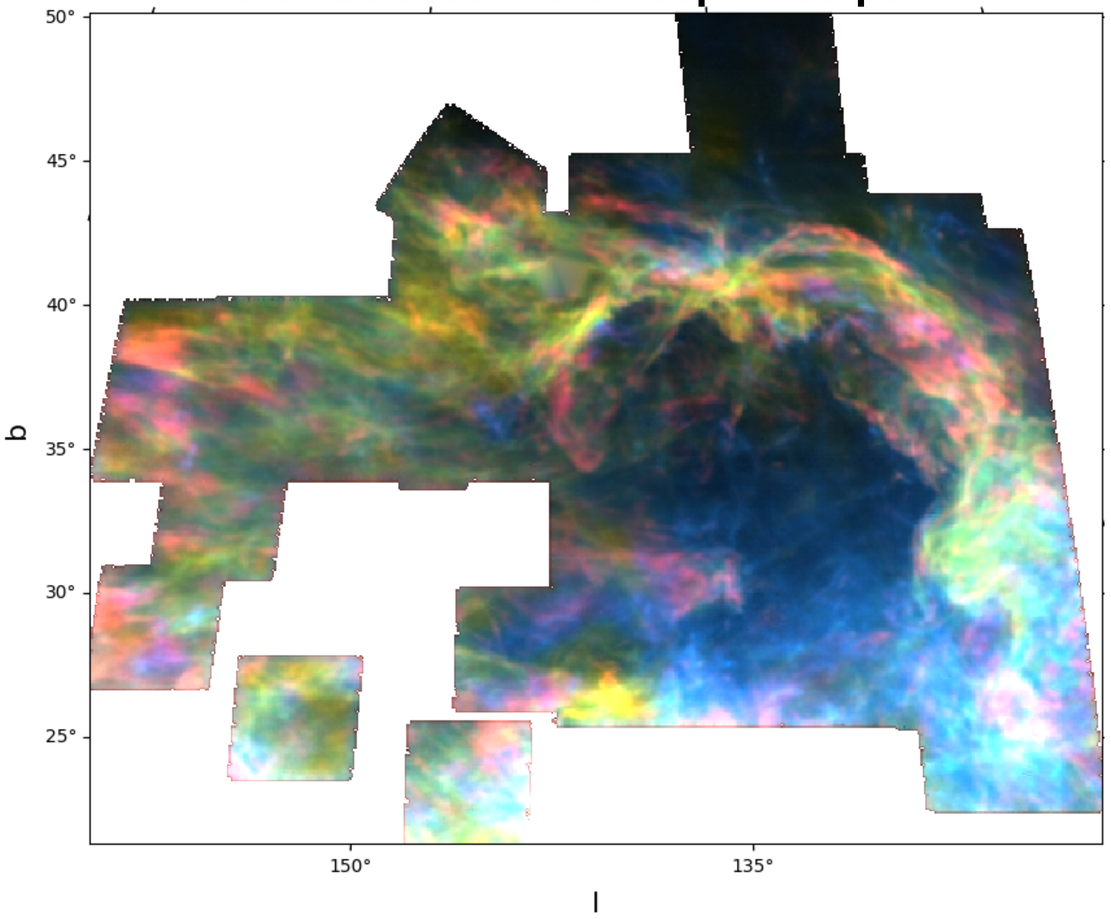
centroid velocity



- The P(k) is flatter due to non-zero filling factor.
- The exact correction depends on the morphology of the voids, and if they are correlated to the density field or not.

Large variability of the CNM fraction as a function of environment

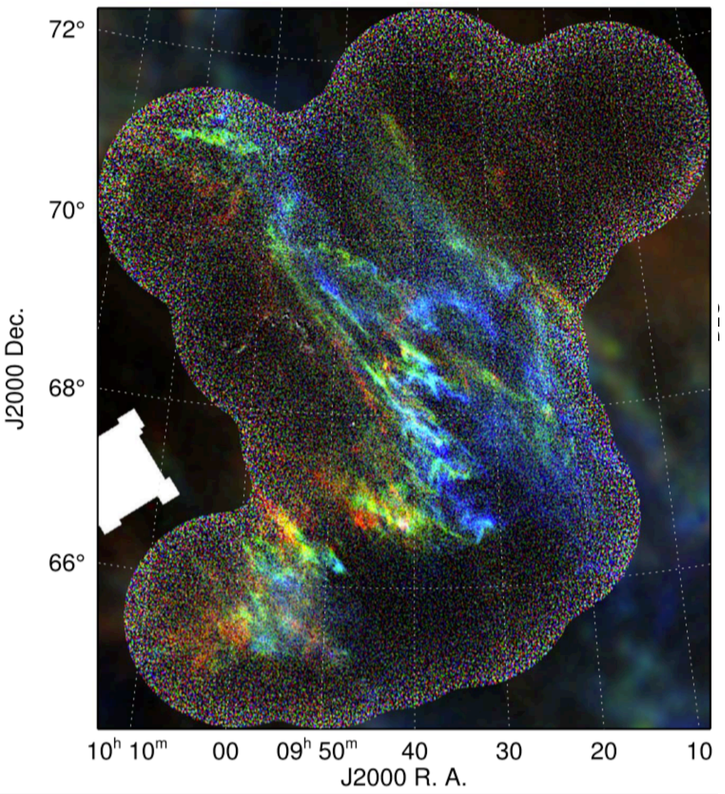
North Celestial Pole Loop ~ 400 pc



GHIGLS data - CNM 30%, up to 70%

Taank, AM et al, submitted

IV Arch - IVC ~ 2-3 kpc

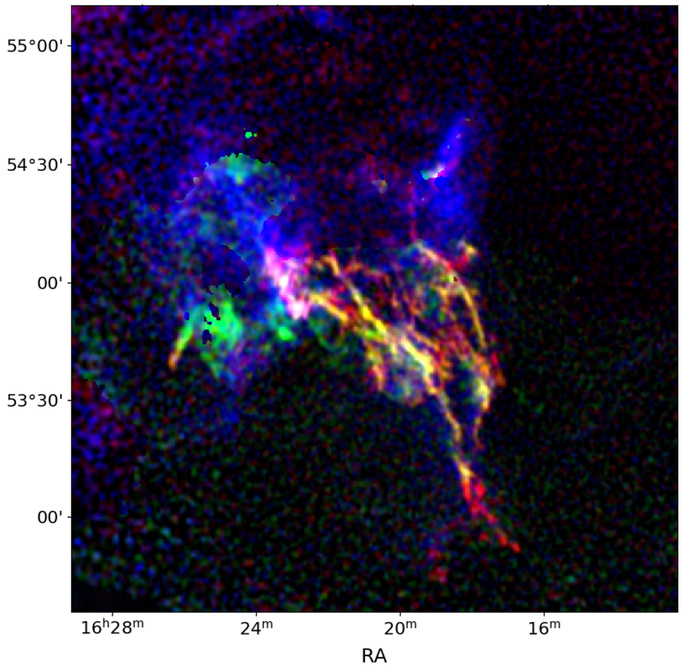


Besson et al, in prep

ROHSA-GPU

DHIGLS data - CNM ~ 20%

Complex C - HVC ~ 10 kpc



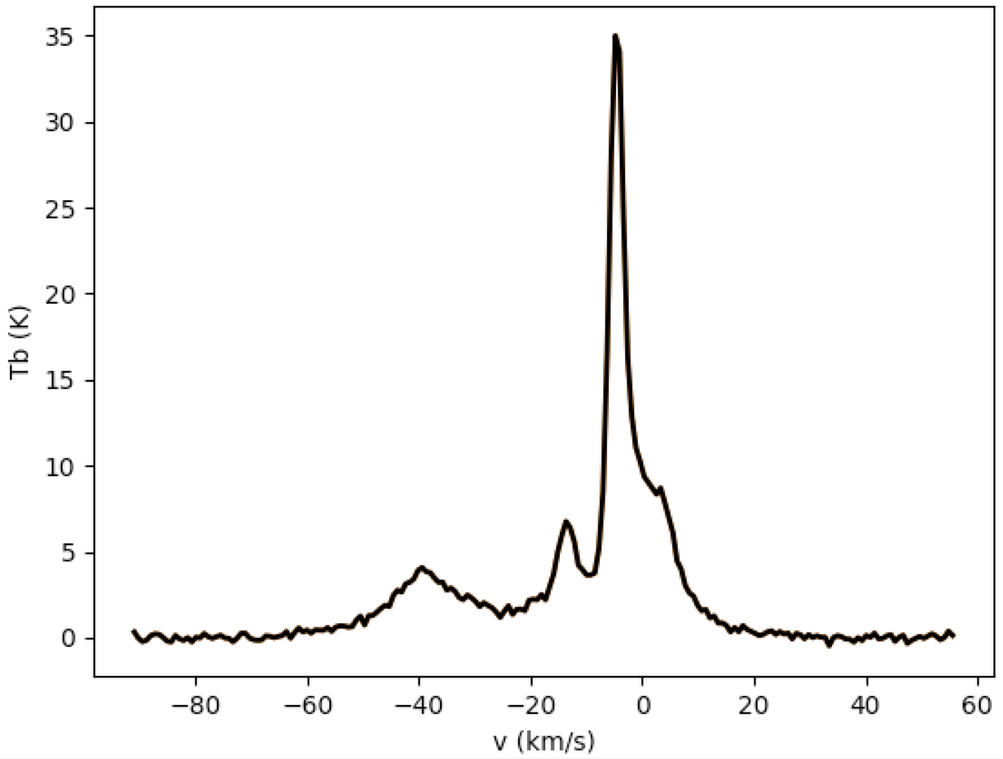
Marchal, et al 2021 ApJ 921, 11

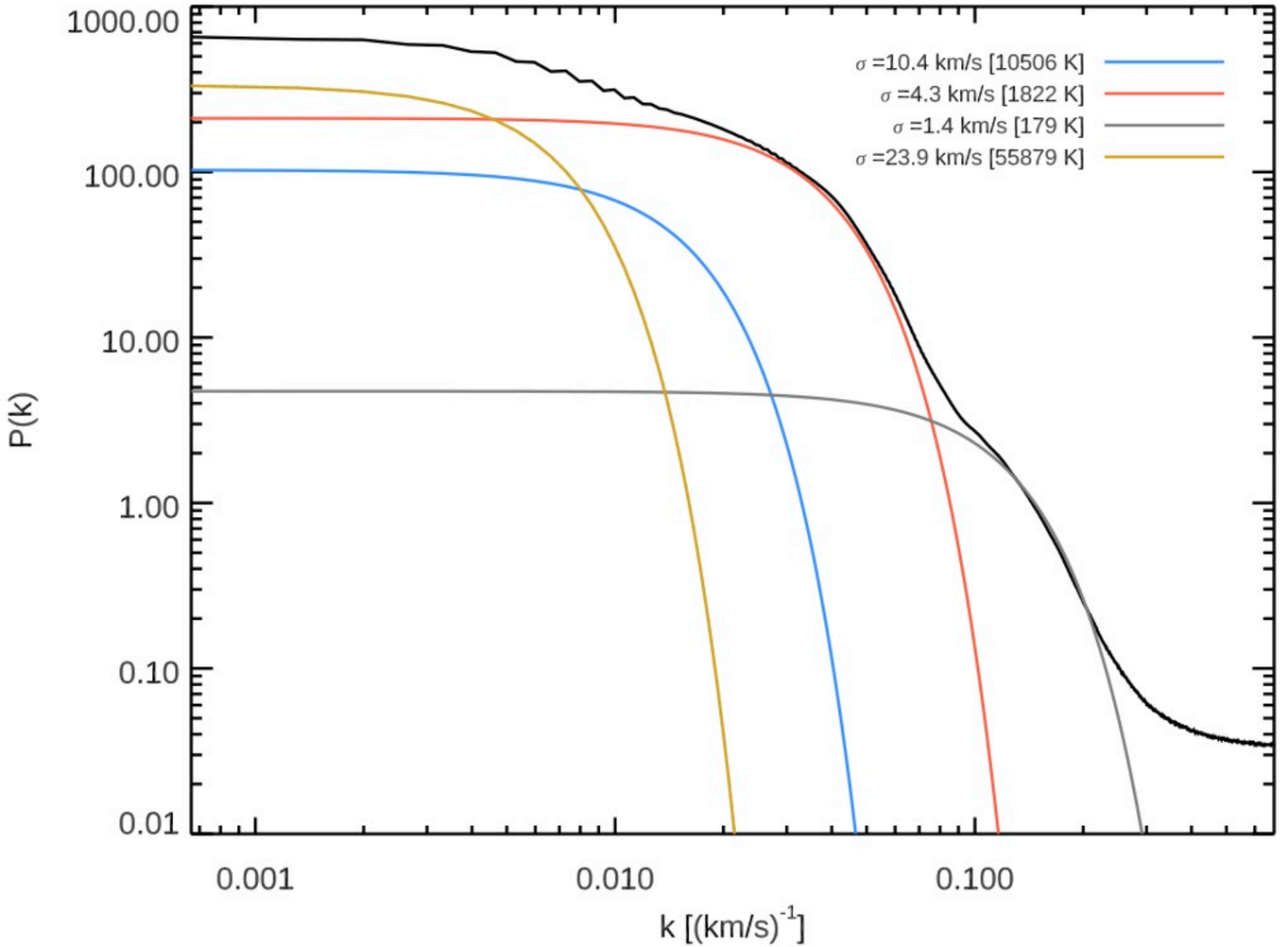
DHIGLS data - CNM ~ 7%

Spectral analysis of 21 cm emission

extracting the widths of features in HI spectra

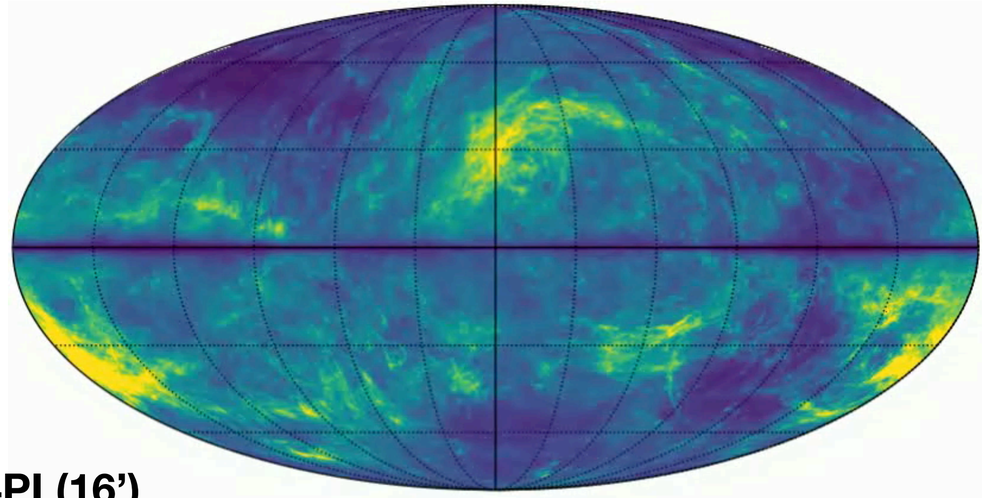
A 21 cm spectrum of the diffuse ISM





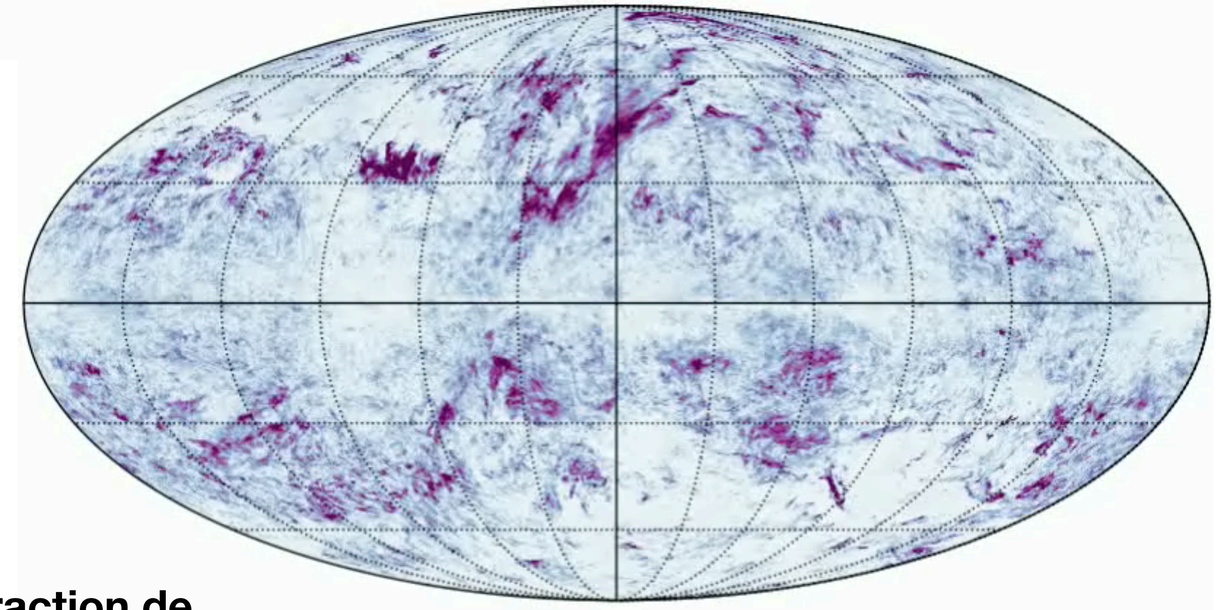
IV. Fourier transform of 21cm data

Marchal et al in prep.



Densité de colonne totale

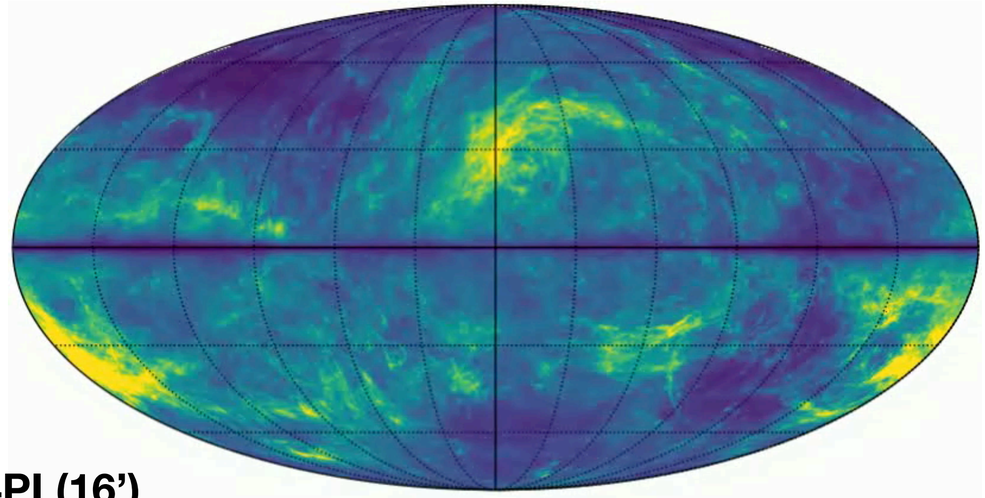
HI4PI (16')



Lower limit fraction de gas froid

IV. Fourier transform of 21cm data

Marchal et al in prep.



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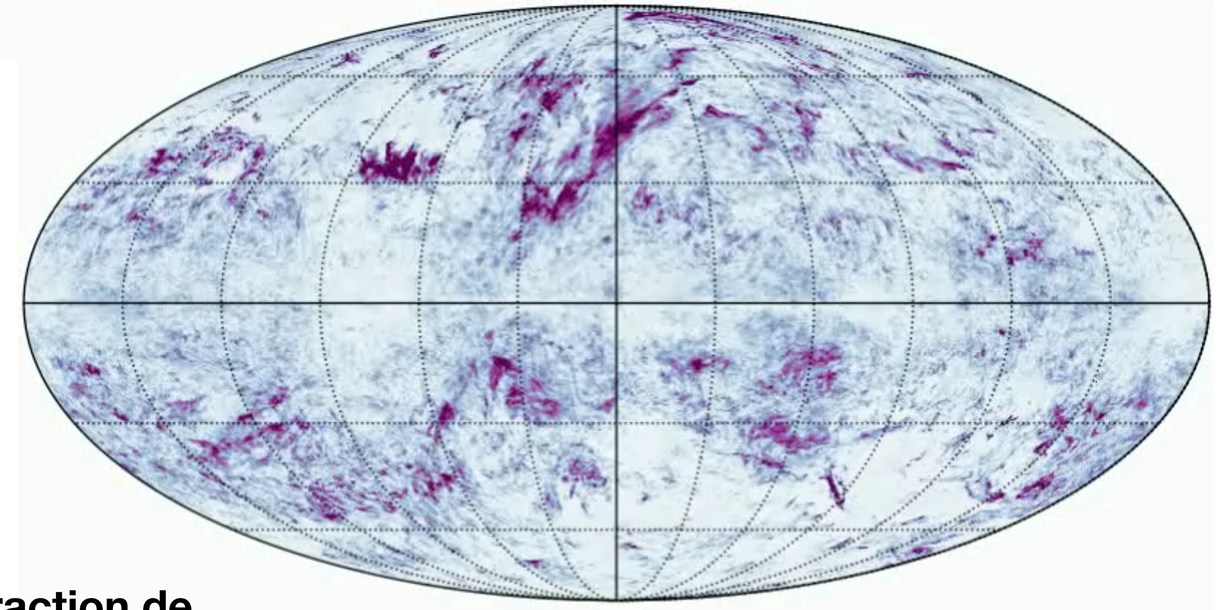


Lower limit fraction de gas froid

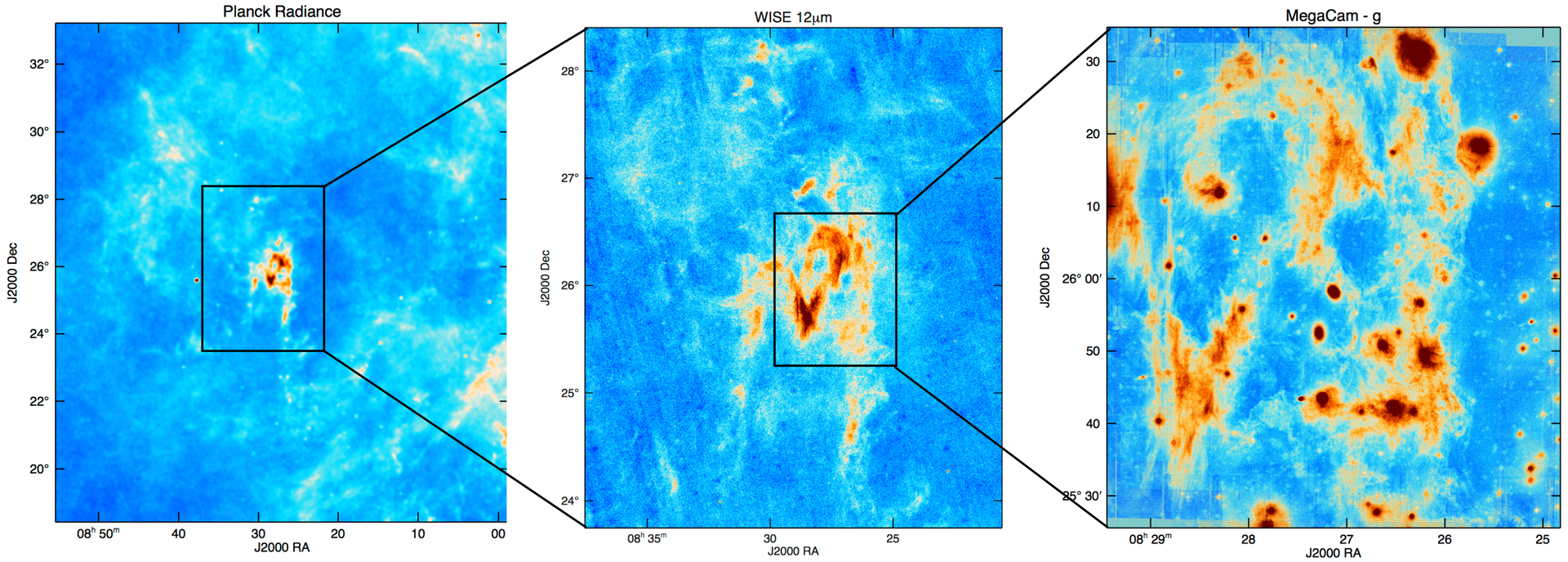
Mapping interstellar turbulence with dust

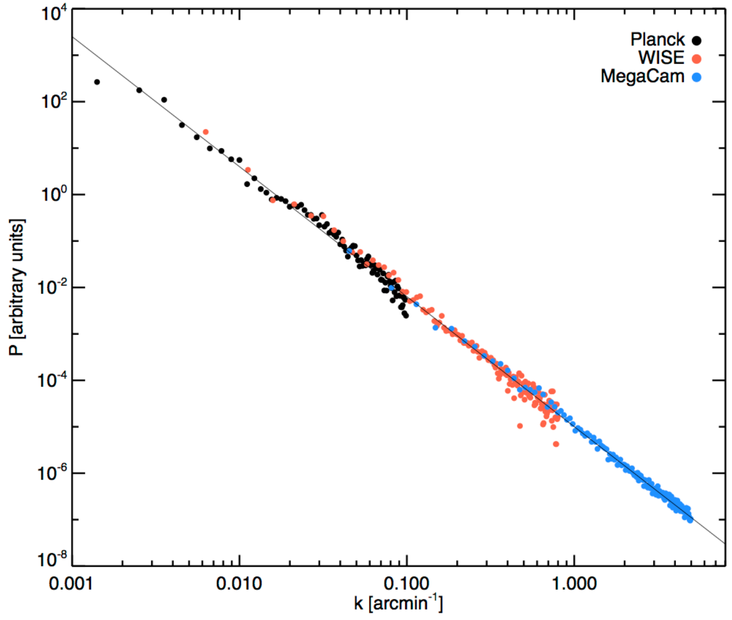
proof of concept

Planck - 5 arcmin

WISE - 15 arcsec

MegaCam - 0.6 arcsec





- Resolution increased by a factor 500
- Slope = -2.9 (0.1)
- No sign of slope change down to 0.01 pc

Miville-Deschênes et al. (2016)

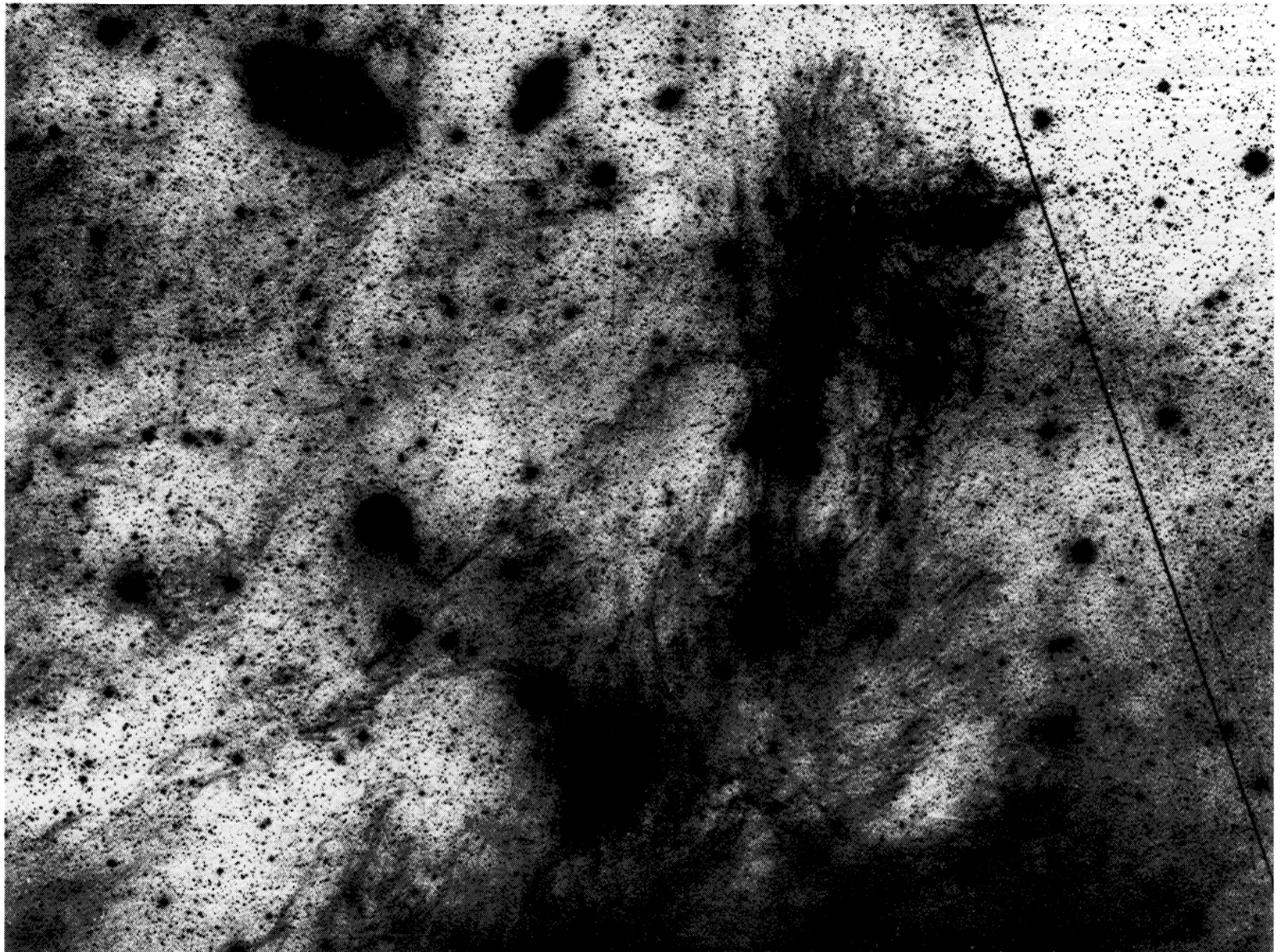
THE ASTRONOMICAL JOURNAL VOLUME 81, NUMBER 11 NOVEMBER 1976

High-latitude reflection nebulosities illuminated by the galactic plane

Allan Sandage

Hale Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena, California 91101

(Received 28 June 1976)



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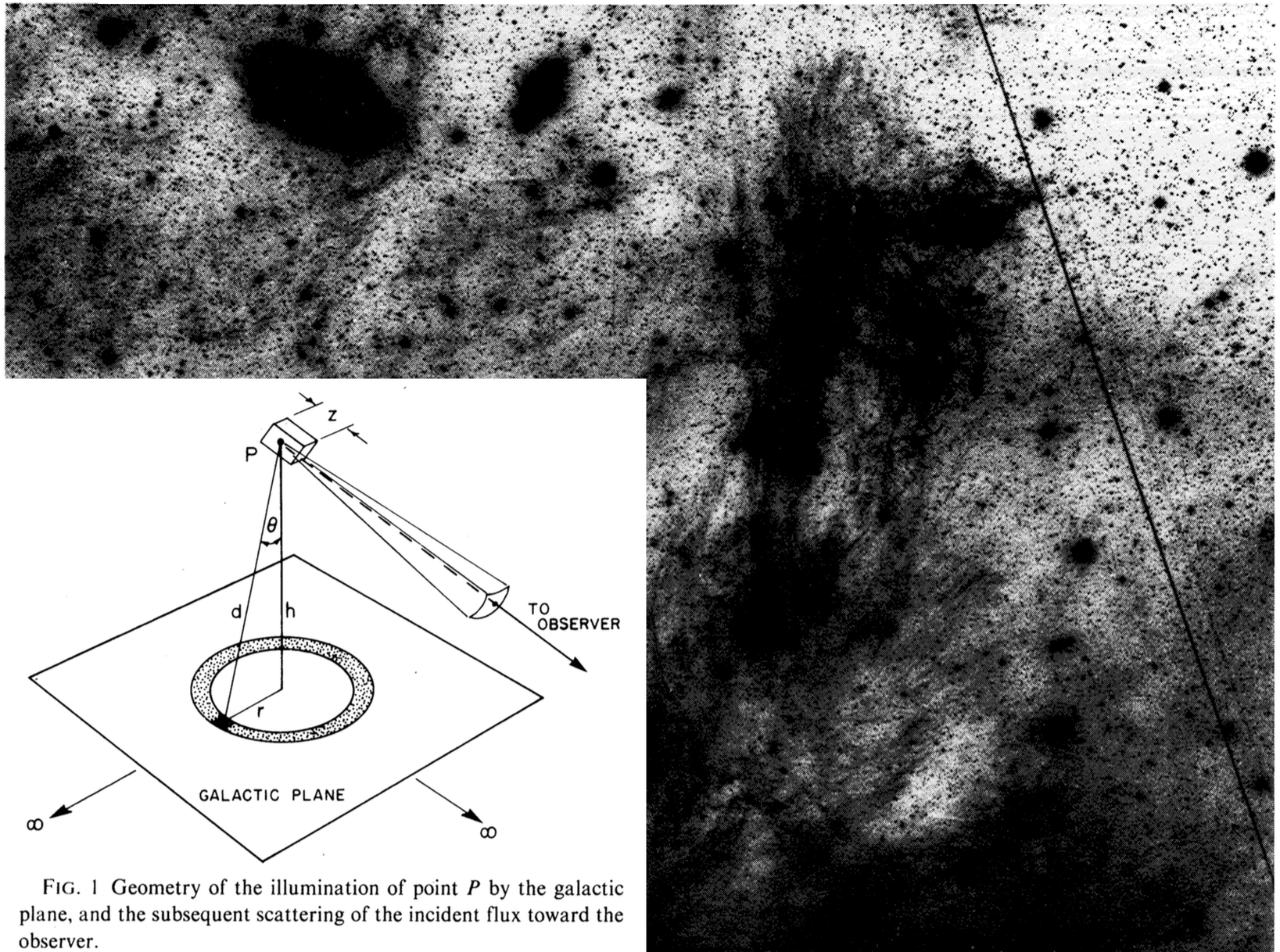
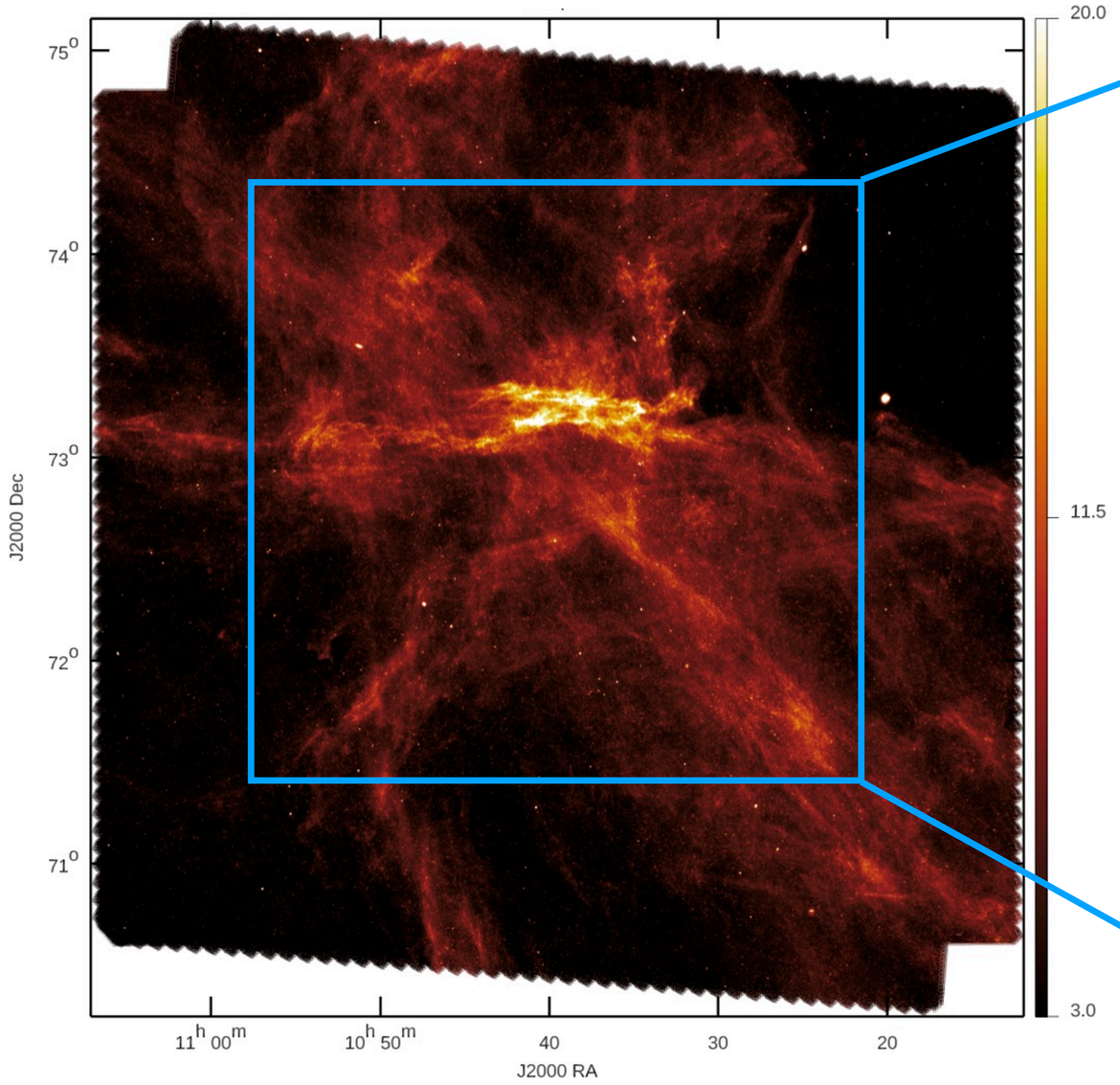


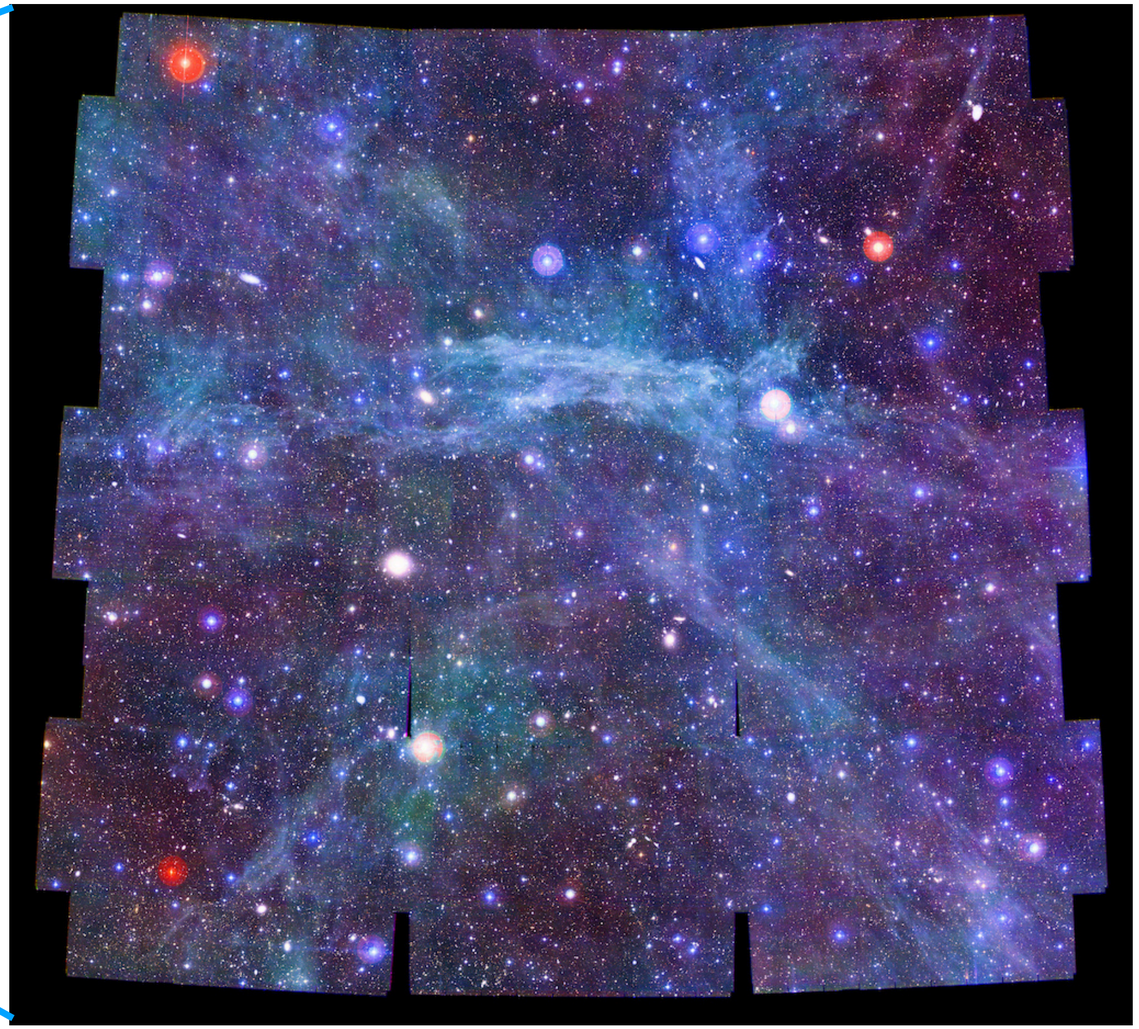
FIG. 1 Geometry of the illumination of point P by the galactic plane, and the subsequent scattering of the incident flux toward the observer.

Optical scaterred light as a tracer of column density ?

Dust emission - Herschel SPIRE 250 micron



Scattered Light - CFHT MegaCam - g,r,i



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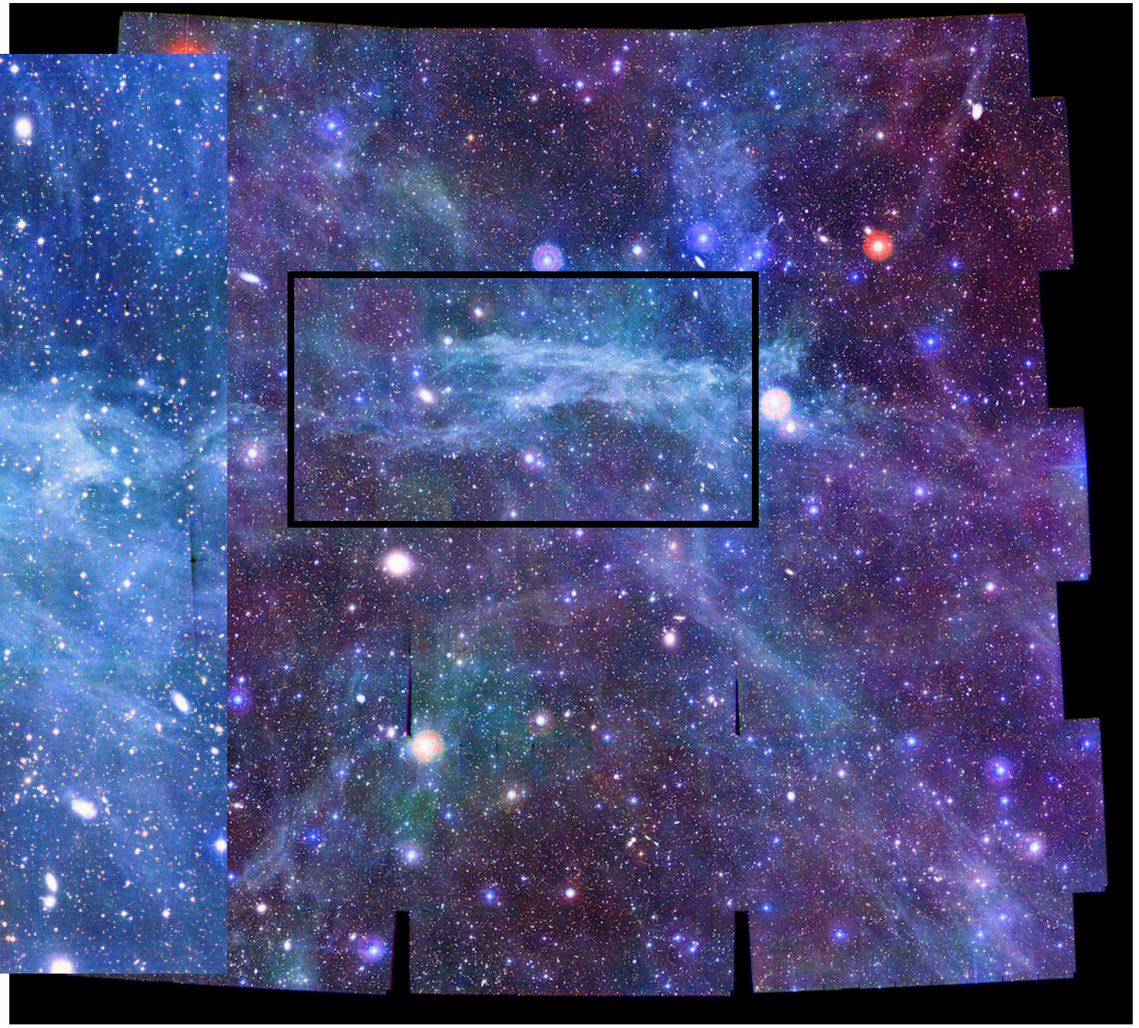
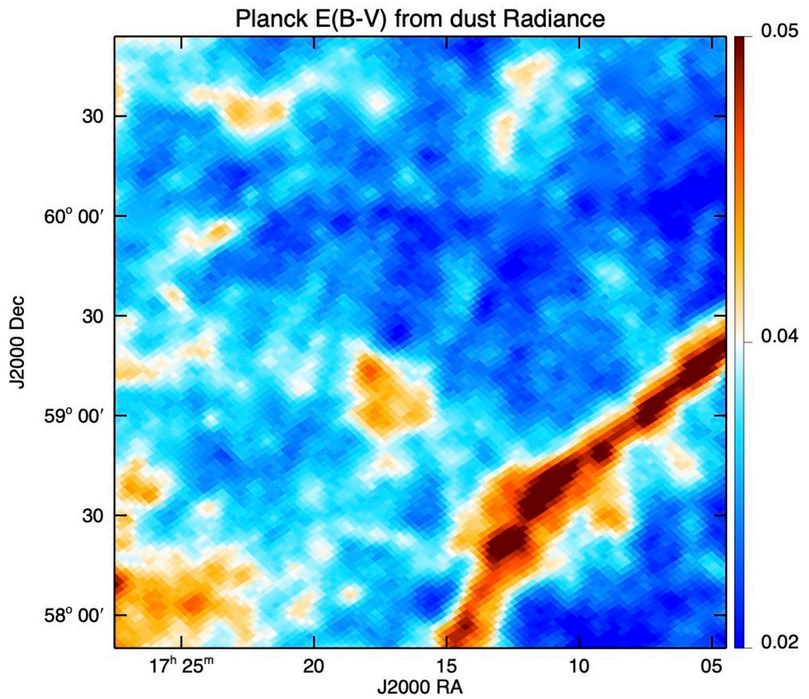
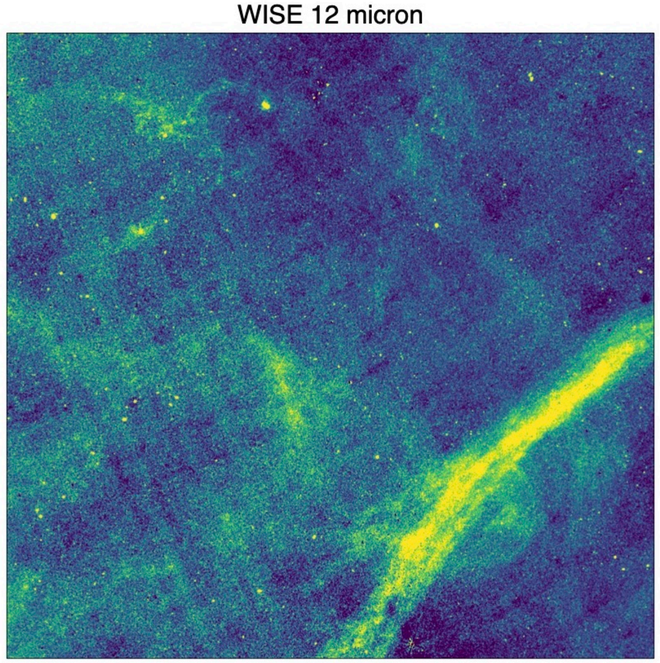
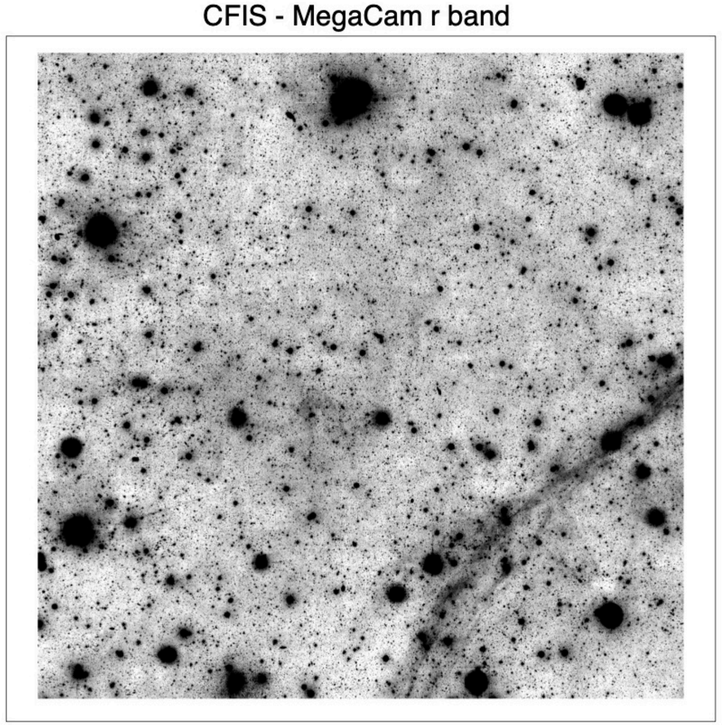


FLS field


Planck E(B-V) from dust Radiance
0.05
0.04
0.02
30
60° 00′
30
59° 00′
30
58° 00′
J2000 Dec
17h 25m
20
15
10
05
J2000 RA


WISE 12 micron


CFIS - MegaCam r band