Connecting ISM structures to star formation processes

Jean-François Robitaille
Marie Curie Fellow

Frédérique Motte
G. Joncas, M.-A. Miville-Deschênes

Tracing the flow, July 4th 2018

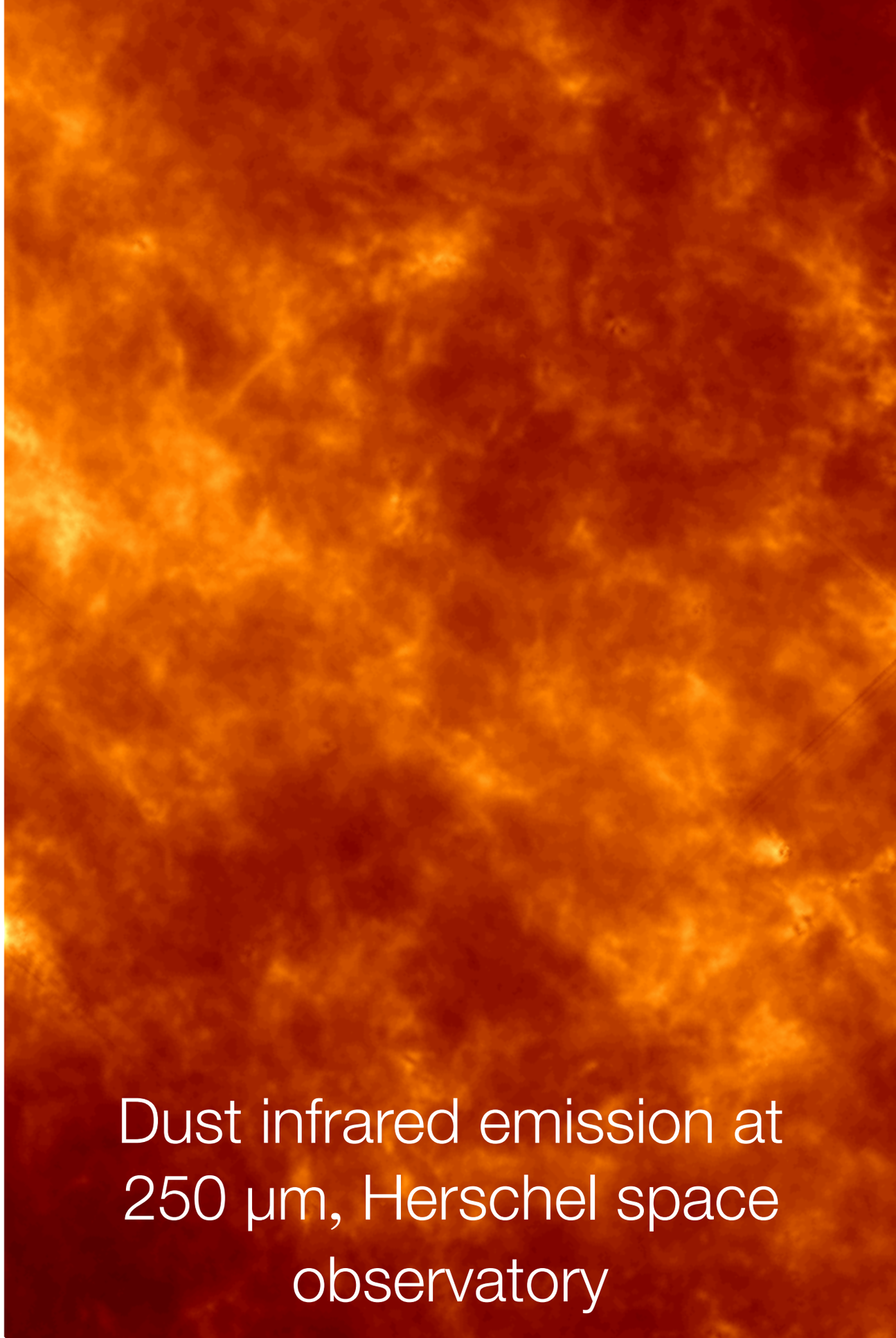
Statistical measurements on molecular clouds

- Probability density distribution function (PDF) : the foundation of many modern theories of star formation

- Power spectrum analysis : one of the best tools to analyse and characterise the turbulence

  - If turbulence dominated, it should be a complete measure of the density distribution (Green 93, Stutzki et al. 98)

  - Scale-free medium

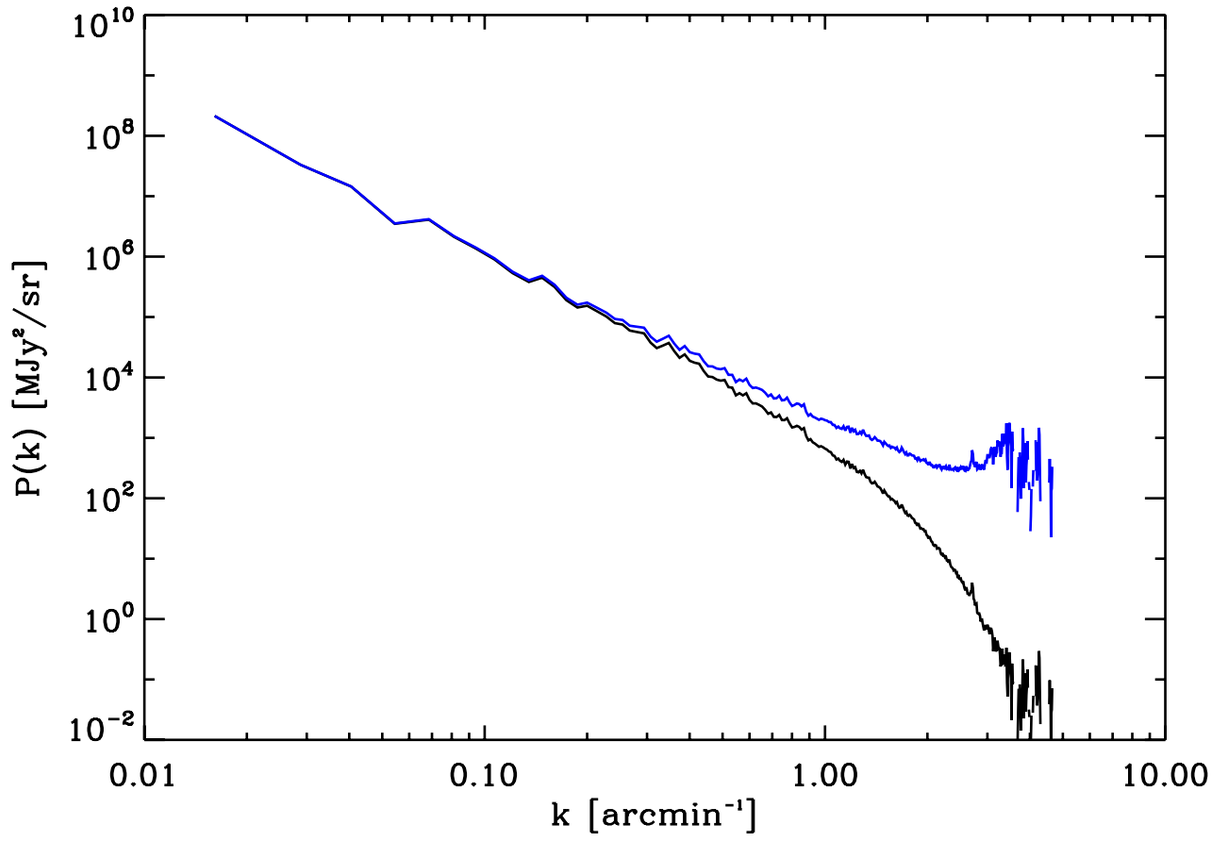


Dust infrared emission at 250 μm, Herschel space observatory

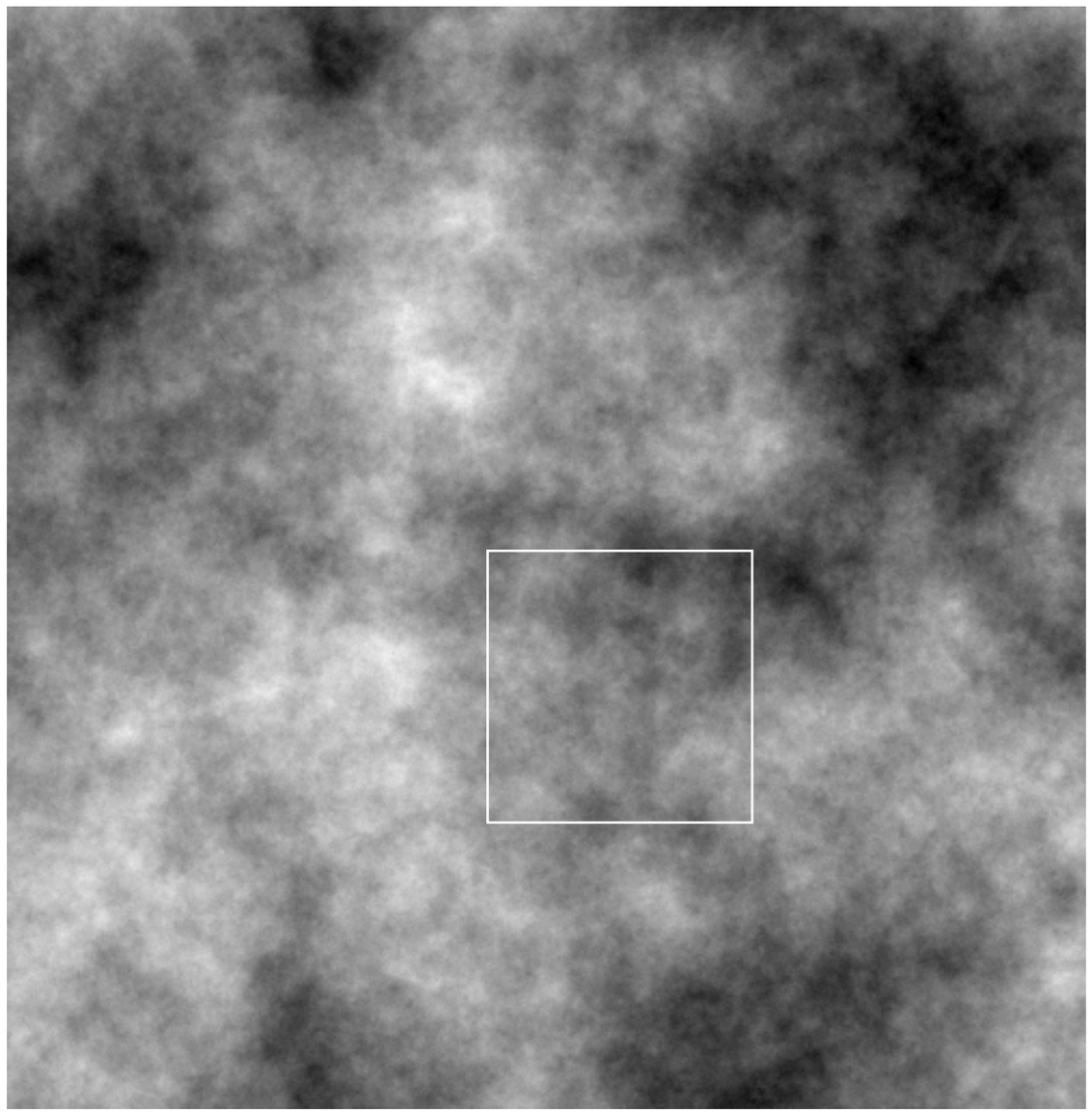
Power spectrum analysis

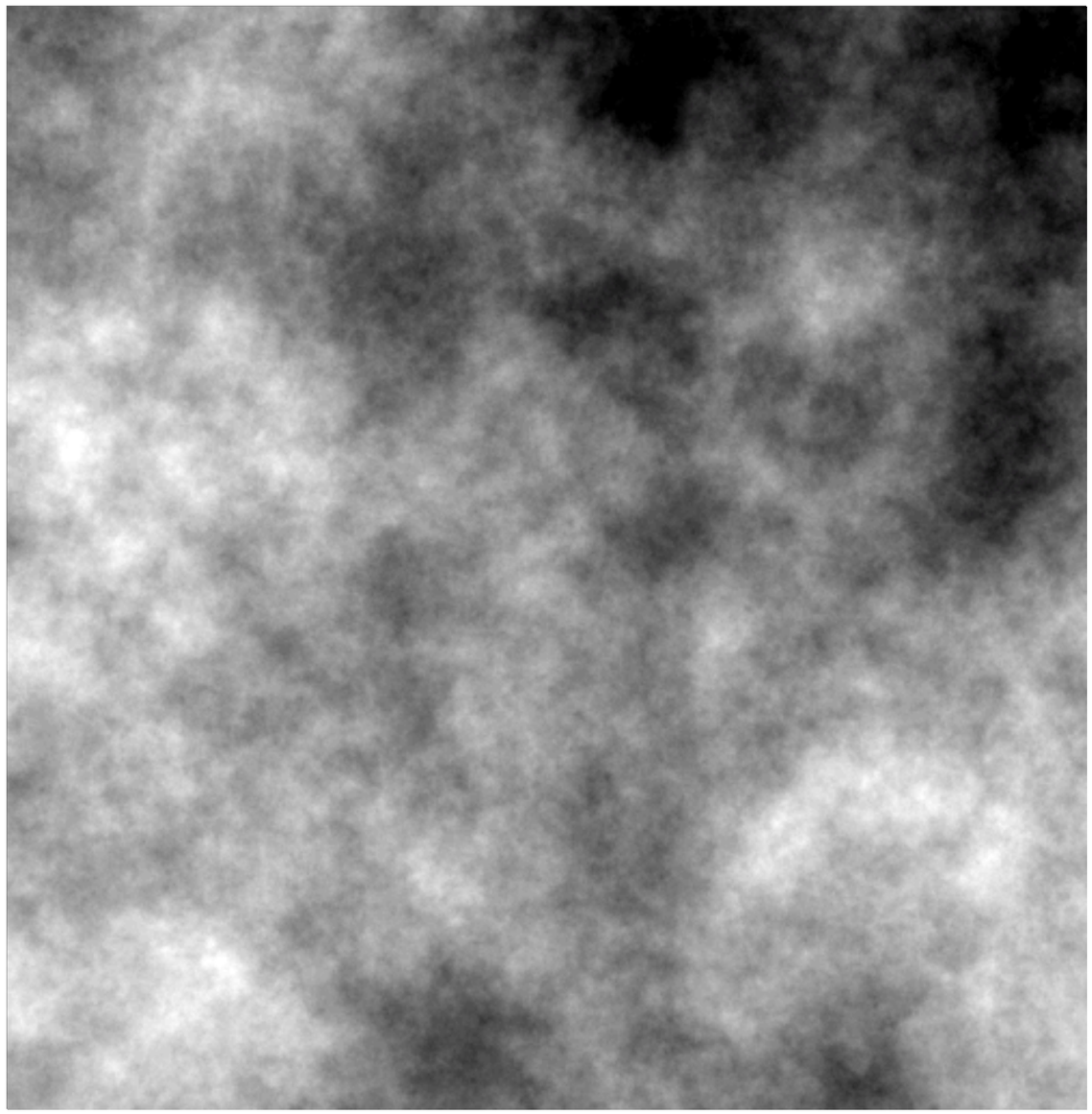
- Scale-free medium:
  - Turbulent isotherm, subsonic, incompressible medium (Kolmogorov 1941)
  - Characteristic of a fractal medium (Elmegreen et al. 01, Miville-Deschênes et al. 07)

Dust emission at l ~ 59°

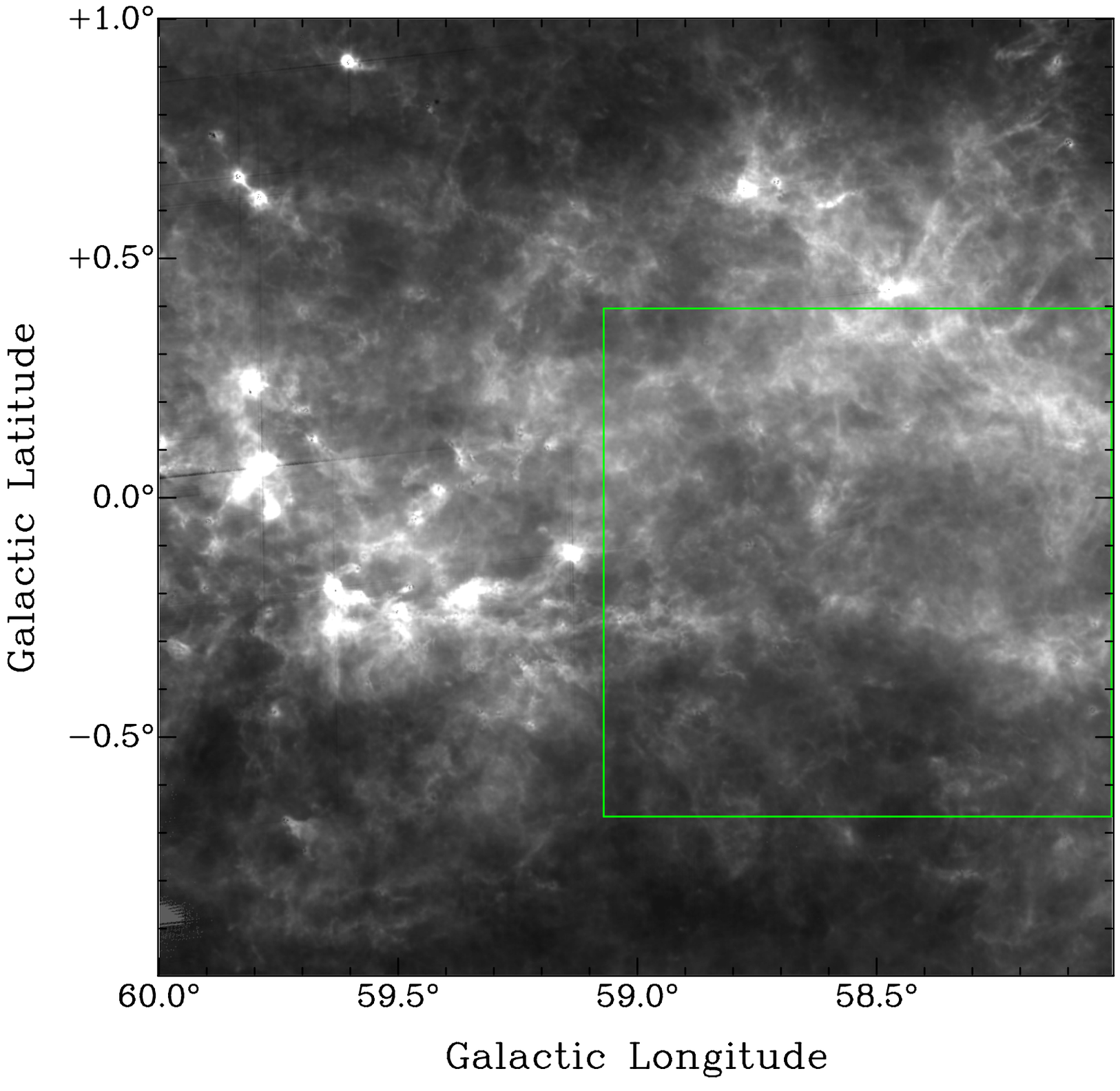


Self-similar distribution



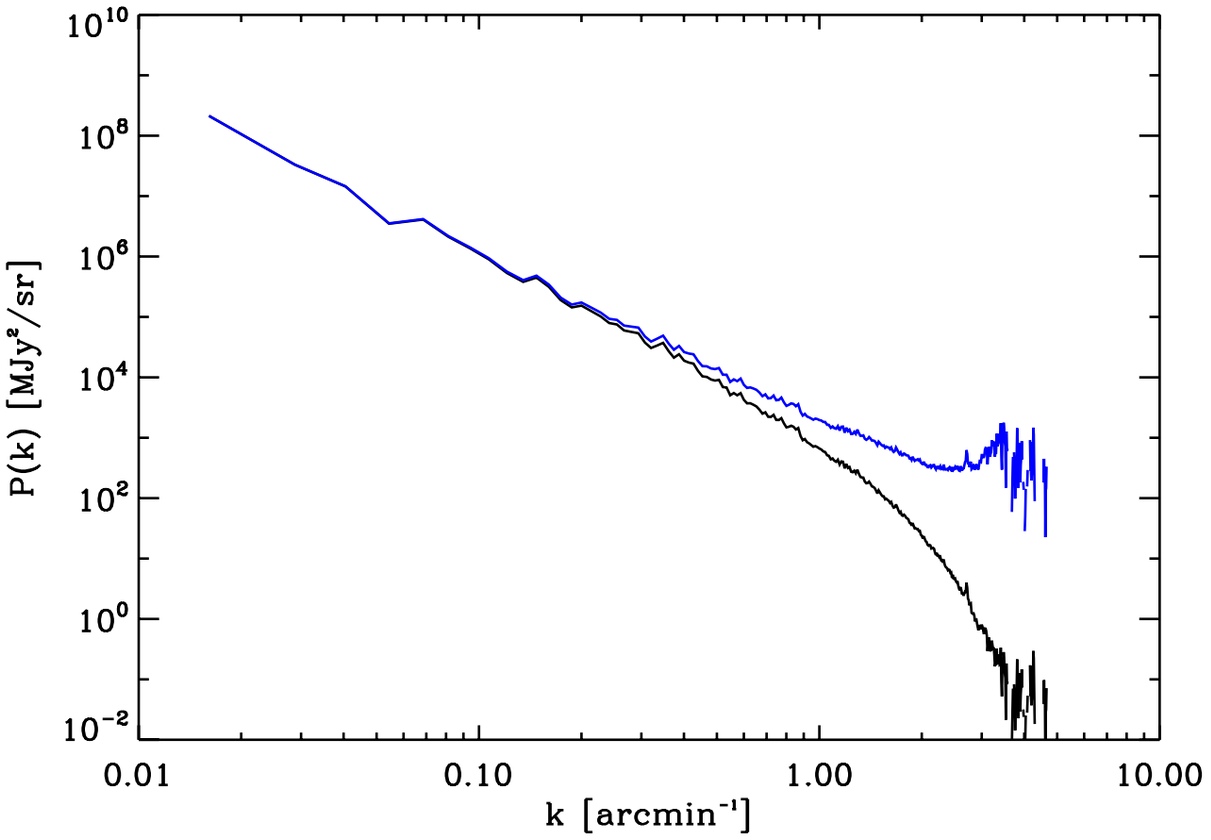


Hi-GAL field at l ~ 59º, 250 μm

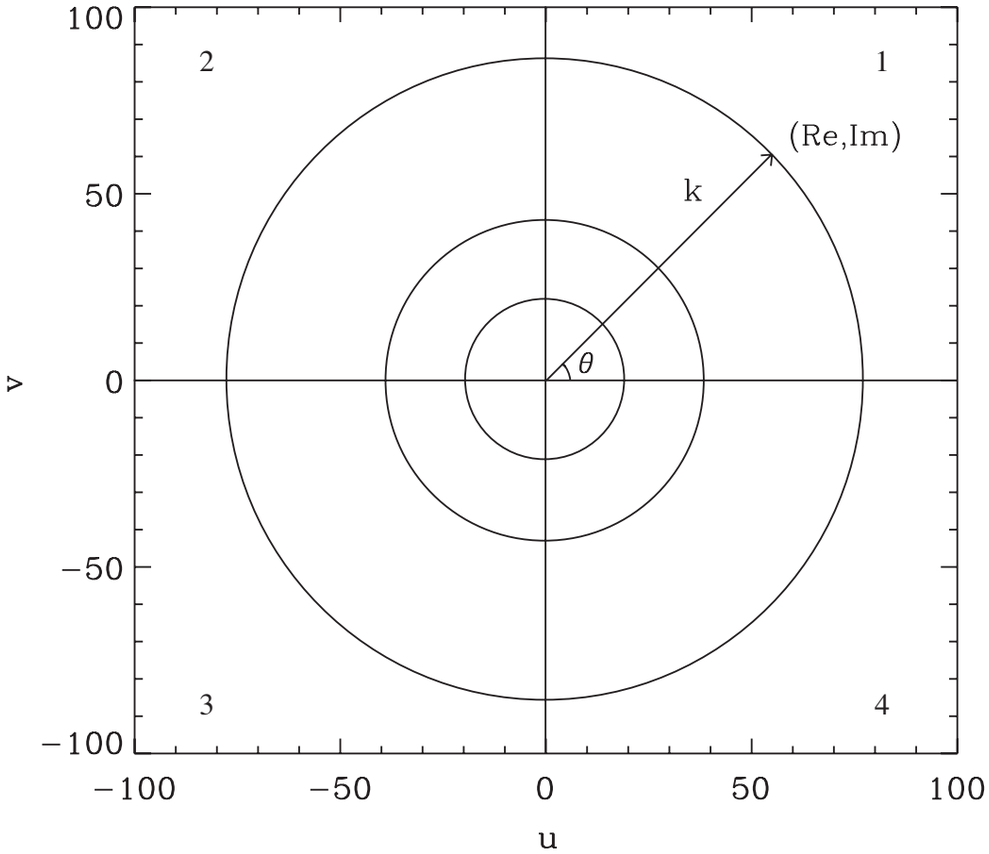


Multi-Scale analysis

Dust emission at l ~ 59^{O}



Fourier transform



Power

$$P(k) = \langle |A(k)|^2 \rangle_\theta$$

Amplitude & Phase

$$A = \sqrt{Re^2 + Im^2}$$

$$\phi = \tan^{-1}(Im/Re)$$

Wavenumber

$$k = \sqrt{u^2 + v^2}$$

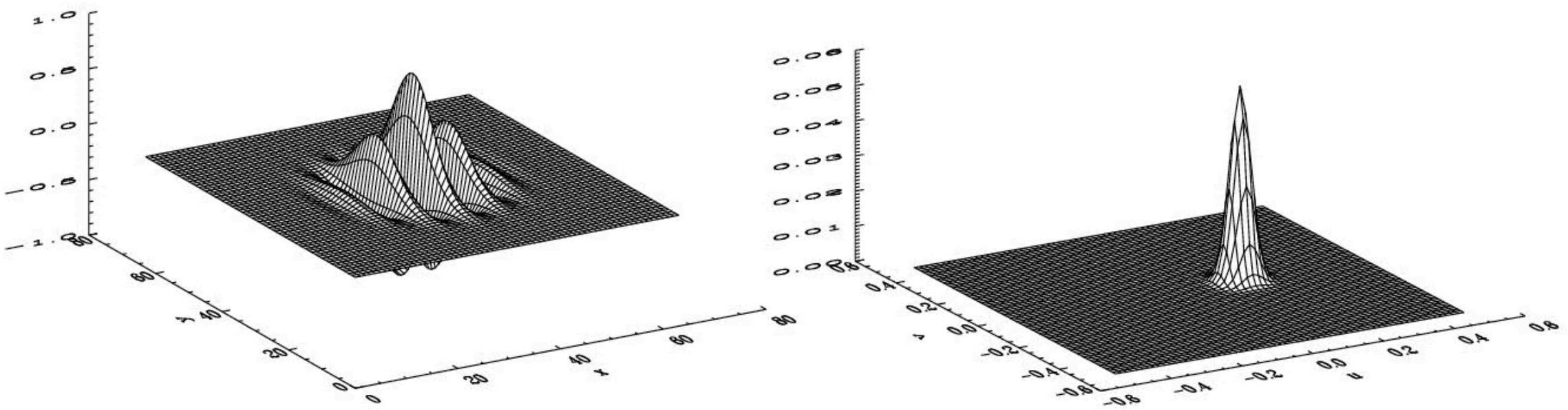
Complex Wavelet transform

$$\psi(\mathbf{x}) = \mathrm{e}^{i\mathbf{k}_0\mathbf{x}}\mathrm{e}^{-|\mathbf{x}|^2/2}$$
$$= [\cos(\mathbf{k}_0\mathbf{x}) - i\sin(\mathbf{k}_0\mathbf{x})]\mathrm{e}^{-|\mathbf{x}|^2/2}$$

Morlet wavelet

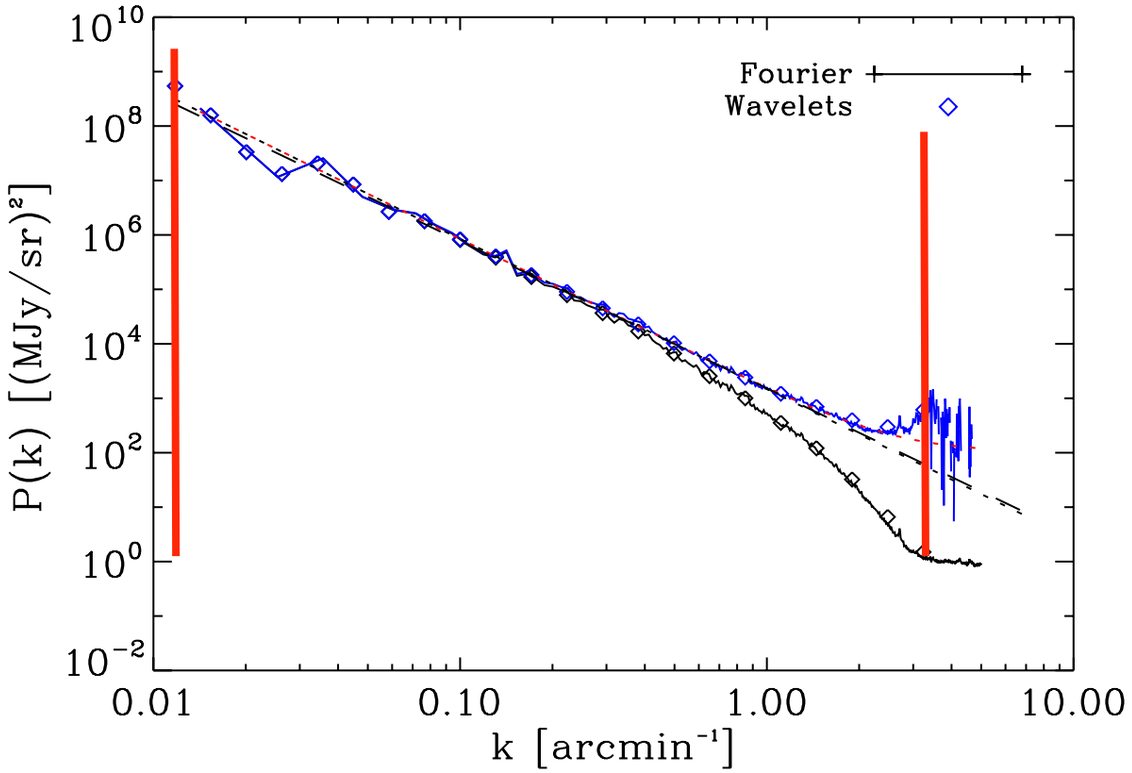
X space

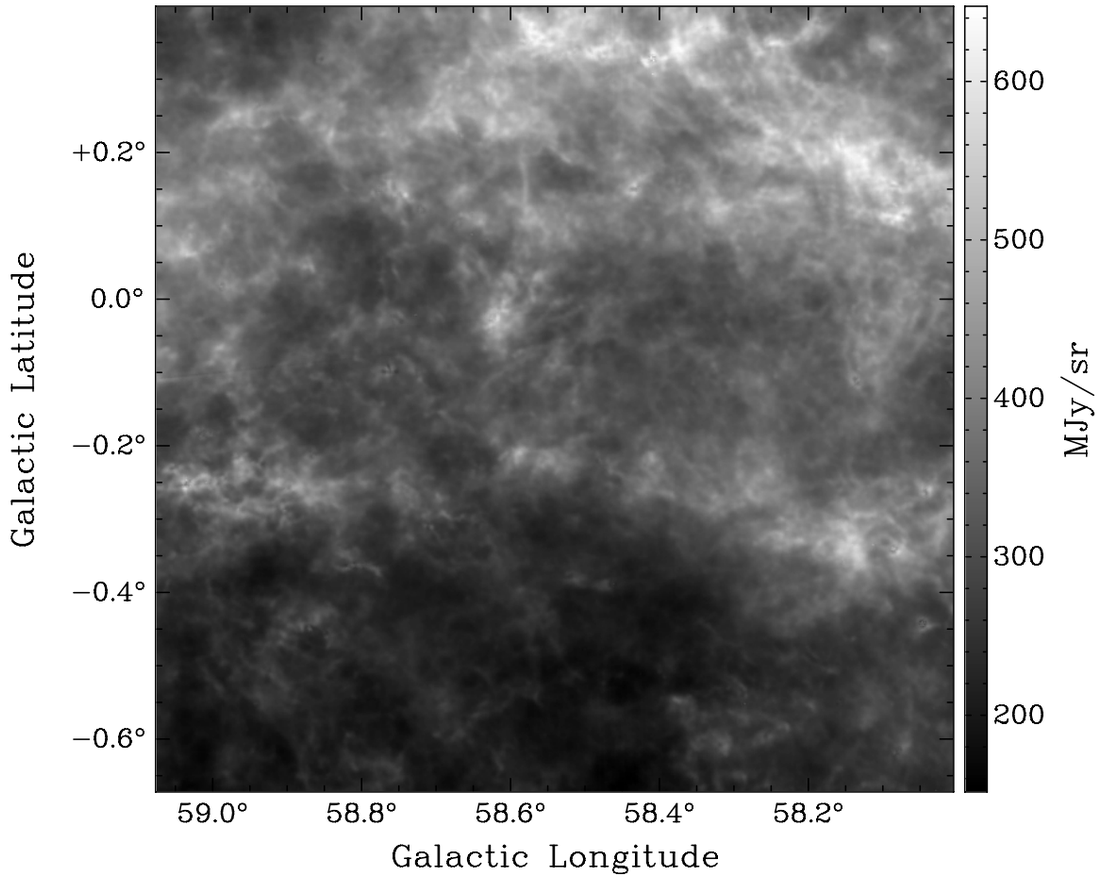
Fourier space



Kirby, J. F. 2005, Computers and Geosciences, 31, 846

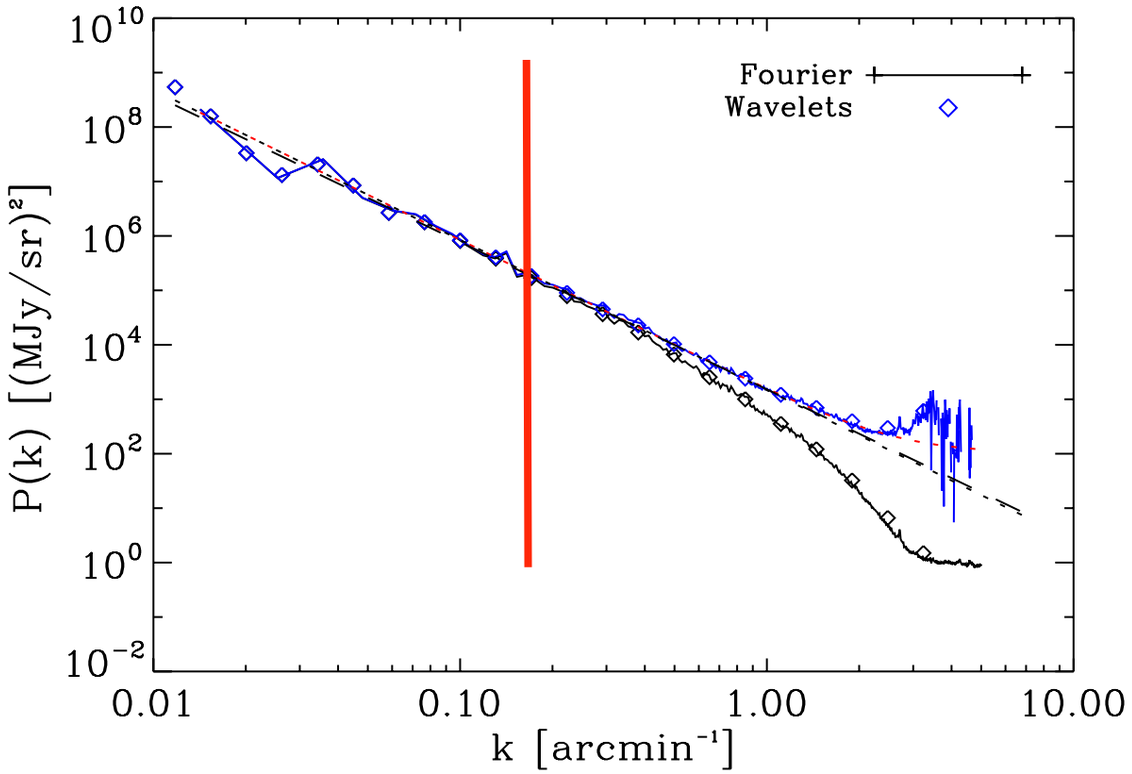
Complex wavelet power spectrum



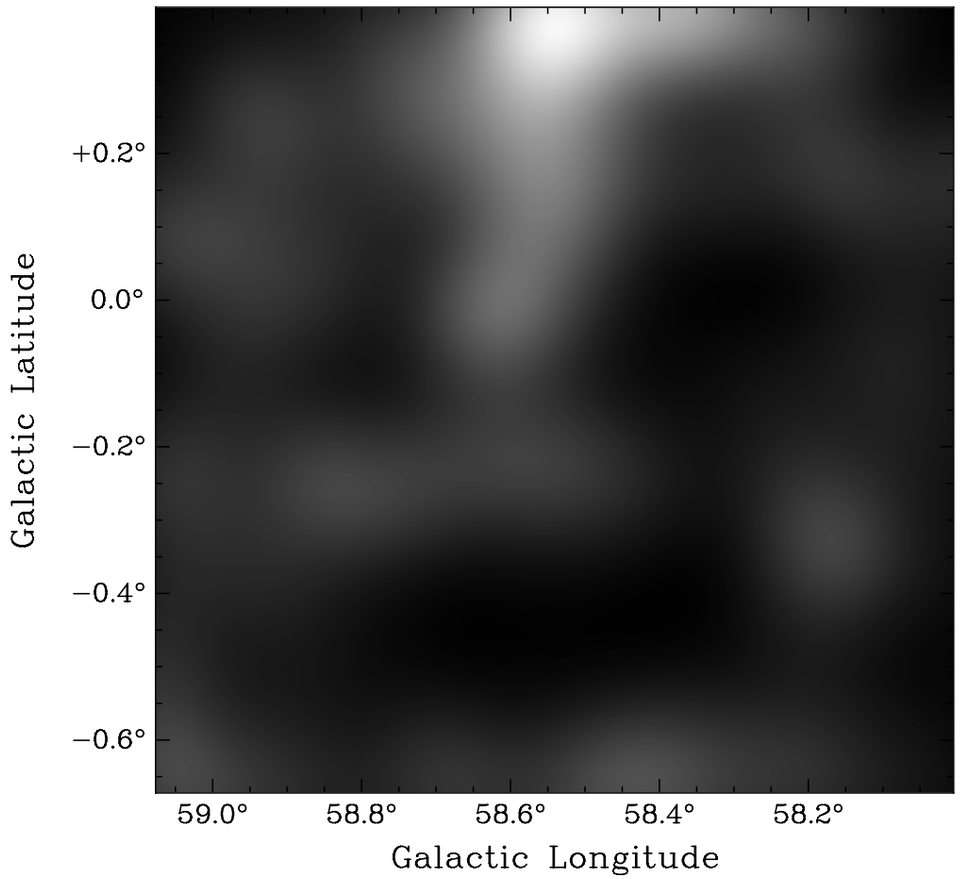


Robitaille, J.-F., Joncas, G., & Miville-Deschênes, M.-A. 2014, MNRAS, 440, 2726

Complex wavelet power spectrum

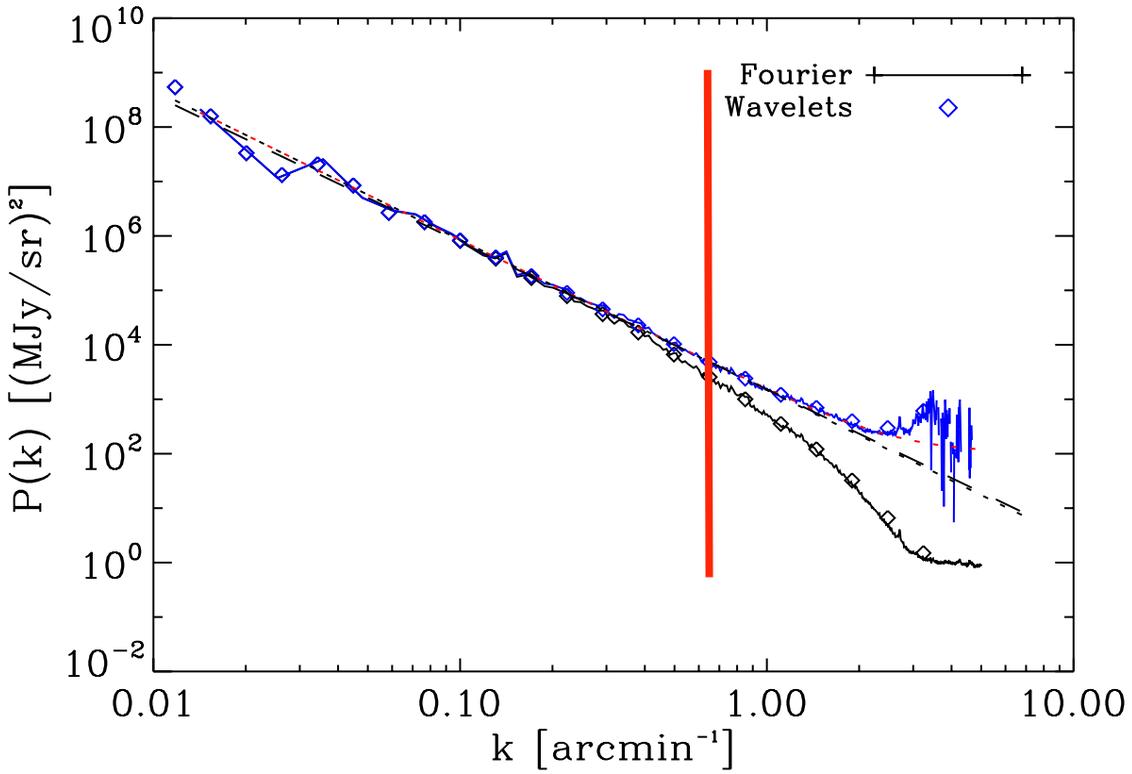


0.17 arcmin^{-1}

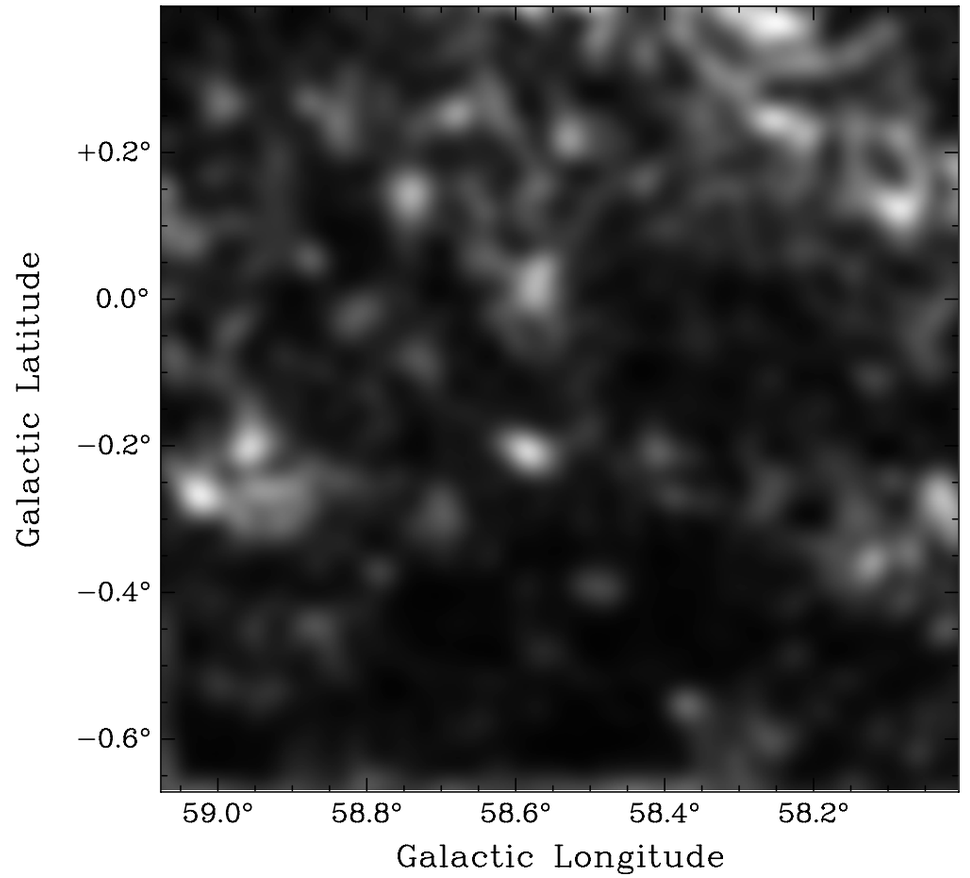


Robitaille, J.-F., Joncas, G., & Miville-Deschênes, M.-A. 2014, MNRAS, 440, 2726

Complex wavelet power spectrum

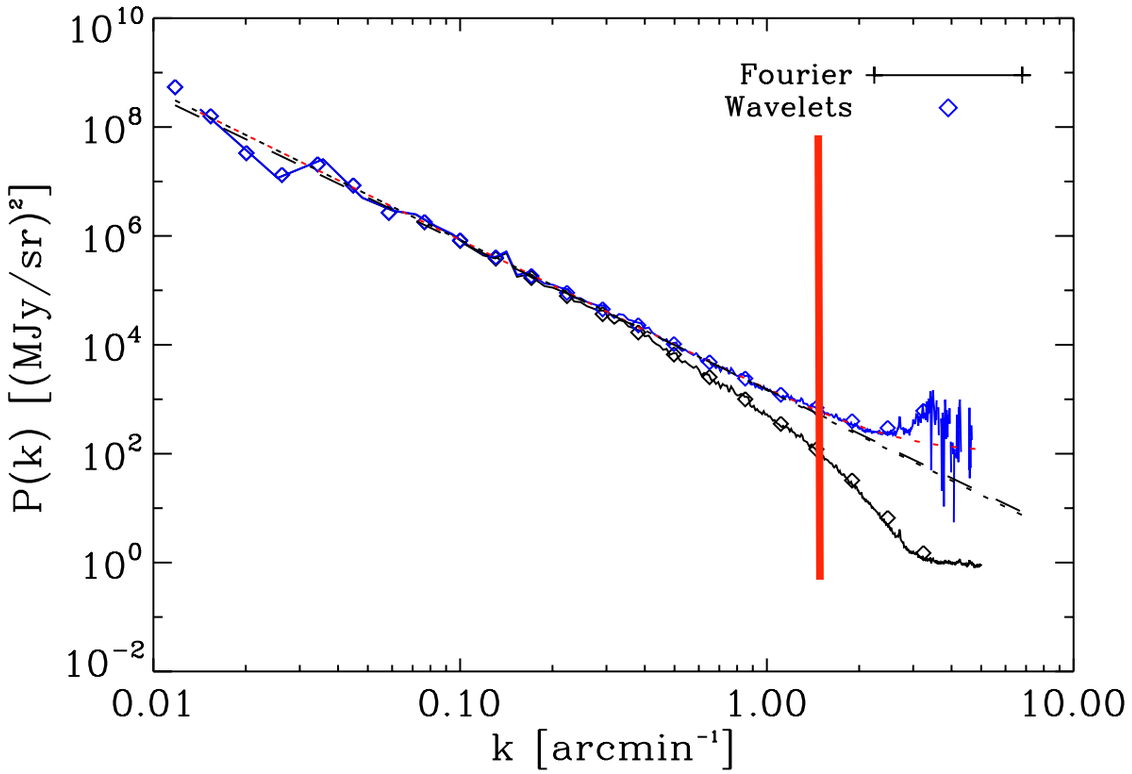


0.65 arcmin^{-1}

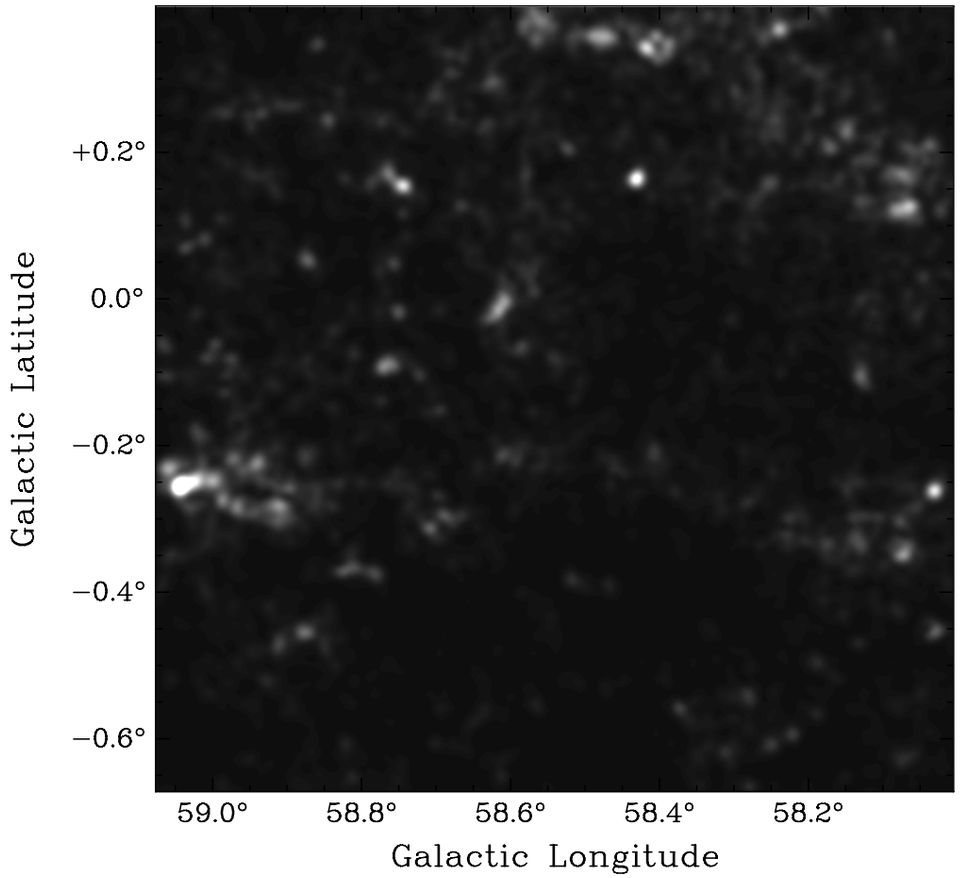


Robitaille, J.-F., Joncas, G., & Miville-Deschênes, M.-A. 2014, MNRAS, 440, 2726

Complex wavelet power spectrum

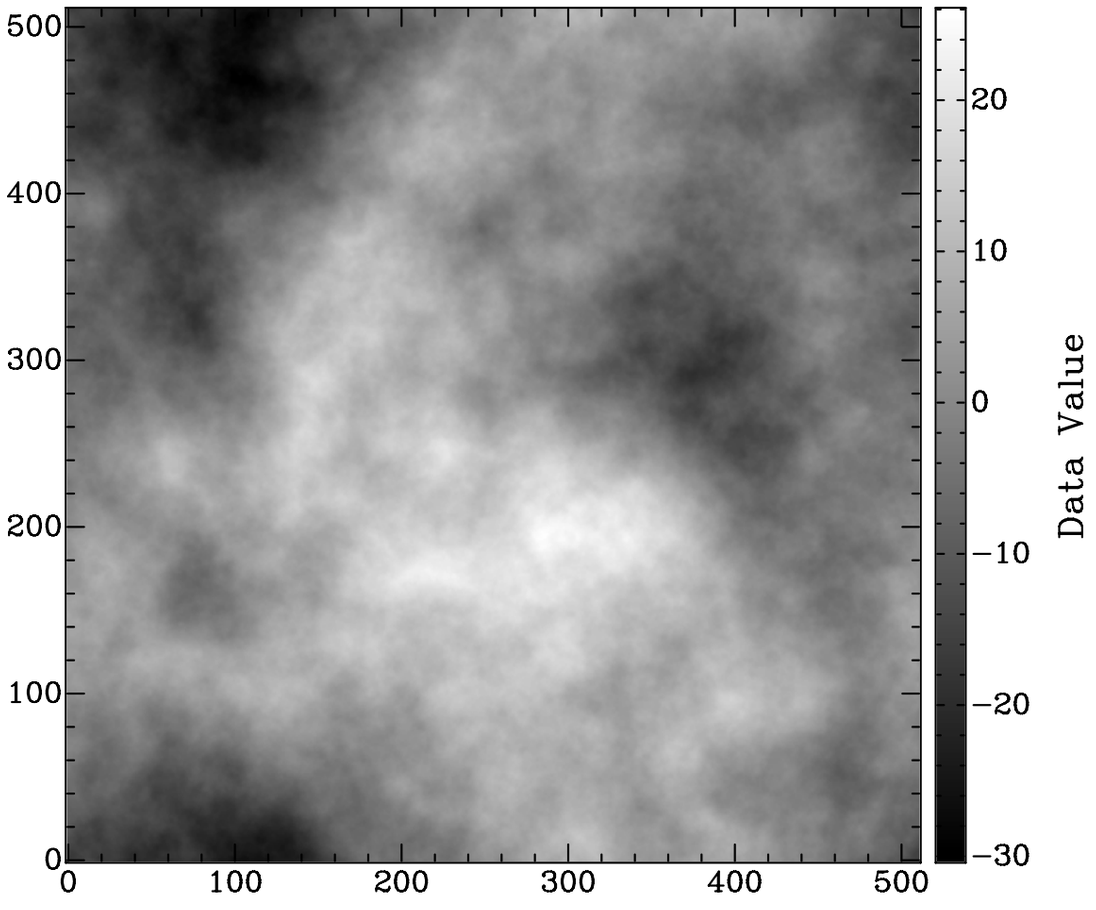


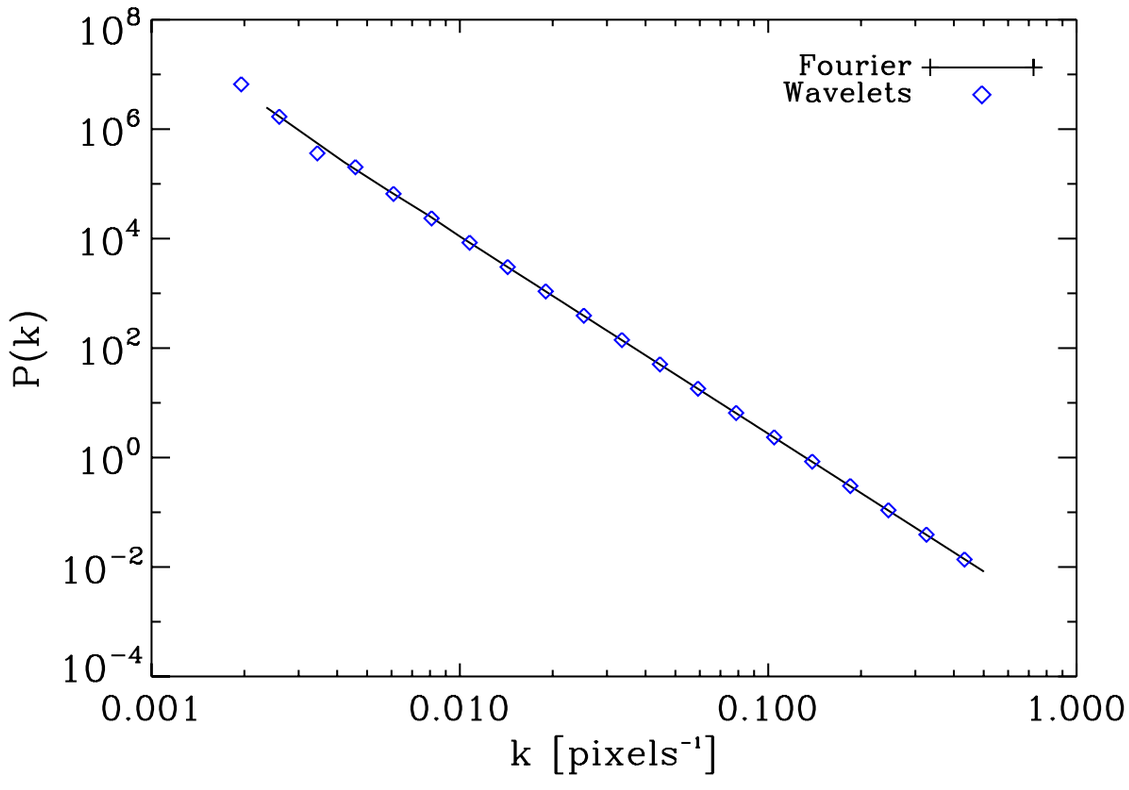
1.45 arcmin^{-1}



Robitaille, J.-F., Joncas, G., & Miville-Deschênes, M.-A. 2014, MNRAS, 440, 2726

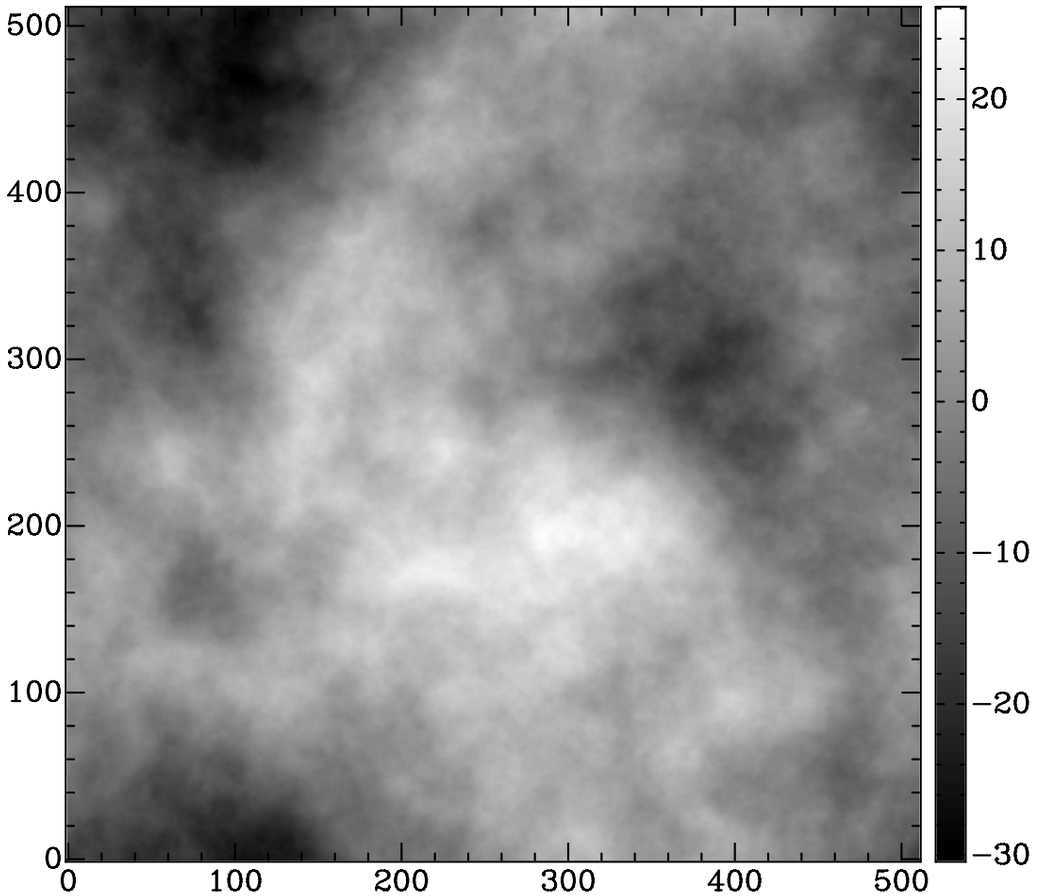
Self-similar distribution



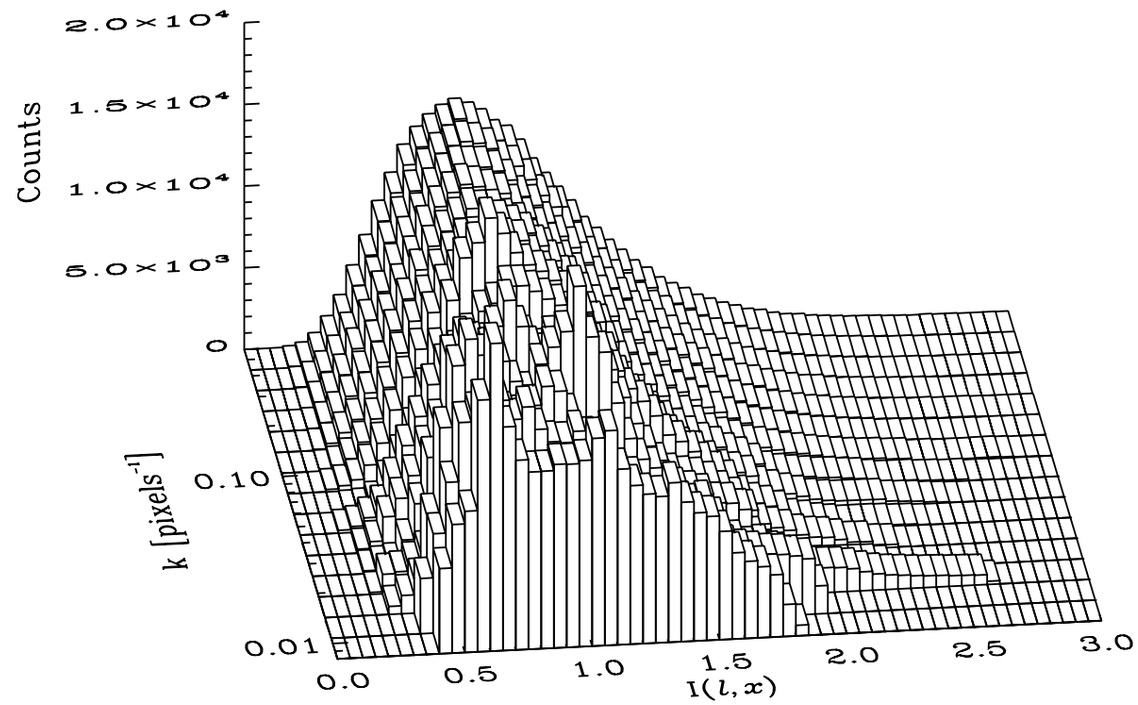


Robitaille, J.-F., Joncas, G., & Miville-Deschênes, M.-A. 2014, MNRAS, 440, 2726

Self-similar distribution

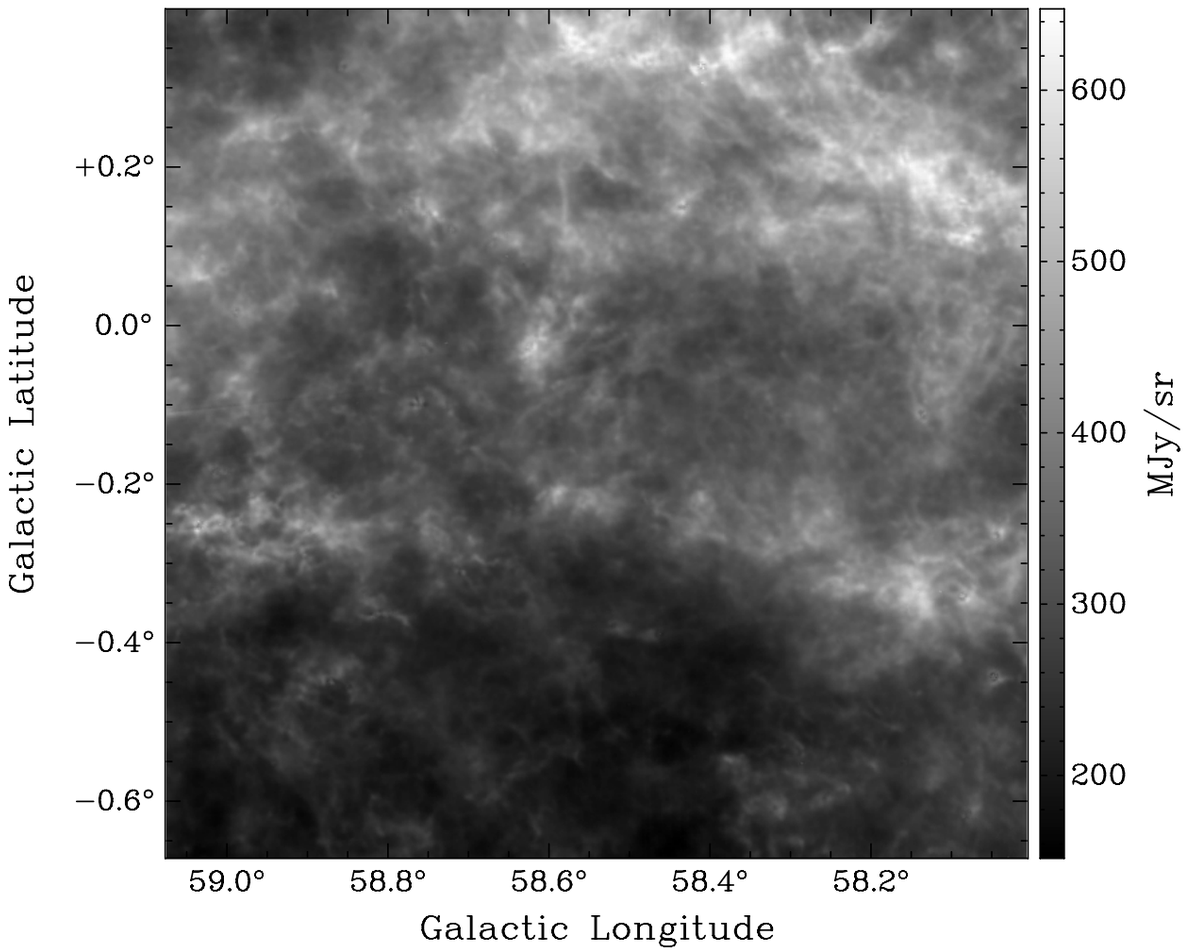


Distribution of the power
as a function of spatial scales

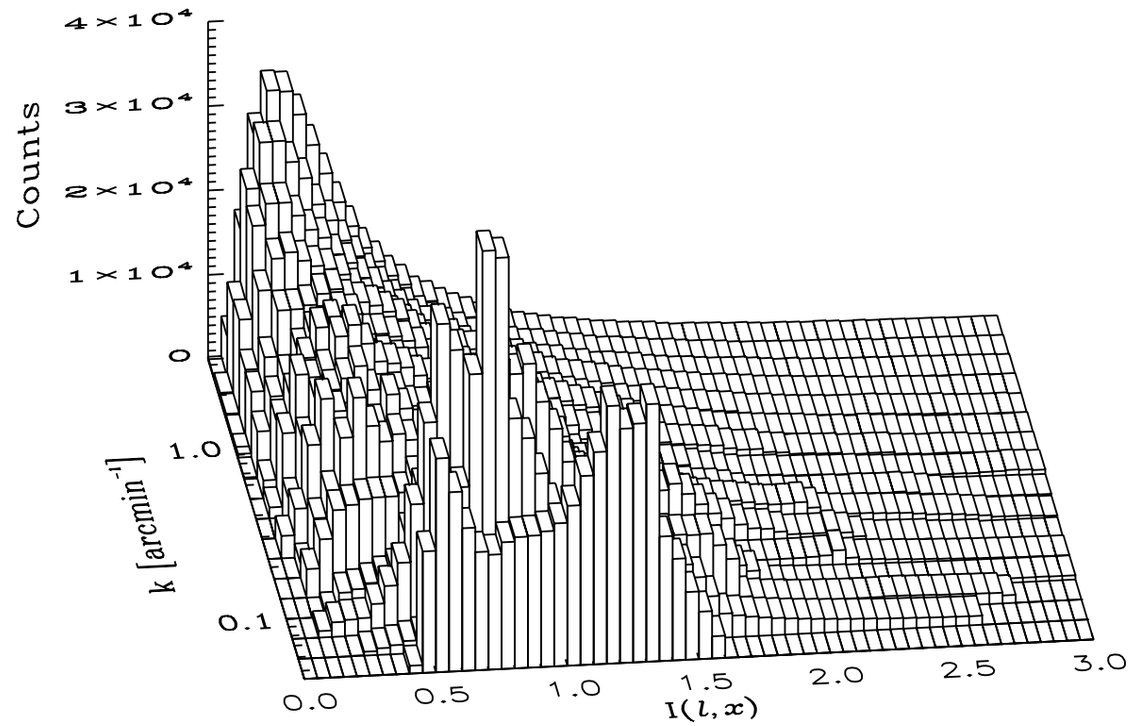


Robitaille, J.-F., Joncas, G., & Miville-Deschênes, M.-A. 2014, MNRAS, 440, 2726

Dust “density” distribution



Distribution of the power
as a function of spatial scales



Robitaille, J.-F., Joncas, G., & Miville-Deschênes, M.-A. 2014, MNRAS, 440, 2726

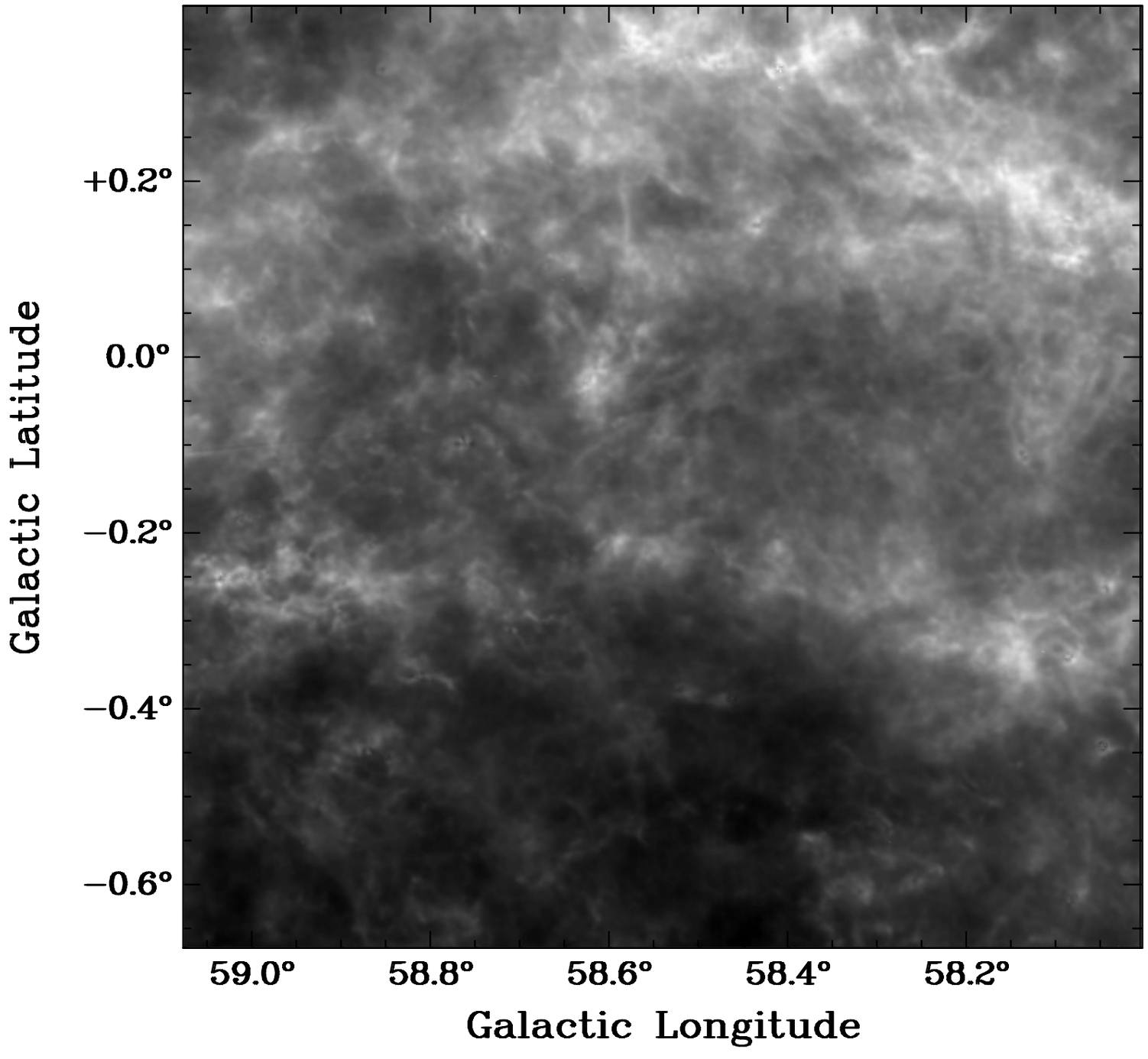
Multi-scale non-Gaussian segmentation

- Excess of power at small scales: high amplitude fluctuations covering a small portion of the field.

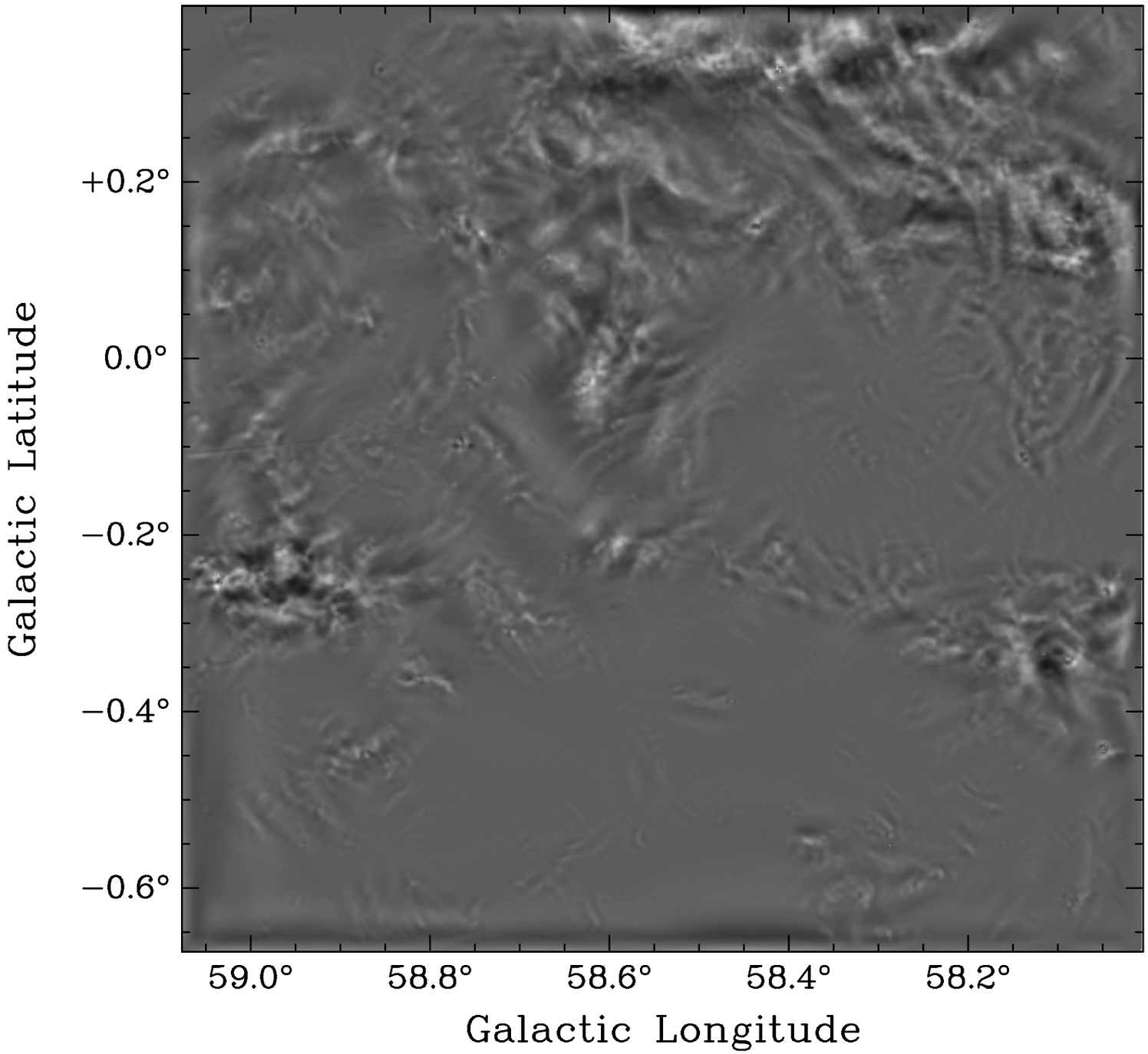
- Segmentation of non-Gaussiannities among wavelet coefficients as a function of the orientation and of the scale (Nguyen van Yen, R., Farge, M., & Schneider, K. 2012, Physica D: Nonlinear Phenomena, 241, 186)

- Image reconstruction from selected wavelet coefficients.

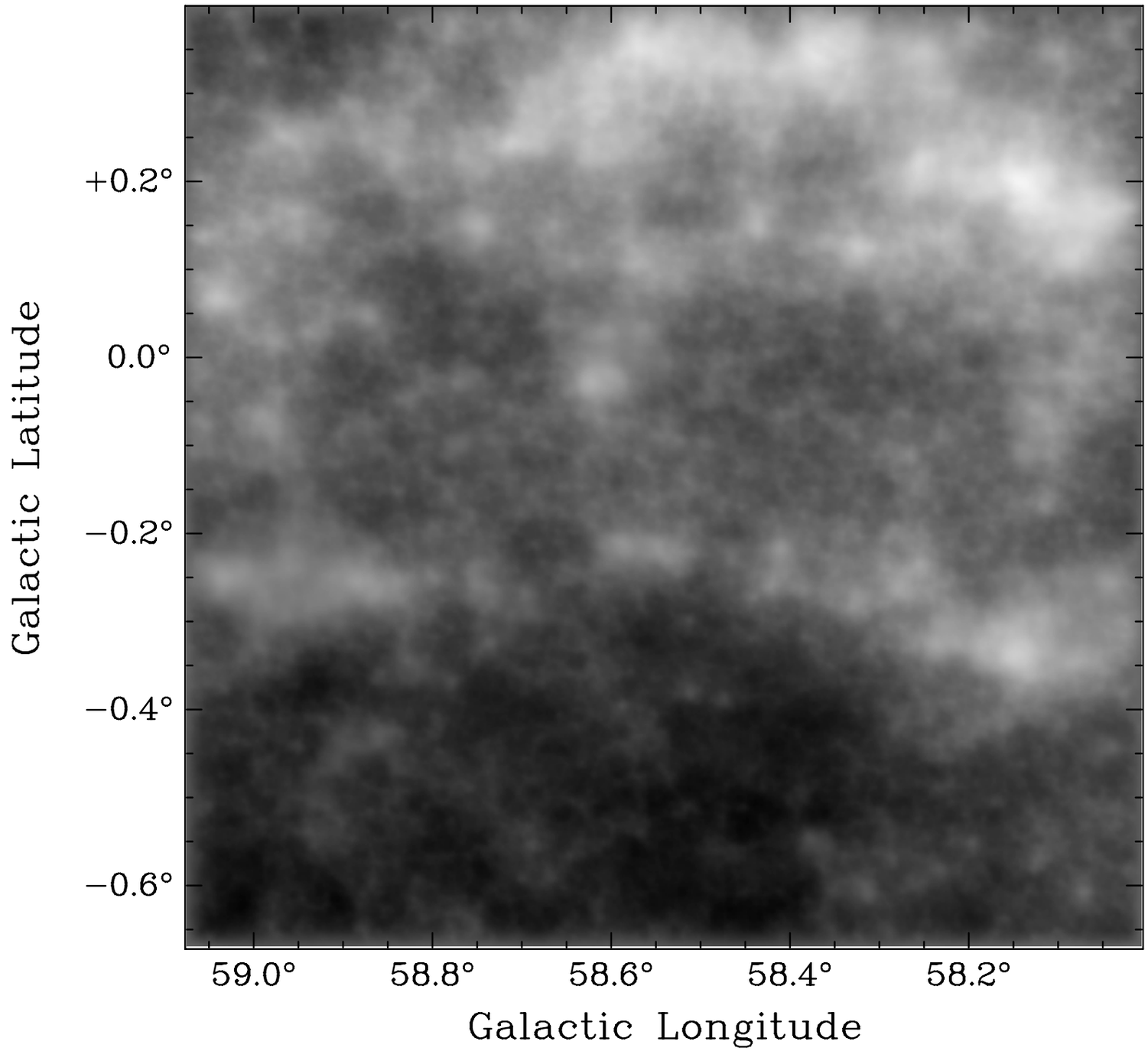
Multi-scale non-Gaussian segmentation



Multi-scale non-Gaussian segmentation

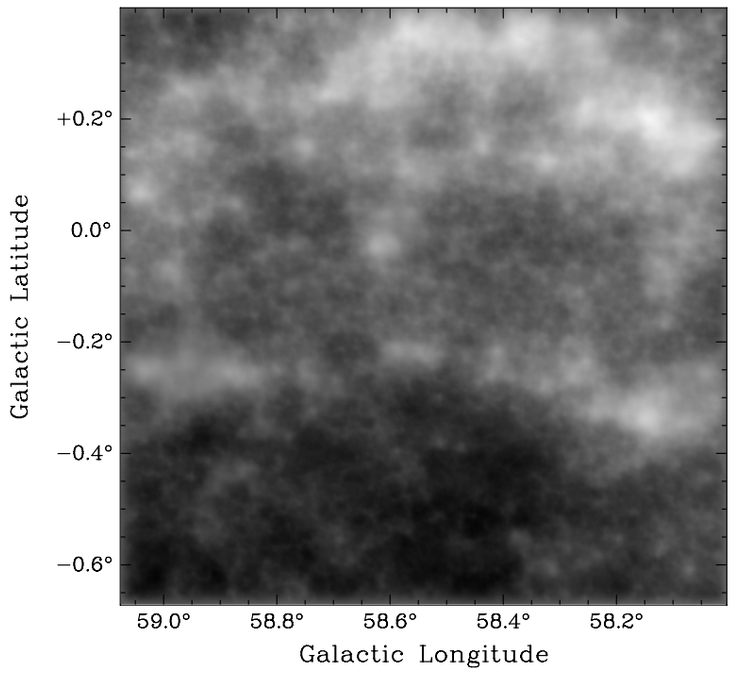


Multi-scale non-Gaussian segmentation

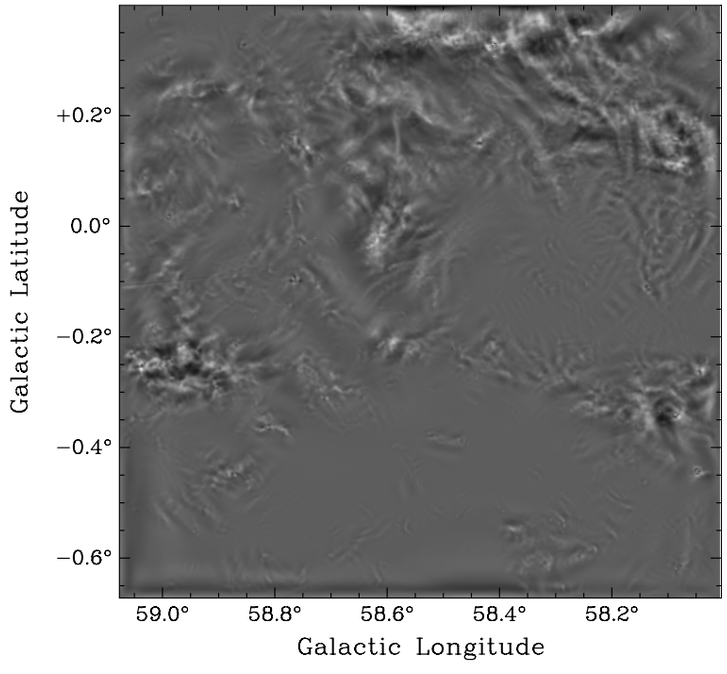


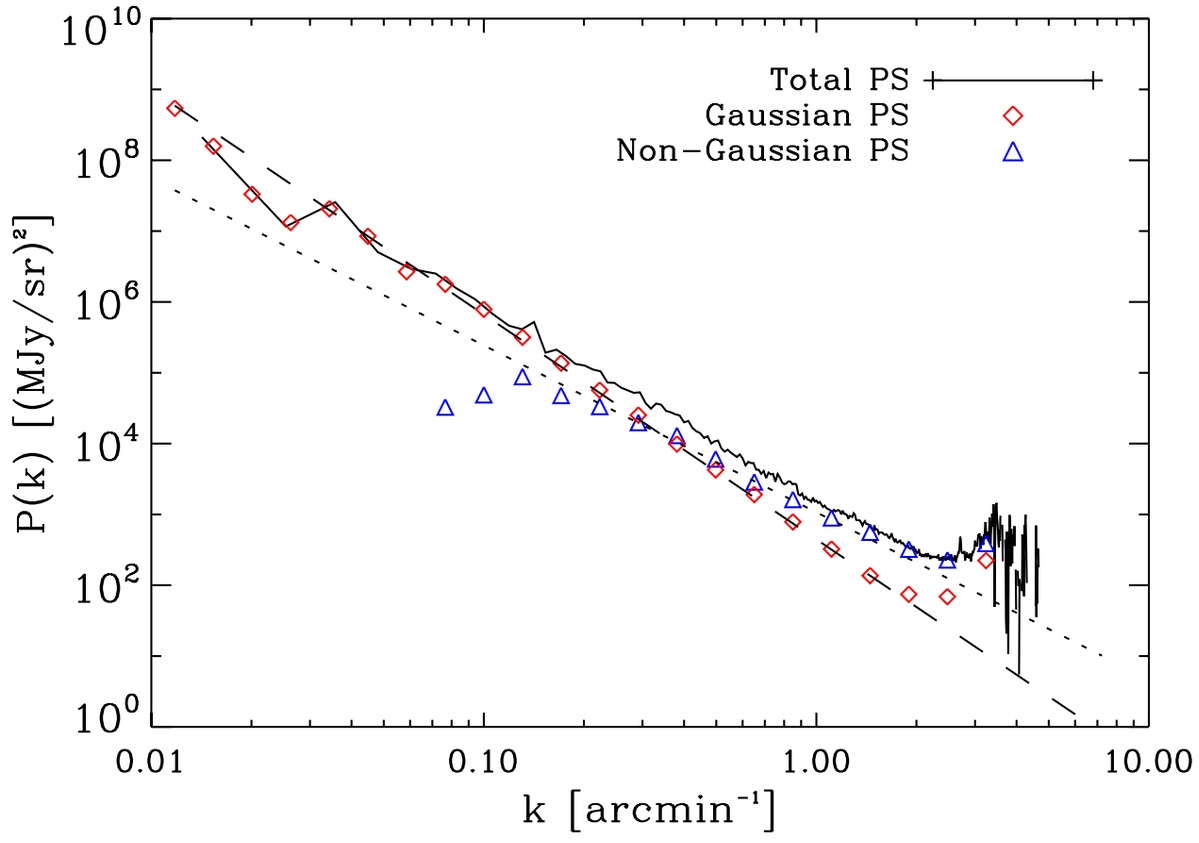
Multi-scale non-Gaussian segmentation

Gaussian



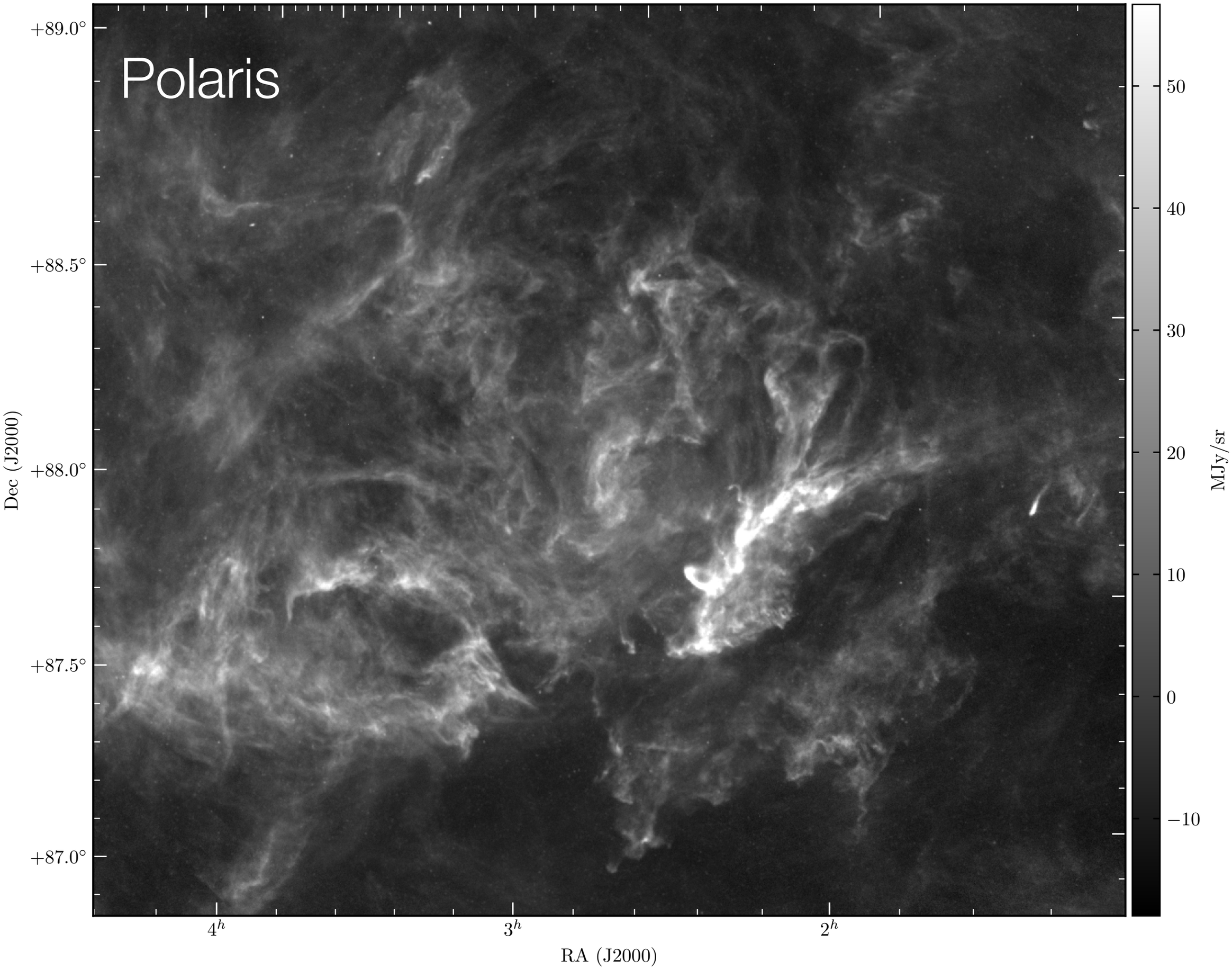
non-Gaussian





$$P(k) = P_0 \cdot k^{-\gamma}$$

	P_0 $(\mathrm{MJy\ sr^{-1}})^2$	Loi de puissance (γ)
Total	$(1.5 \pm 0.08) \times 10^3$	2.70 ± 0.03
Gauss	$(4.4 \pm 0.4) \times 10^2$	3.17 ± 0.05
N-Gauss	$(10.7 \pm 0.8) \times 10^2$	2.35 ± 0.07
^{13}CO	8 ± 1	2.52 ± 0.01


Polaris
+89.0°
+88.5°
+88.0°
+87.5°
+87.0°
Dec (J2000)
4h
3h
2h
RA (J2000)
50
40
30
20
10
0
−10
MJy/sr

Polaris

+89.0°
+88.5°
+88.0°
+87.5°
+87.0°

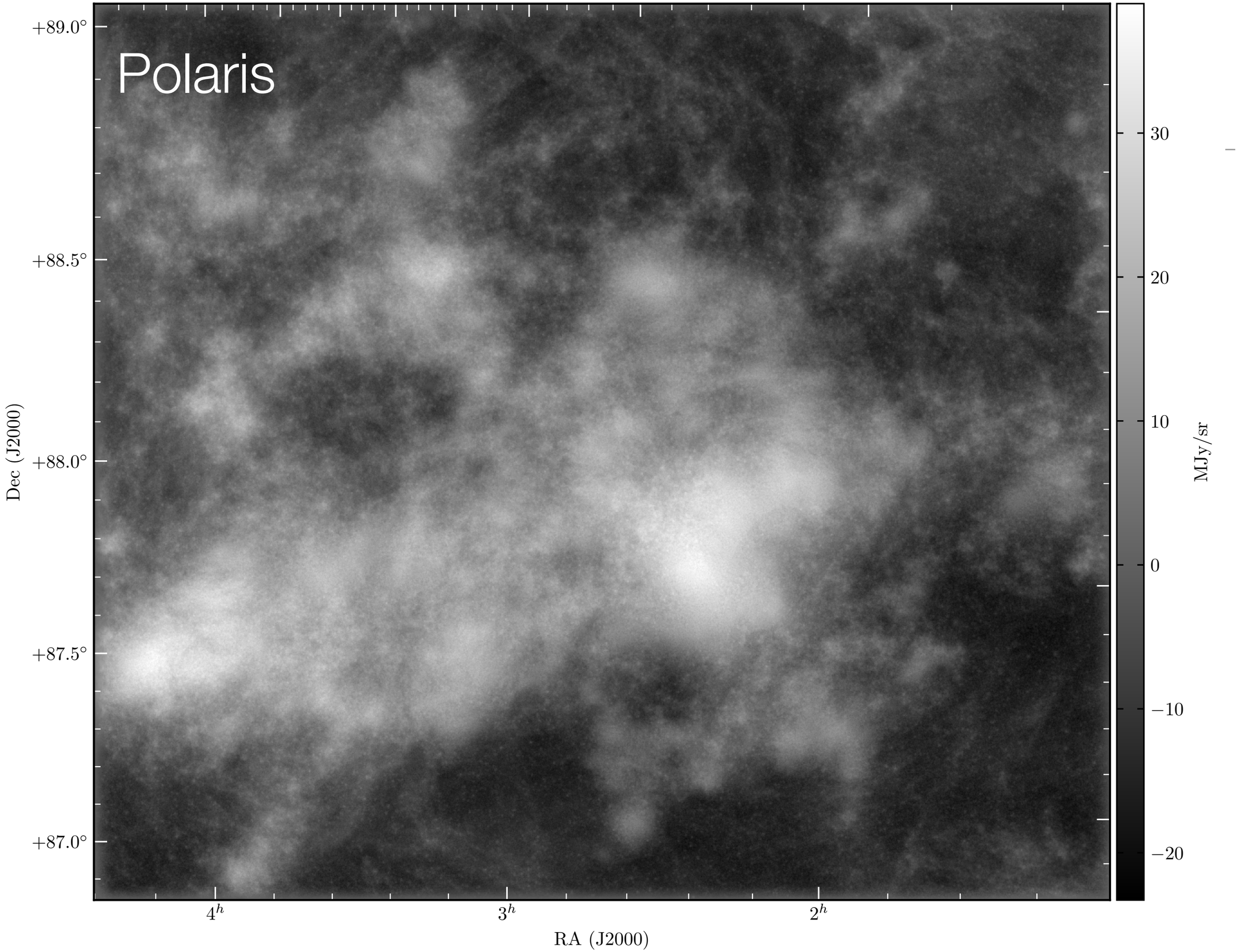
Dec (J2000)

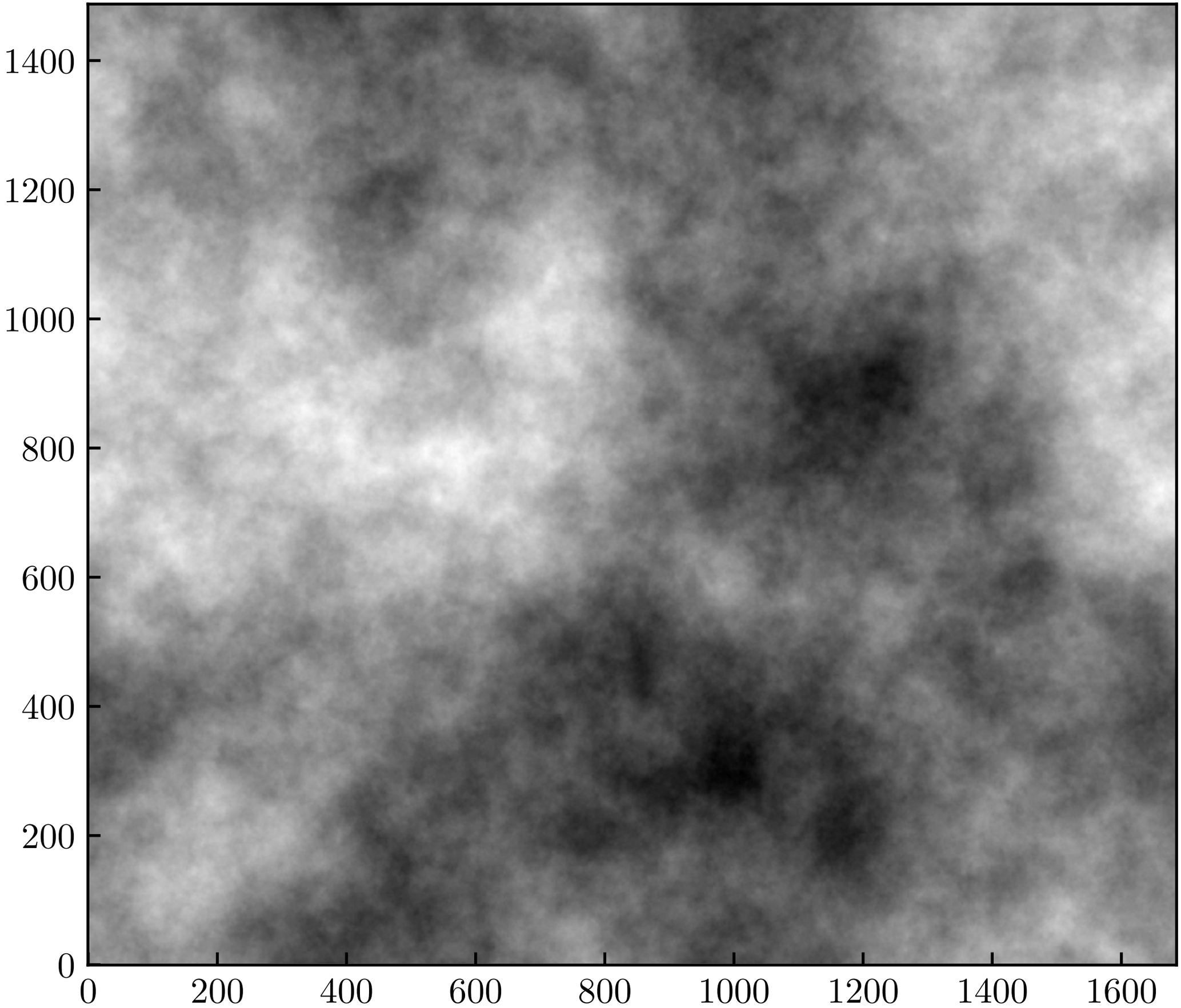
4^h
3^h
2^h

RA (J2000)

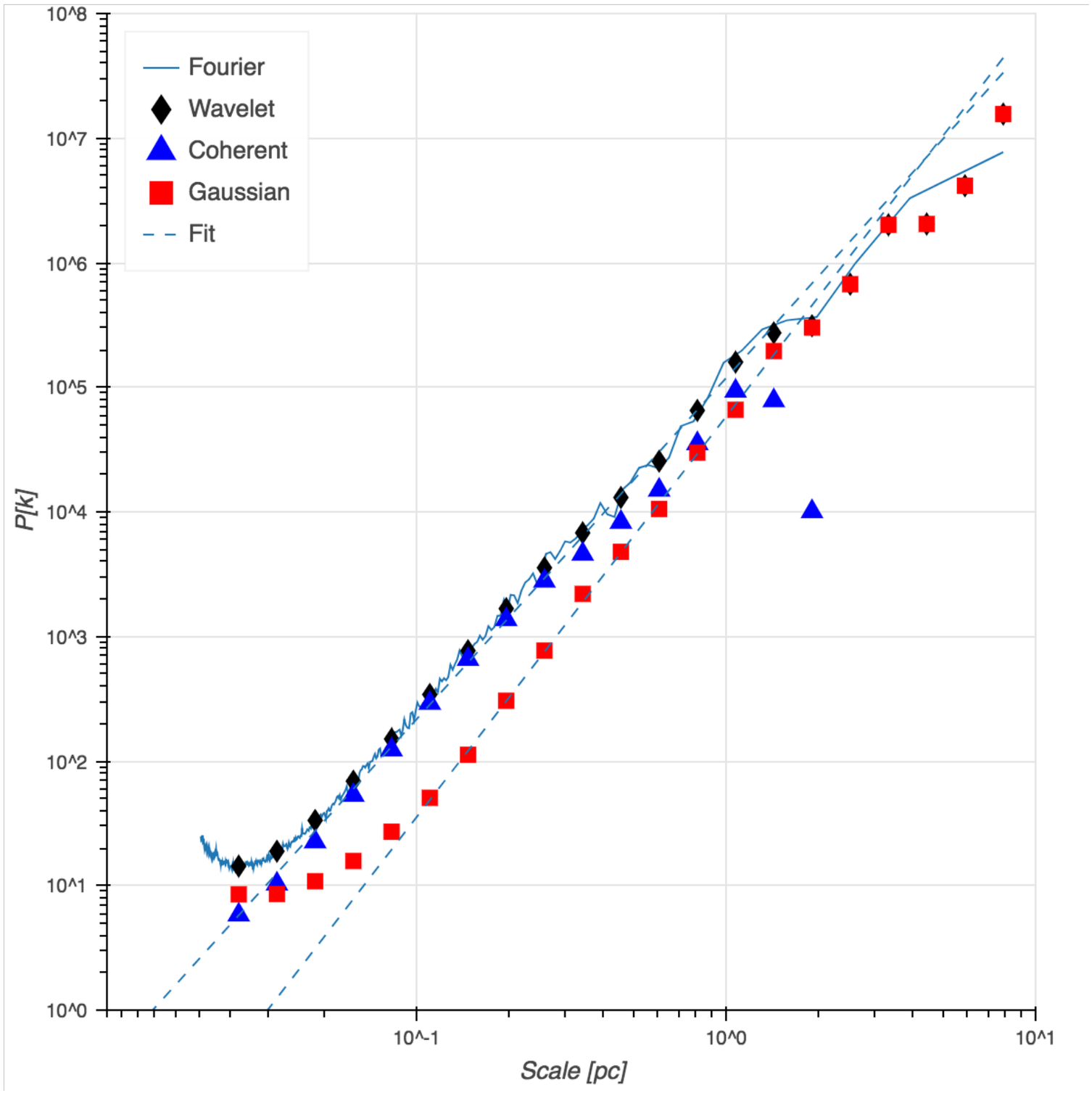
50
40
30
20
10
0
−10
−20

MJy/sr


Polaris
+89.0°
+88.5°
+88.0°
+87.5°
+87.0°
Dec (J2000)
4^h
3^h
2^h
RA (J2000)
30
20
10
0
−10
−20
MJy/sr

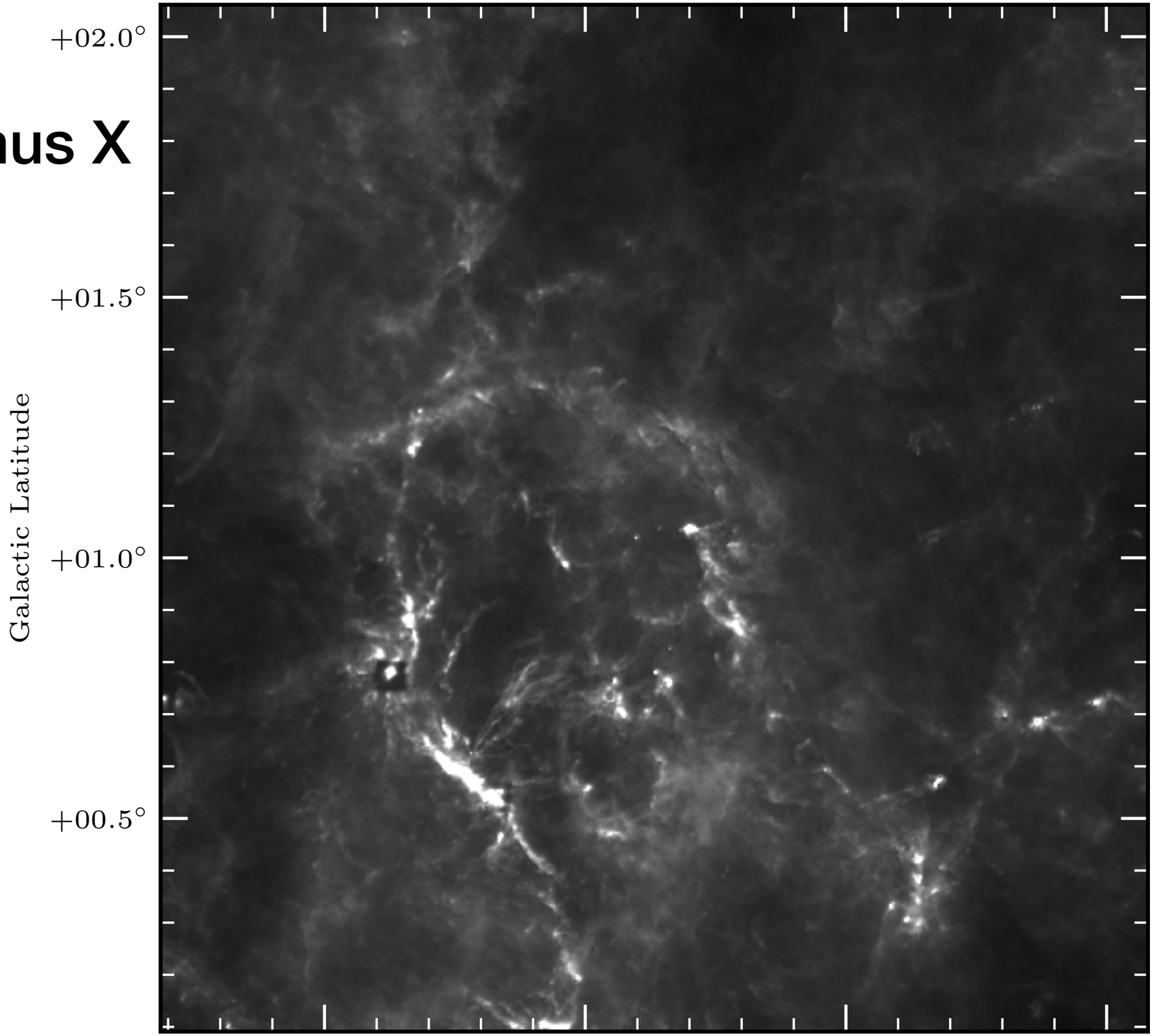

1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
1400
1600

Polaris

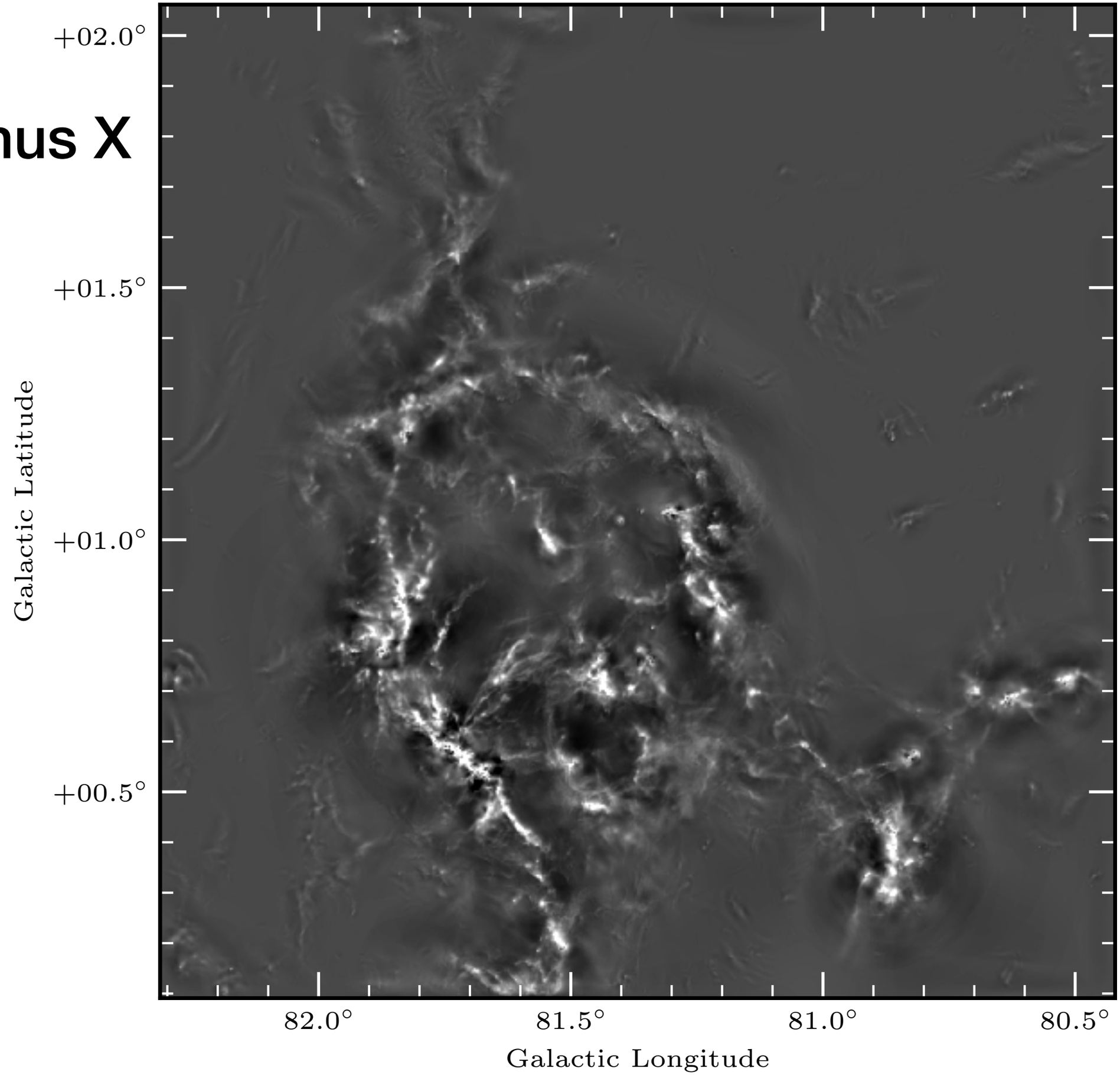


Slopes
Gaussian = 3.22 ± 0.05
Coherent = 2.7 ± 0.1

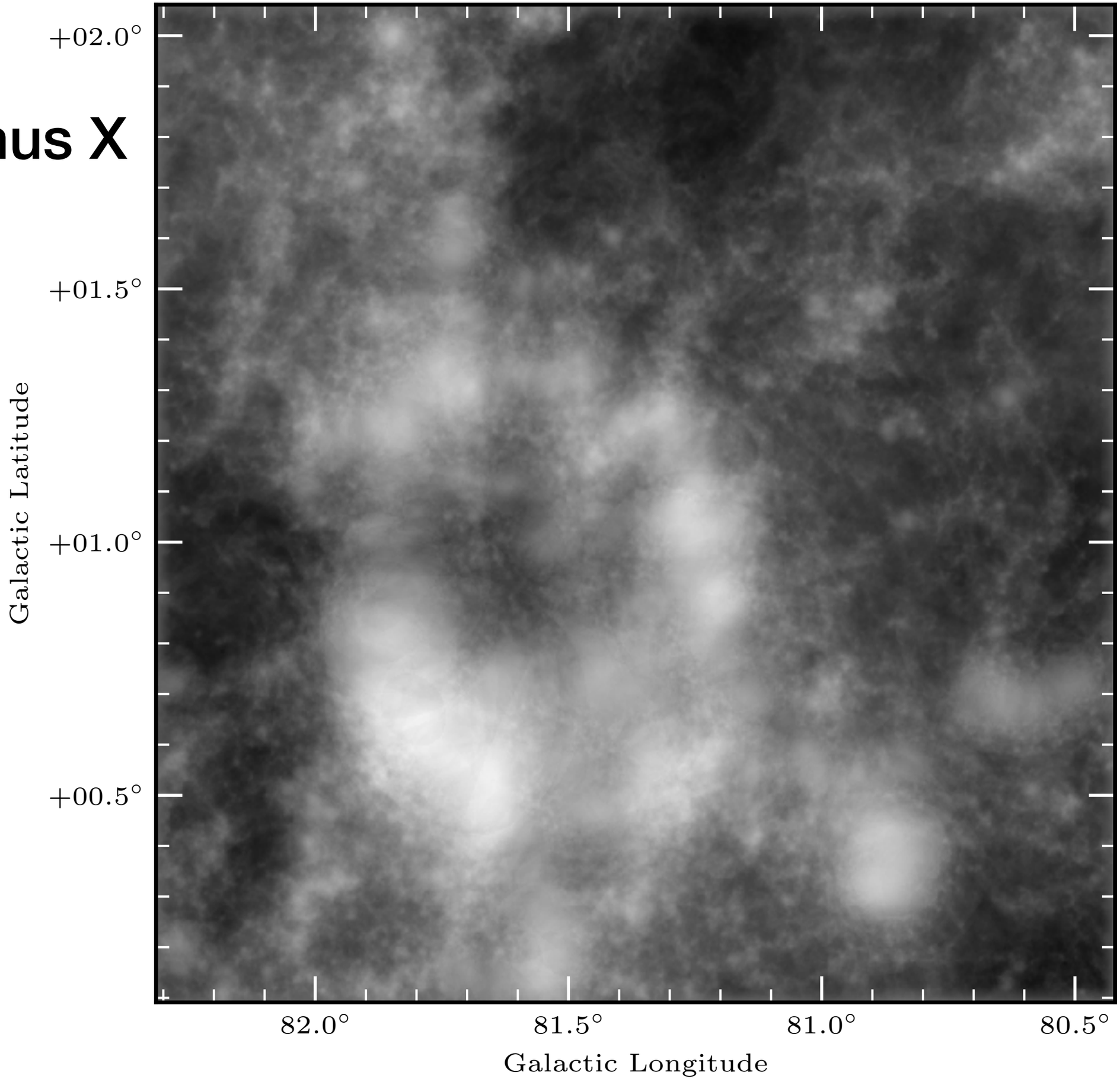
Cygnus X


+02.0°
+01.5°
+01.0°
+00.5°
Galactic Latitude
82.0°
81.5°
81.0°
80.5°
Galactic Longitude

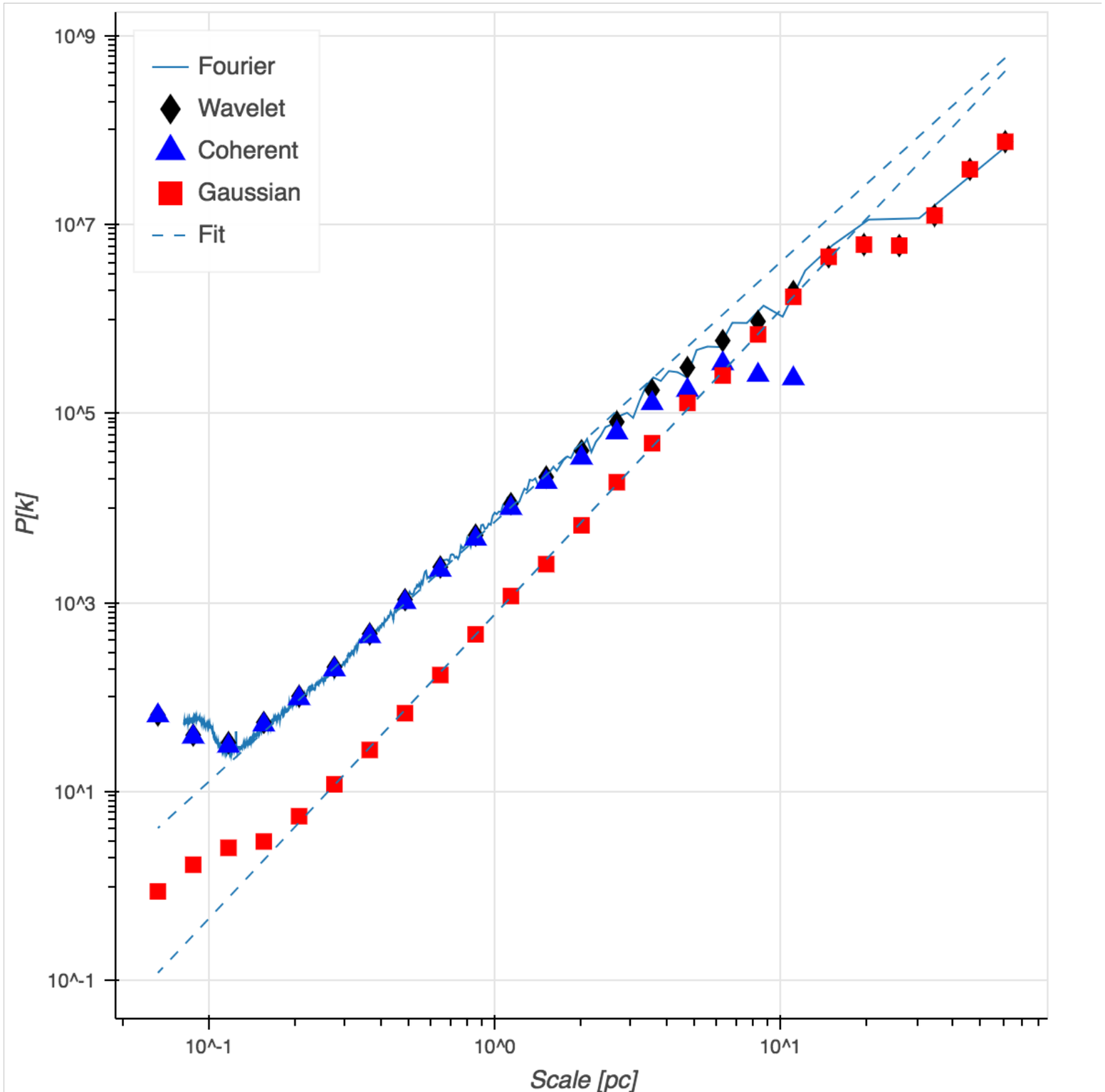
Cygnus X


+02.0°
+01.5°
+01.0°
+00.5°
Galactic Latitude
82.0°
81.5°
81.0°
80.5°
Galactic Longitude

Cygnus X

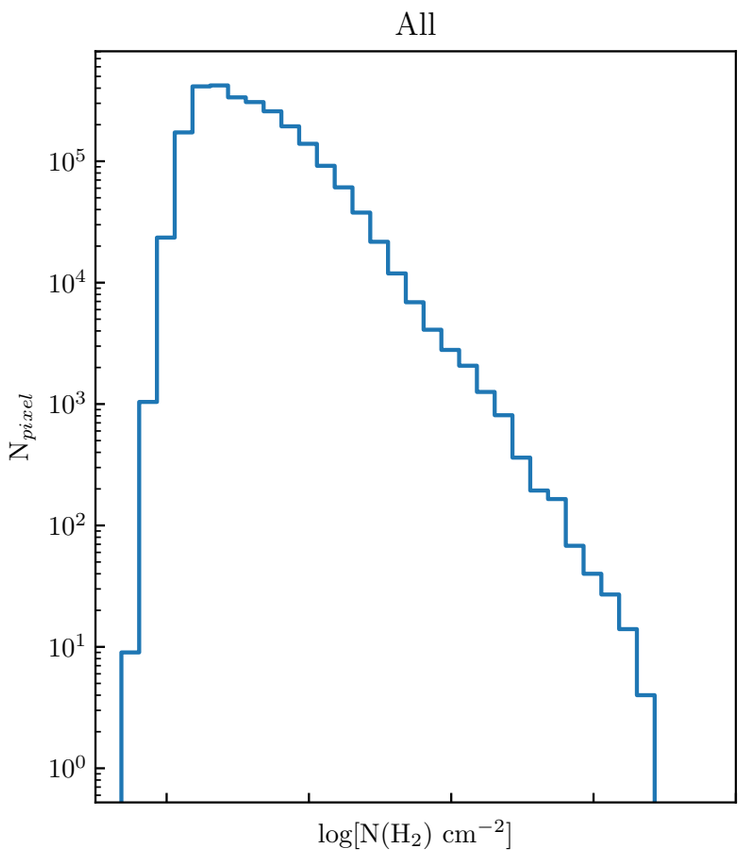

+02.0°
+01.5°
+01.0°
+00.5°
Galactic Latitude
82.0°
81.5°
81.0°
80.5°
Galactic Longitude

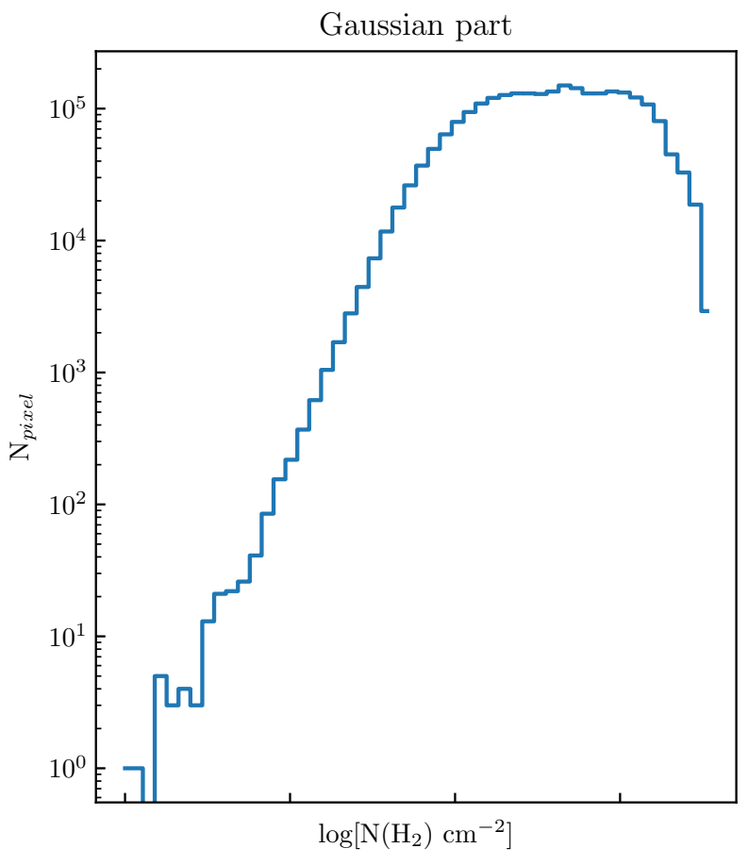
Cygnus X & DR21

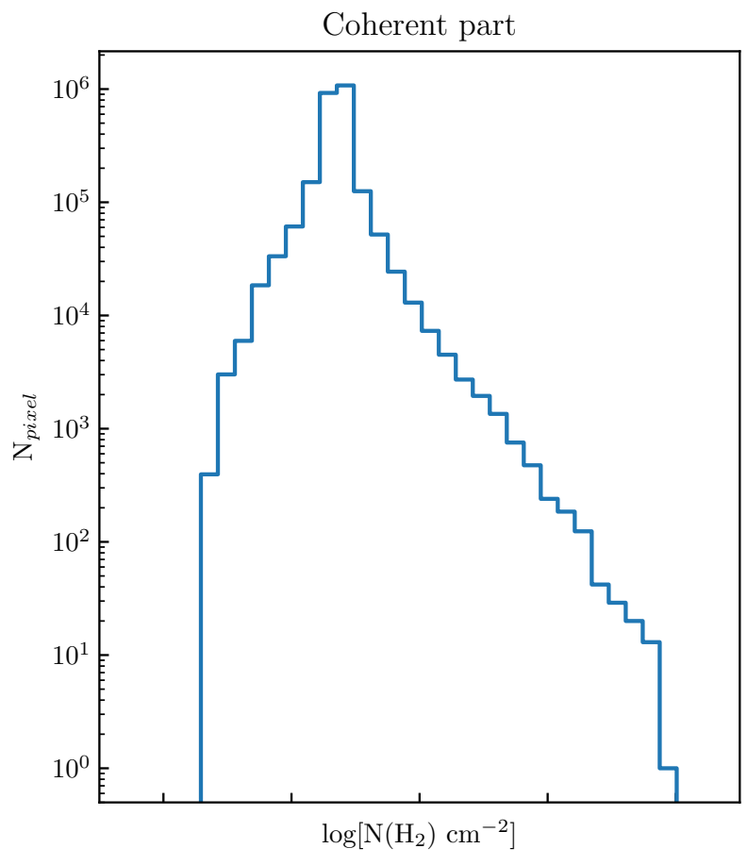


Slopes
Gaussian = 3.22 ± 0.02
Coherent = 2.75 ± 0.03

Polaris PDFs







A&A 584, A111 (2015)
DOI: 10.1051/0004-6361/201526431

Astronomy & Astrophysics

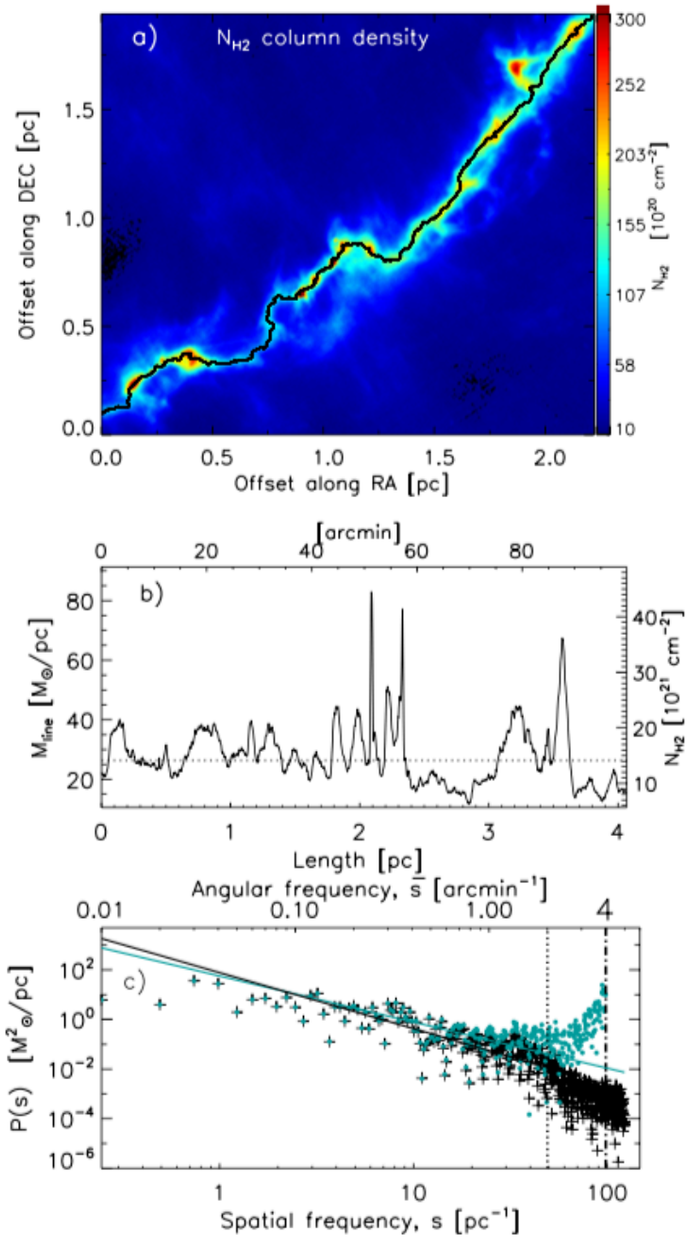
Possible link between the power spectrum of interstellar filaments and the origin of the prestellar core mass function★

A. Roy[1], Ph. André[1], D. Arzoumanian[1,2], N. Peretto[3], P. Palmeirim[1], V. Könyves[1], N. Schneider[1,4], M. Benedettini[5], J. Di Francesco[6,7], D. Elia[5], T. Hill[1,8], B. Ladjelate[1], F. Louvet[9], F. Motte[1], S. Pezzuto[5], E. Schisano[5], Y. Shimajiri[1], L. Spinoglio[5], D. Ward-Thompson[10], and G. White[11,12]

- Through observations, can we reconcile the fact that the CMF/ IMF is determined by local ISM conditions (notably, its density distribution)?

- The complex wavelet analysis allows us to preserve the link between density fluctuations in the diffuse and the dense medium.

- The wavelet power spectrum analysis of dense regions do not assign any morphology to the molecular clouds.



Summary

- From simple assumptions, we can separate the true scale-free component of the ISM.

- This technique naturally extracts filamentary structures associated with star formation from a non-uniform background.

- From this segmentation, power spectrum analysis et PDF analysis of star formation regions can be revisited.

- Possibly link ISM structures to the core mass distribution.