Linear Features & Magnetization in the Diffuse ISM

Joshua E. G. Peek

Space Telescope Science Institute

Columbia University

Mary Putman *Columbia*

Susan Clark *Columbia*

October 10, 2014 *NRAO*

Look up here if you get lost!

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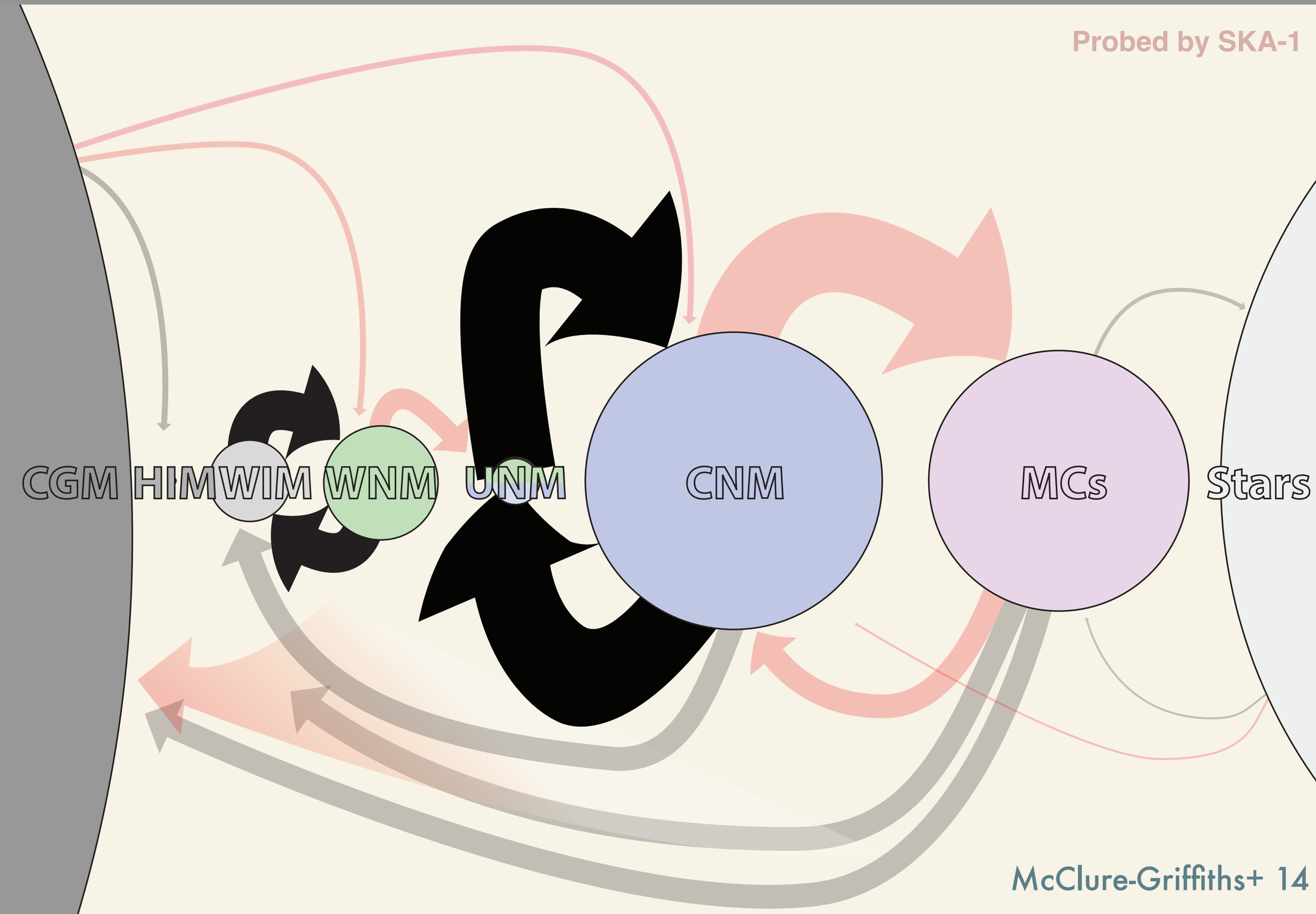
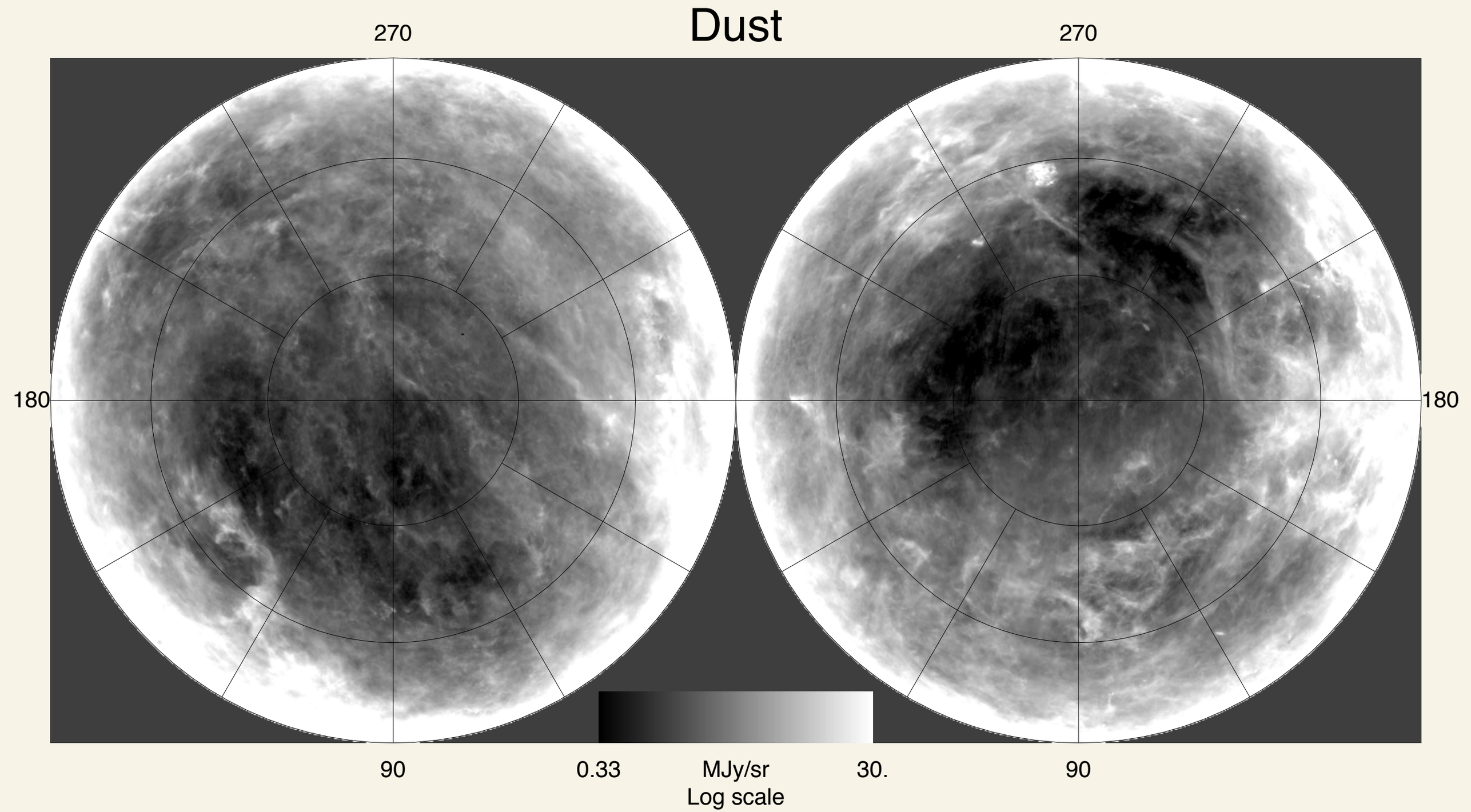
HI is an integral part of the mass cycle of formation

Probed by SKA-1



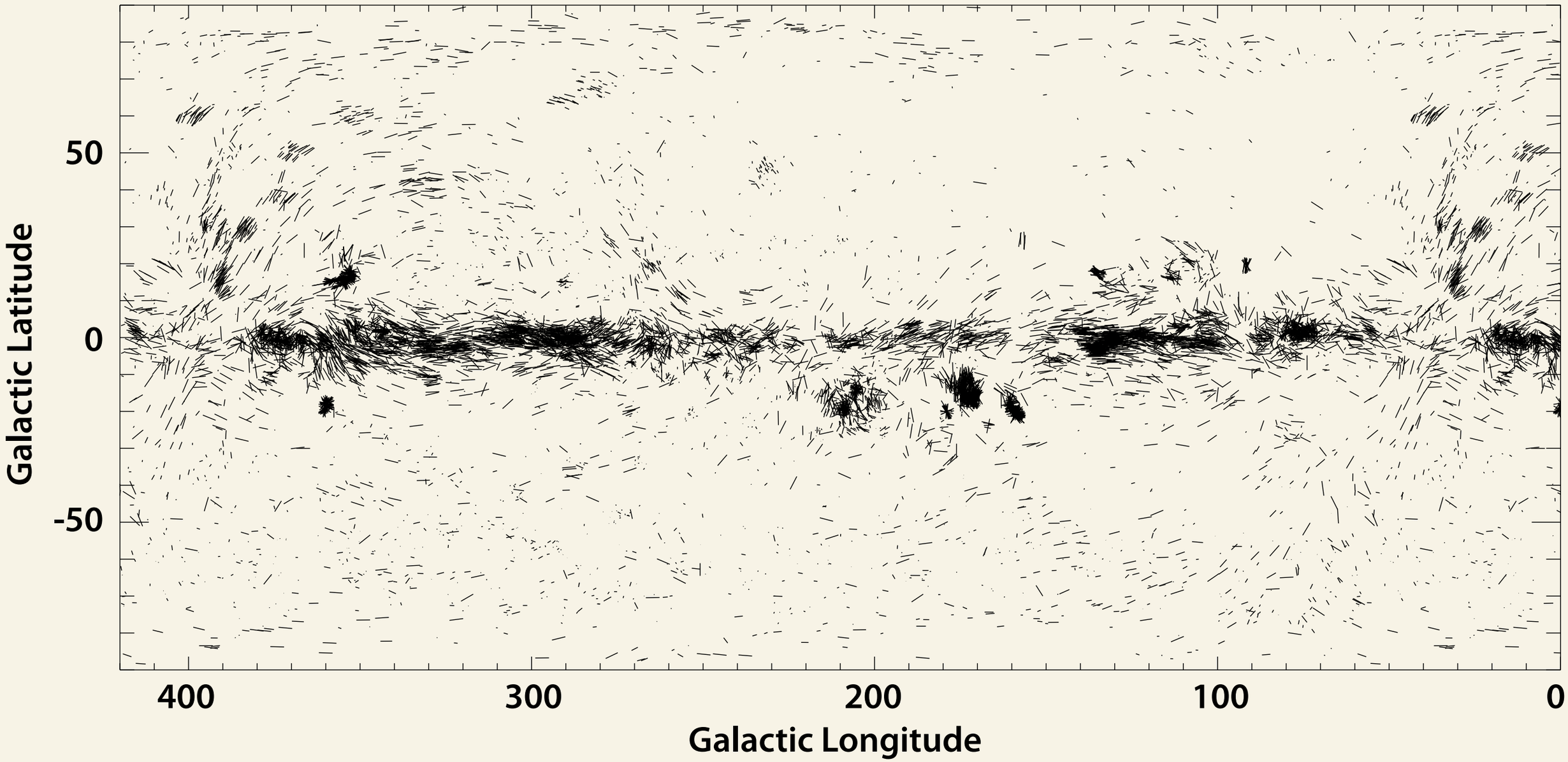
McClure-Griffiths+ 14

The *IRAS* showed us lines in the ISM on large scale



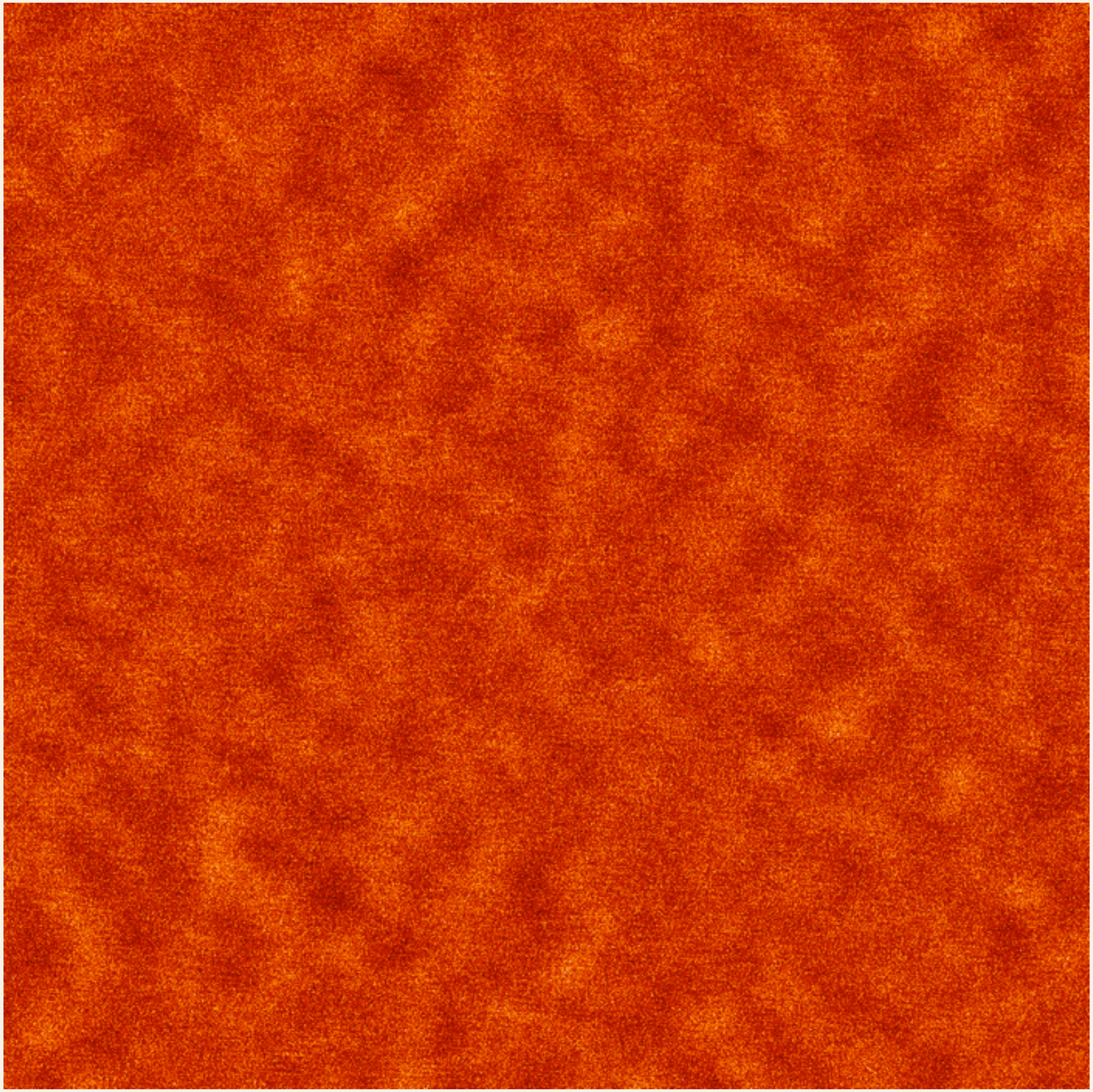
Low 1984; (image Schlegel, Finkbeiner, & Davis 98)

Starlight polarization captures stringy magnetic fields



Heiles 2000; Crutcher & Heiles 2005

Phase information can be ignored in the CMB



SPT

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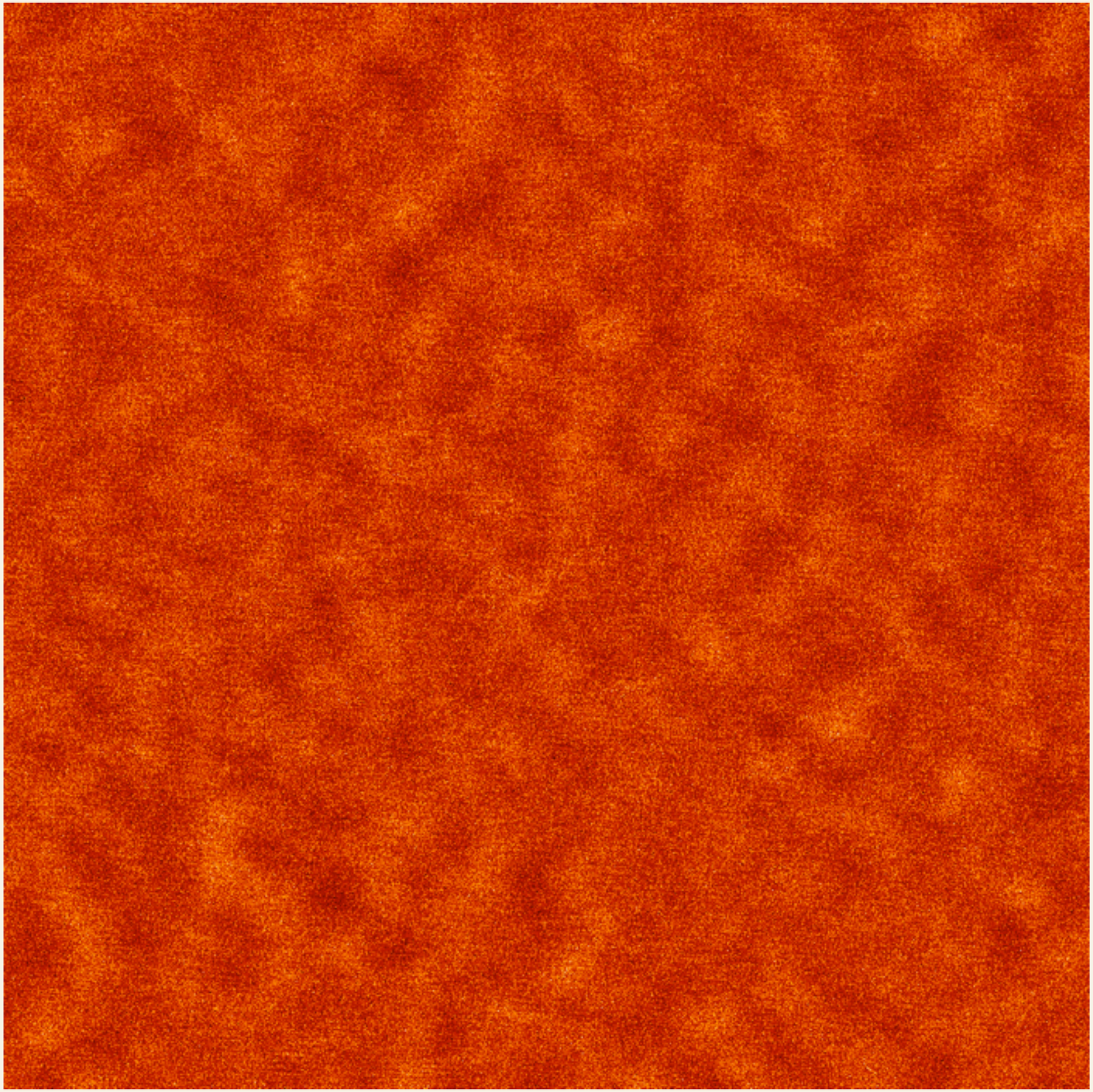

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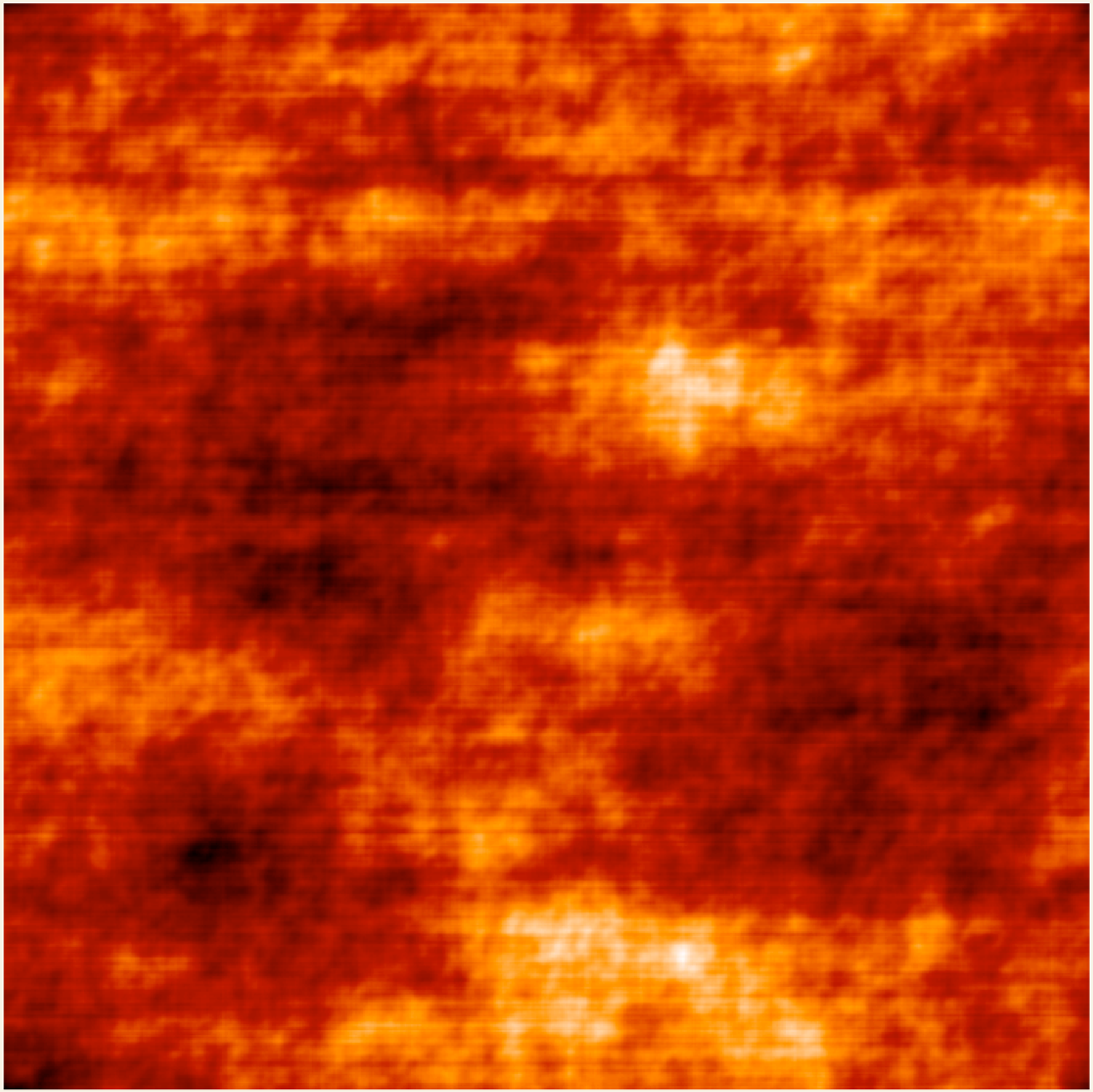
Phase information is a critical in the modern universe



GASS

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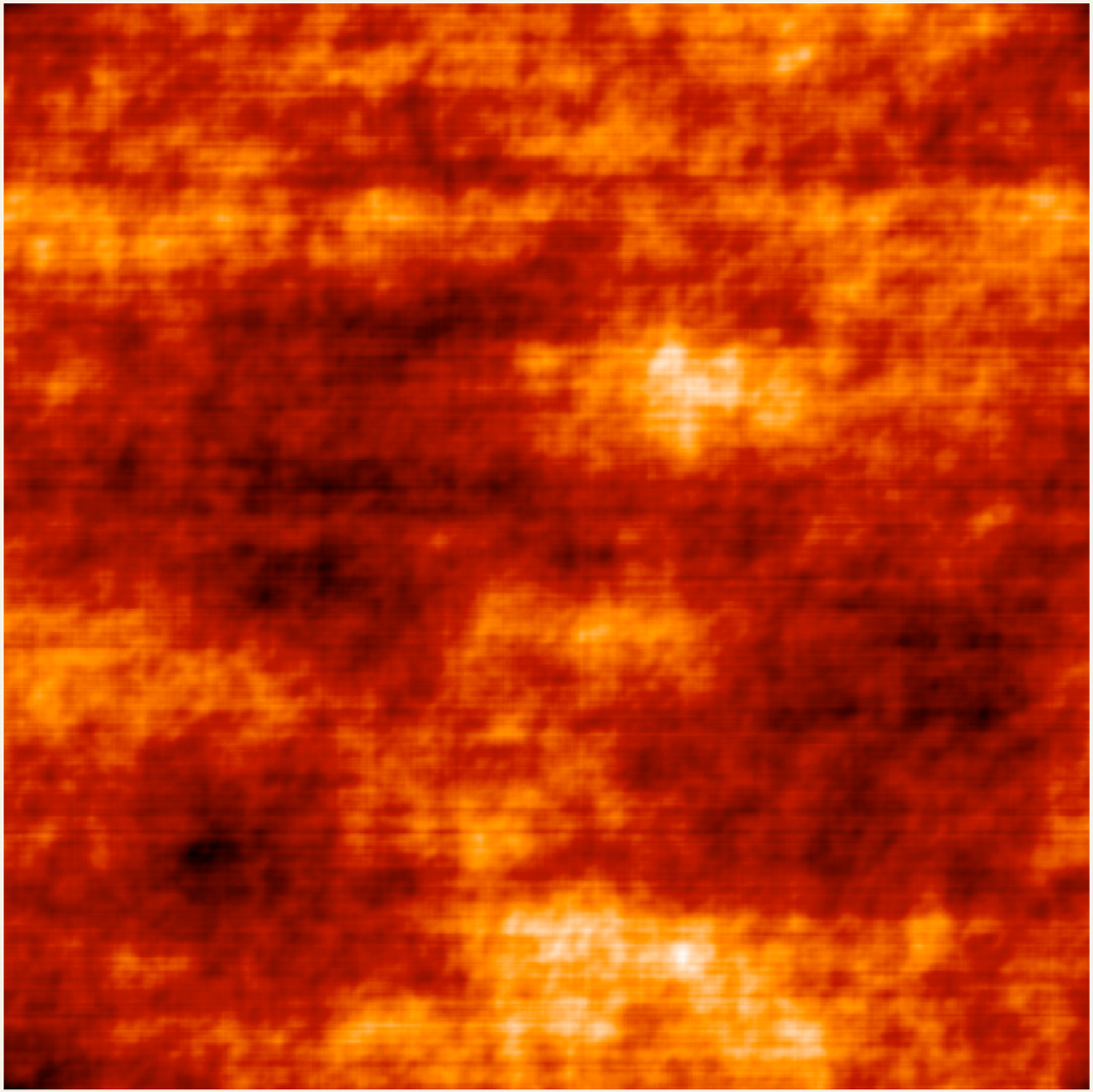
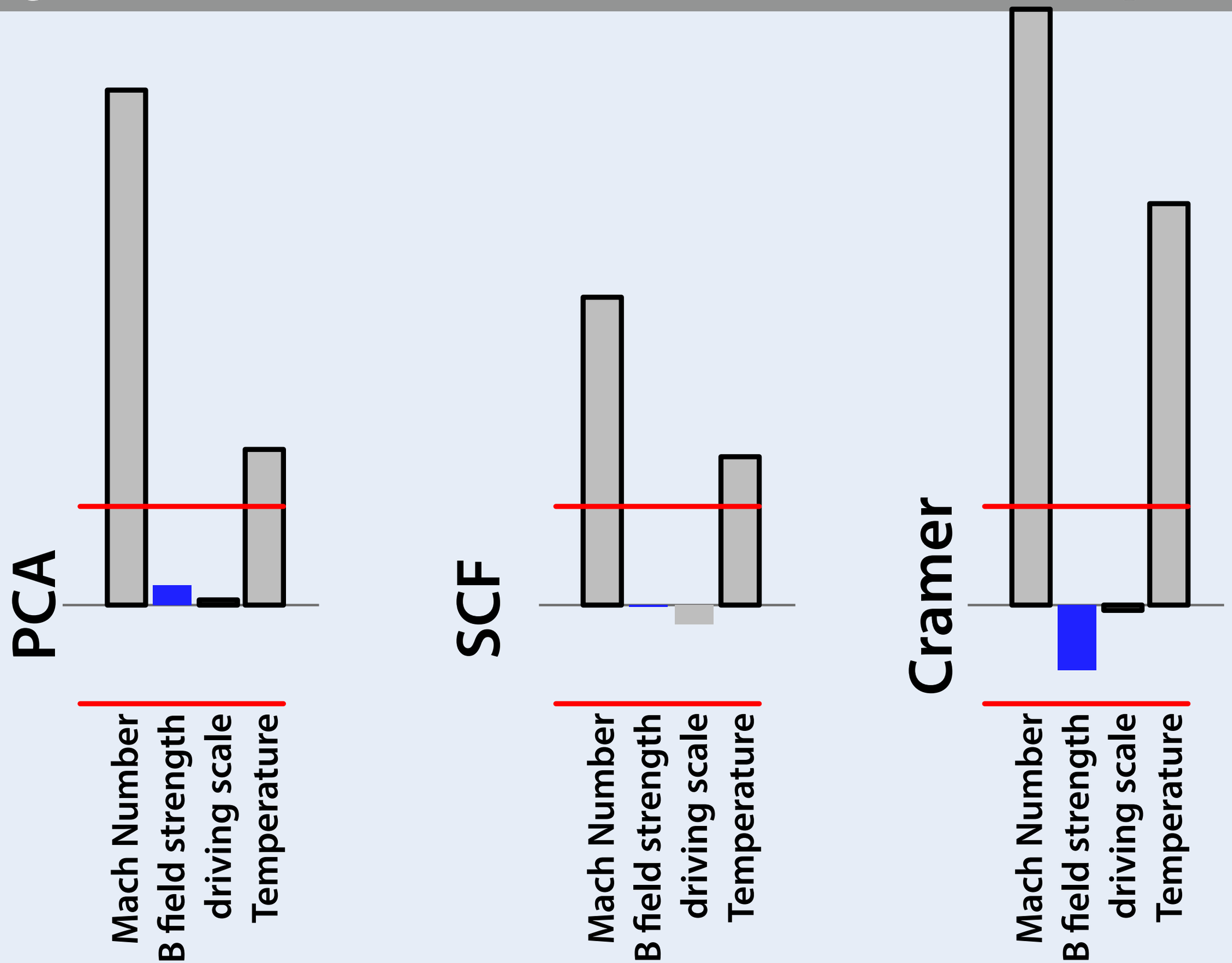


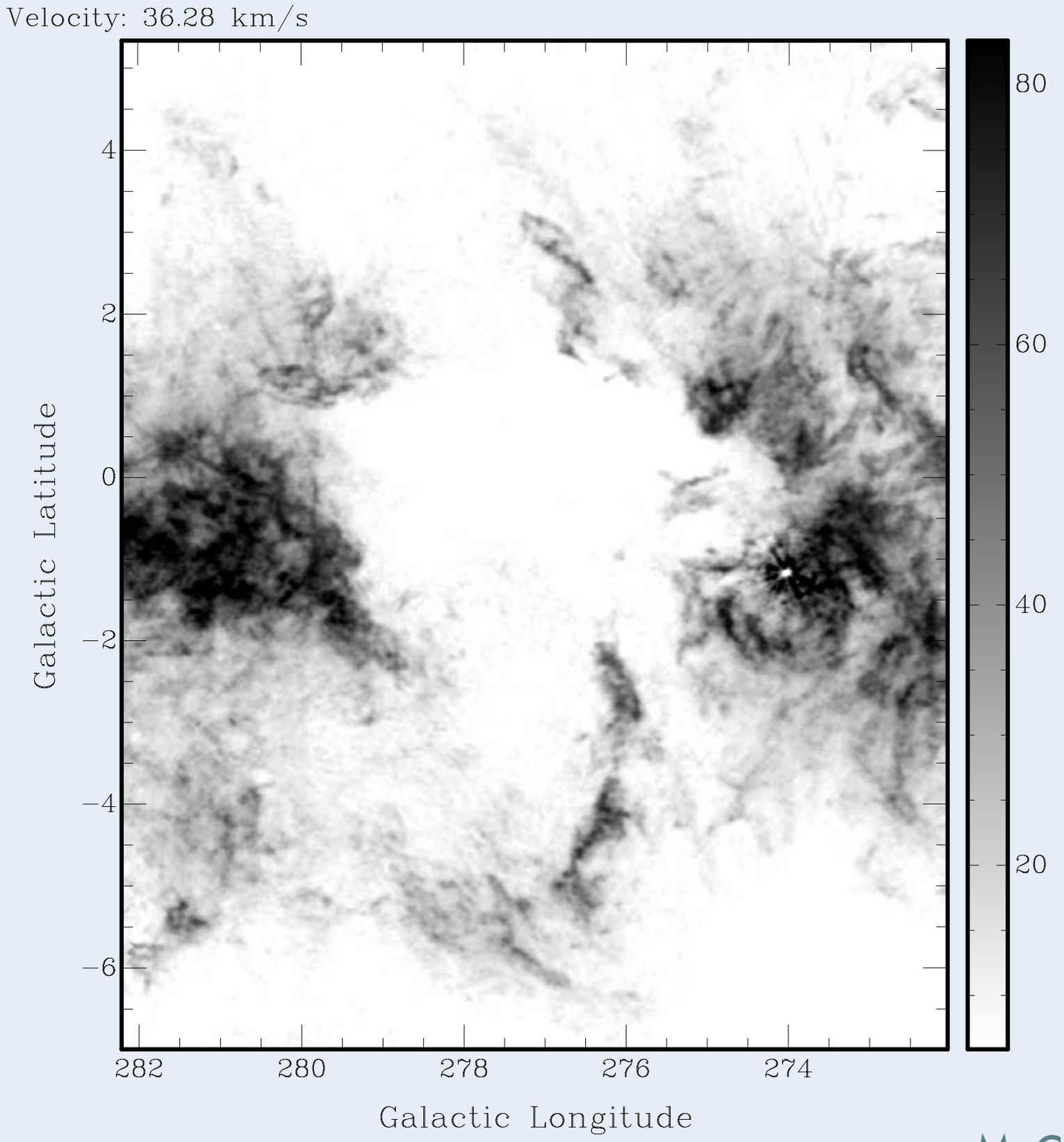
GASS

Magnetic fields are hard to measure without shape info



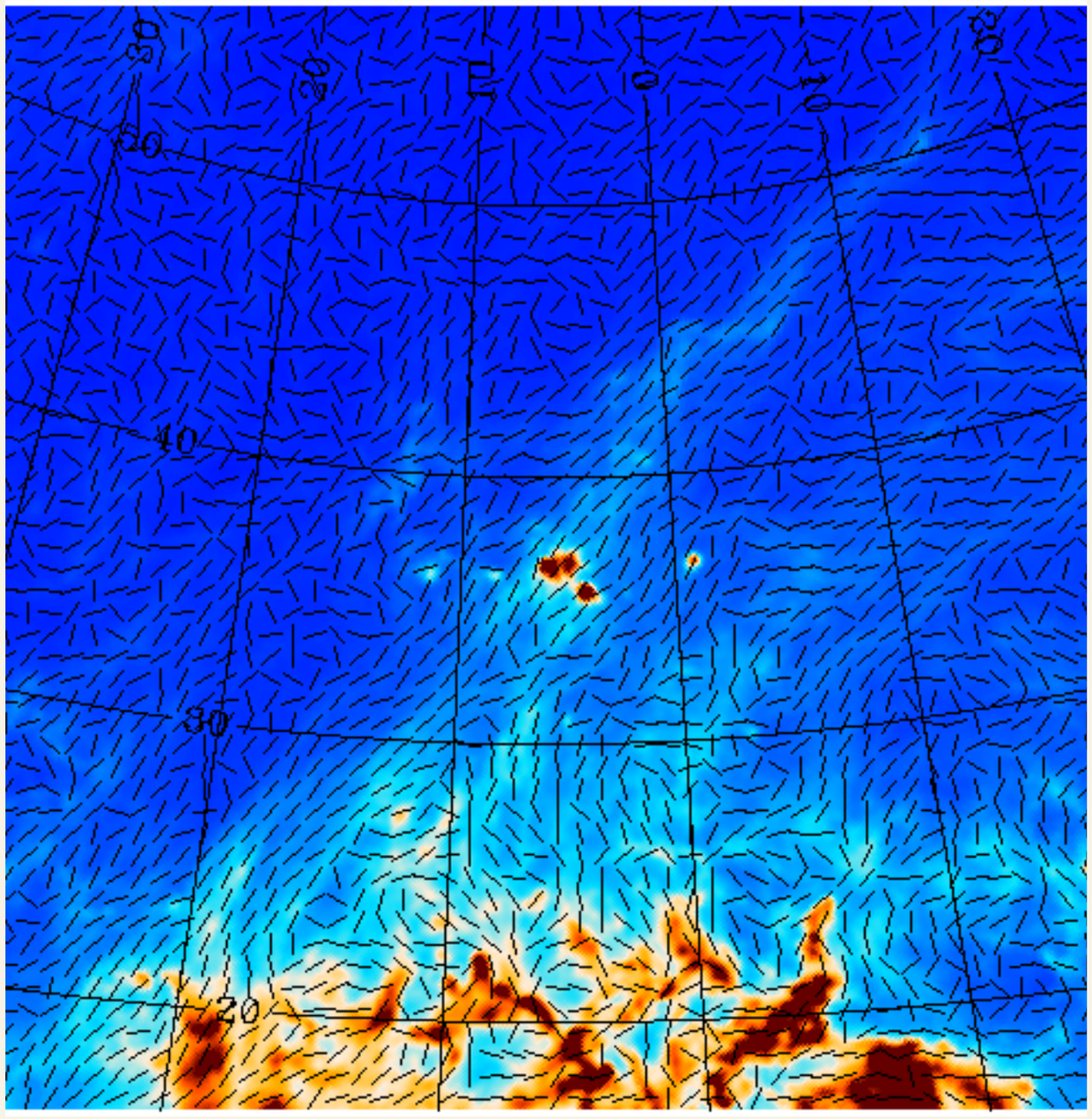
Yeremi+ 14

Historically, we have *looked* at data to harness shape info

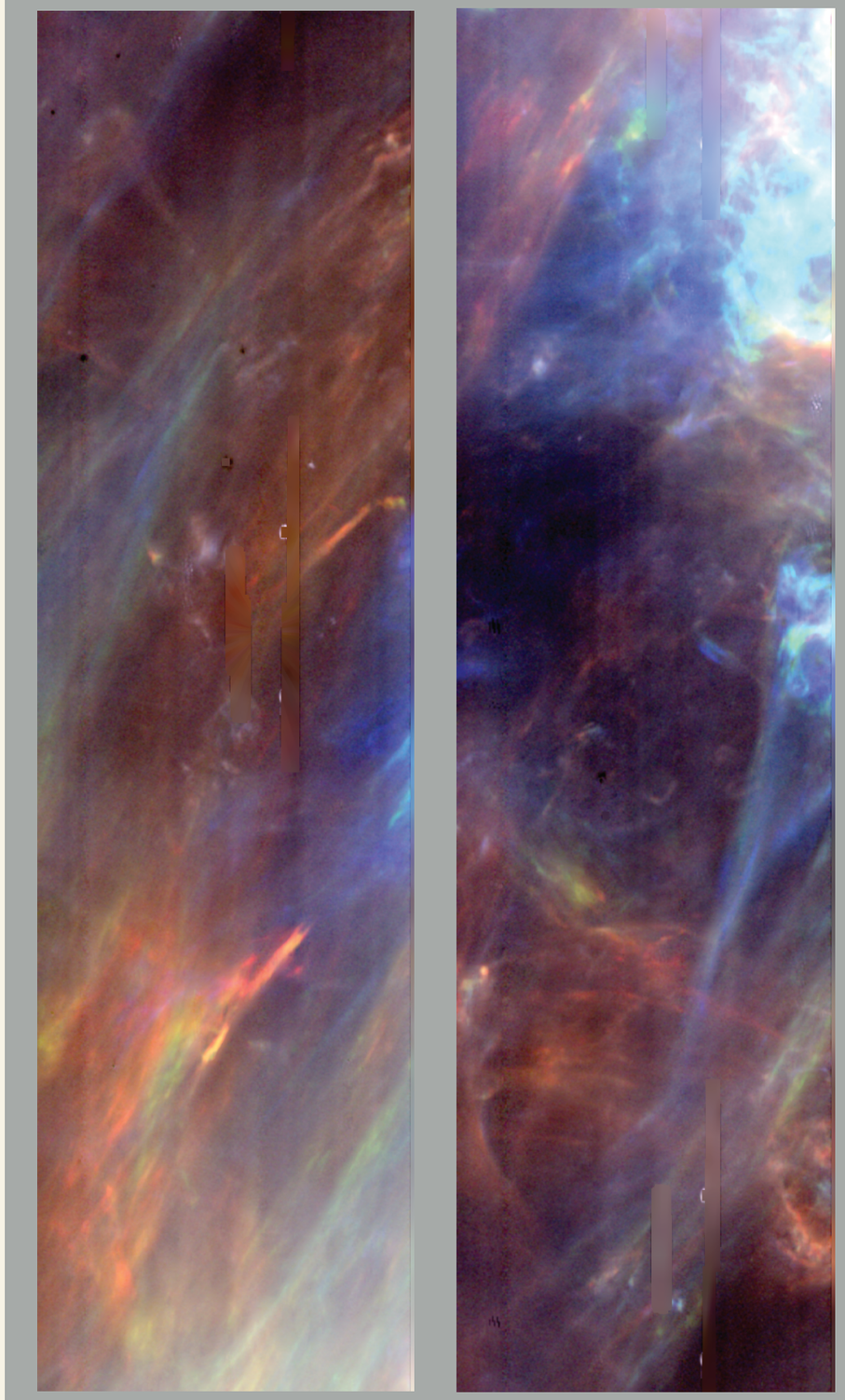


McClure-Griffiths 2009

Two 2014 papers examine magnetized diffuse “filaments”



Planck Collaboration XXXII 14



Clark, JEGP, Putman 14

	Fibers	Planck 32
Mass Tracer	**21 cm HI**	**FIR dust emission**
Magnetic Tracer	**Starlight polarization**	**Dust emission polarization**
Vision Method	**Rolling Hough Transform**	**Hessian**

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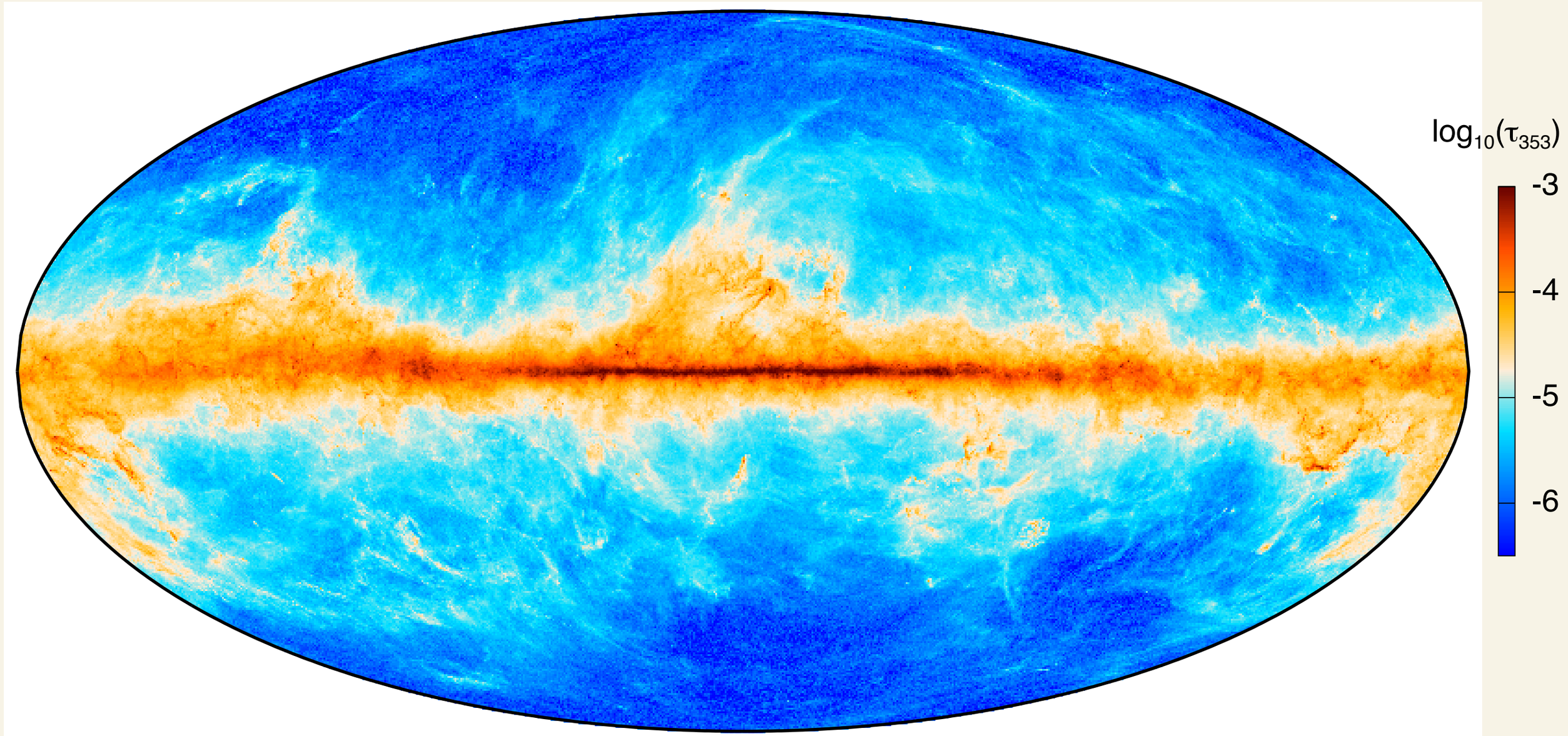
Planck FIR is a great tracer of neutral column



Planck Collaboration XXXI 13

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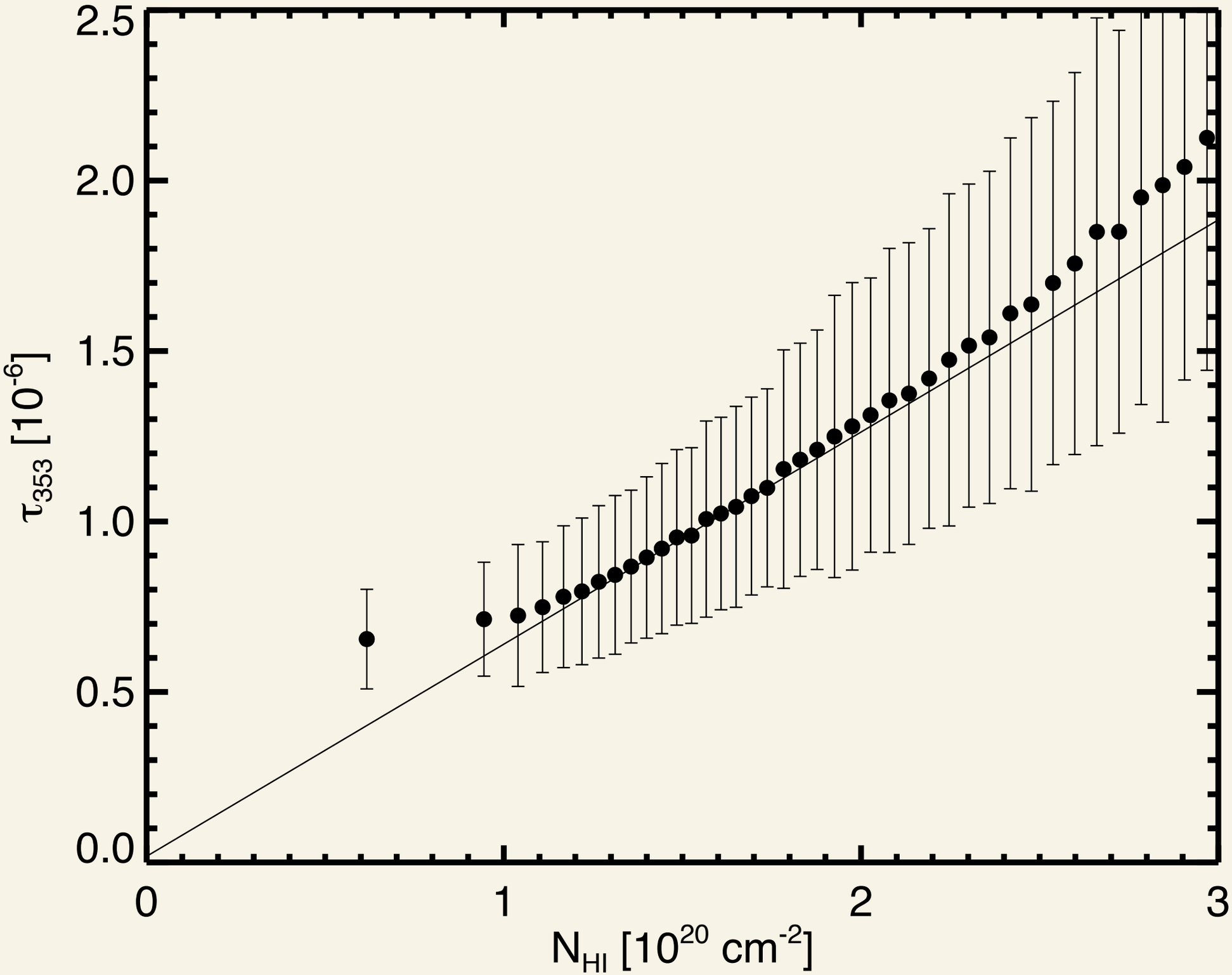


Planck Collaboration XXXI 13

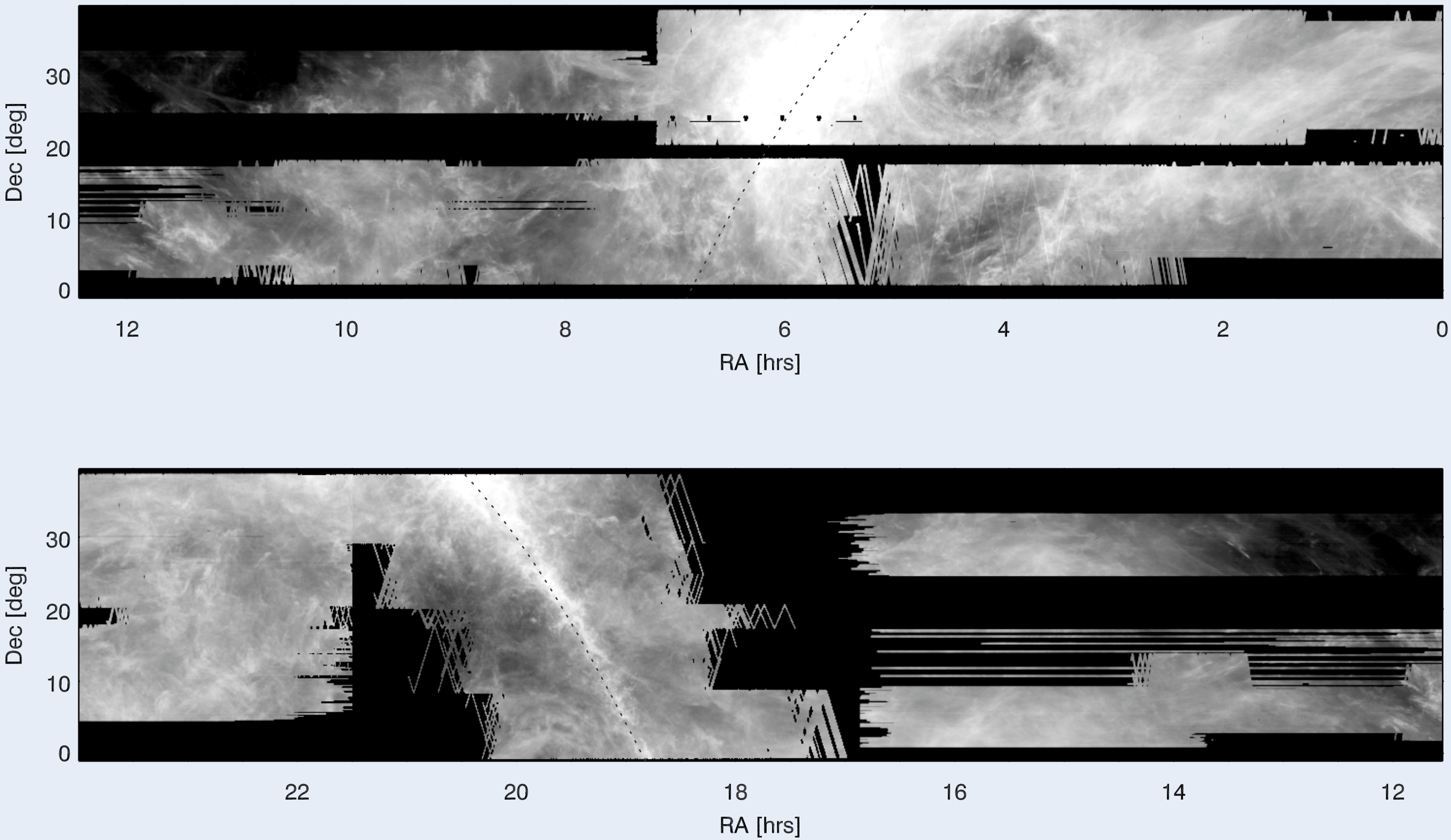
GALFA-HI is the largest Galactic HI survey

Arecibo 305 m

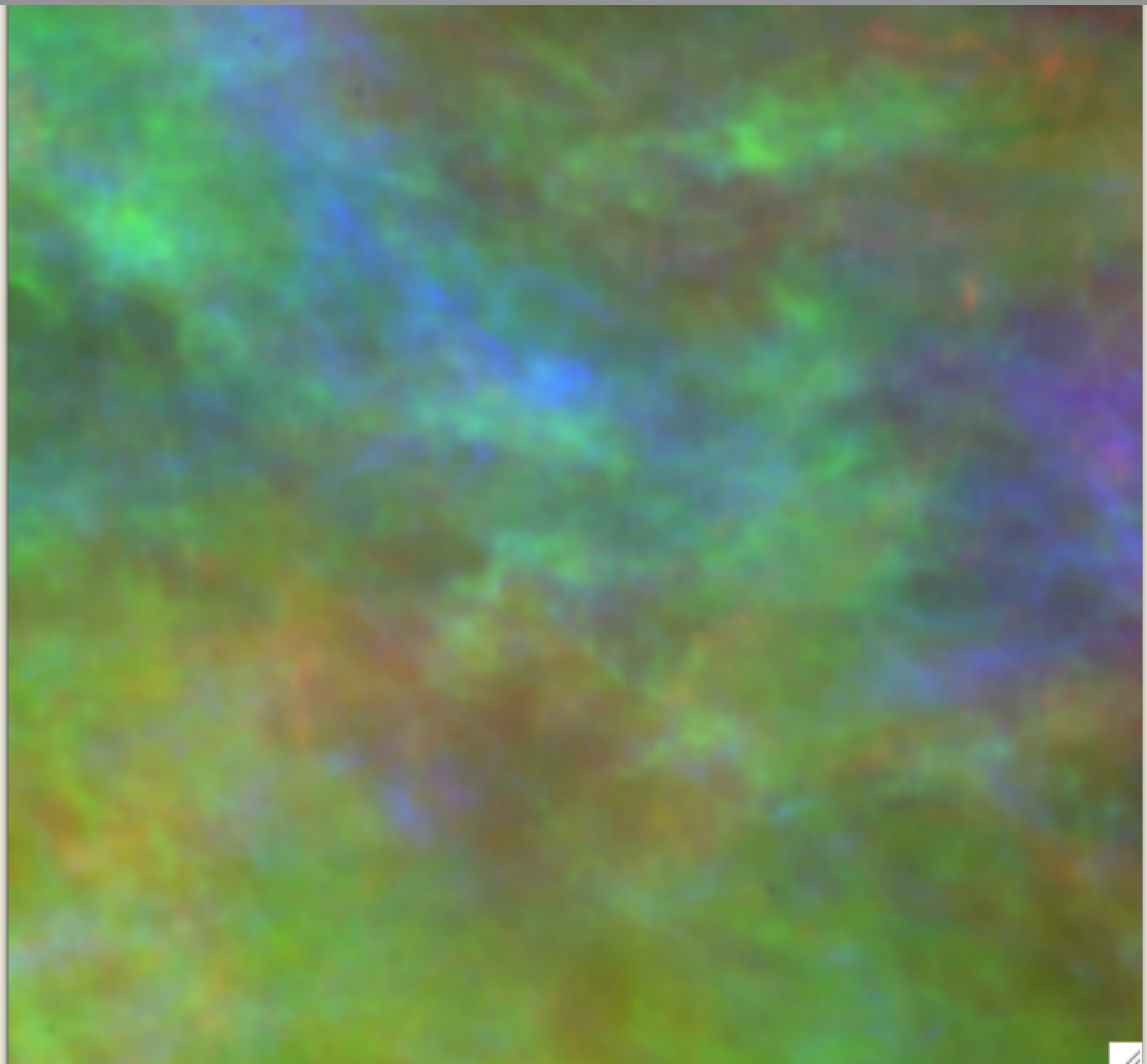
ALFA

GALSPECT

GALFA-HI DR1 is available to the public. DR2 soon!



GALFA-HI matches IRAS / Planck resolutions



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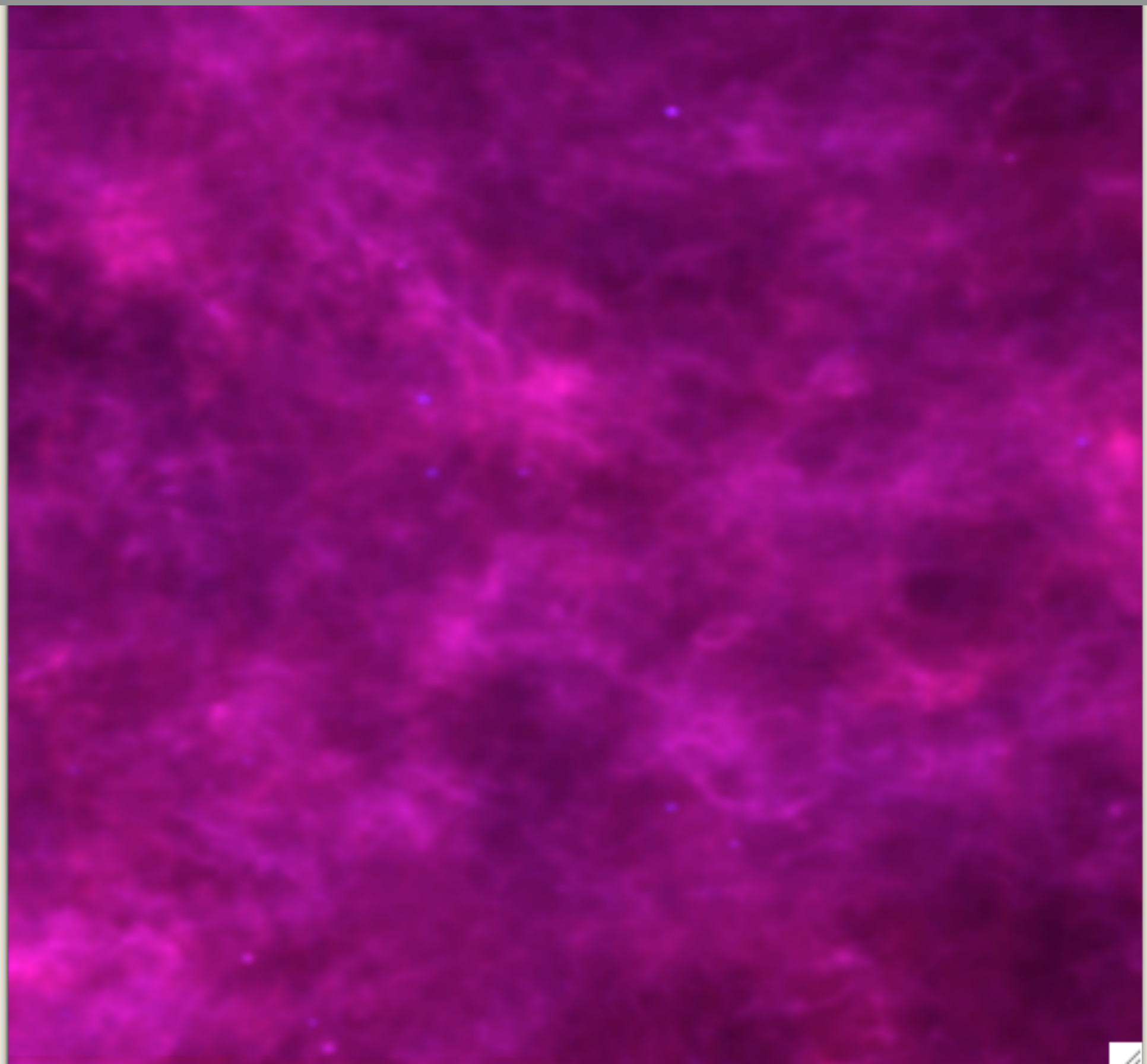
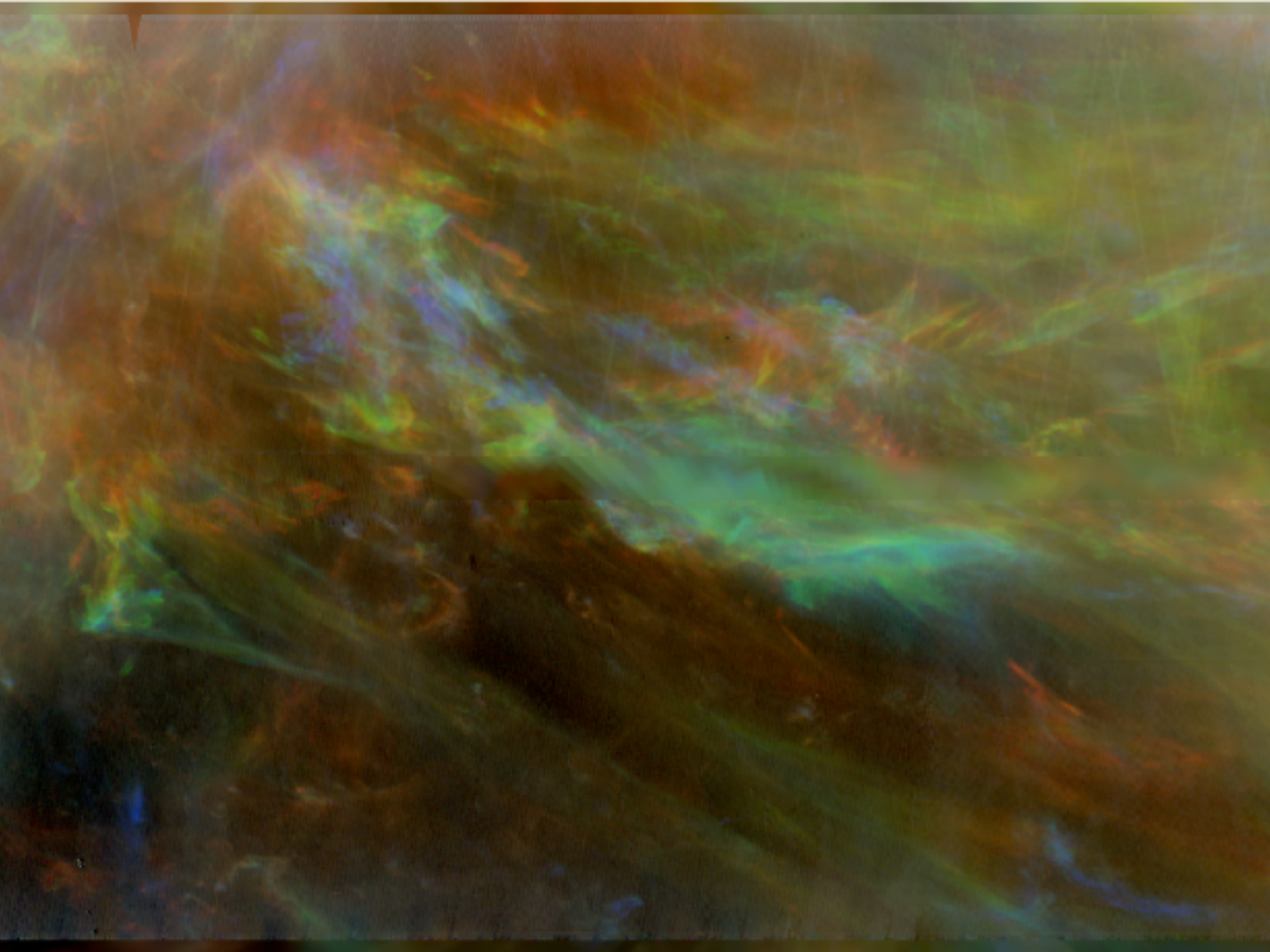
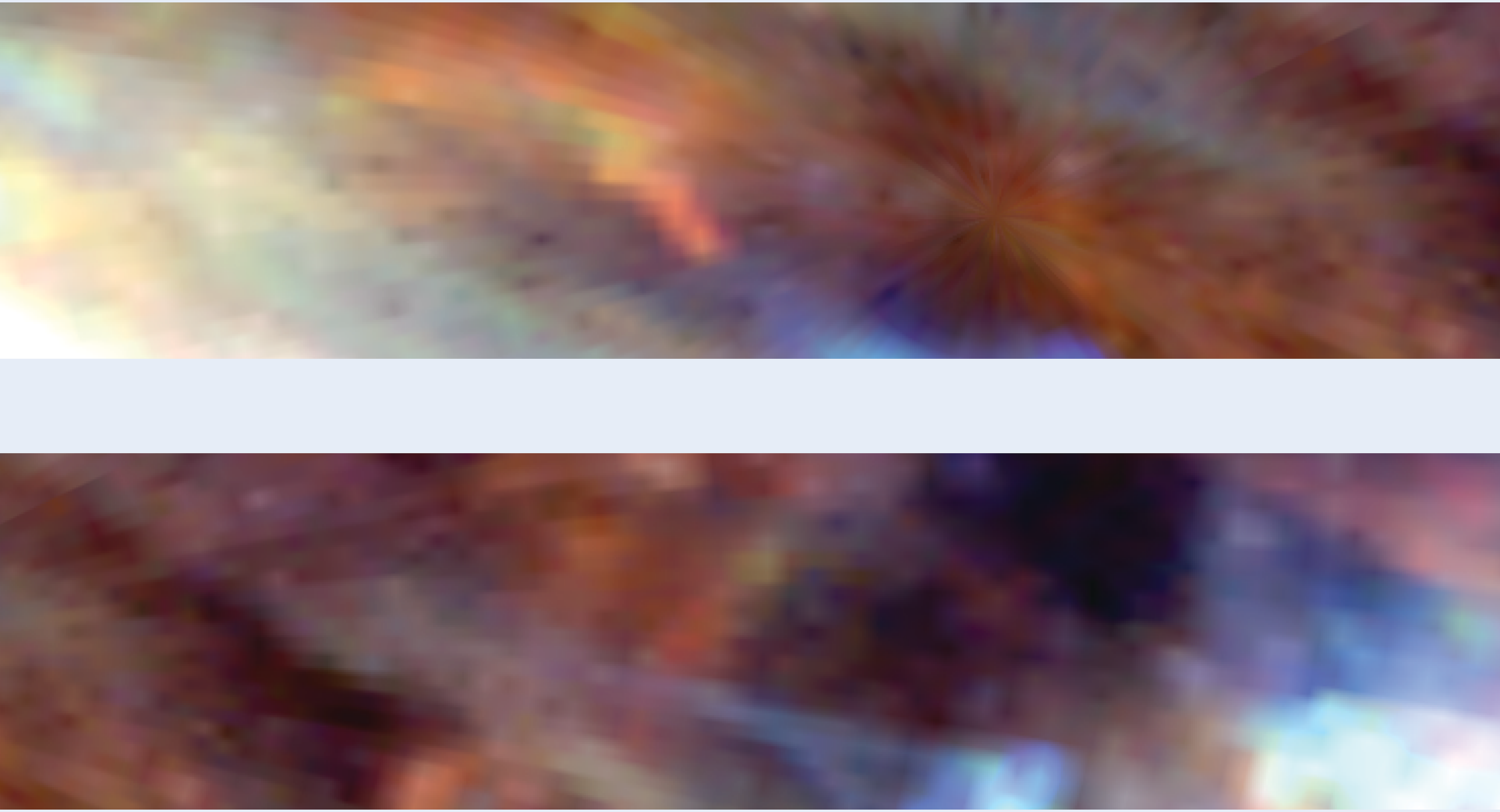




We noticed fibrous features in the ISM above the plane

LAB Survey: 2005



Clark, JEGP, Putman 14

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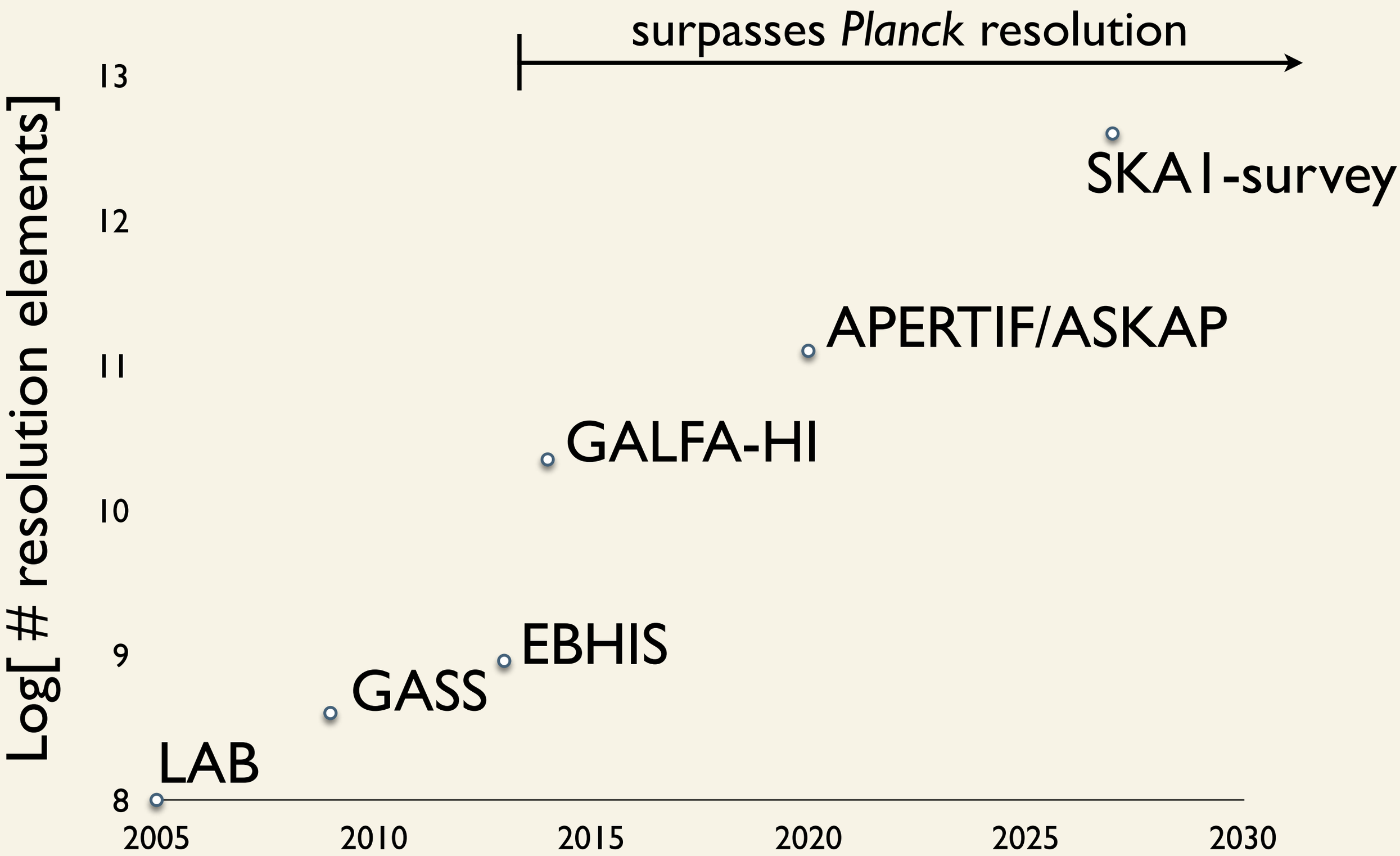
GALFA-HI Survey: 2011

3^o

Clark, JEGP, Putman 14

Huge Galactic HI surveys are on the horizon



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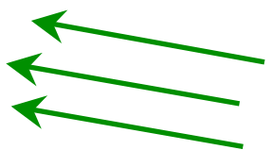
USRA

magnetic
fields

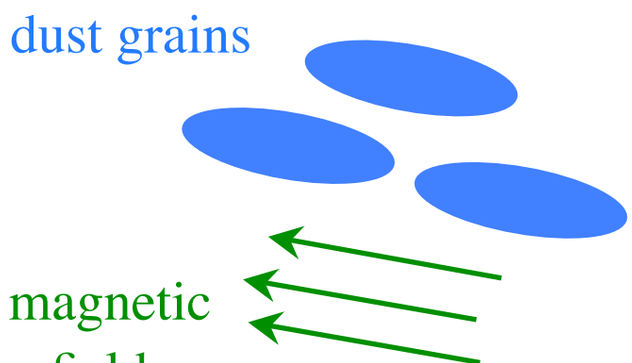


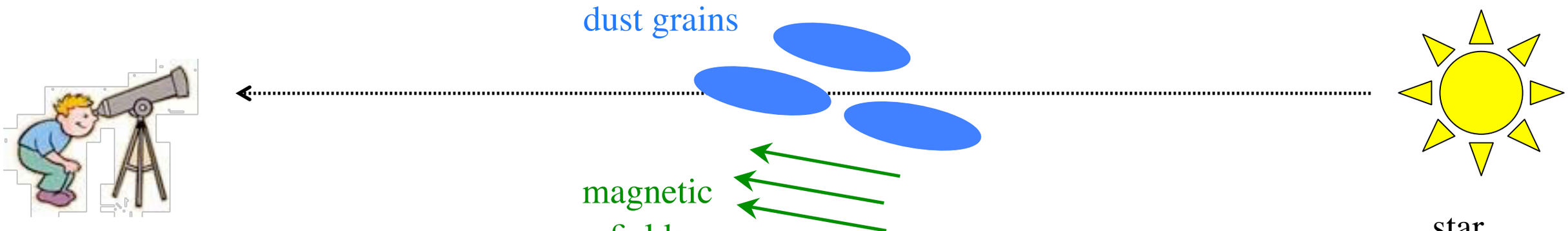
USRA

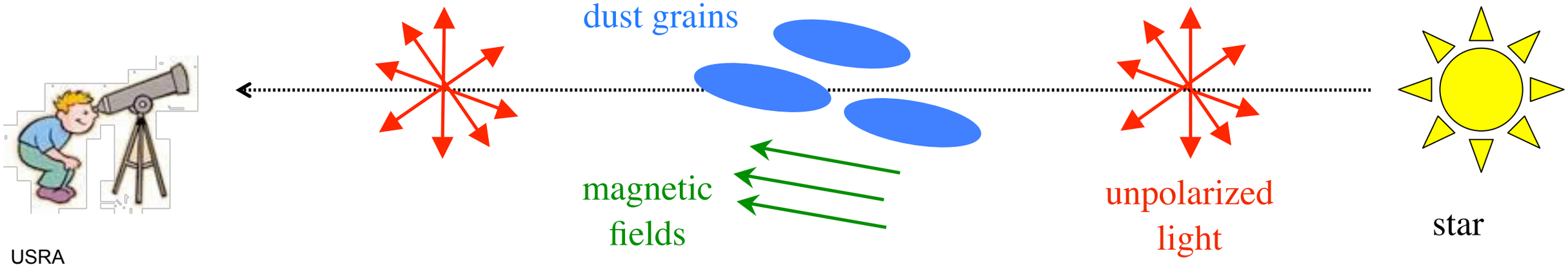
dust grains

magnetic
fields

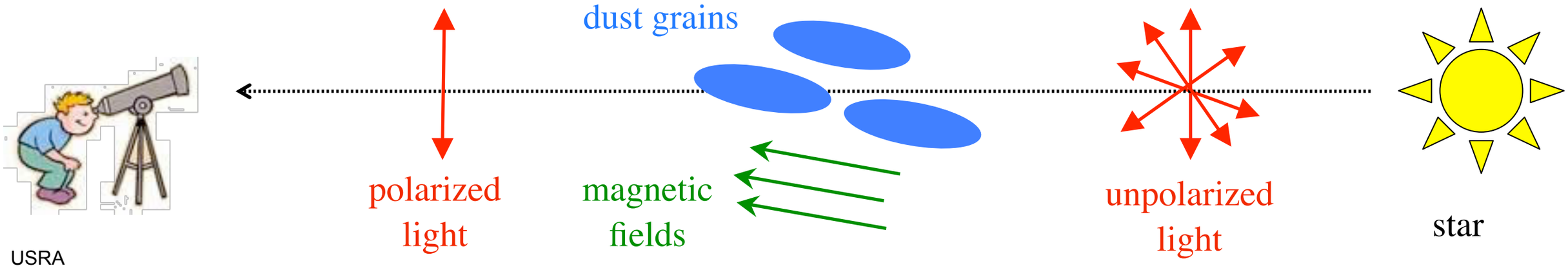
USRA



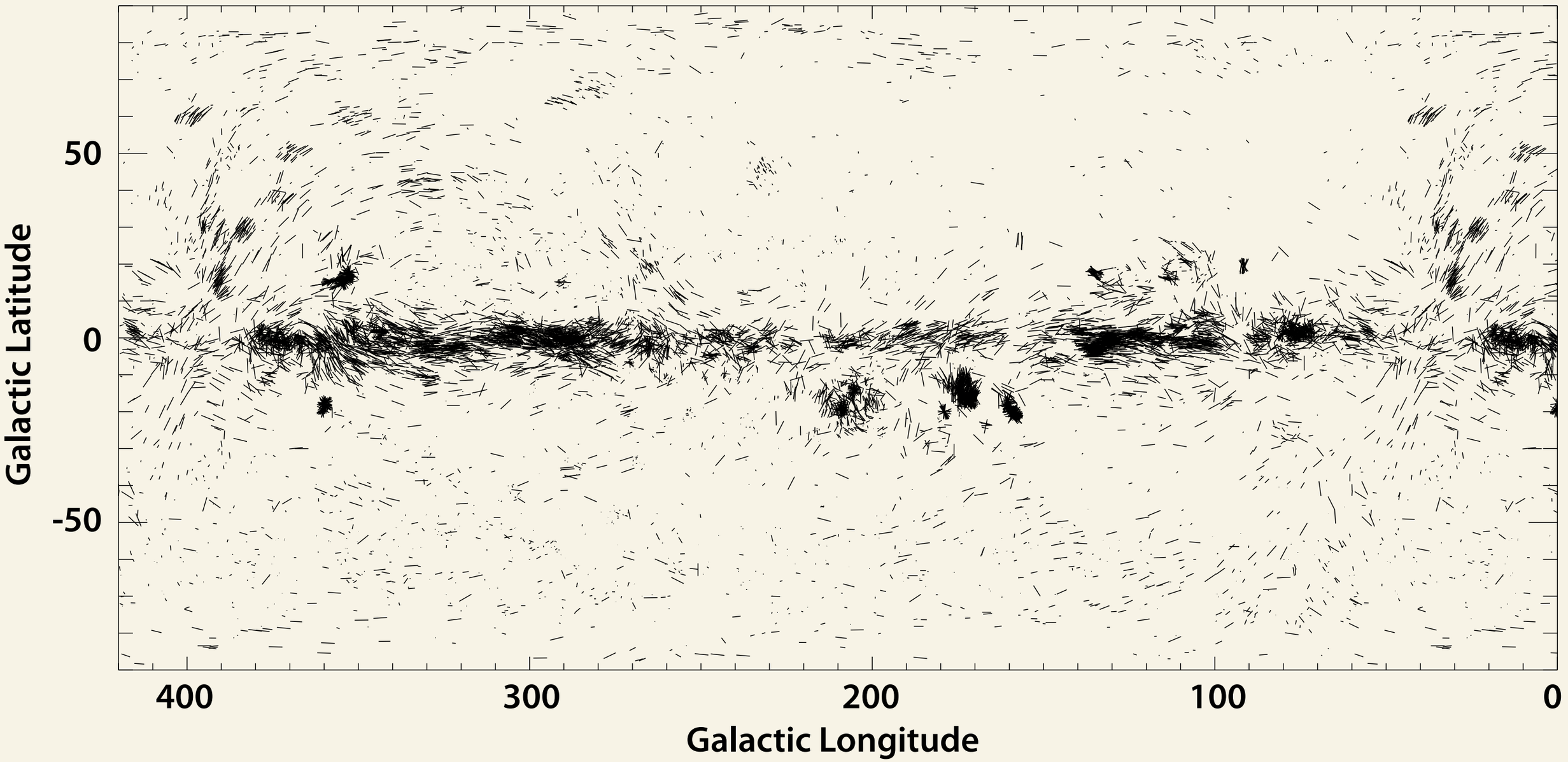

dust grains
magnetic
fields
star



USRA

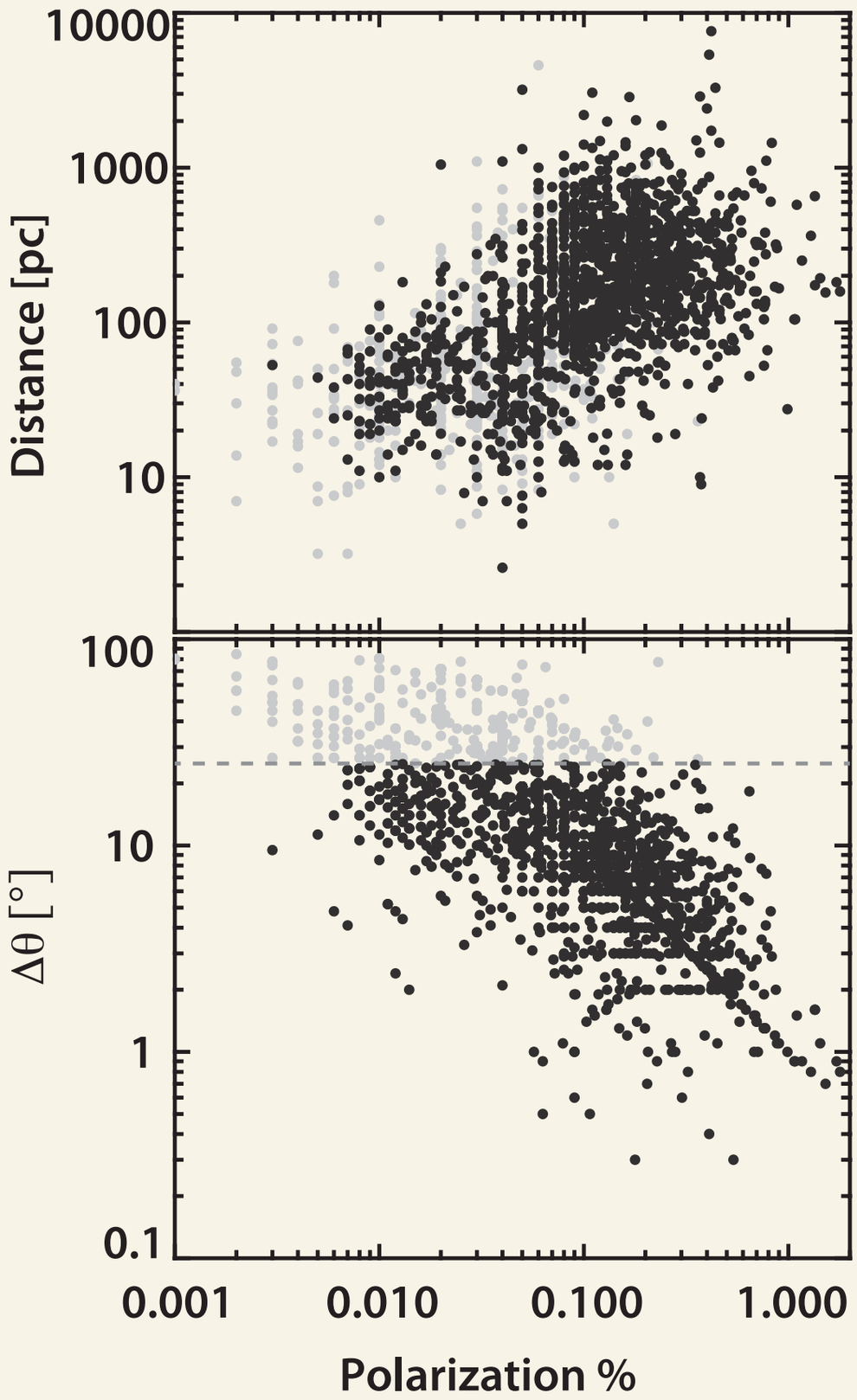

dust grains
polarized light
magnetic fields
unpolarized light
star
USRA

These 10,000 observations are quite sensitive!

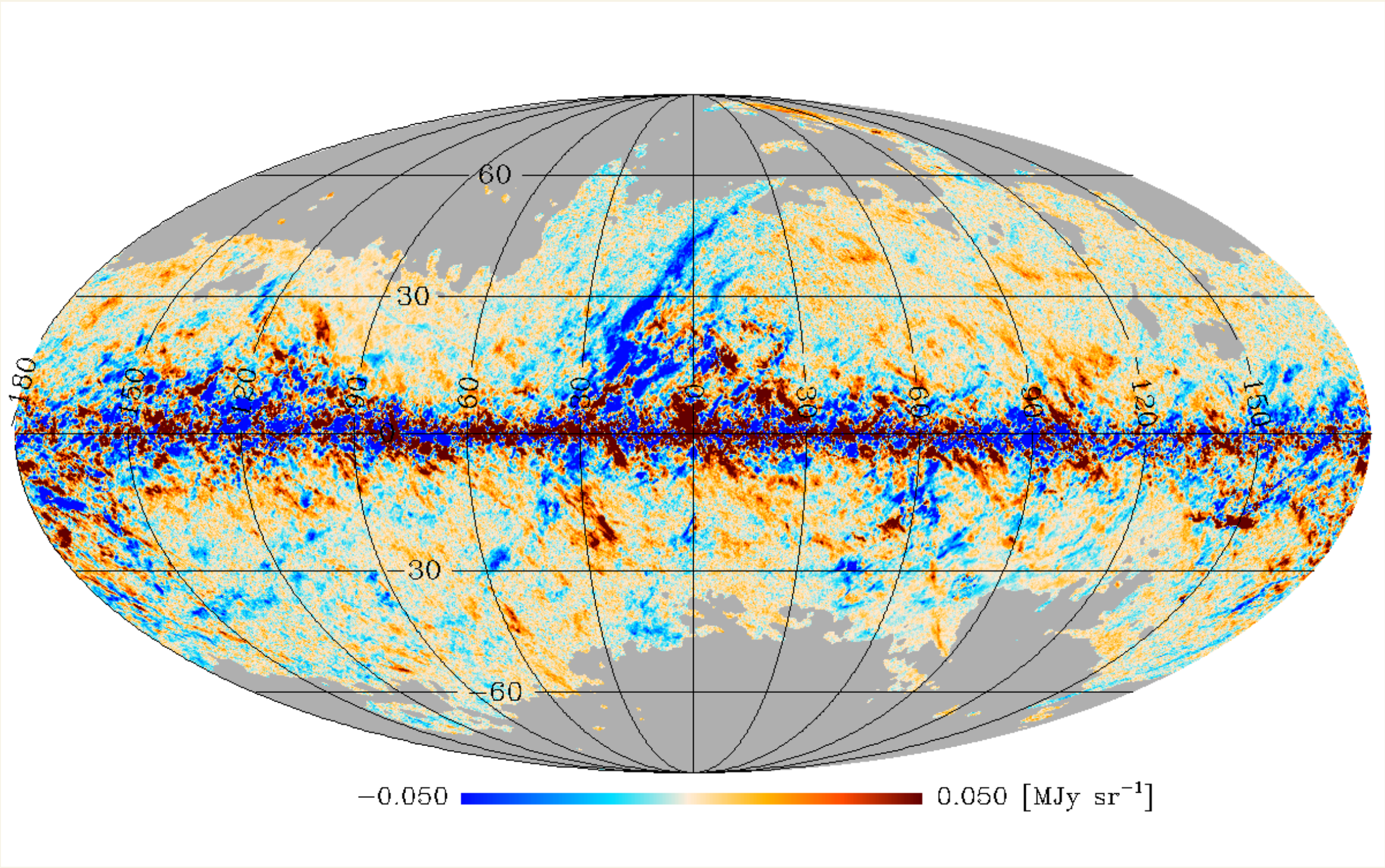


Heiles 2000

Starlight polarization can be sensitive to very low columns



Polarized dust emission is ubiquitous, but less sensitive



Planck Collaboration XXXII 14

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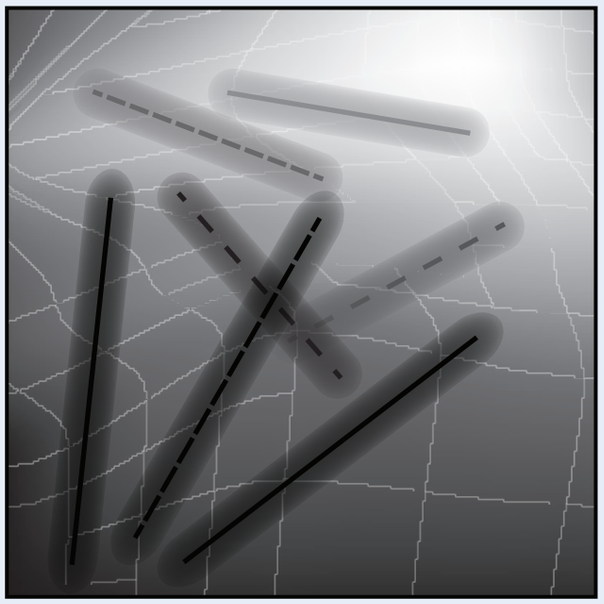

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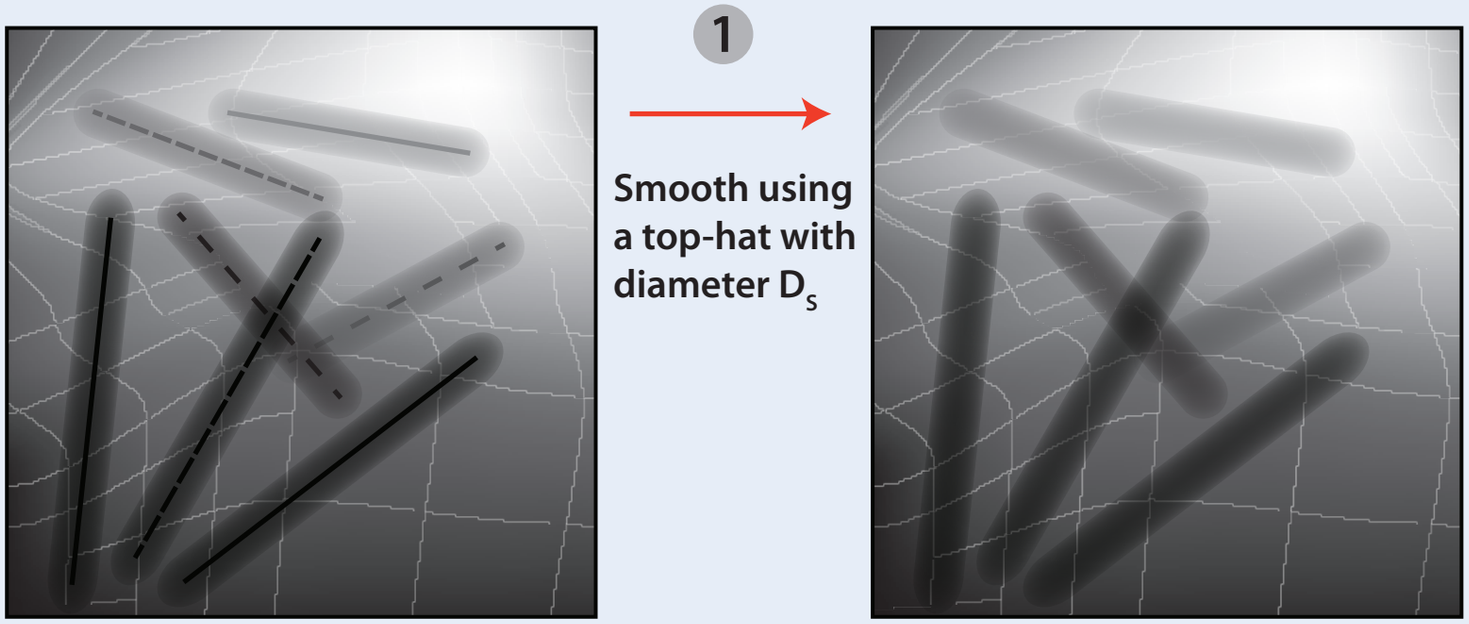

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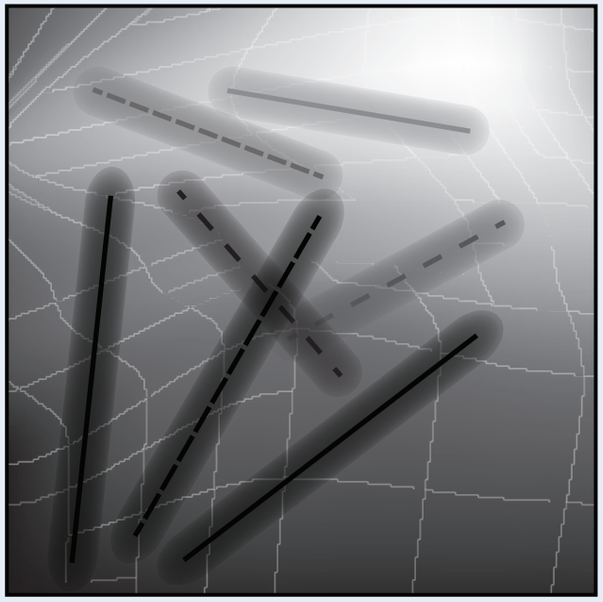
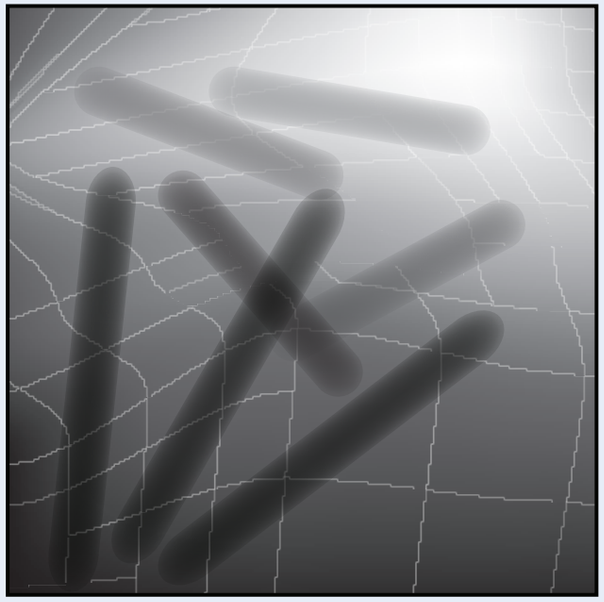
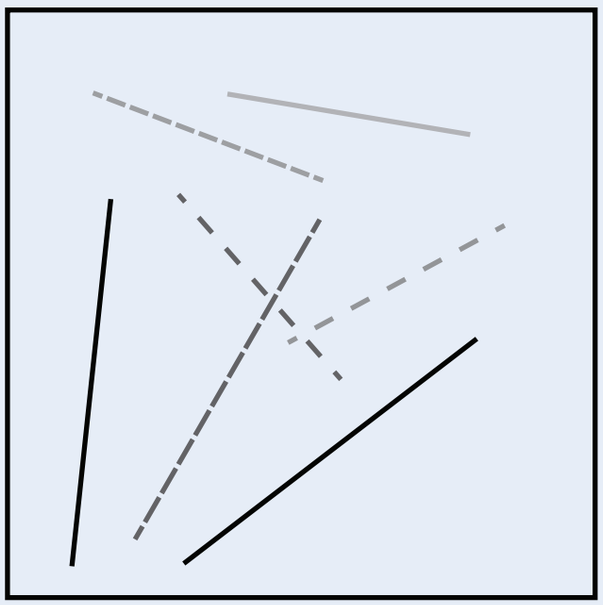


1

Smooth using a top-hat with diameter D_s



2 Subtract smoothed component to unsharp mask



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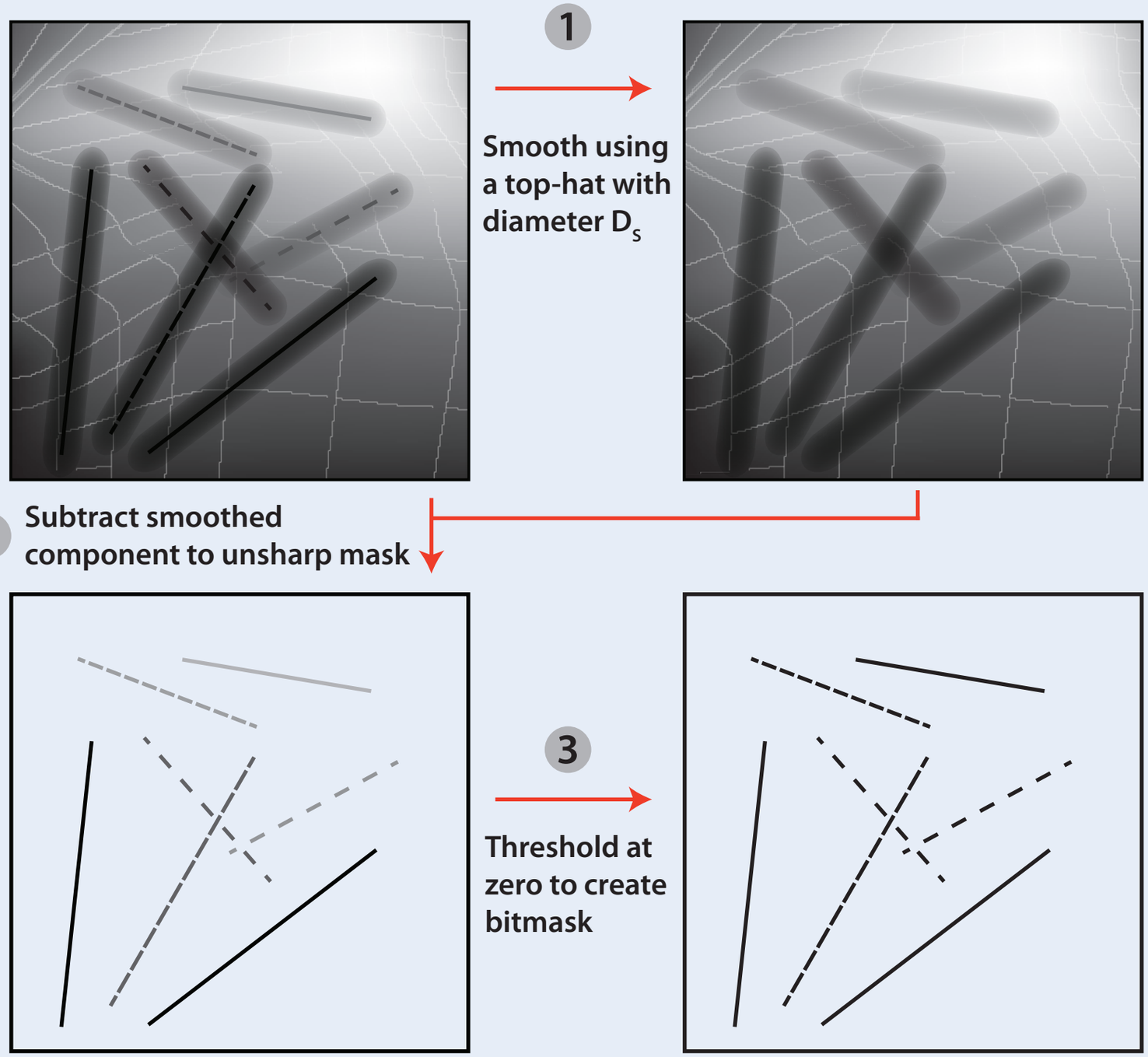

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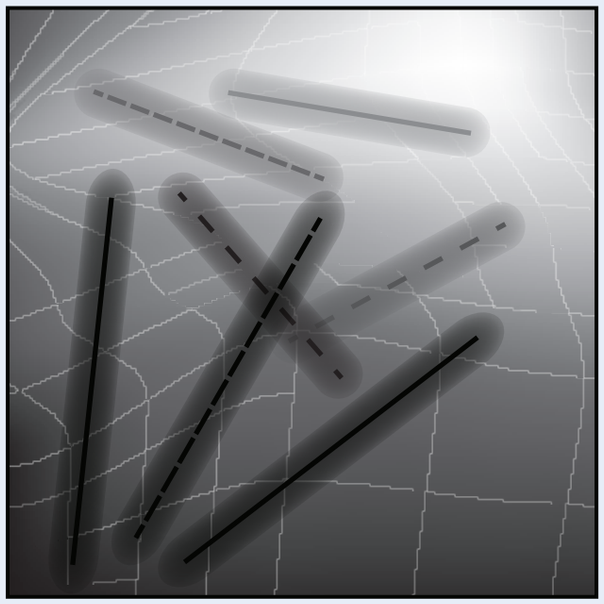

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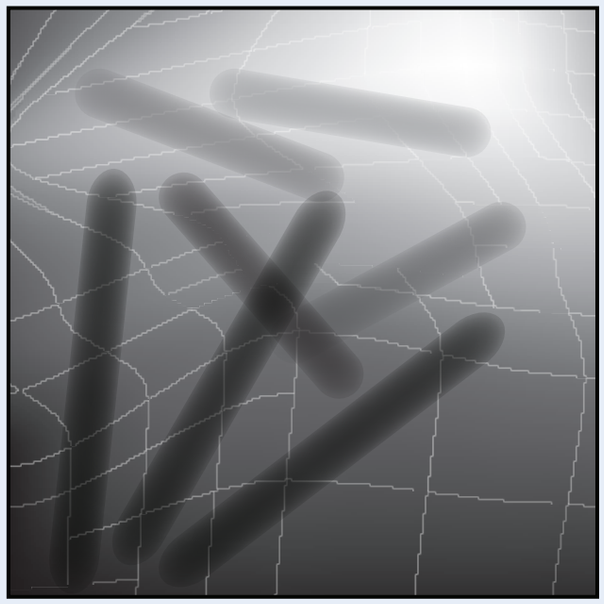

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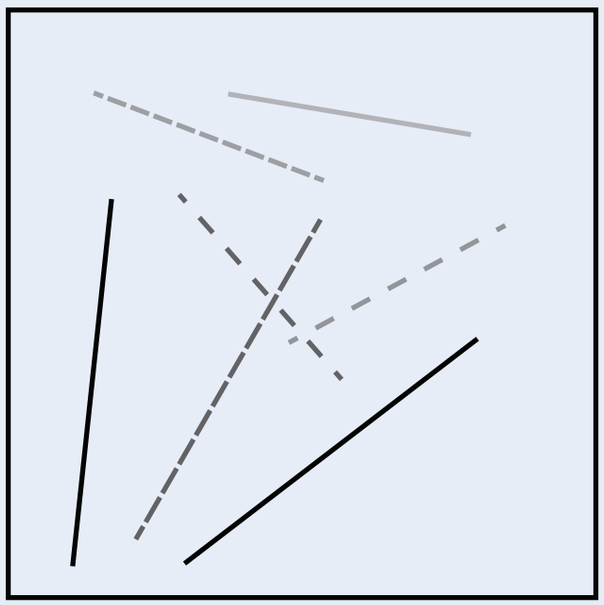
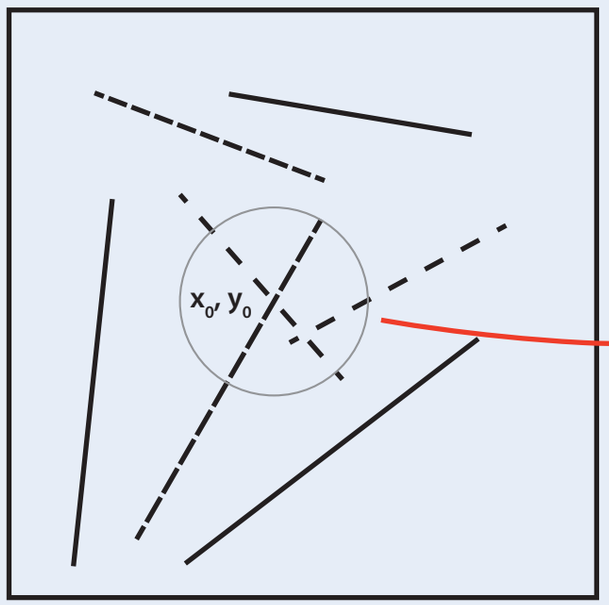


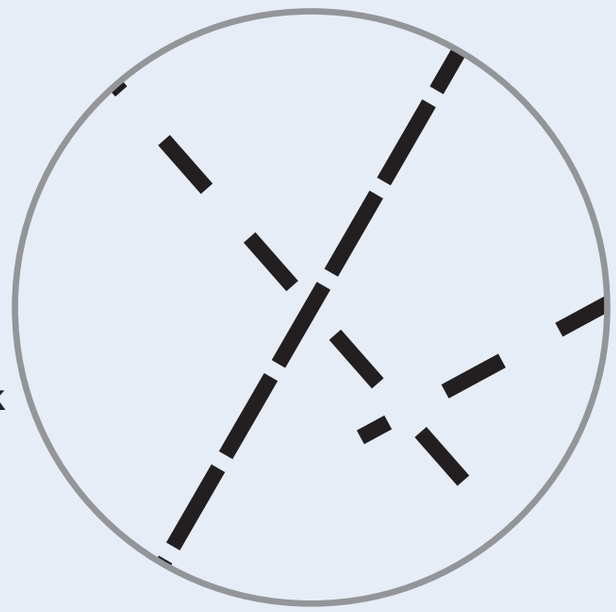
3

Threshold at zero to create bitmask



4

Extract a disk of diameter D_W around each point in image



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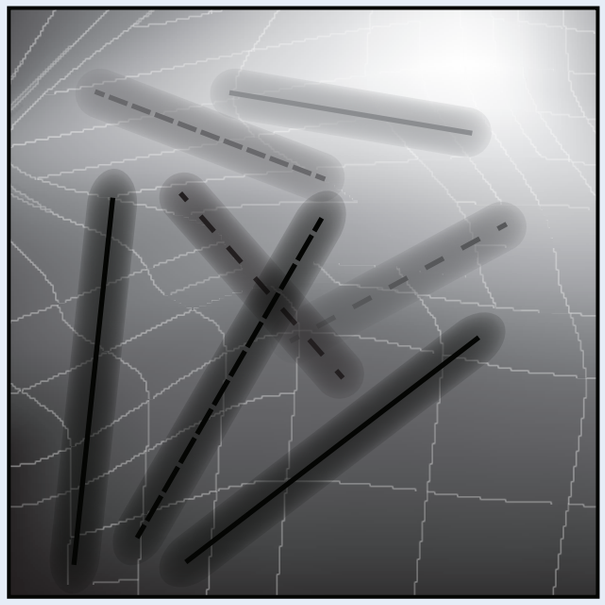

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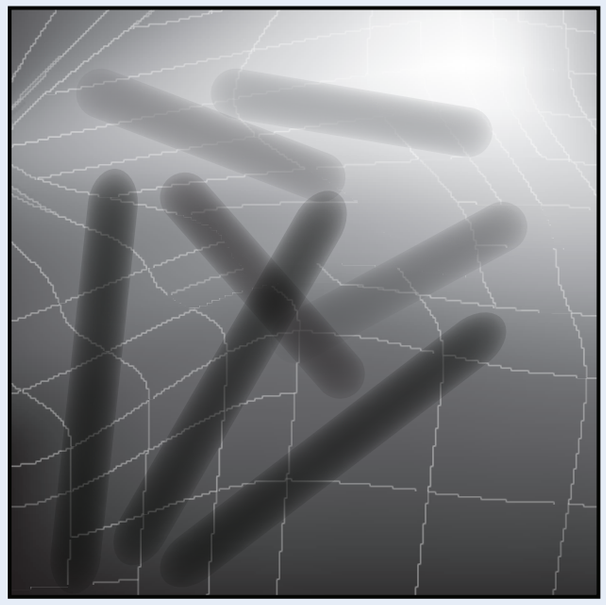

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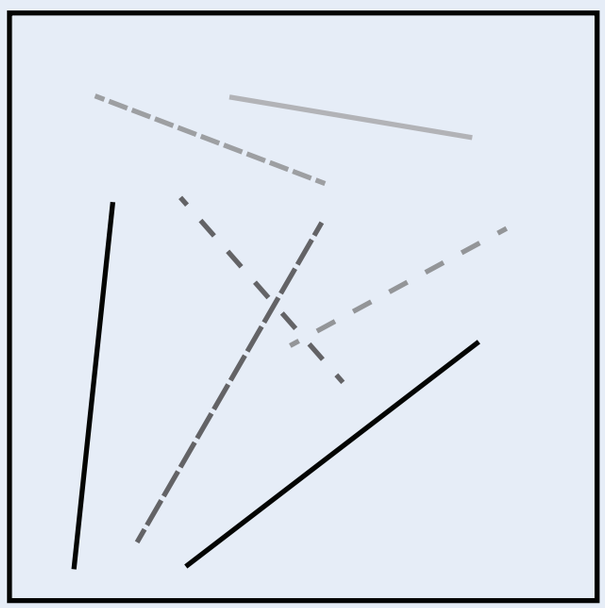

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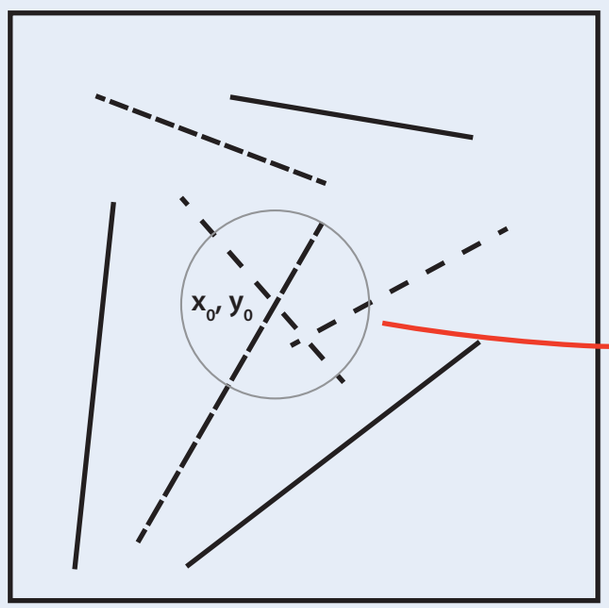

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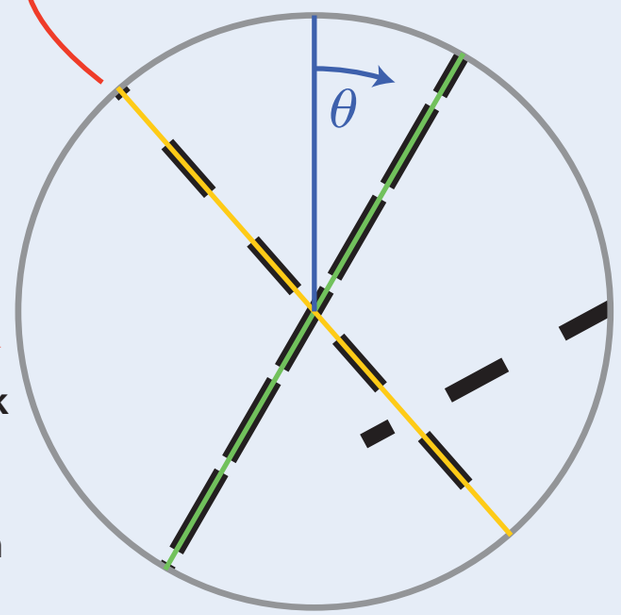
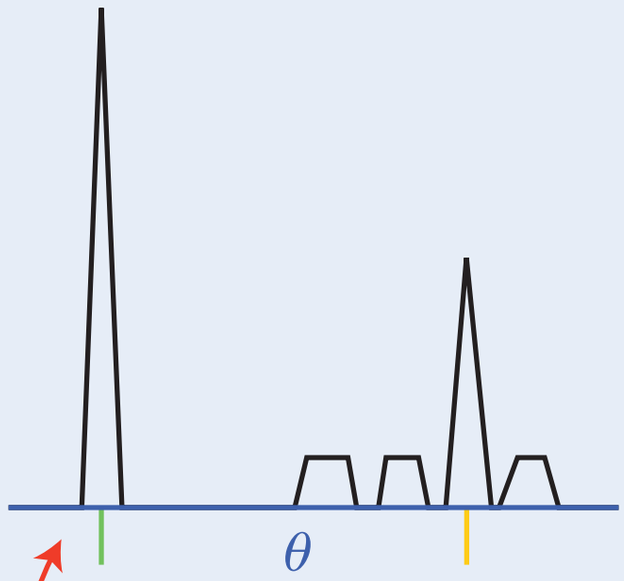


5

Apply Hough transform to disk for ρ=0



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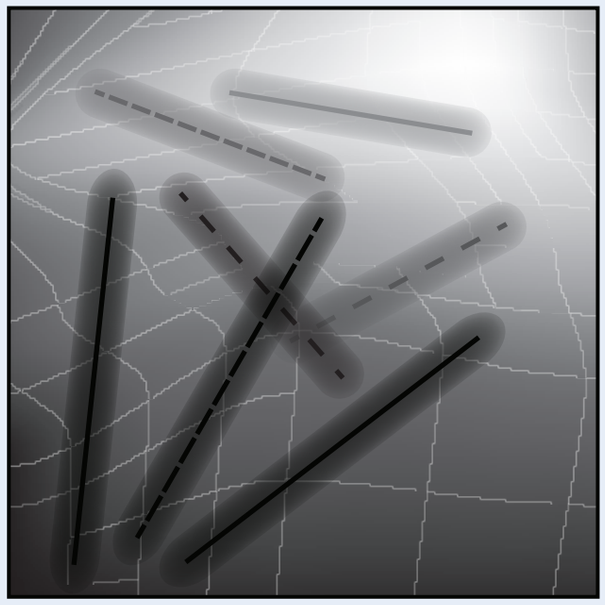

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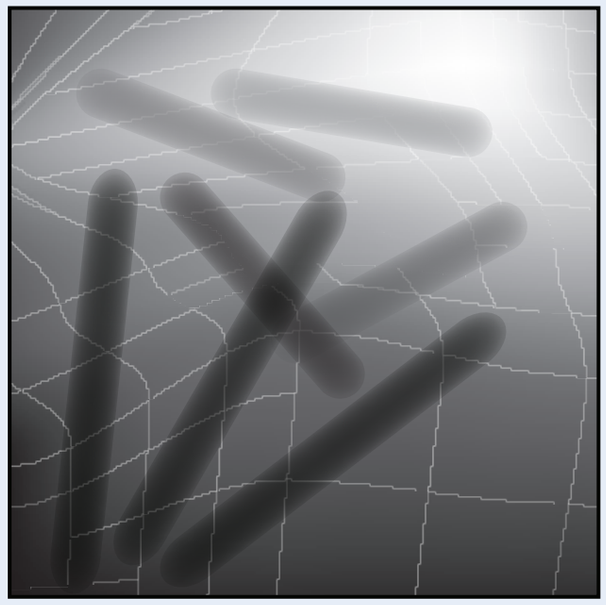

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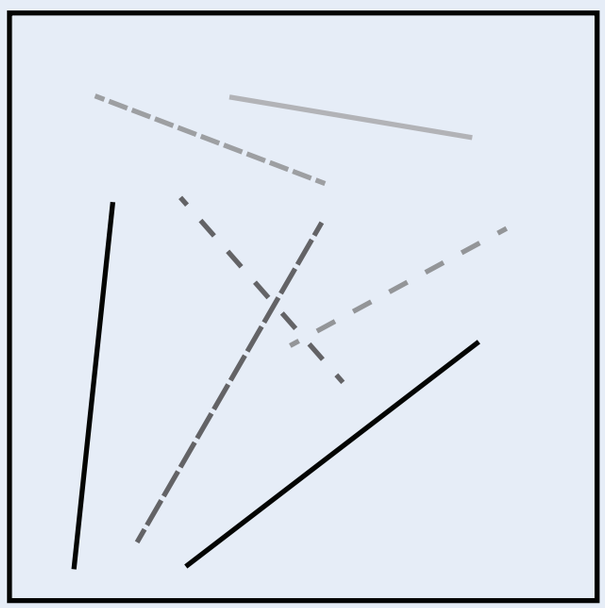

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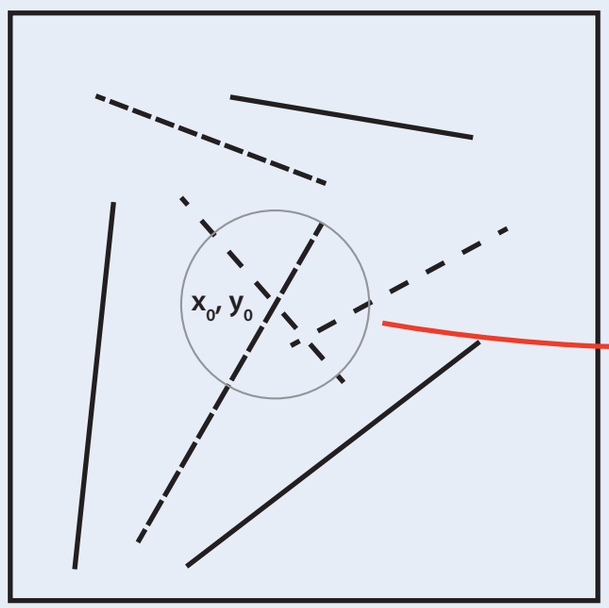

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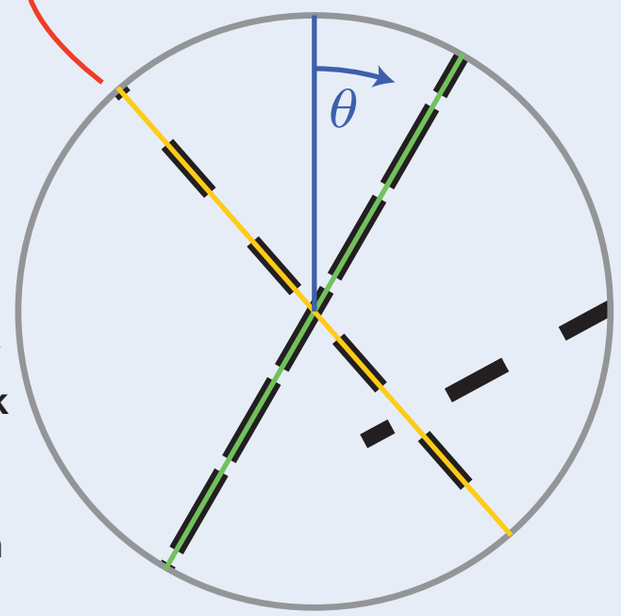

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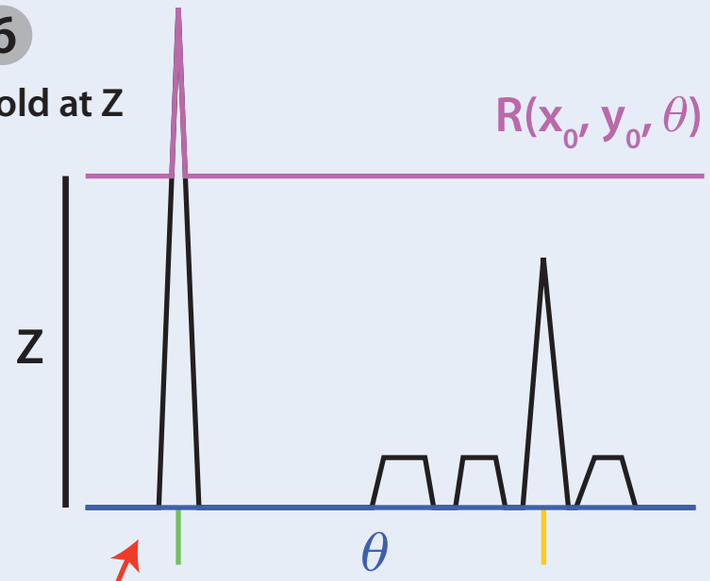


6

Threshold at Z

Clark, JEGP, Putman 14

Using the RHT is two lines of code

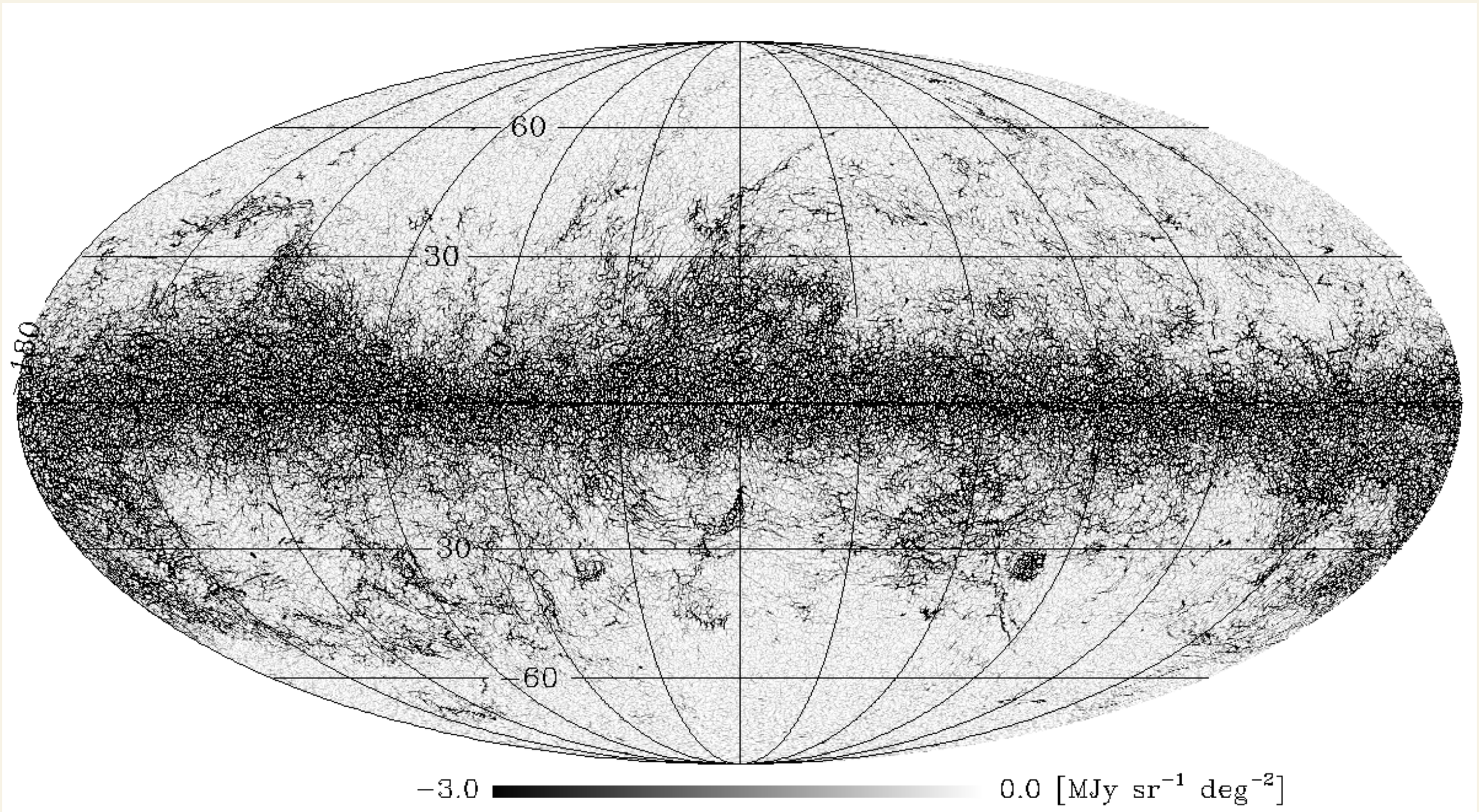
```
git clone https://github.com/seclark/RHT.git
```

```
python rht.py image.fits
```

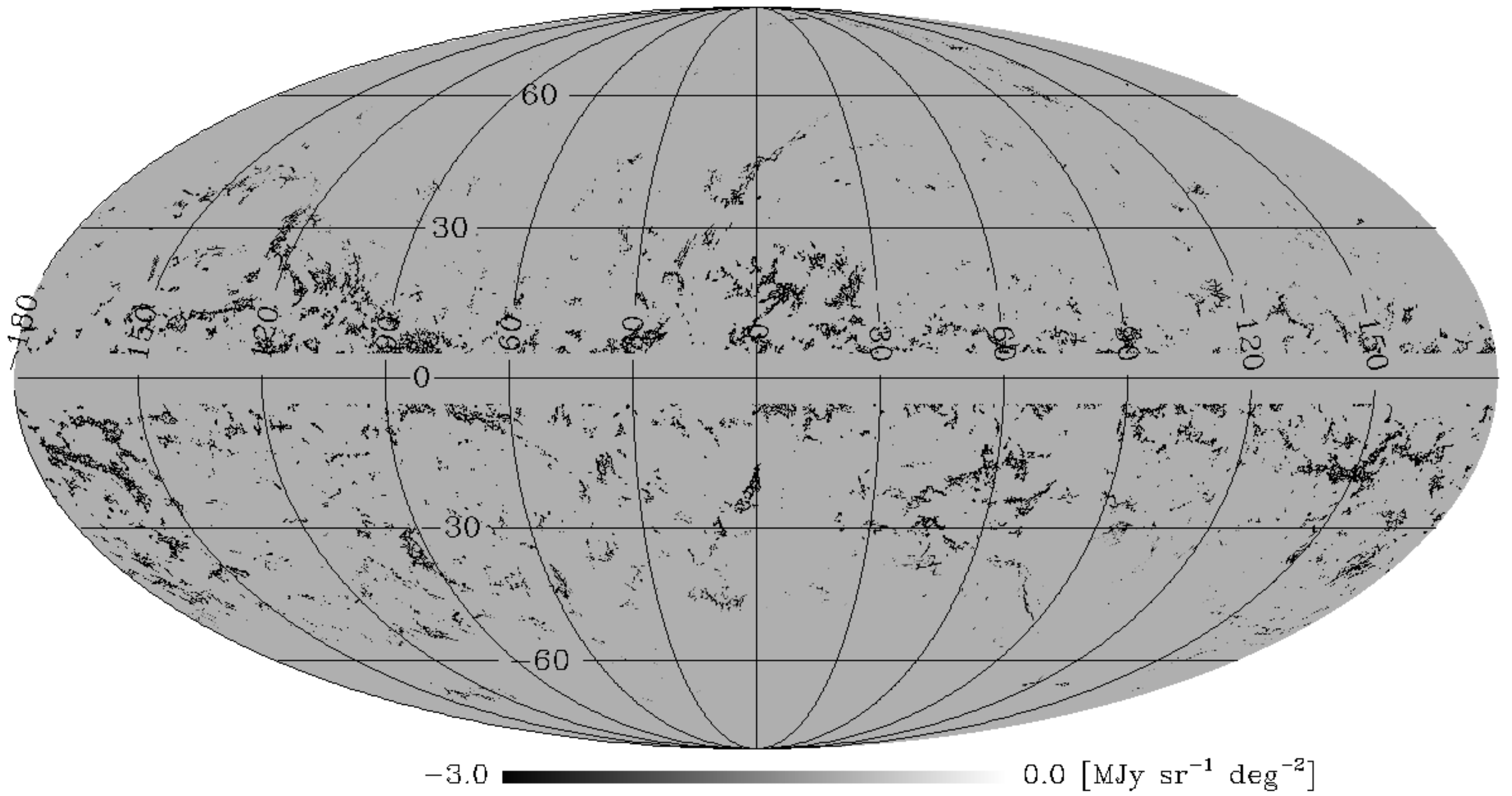
Planck32 uses a Hessian matrix to determine orientation

$$\theta = \frac{1}{2}\tan^{-1}\left(\frac{\frac{\partial^2 D_{353}}{\partial x \partial y} + \frac{\partial^2 D_{353}}{\partial y \partial x}}{\frac{\partial^2 D_{353}}{\partial x^2} - \frac{\partial^2 D_{353}}{\partial y^2}}\right)$$

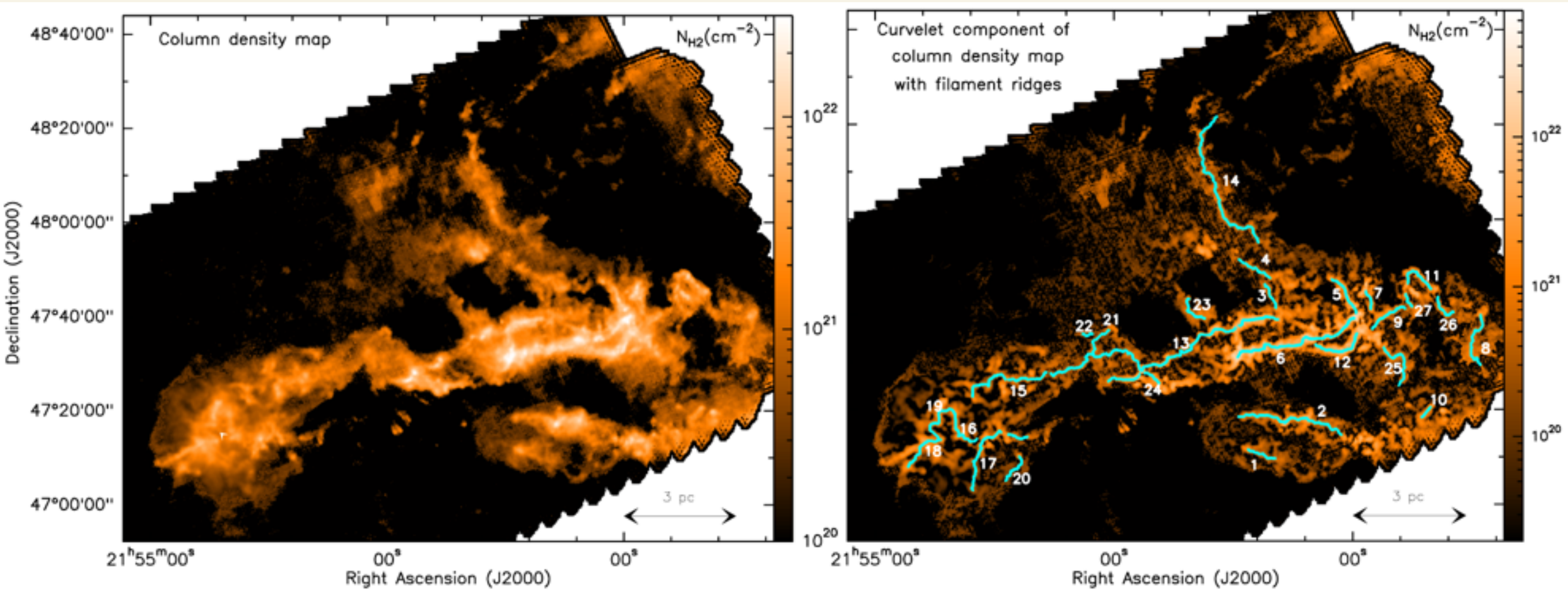
The Hessian-ized sky is quite complex



Though Planck 32 examines a small fraction of that



Both these methods are *transforms* not *source finders*



Arzoumanian+ 11

somewhat ranty interlude !

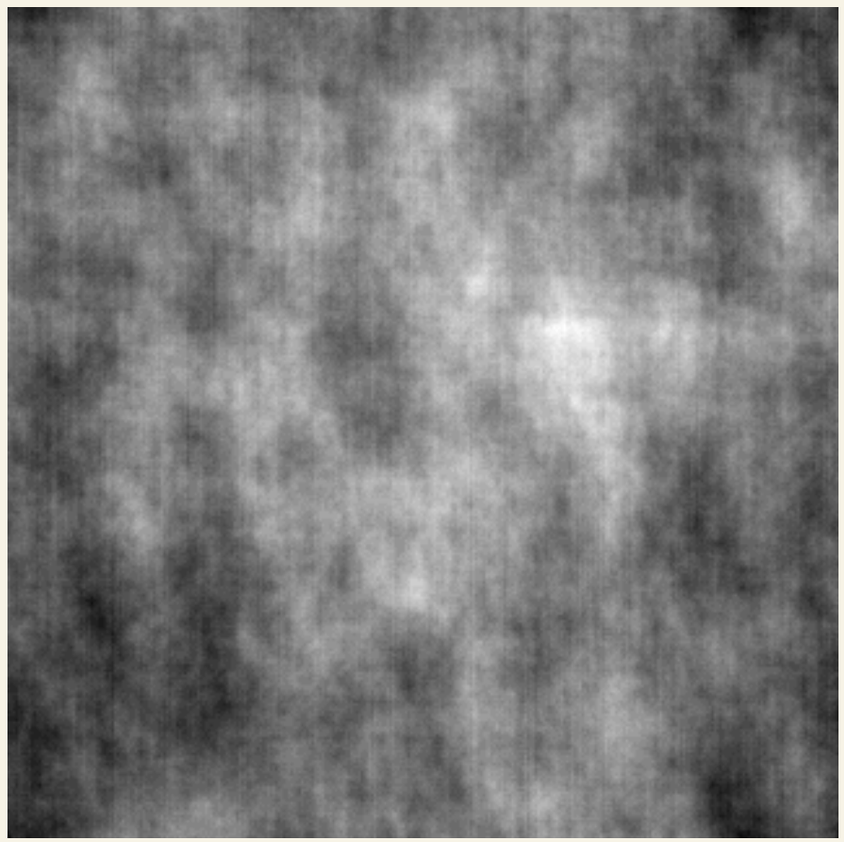
An image with phase information is *always* “filamentary”

Fred

An image with phase information is *always* "filamentary"

Fred

Power Fred



An image with phase information is *always* "filamentary"

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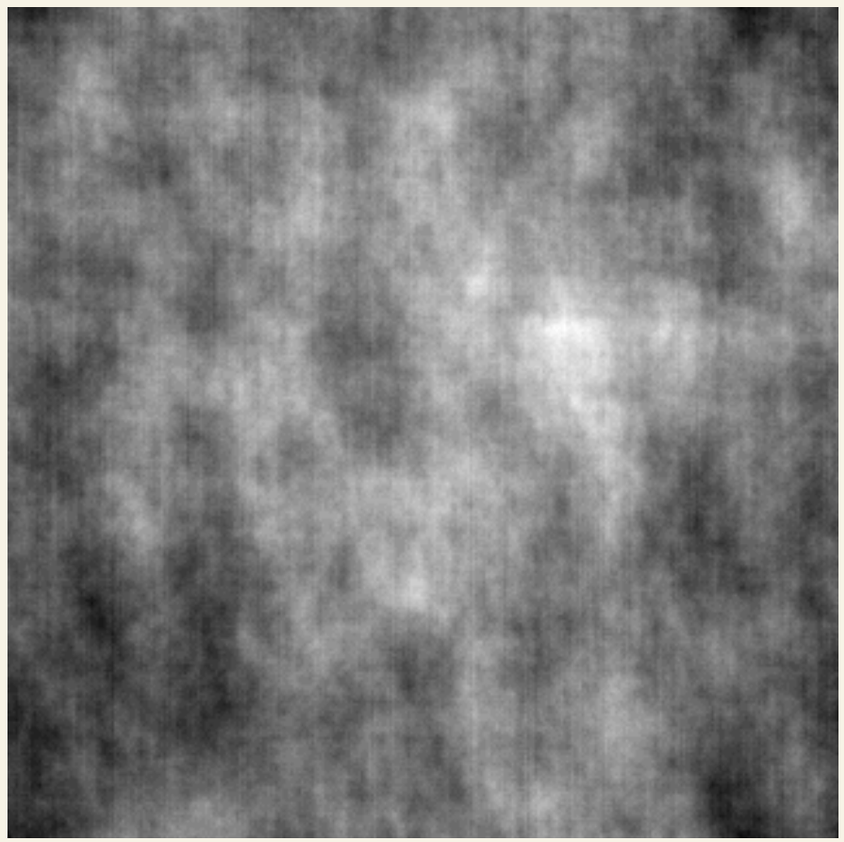
Power Fred



Phase Fred

“Filament” means many things to many astronomers

“Filament” means many things to many astronomers

Extract of a Letter from W. S. Jacob, Esq. inclosing two Sheets of Diagrams of Solar Spots observed at Poona, in December 1848, and January and February 1849.

“I beg to call your attention to a remarkable phenomenon that I do not remember to have seen or heard of before, viz. an *annular* spot, which was seen on the 1st of February: it is marked *a* in the diagram of that date, and I have also sketched it on the margin on an enlarged scale: the dark spot was of an irregular pentagonal shape, with a bright speck not quite in the centre. I had a suspicion of a filament uniting it to the side of the penumbra, but the power of my instrument (a $3\frac{1}{2}$ feet) was insufficient to verify this. A similar phase has this day appeared in another spot, which will be shewn in the next sheet.”

Captain Shea exhibited a book, “containing daily observations of the spots which pass over the sun's disc, taken with a three-foot telescope, by Carey.” There are four rows of circles in each page, and the book, if complete, would shew a picture of the disc on every day when the sun is visible. The corresponding days in each year are under each other. Captain Shea says his drawings prove “that spots which disappear on the thirteenth day do *not* reappear on the thirteenth day afterwards, and that they cannot be considered as fixtures.”

On the 9th and 10th of last November, Captain Shea “clearly

* The circumstance of streams of light crossing solar spots was seen by Mr. Lawson the day of the solar eclipse of May 15, 1836, in a spot whose *umbra* was of the shape of the ace of clubs, only the *penumbra* in this case was not of usual aspect, but resembled flocculent clouds. The streams of light closely resembled coruscations of *aurora borealis*. The *umbra* of this spot was 10080 miles in diameter, and the surrounding shade 32200 miles.

Shea 1849

“Filament” means many things to many astronomers

Extract of a Letter from
of Diagrams of Solar
1848, *and January a*

“I beg to call your at
I do not remember to hav
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On the 9th and 10th

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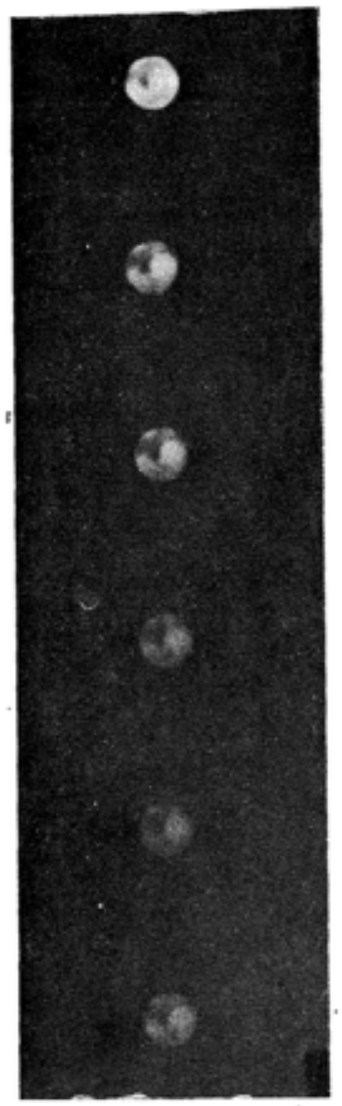

Shea 1849

PHOTOGRAPH OF DRAWING OF MARS
BY PERCIVAL LOWELL
MAY 11^d 18^h 35^m G. M. T.
$\lambda = 284°$

PHOTOGRAPH OF MARS
BY C. O. LAMPLAND
MAY 11^d 19^h 44^m-48^m G. M. T.
$\lambda = 303°$

Lowell 1905

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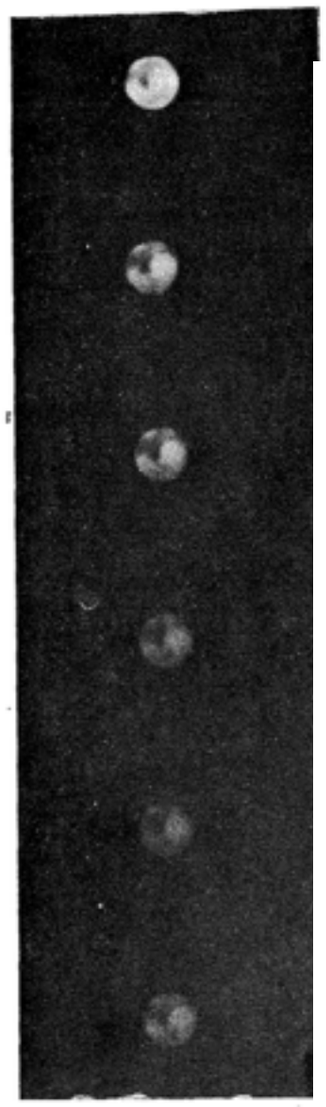

Shea 1849

Lowell 1905

THE JOURNAL

OF THE

ROYAL ASTRONOMICAL SOCIETY

OF CANADA

VOL. XIII. MAY—JUNE, 1919 No. 5

THE PRESENT POSITION OF THE NEBULAR HYPOTHESIS.

BY J. H. JEANS.*

AMONG scientific speculations, the Nebular Hypothesis holds, and for over a century has held, a unique position. It is unique in its absorbing interest and in its world-wide fame—these are mere commonplaces. It is unique also in the remarkable longevity of its speculative aspects. Put forward in 1755 by Kant, and again independently in 1796 by Laplace, it is still in 1918, in the opinion of most astronomers, a speculation which has been neither proved nor disproved. Such a length of life, although it would be small for the speculations of metaphysics, is almost unparalleled in natural science. The

Jeans 1919

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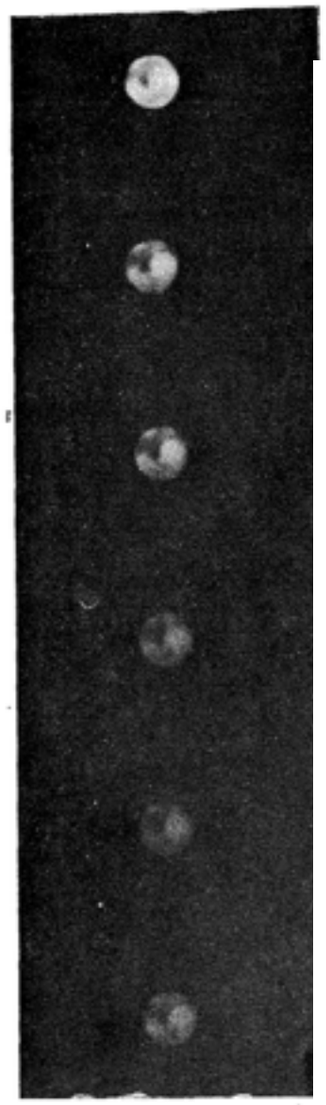

Shea 1849

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Lowell 1905

Jeans 1919

THE JOURNAL

A DENSE GROUP OF GALAXIES IN SERPENS

CARL K. SEYFERT
Barnard Observatory of Vanderbilt University

During an investigation of faint galaxies being made at the Barnard Observatory of Vanderbilt University, an exceedingly compact group of six galaxies was found in the constellation Serpens. The plate on which they were found was one of a number of Jewett schmidt photographs sent to us by the Harvard College Observatory through the courtesy of Dr. Harlow Shapley.

The group, including as its brightest member NGC 6027, falls within a circle 120″ in diameter at:

R.A. $15^h\ 54^m.8$	Decl. +21° 3′ (1900)
Gal. Long. 2°	Gal. Lat. +45°

Photographic magnitudes of the six galaxies were estimated by Muriel Mussells Seyfert from Jewett plates and from smaller scale plates by comparison with a near-by stellar magnitude sequence established by star counts. An investigation by the writer[1] indicates that the expected probable error of such nebular magnitudes is of the order of ± 0.19 mag. The apparent magnitudes of the six objects lie between 14.7 and 16.9. An enlargement from a 200-inch photograph of the Serpens group taken by Dr. Walter Baade is shown in Plate IV.

Dr. Milton Humason has obtained radial velocities of two of the brightest members of the group. His values, uncorrected for galactic rotation, are:

Seyfert 1951

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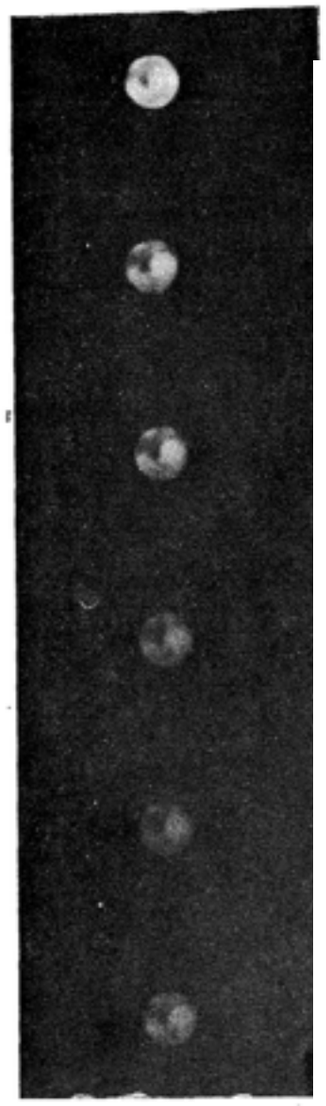

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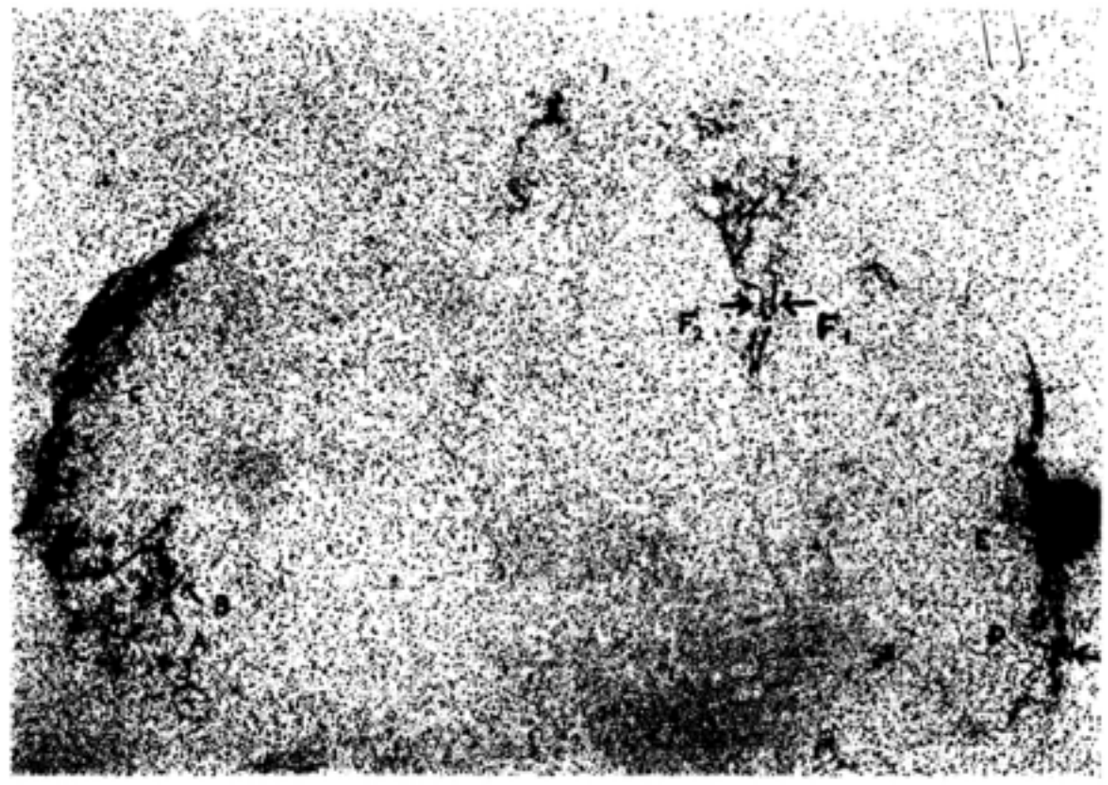
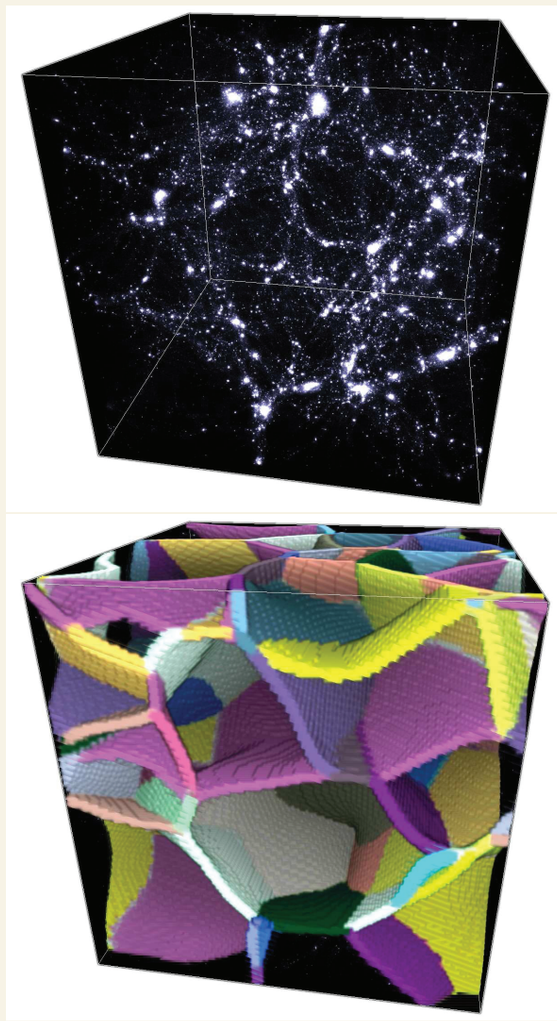


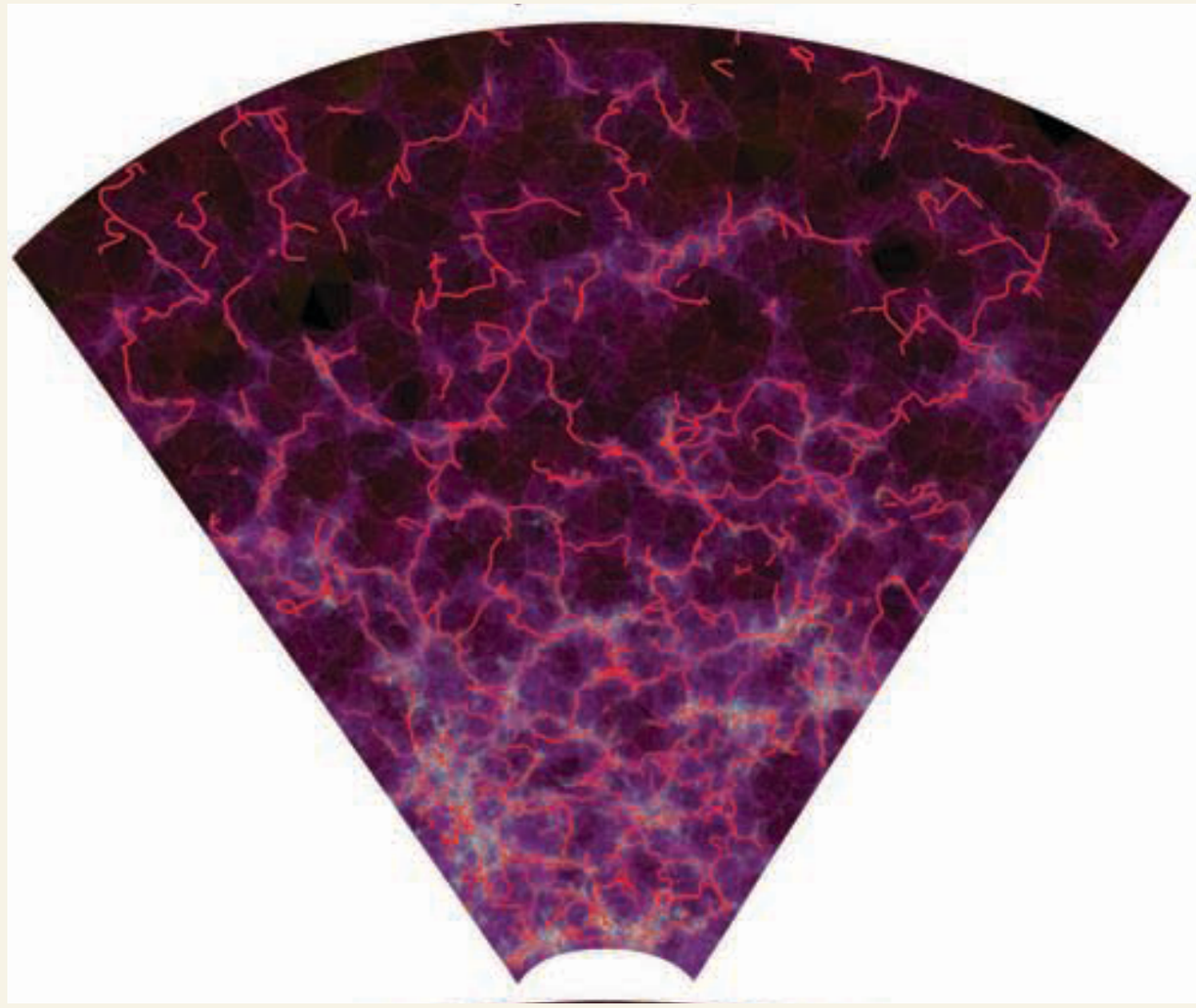
FIG. 1.—Network nebulae photographed in $H\alpha$. The arrows indicate the paths traced with the microdensitometer

Chamberlain 1953

DisPerSE is specific about the definition of "filament"

"In this paper, we focus on presenting DisPerSE, a formalism and corresponding software specifically designed for analyzing the cosmic web and its filamentary network."

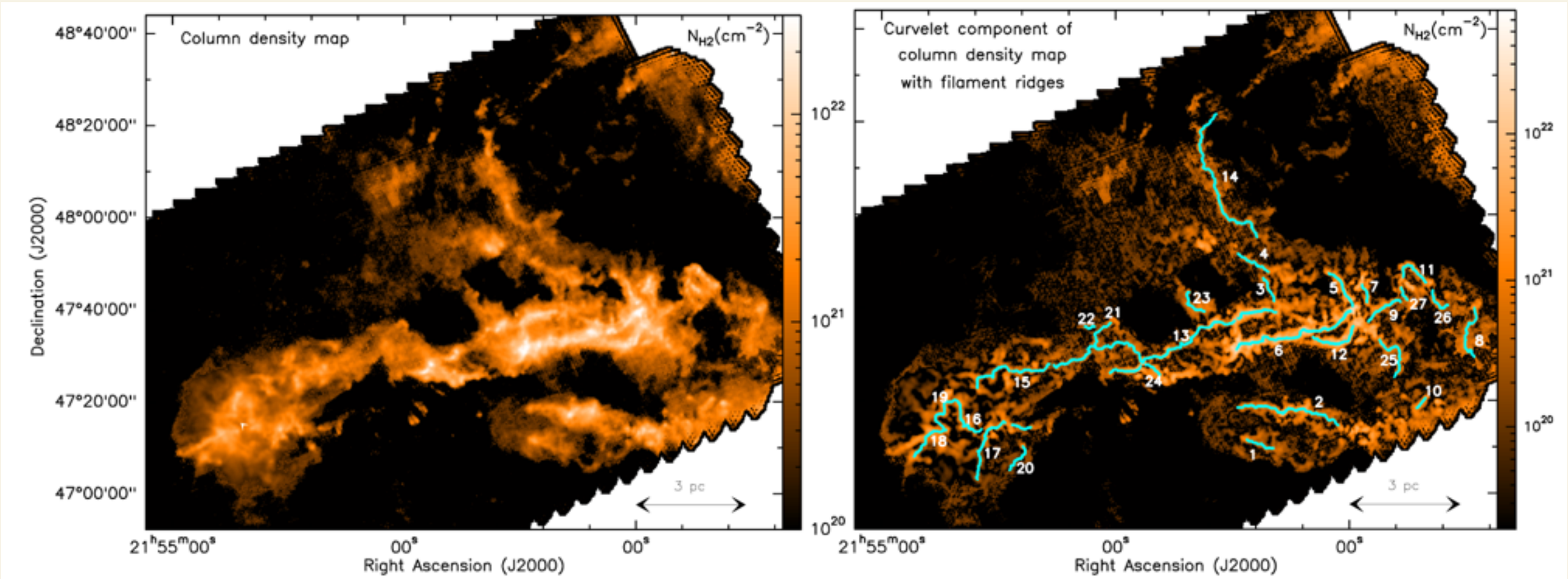




Sousbie 11, Sousbie+ 11

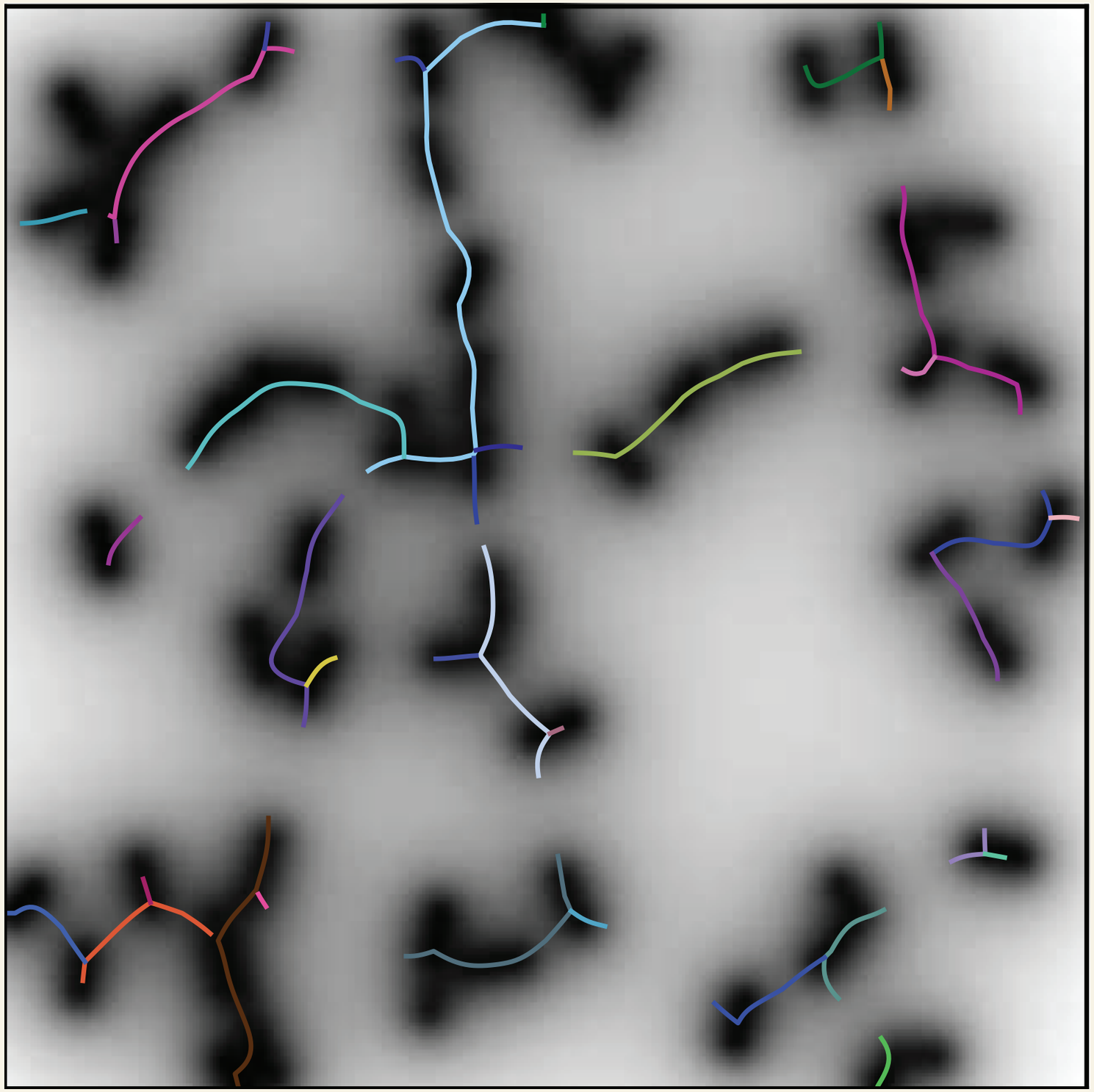
The question you ask should motivate the method you use

"DisPerSE is a general method to identify structures such as filaments and voids in astrophysical data sets (e.g. gridded maps)"



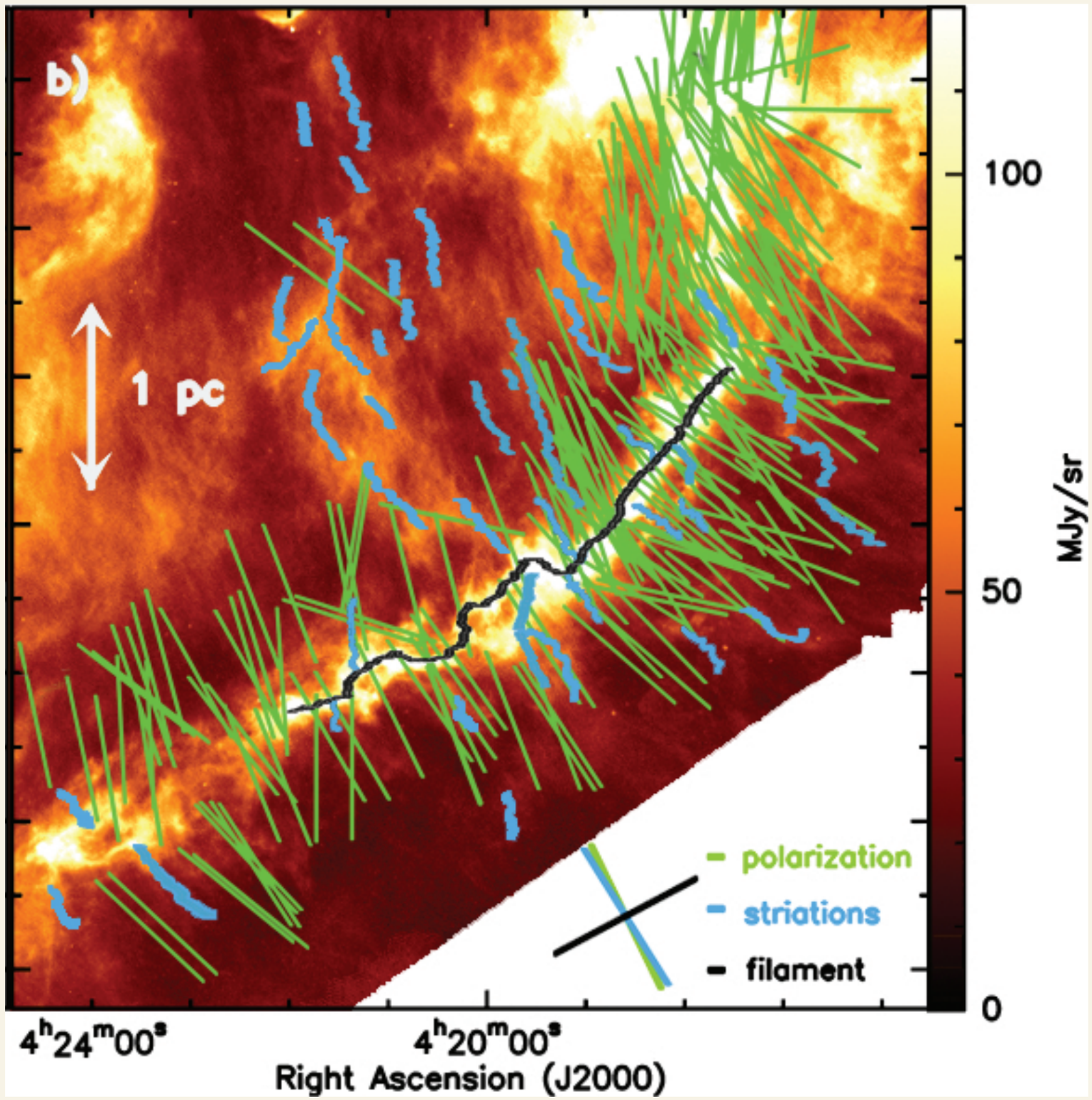
Arzoumanian+ 11

if densities *define* filaments densities are *always* on filaments



Panopoulou+ 2014

Striations are not similar to cosmological filaments



Palmeirim+ 2013

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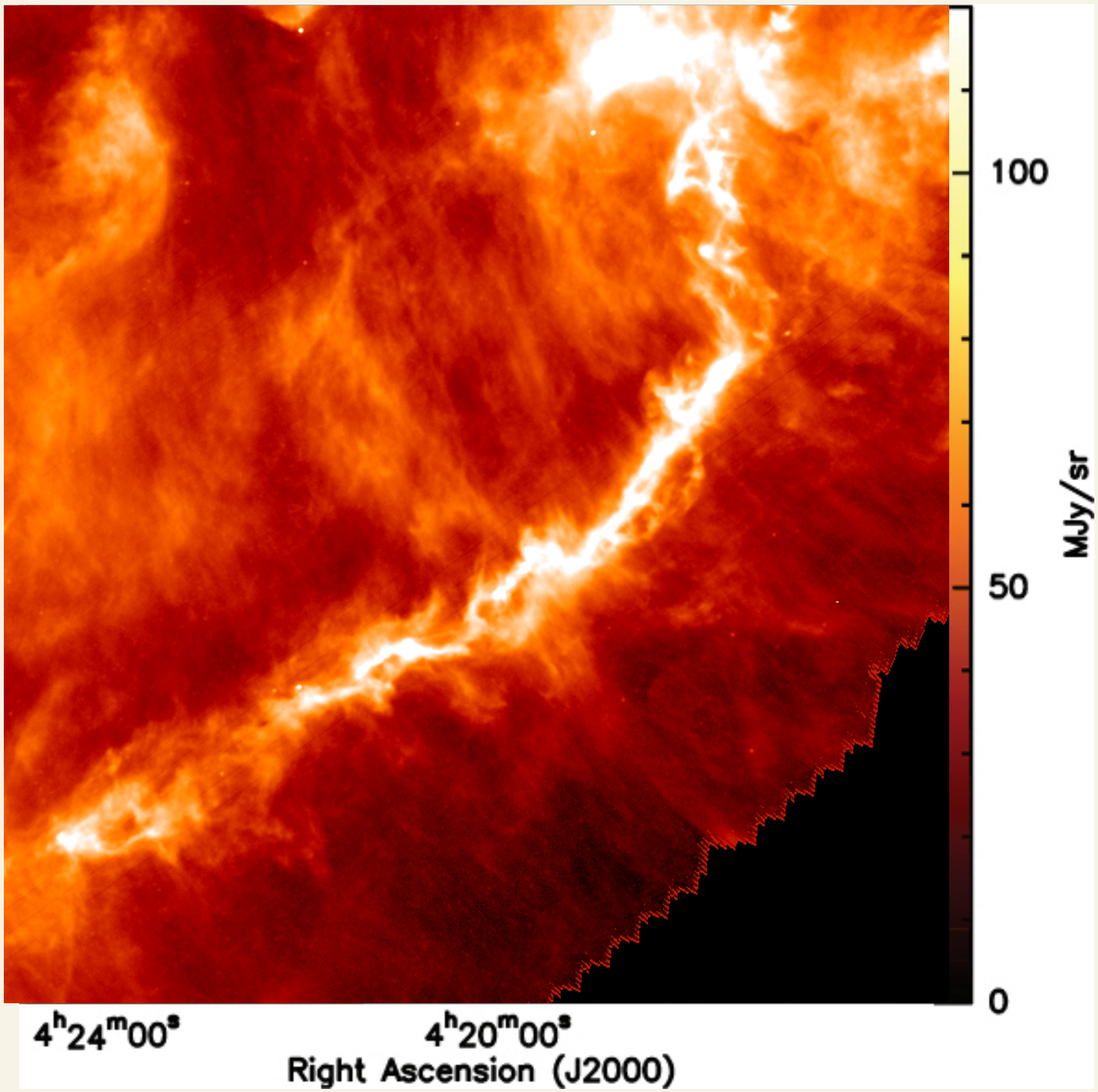

Palmeirim+ 2013

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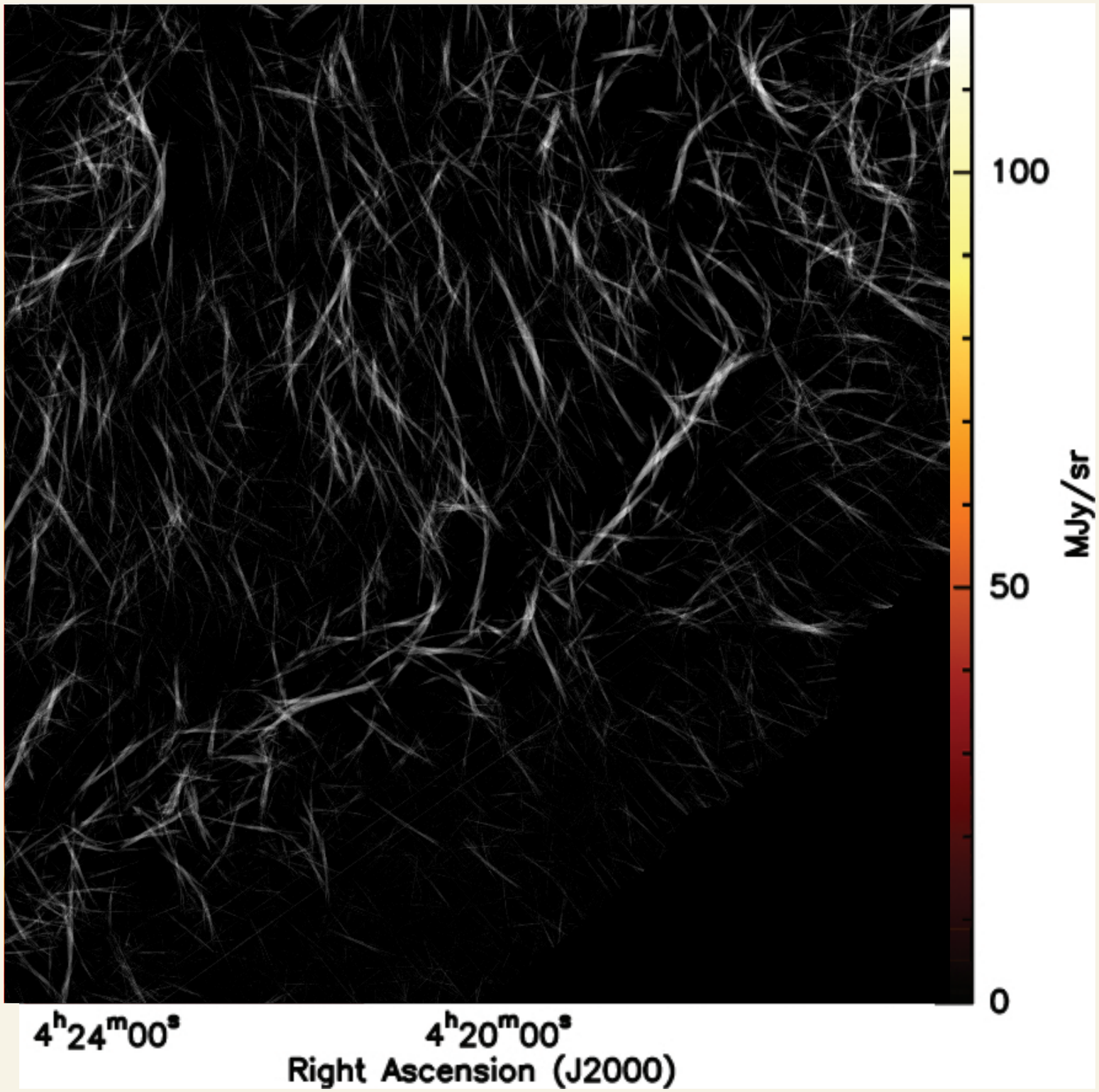
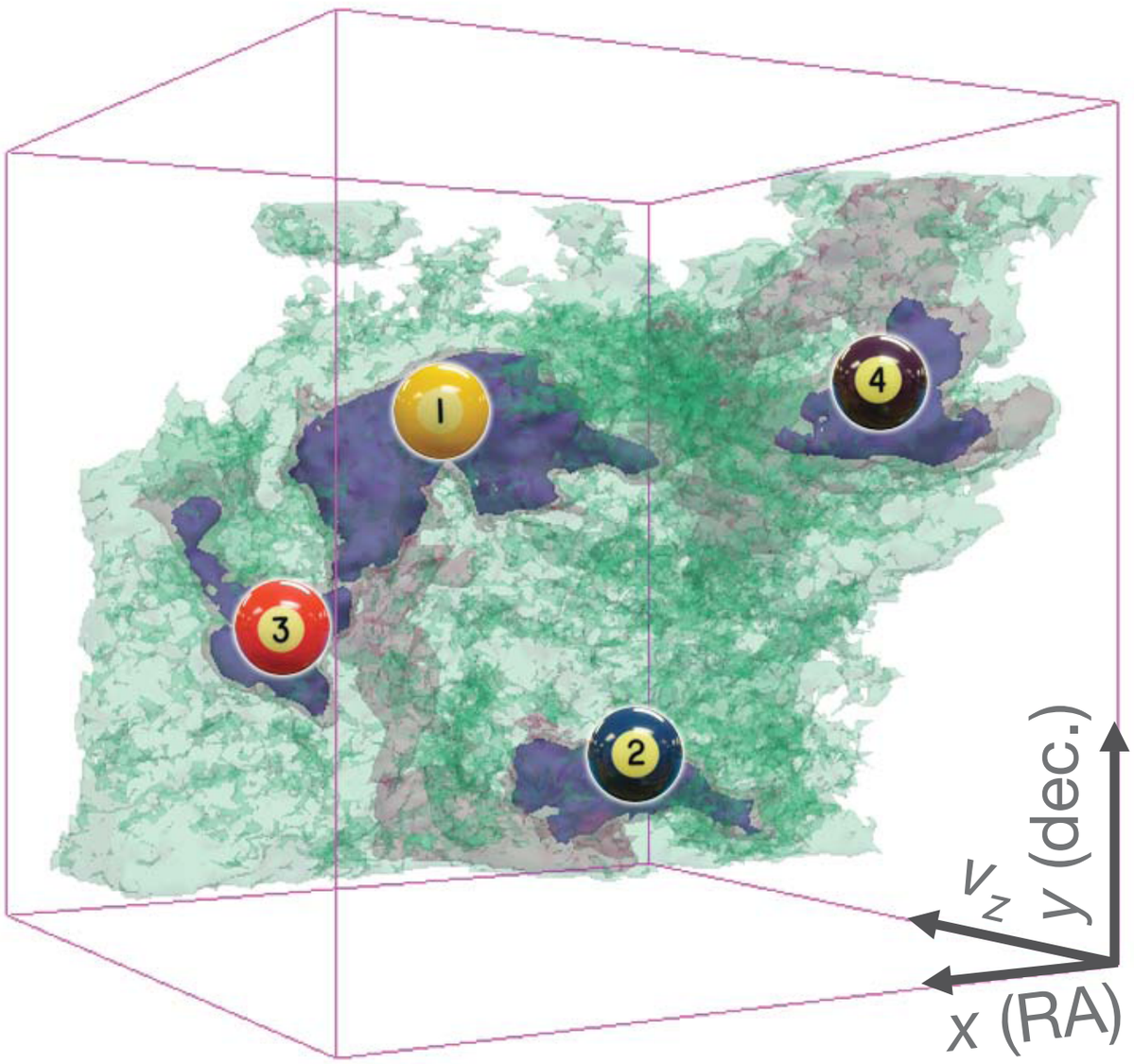
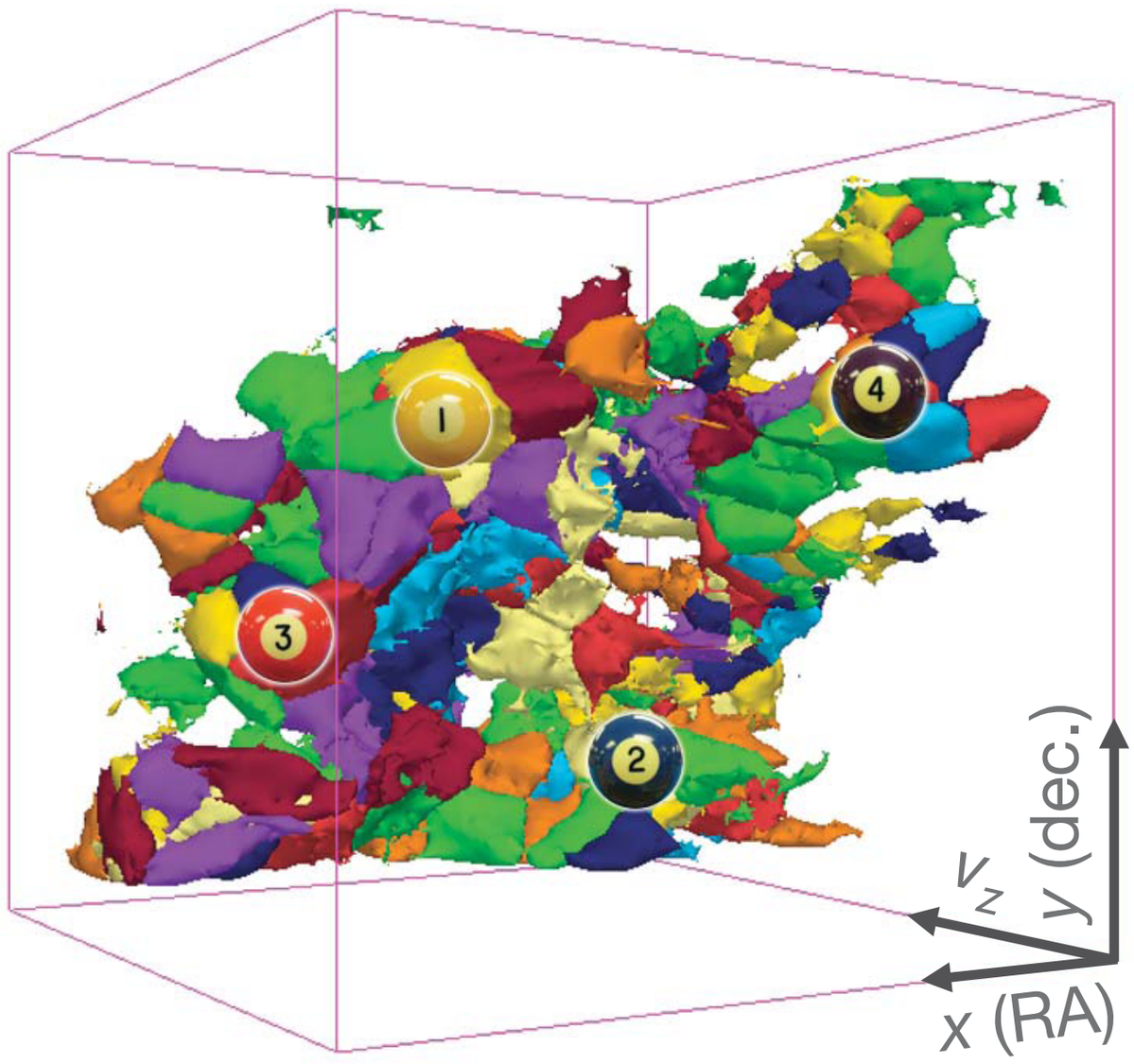


Palmeirim+ 2013

We've been here before...





Dendrogram

Clumpfind

Goodman+ 09

How do we build tools to quantify these qualities?

Smooth

Filamentary

Fibrous

Networked

Sinuous

Parallel

Hierarchical

Clumpy

Converging

Fertile

There are two bad options...

The Slow Way

The Wrong Way

There are two bad options...

~~The Slow Way~~

The Wrong Way

There are two bad options...

~~The Slow Way~~

~~The Wrong Way~~

There are two bad options...

~~The Slow Way~~

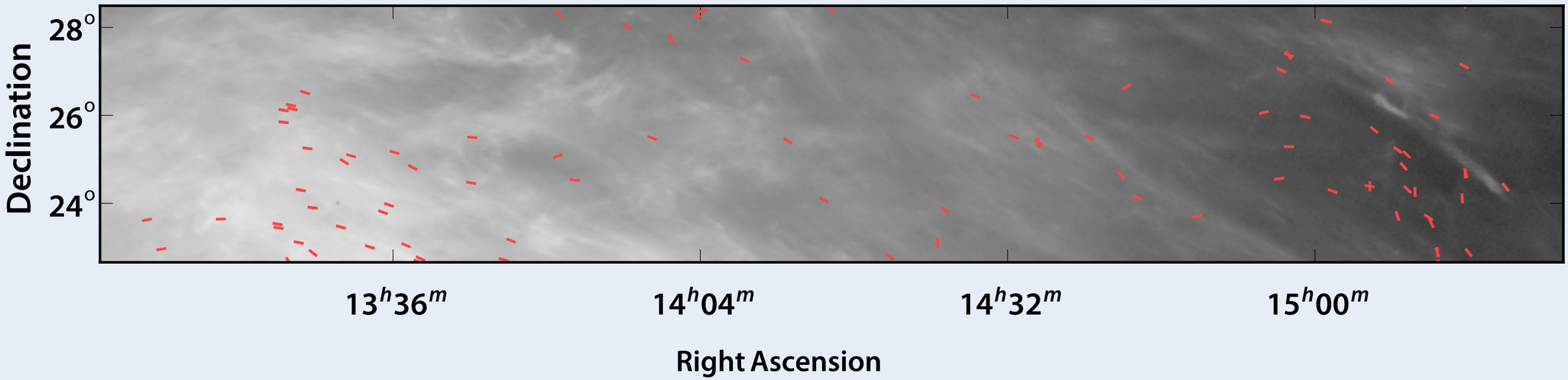
~~The Wrong Way~~

The Friendly Way

Now let's compare *results*

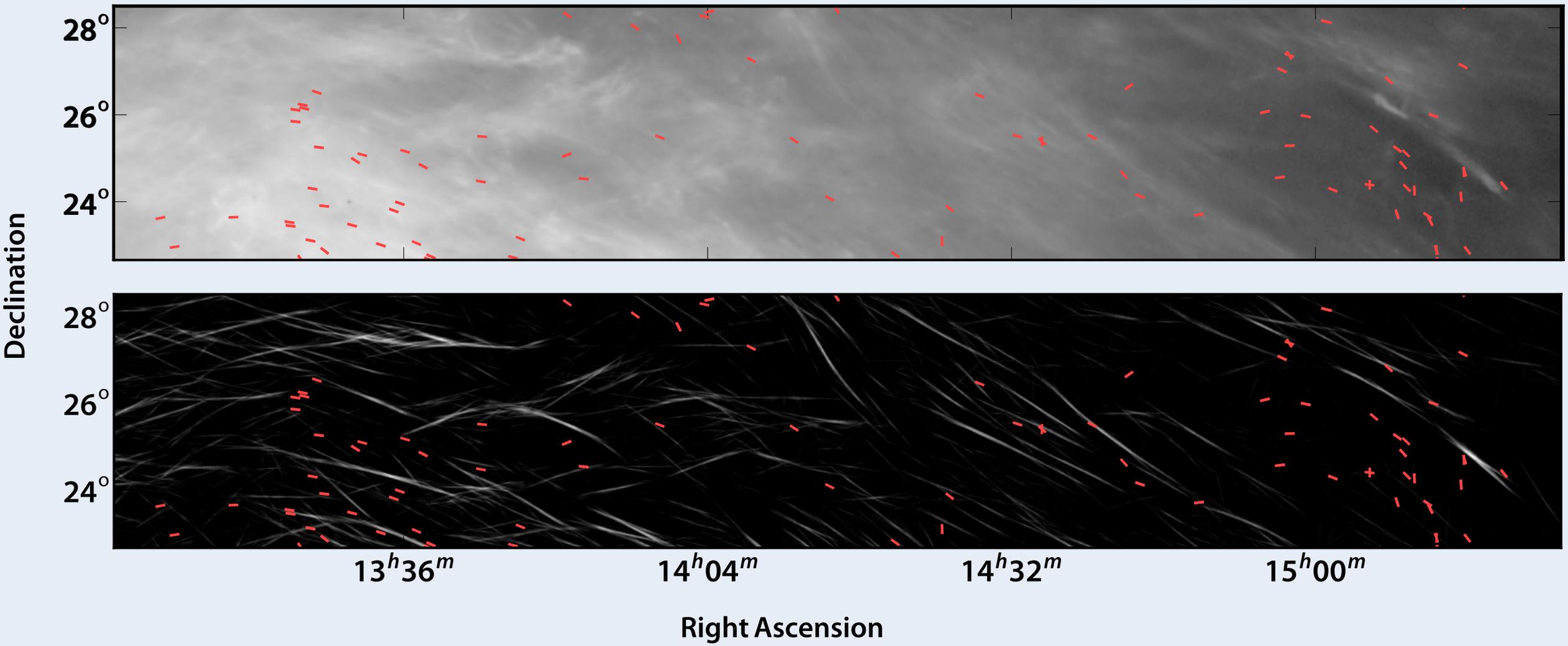
	Fibers	Planck 32
Mass Tracer	**21 cm HI**	**FIR dust emission**
Magnetic Tracer	**Starlight polarization**	**Dust emission polarization**
Vision Method	**Rolling Hough Transform**	**Hessian**

The RHT measures correlation between fibers and B



Clark, JEGP, Putman 14

The RHT measures correlation between fibers and B



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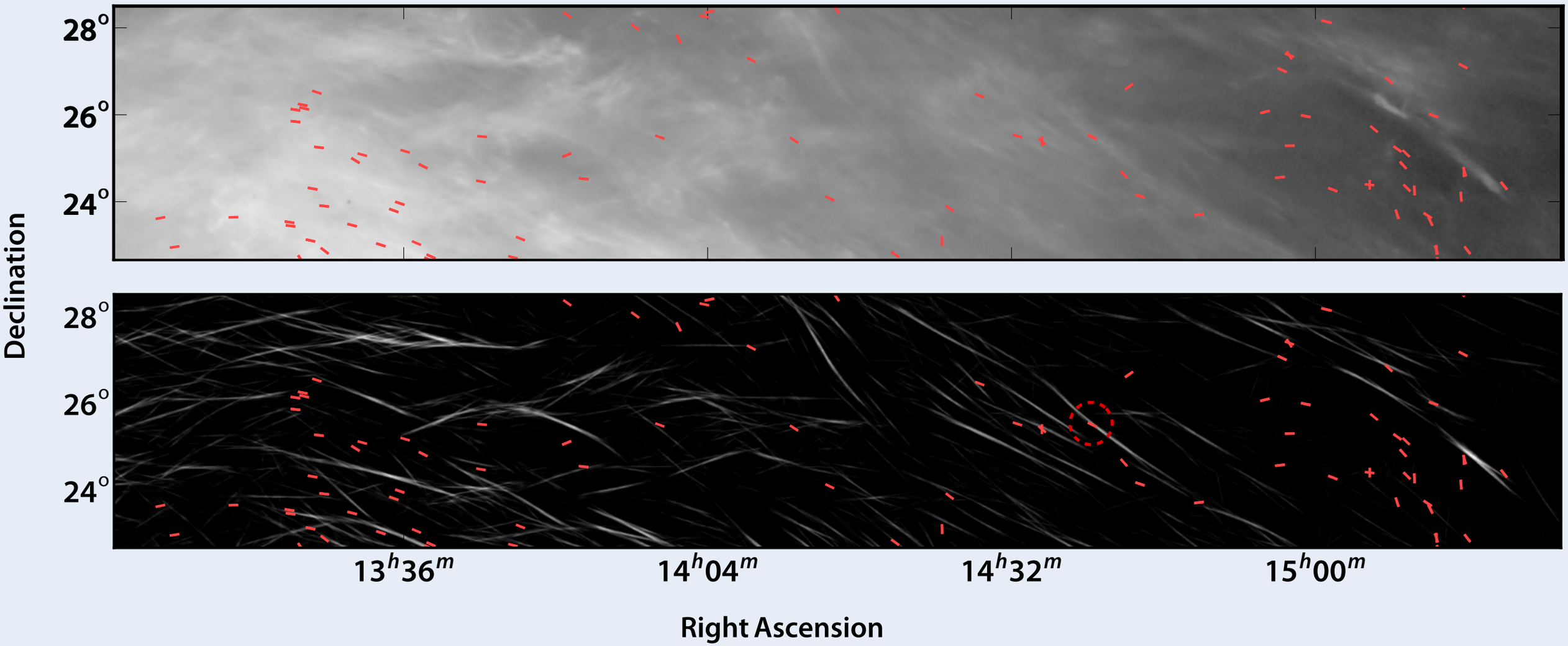
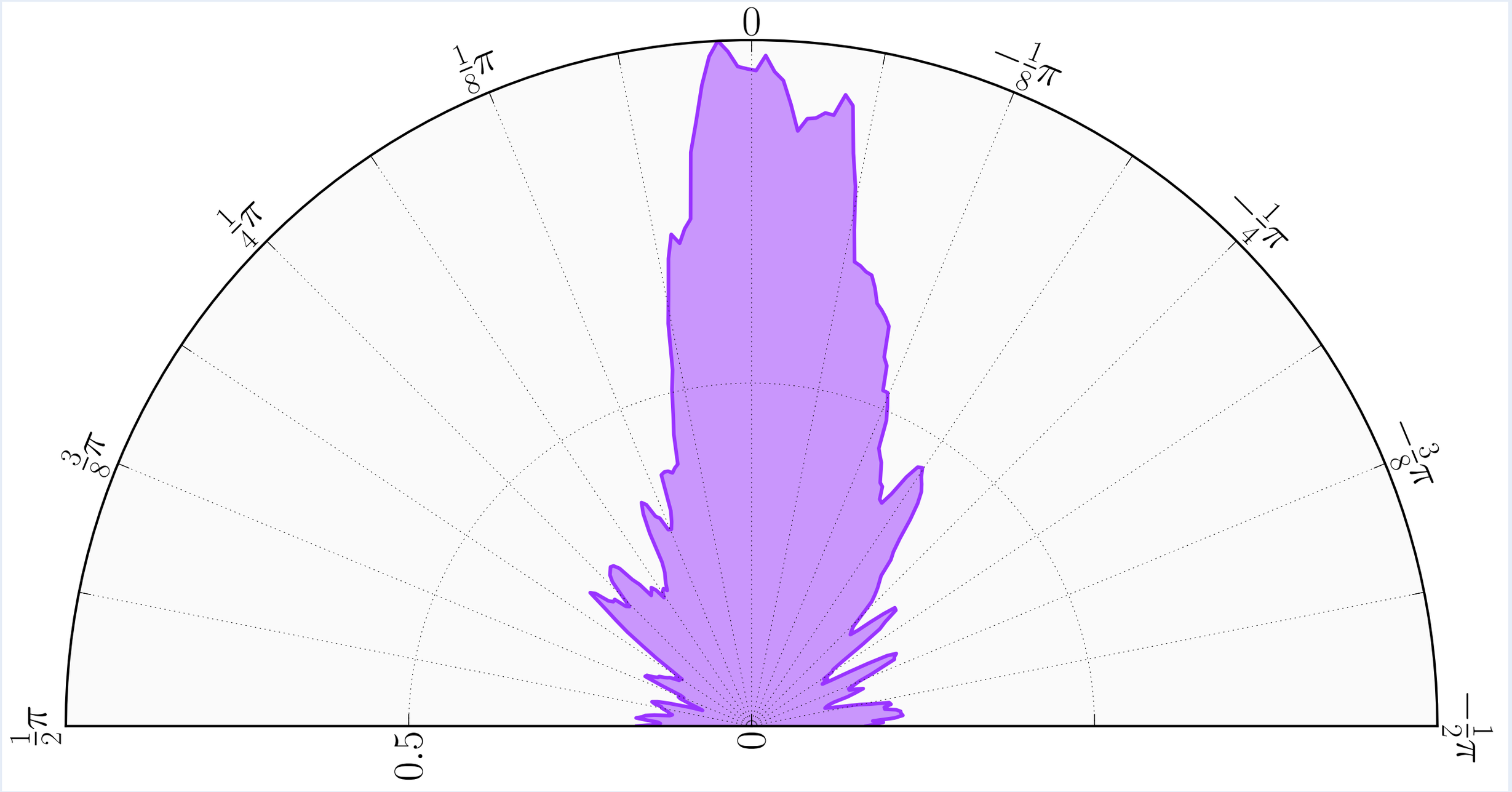


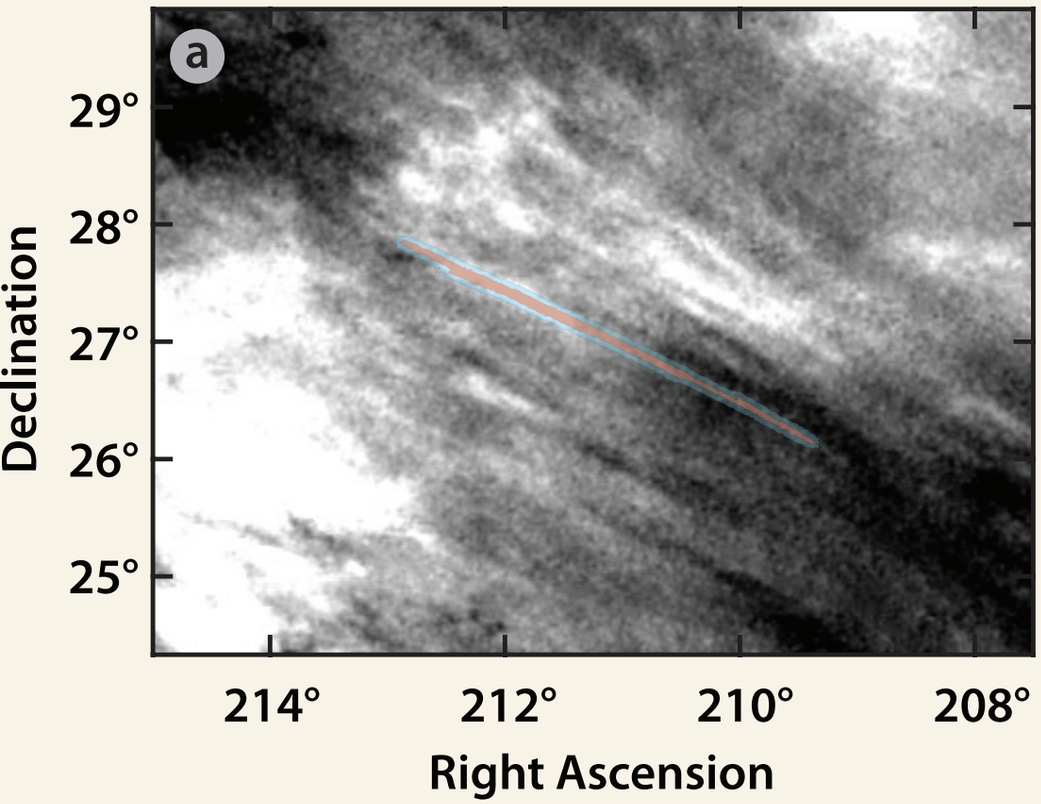
Clark, JEGP, Putman 14

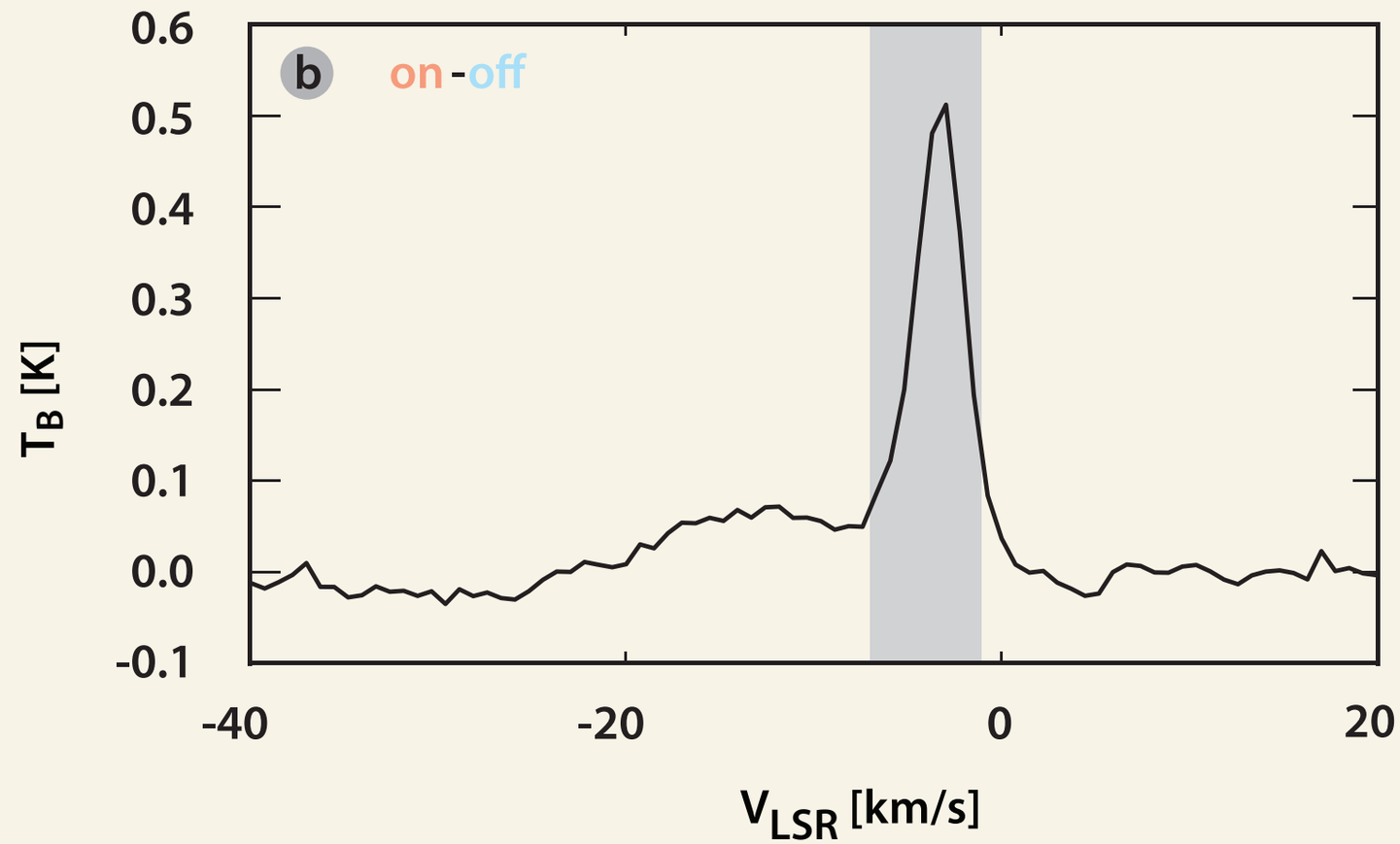
Fibers correlate tightly with starlight polarization



Clark, JEGP, Putman 14

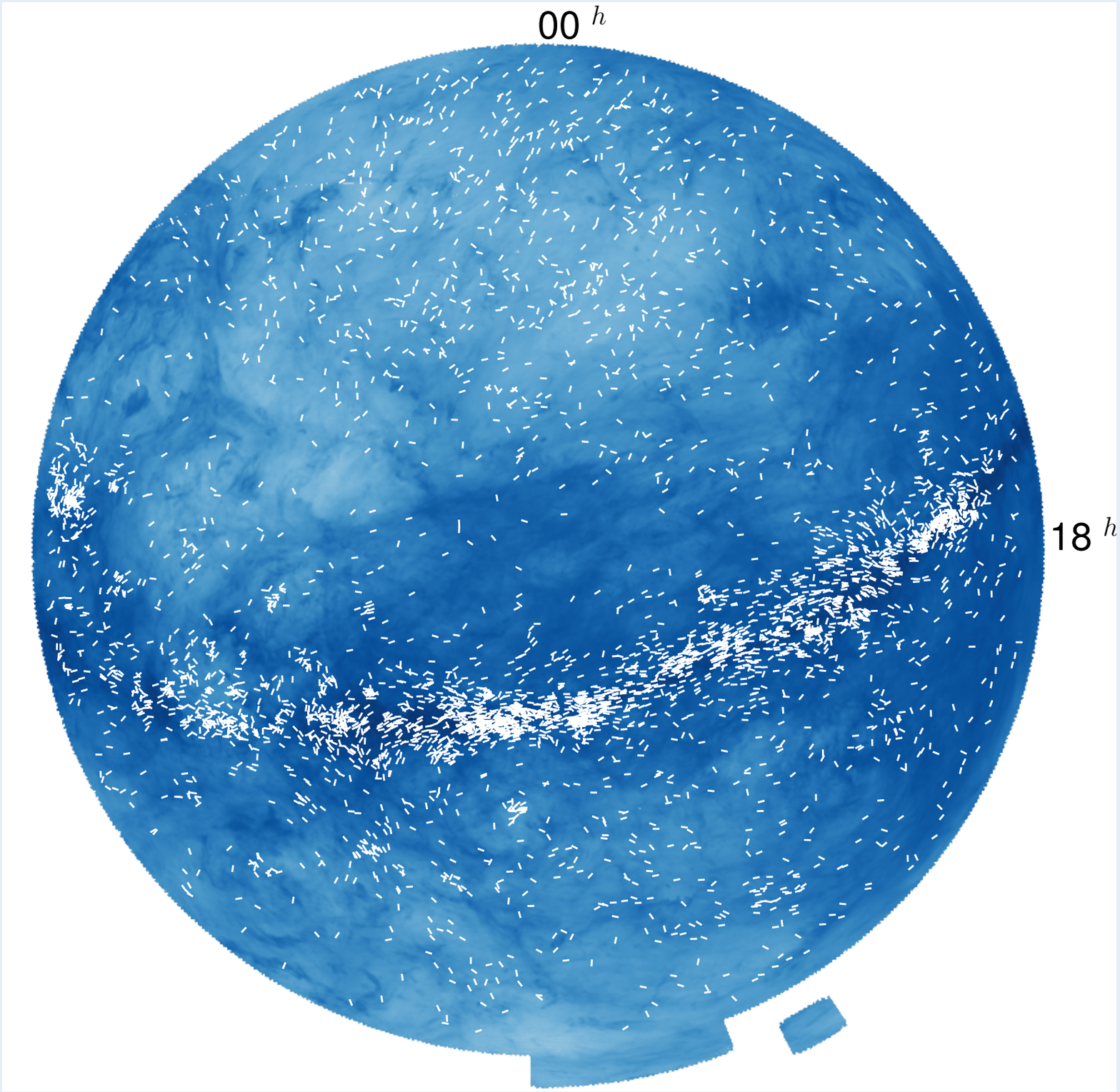
Fibers are CNM features, and do not dominate the column





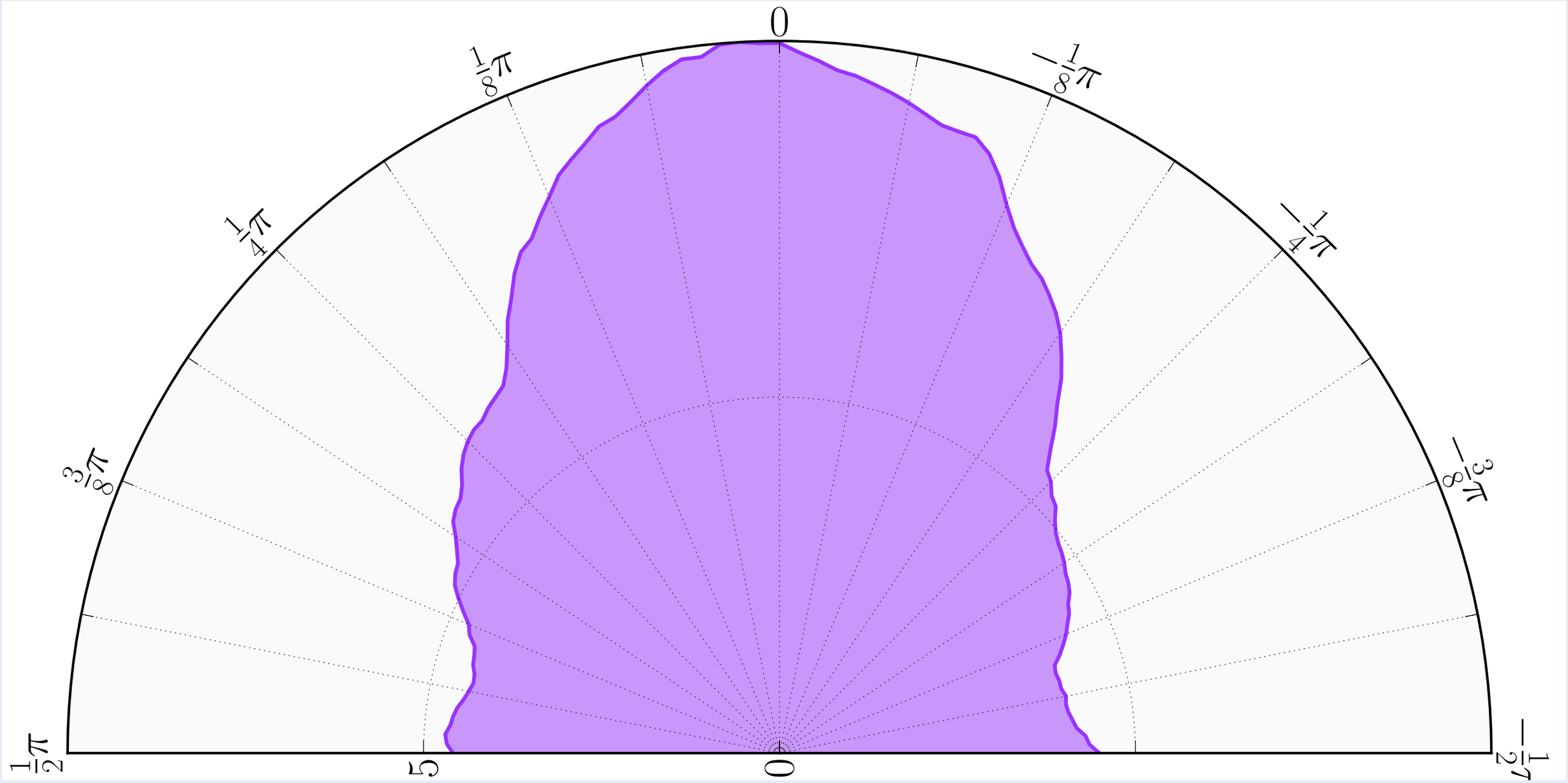
Clark, JEGP, Putman 14

We examine the same correlation in the Southern Sky



Clark, JEGP, Putman 14

A weaker correlation: ubiquitous but not scale-free

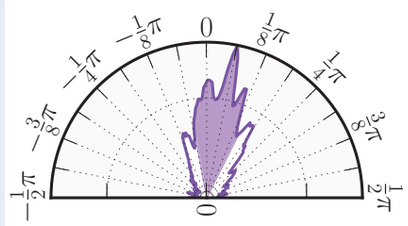


Clark, JEGP, Putman 14

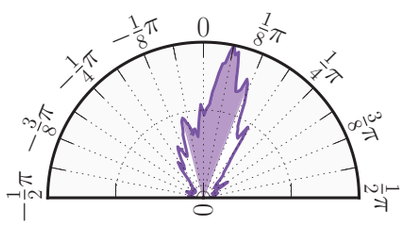
Fiber orientation does not weaken with distance

GALFA-HI

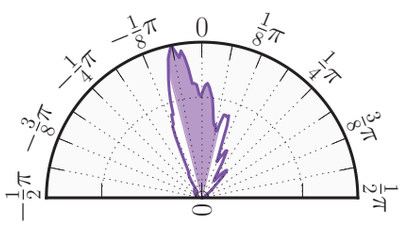
13 – 84 pc



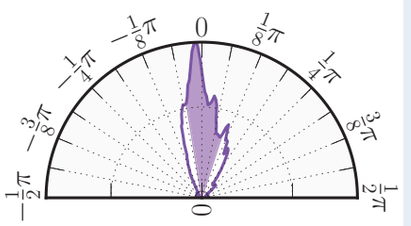
84 – 133 pc



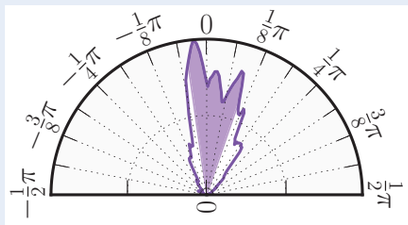
133 – 175 pc



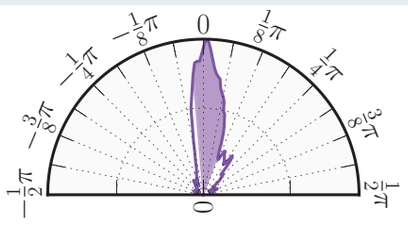
175 – 253 pc



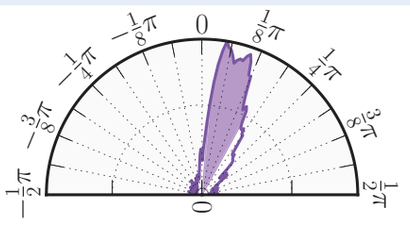
253 – 375 pc



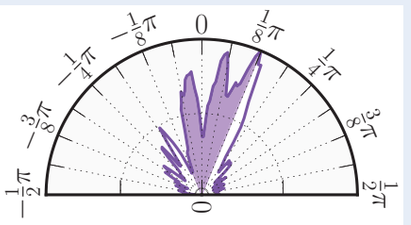
375 – 442 pc



442 – 607 pc

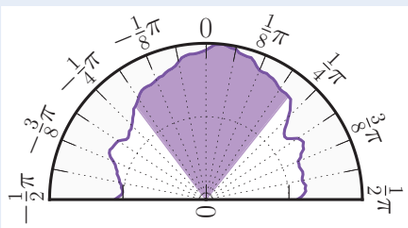


607 – 1459 pc

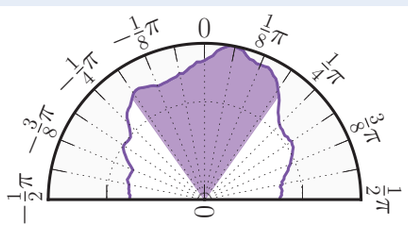


GASS

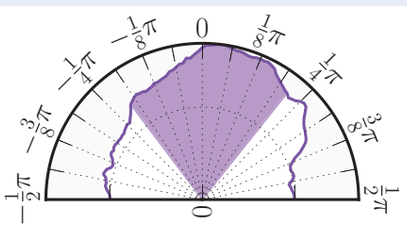
8.7 – 127 pc



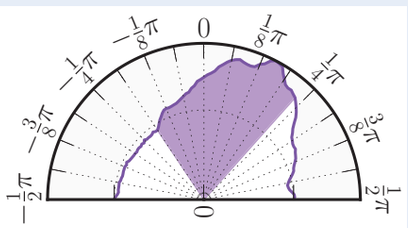
127 – 291 pc



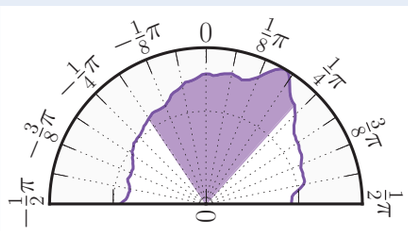
291 – 575 pc



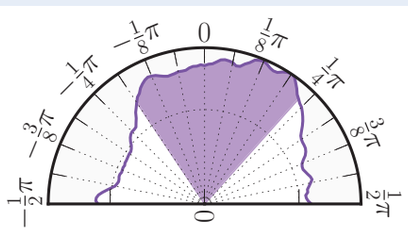
575 – 1140 pc



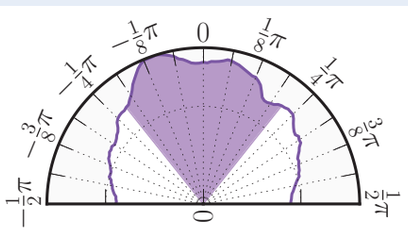
1.14 – 1.66 kpc



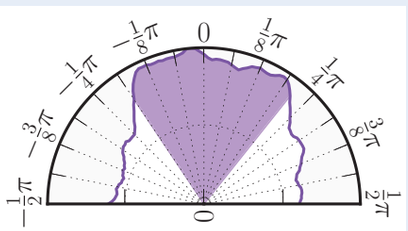
1.66 – 2.22 kpc



2.22 – 3.13 kpc

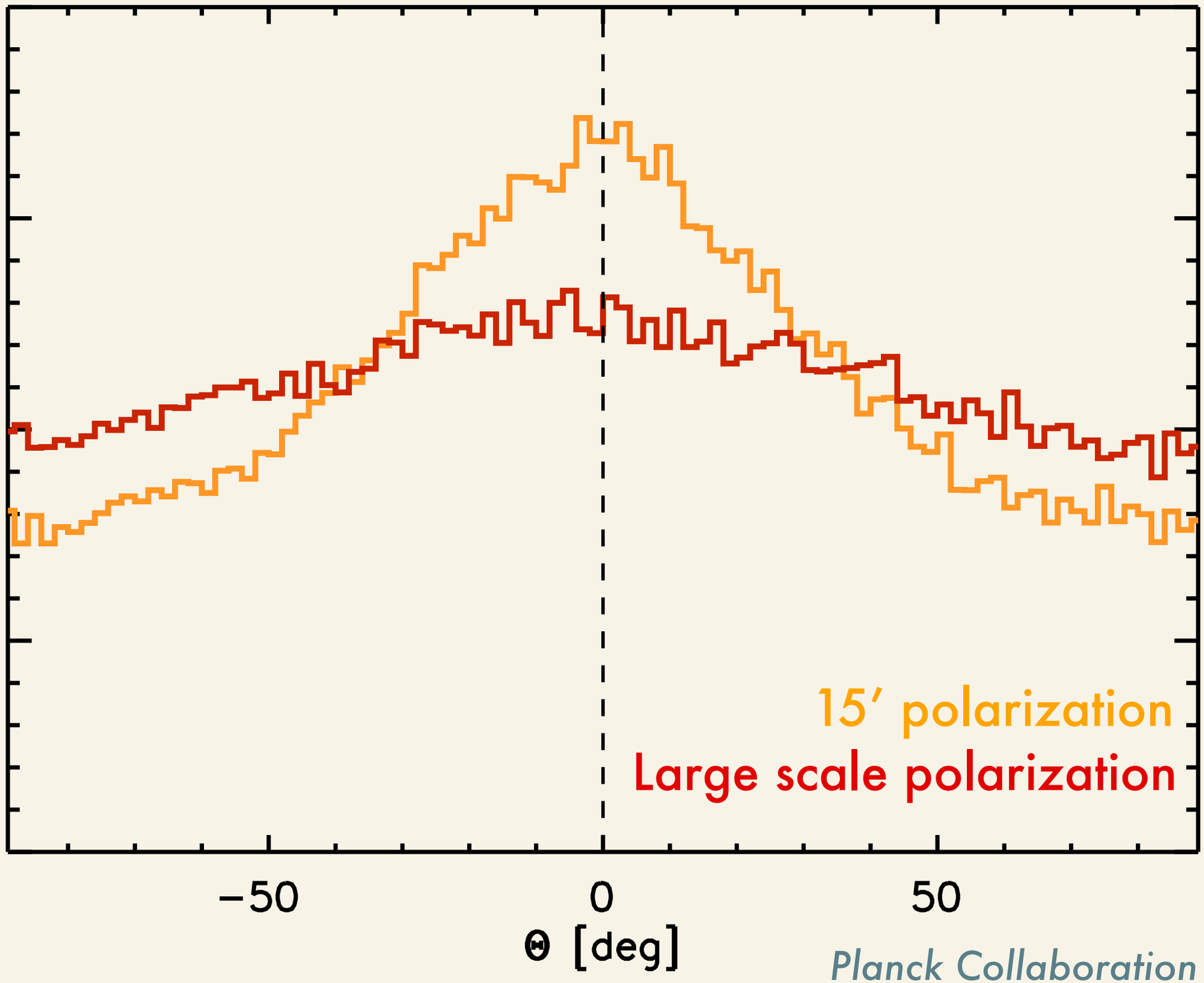


3.13 – 27.5 kpc



Clark, JEGP, Putman 14

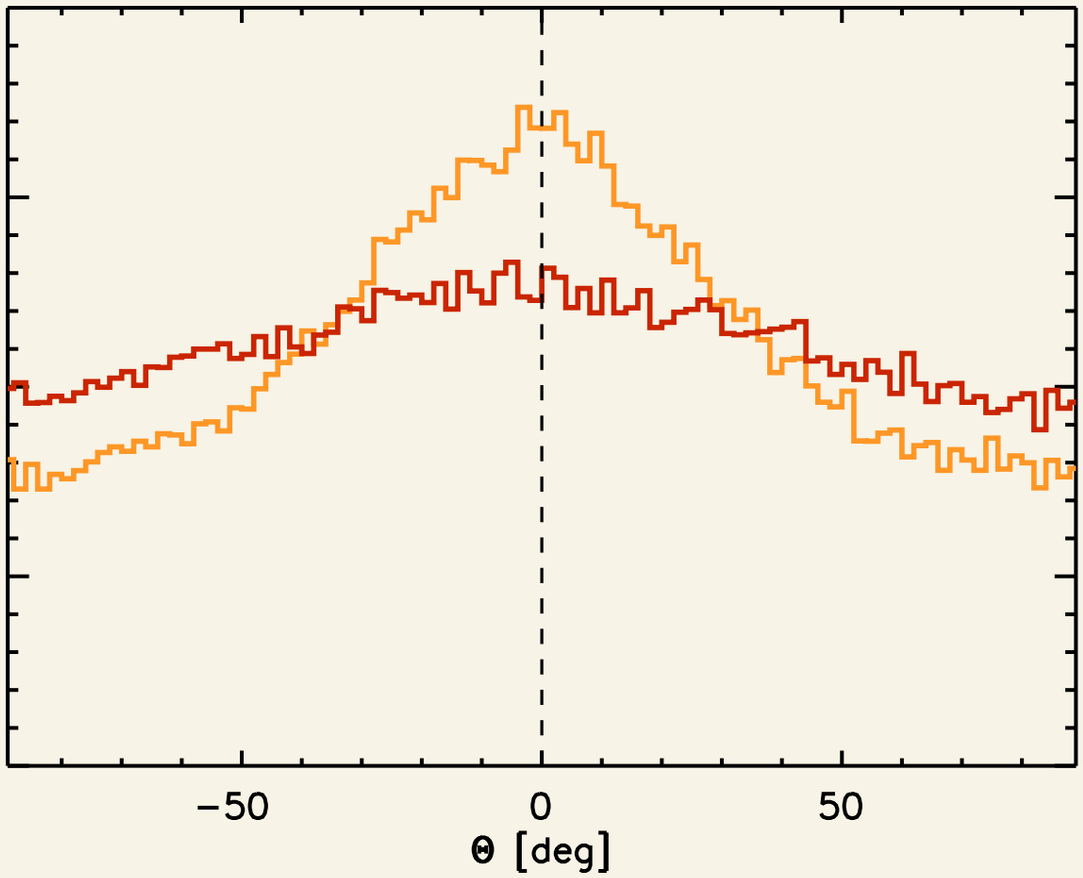
*Planck*32 also shows correlation between lines and B field



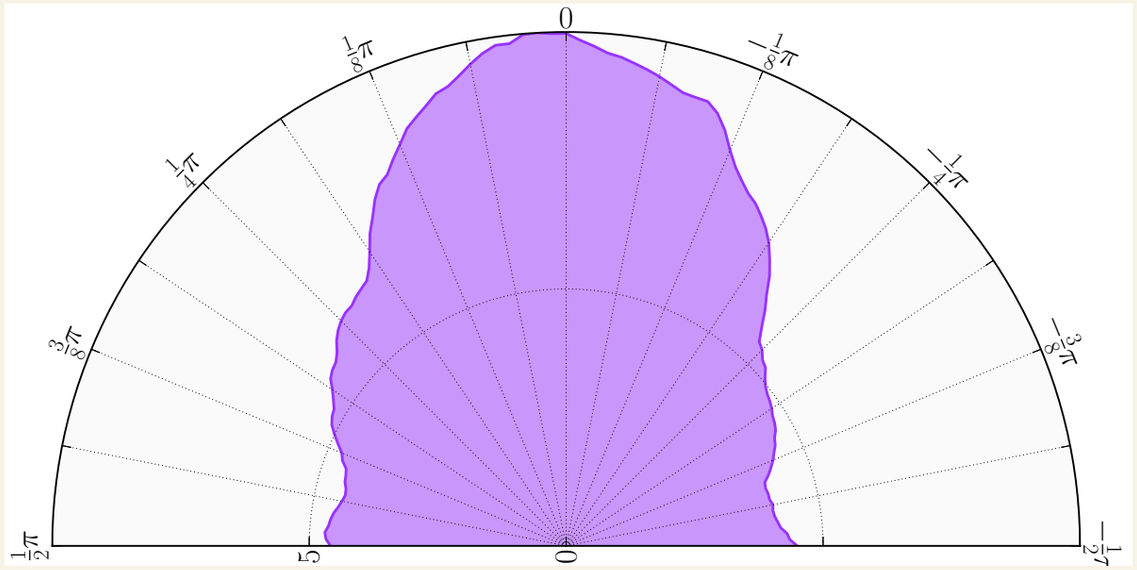
Planck Collaboration XXXII 14

Magnetic correlation is a function of scale

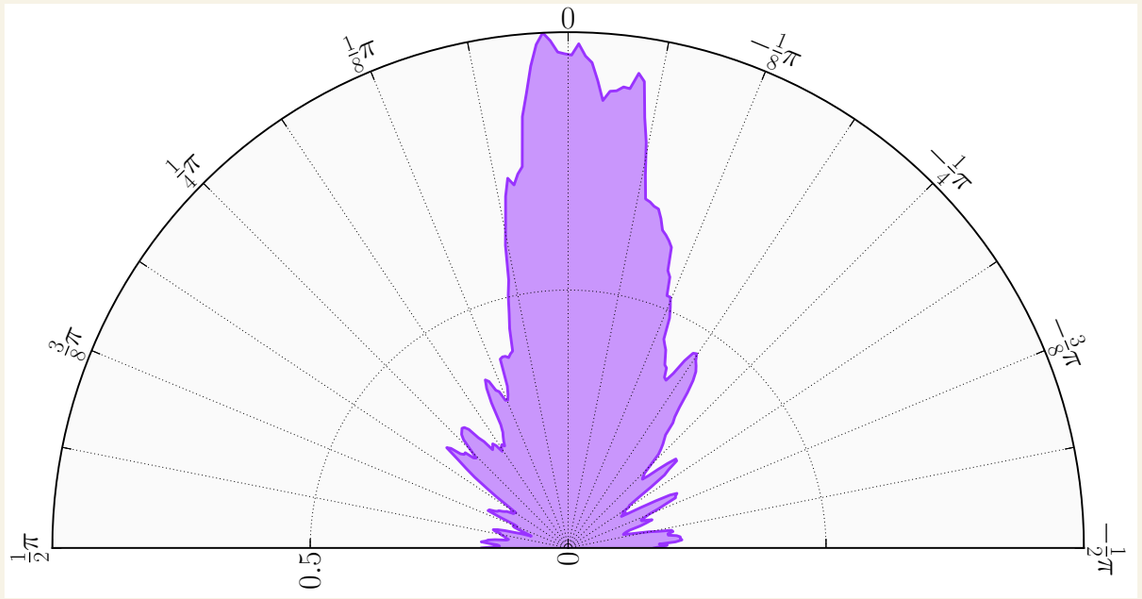
Planck, 15′ — 2:1



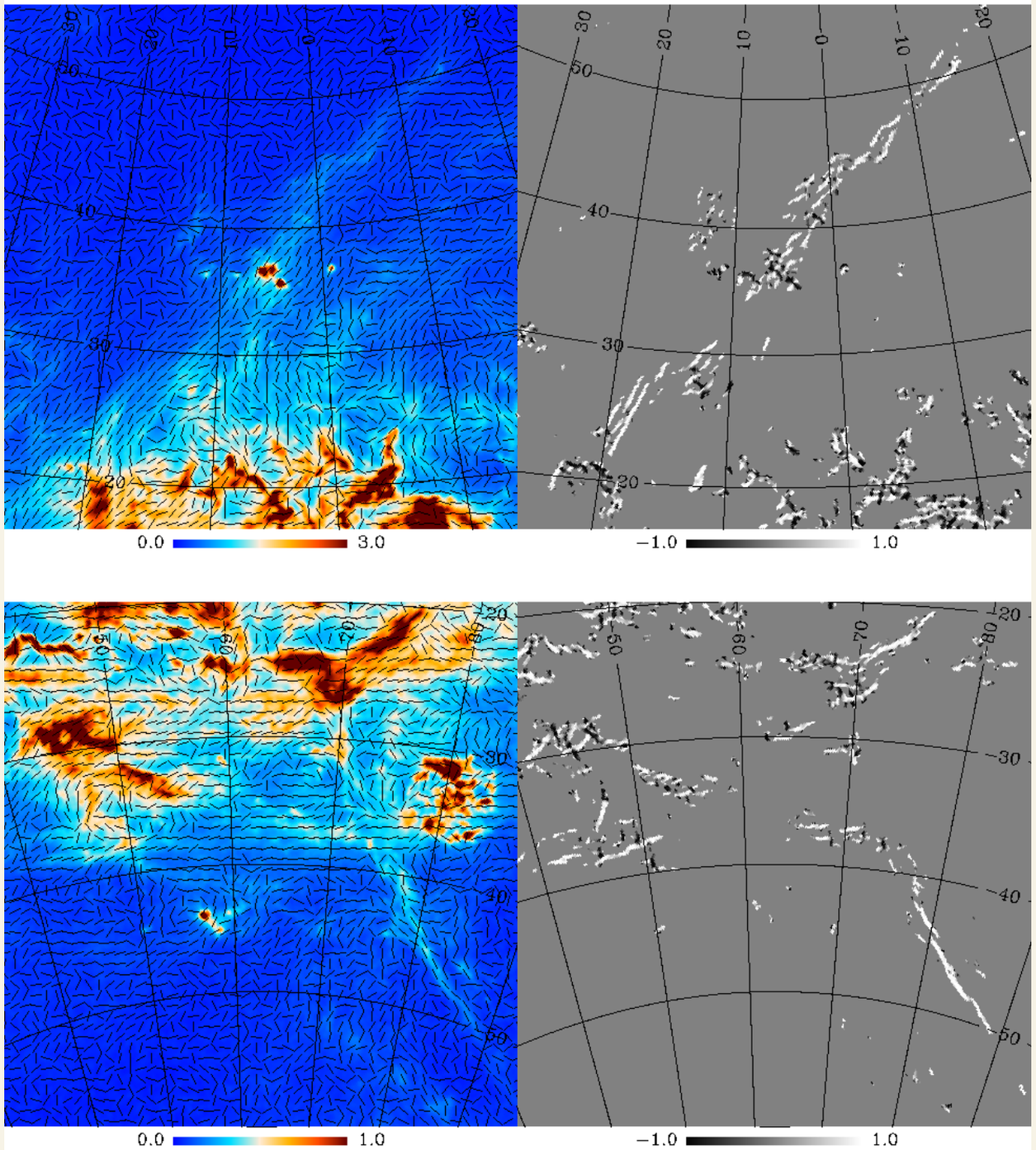
GASS, 15′ — 2:1

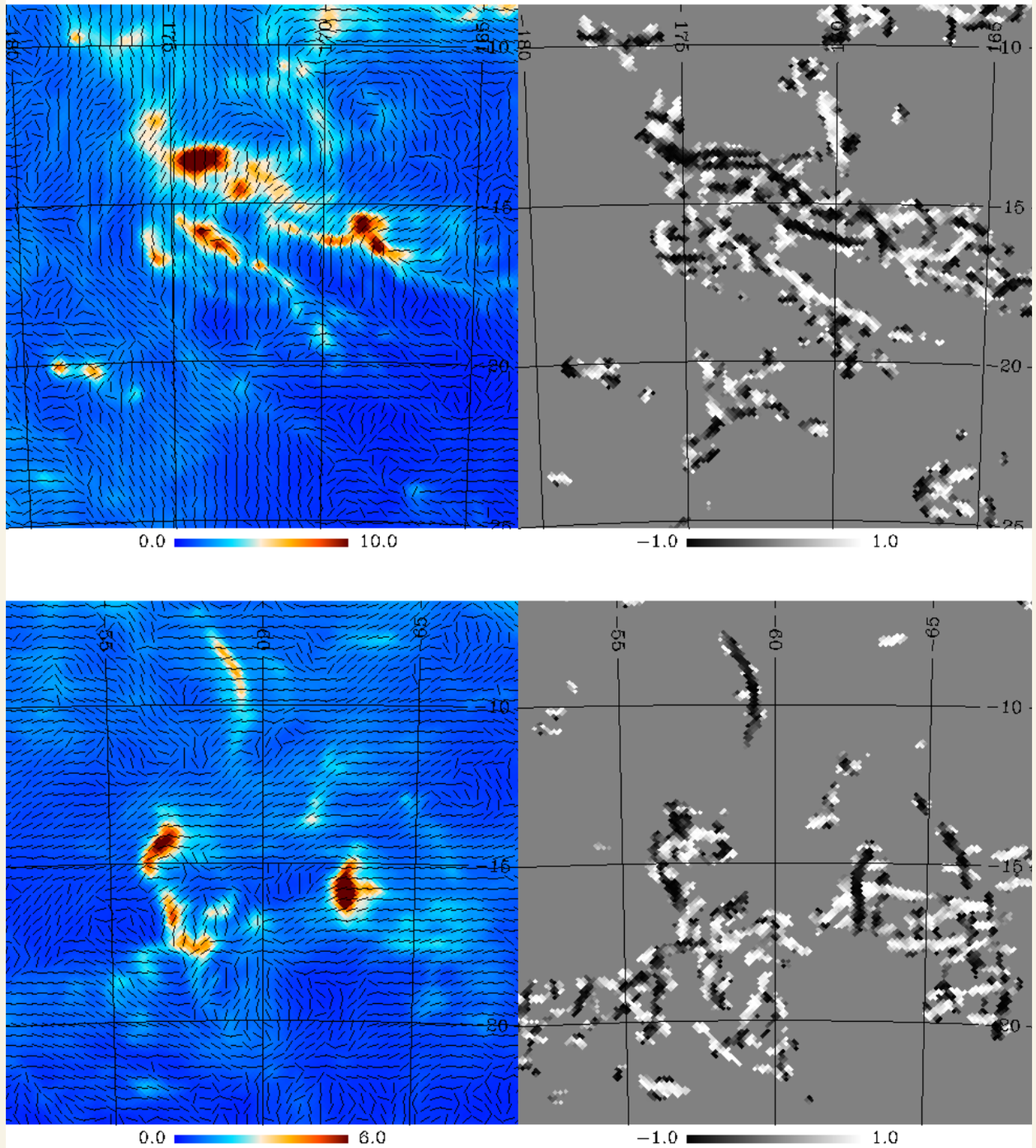


GALFA-HI, 4′ — 8:1

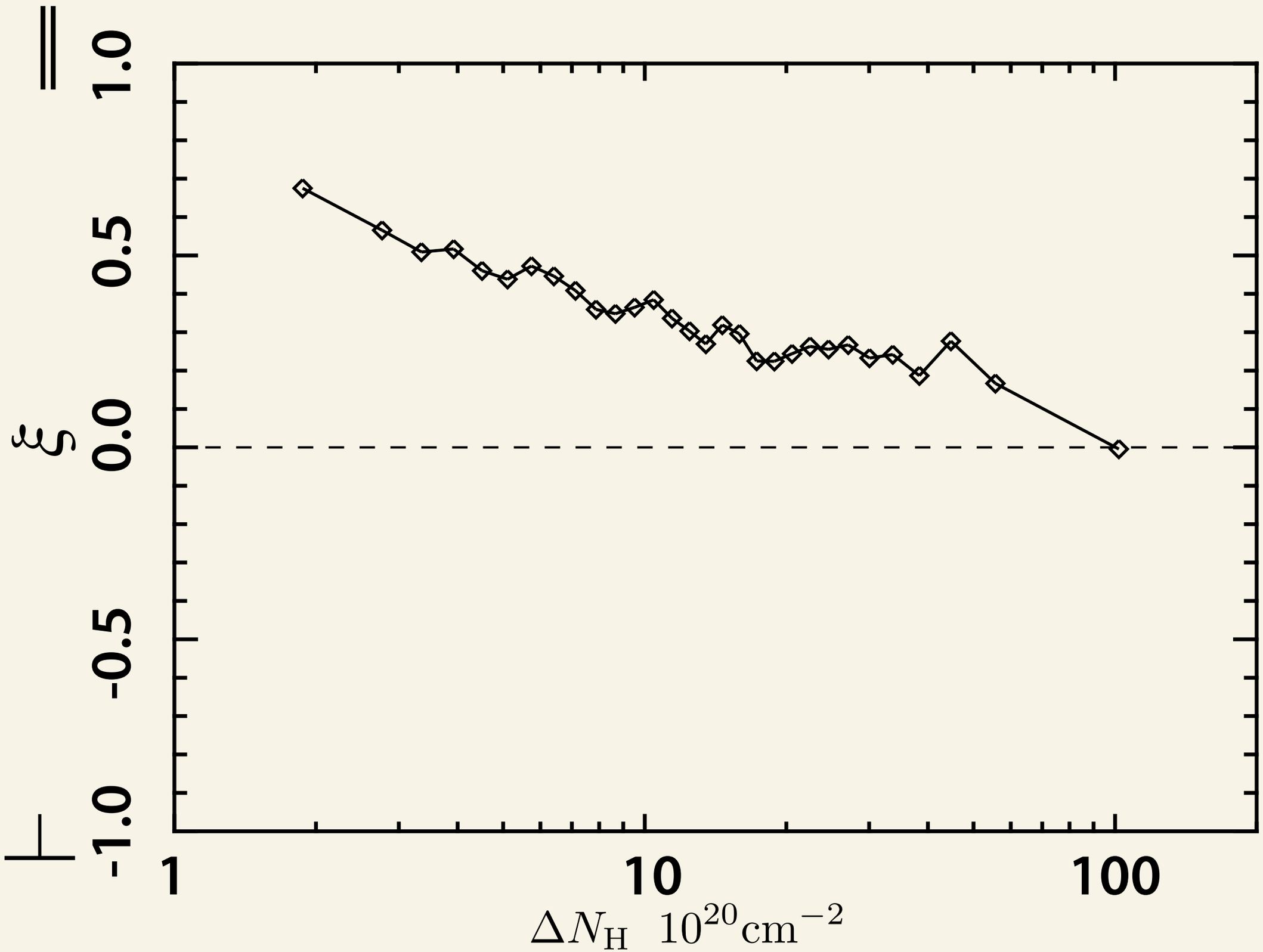


Field-"filament" correlation weakens at higher column



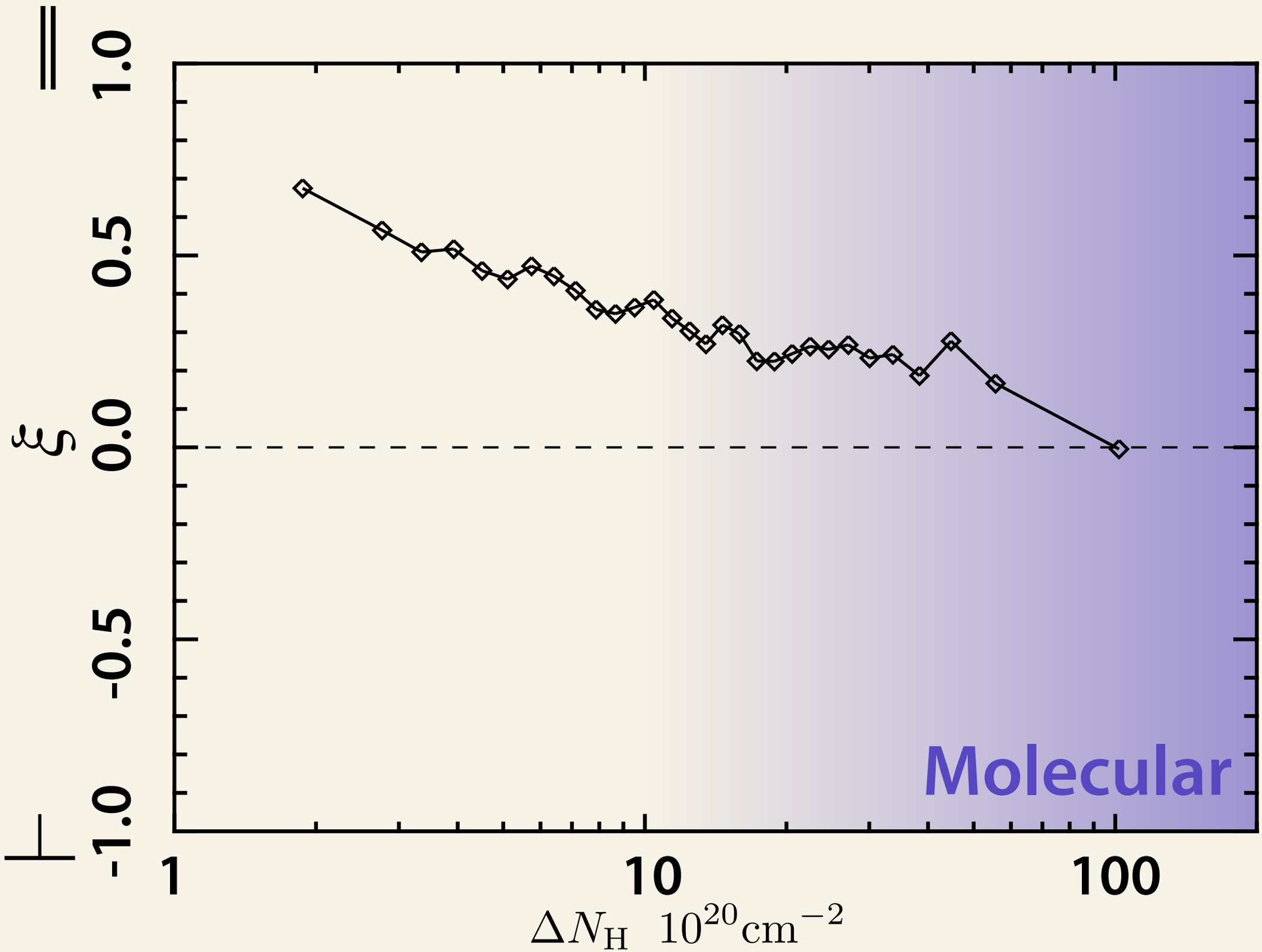


Field-"filament" correlation weakens at higher column



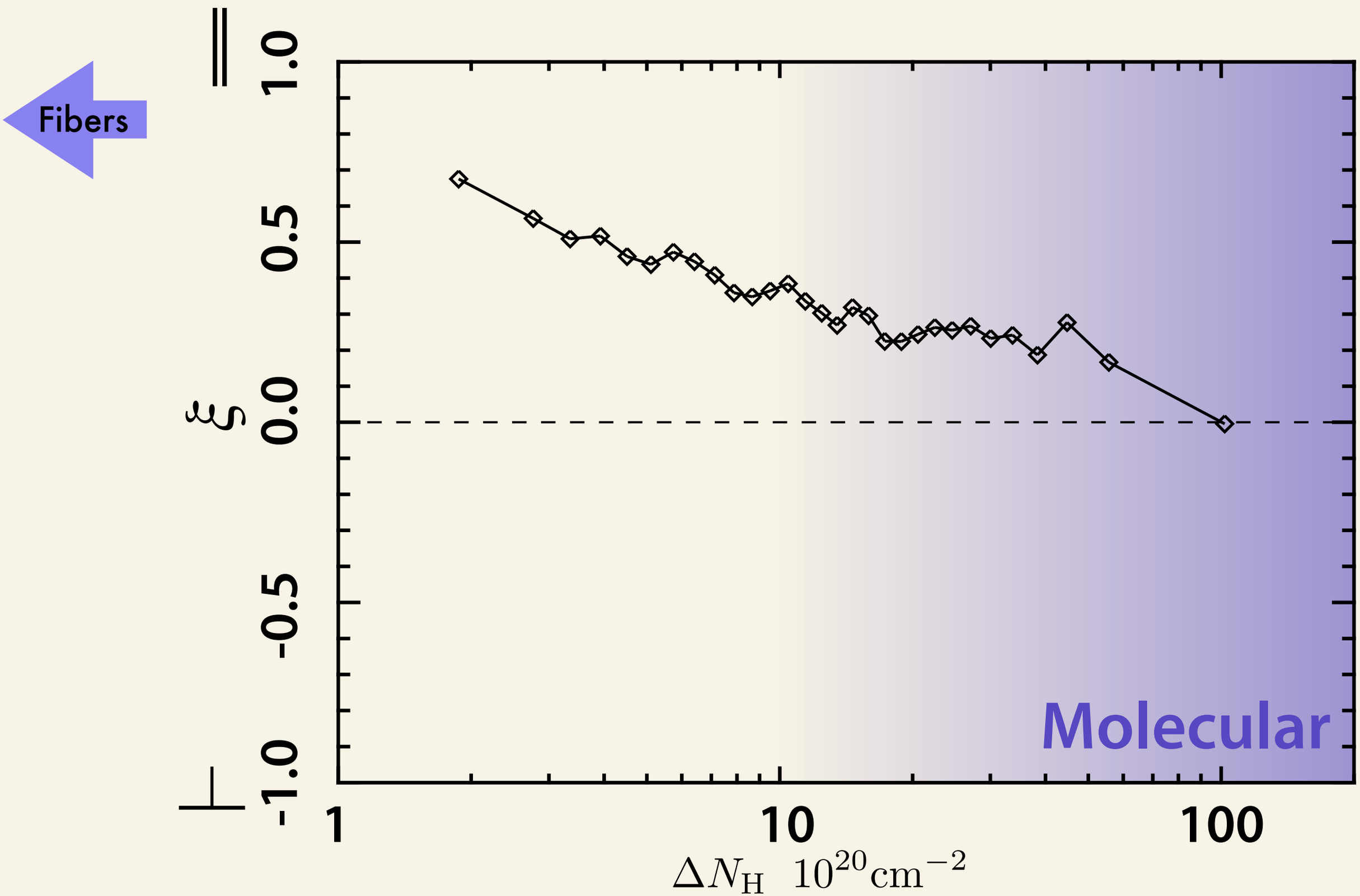
Planck Collaboration XXXII 14 ; Soler+ 13

Field-"filament" correlation weakens at higher column



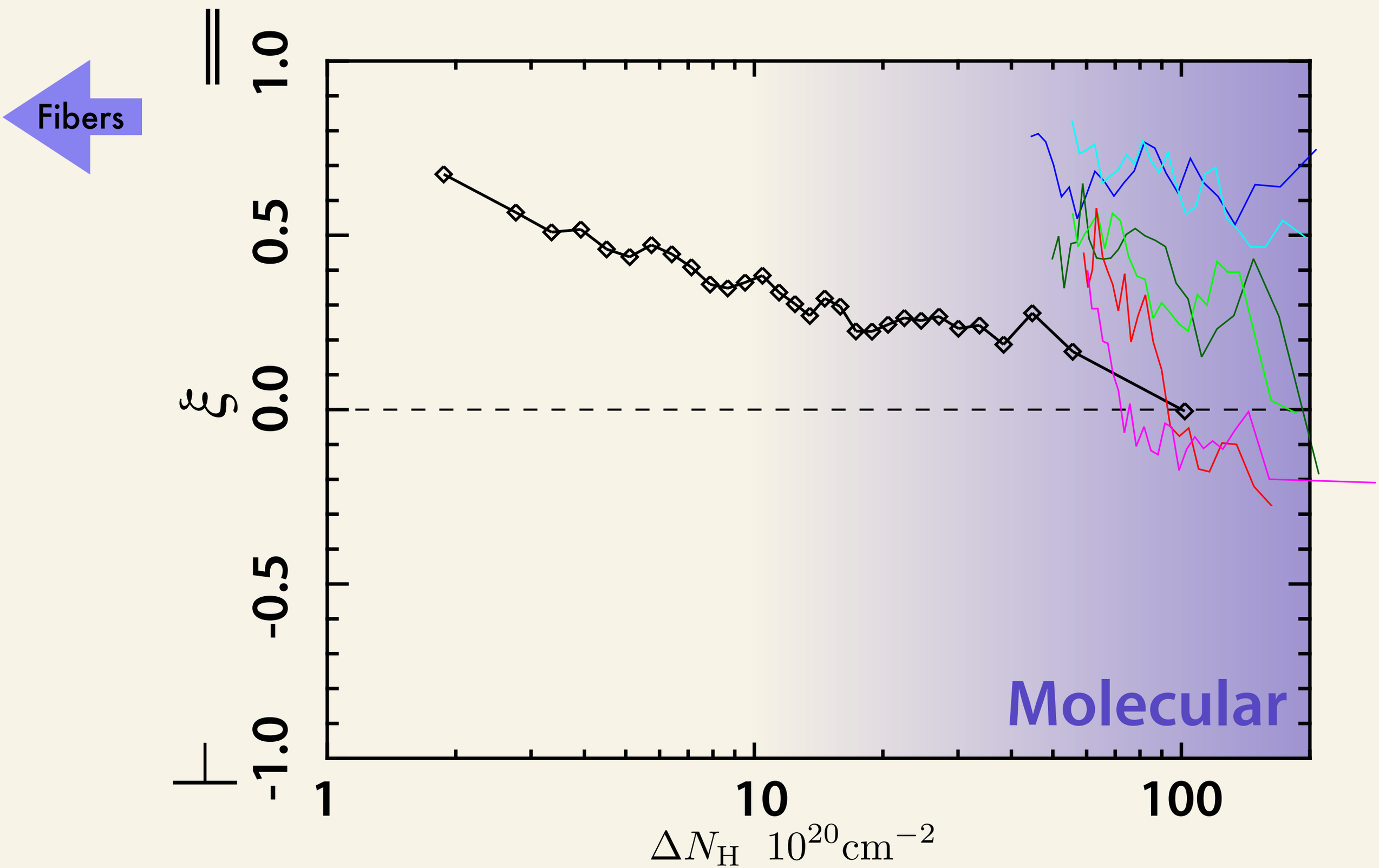
Planck Collaboration XXXII 14 ; Soler+ 13

Field-"filament" correlation weakens at higher column



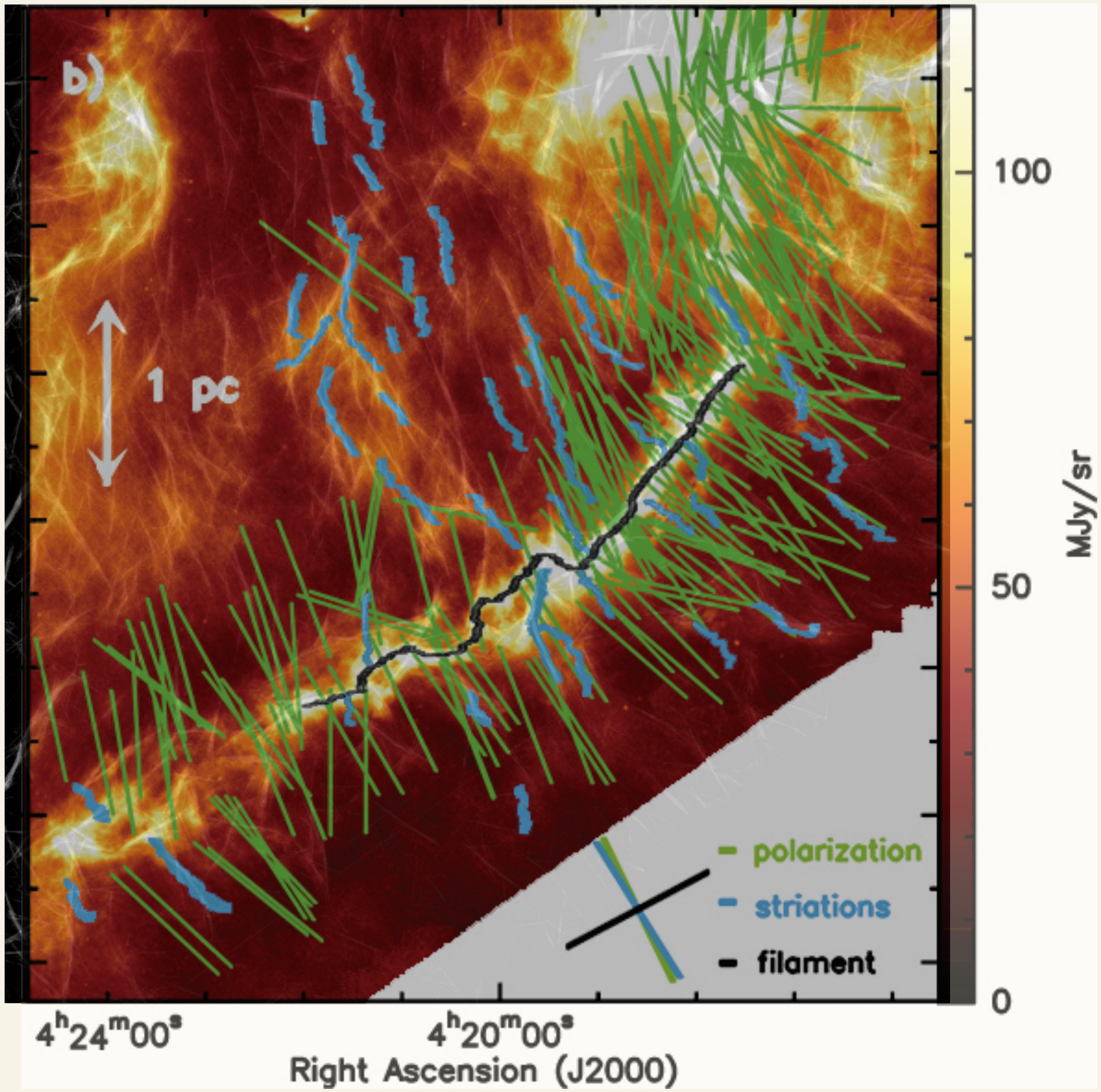
Planck Collaboration XXXII 14 ; Soler+ 13

Field-"filament" correlation weakens at higher column



Planck Collaboration XXXII 14 ; Soler+ 13

Can we find B/filament anti-correlation statistically?

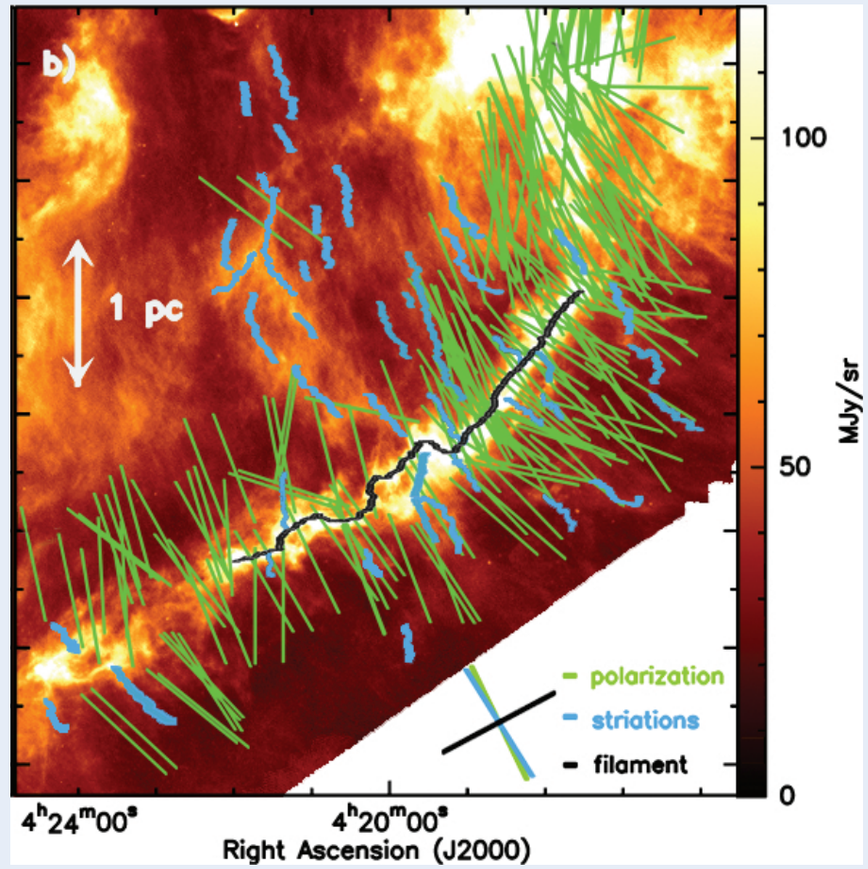


Palmeirim+ 2013

The study of the interaction of B fields and gas structure requires measuring image phase info

The study of the interaction of B fields and gas structure requires measuring image phase info

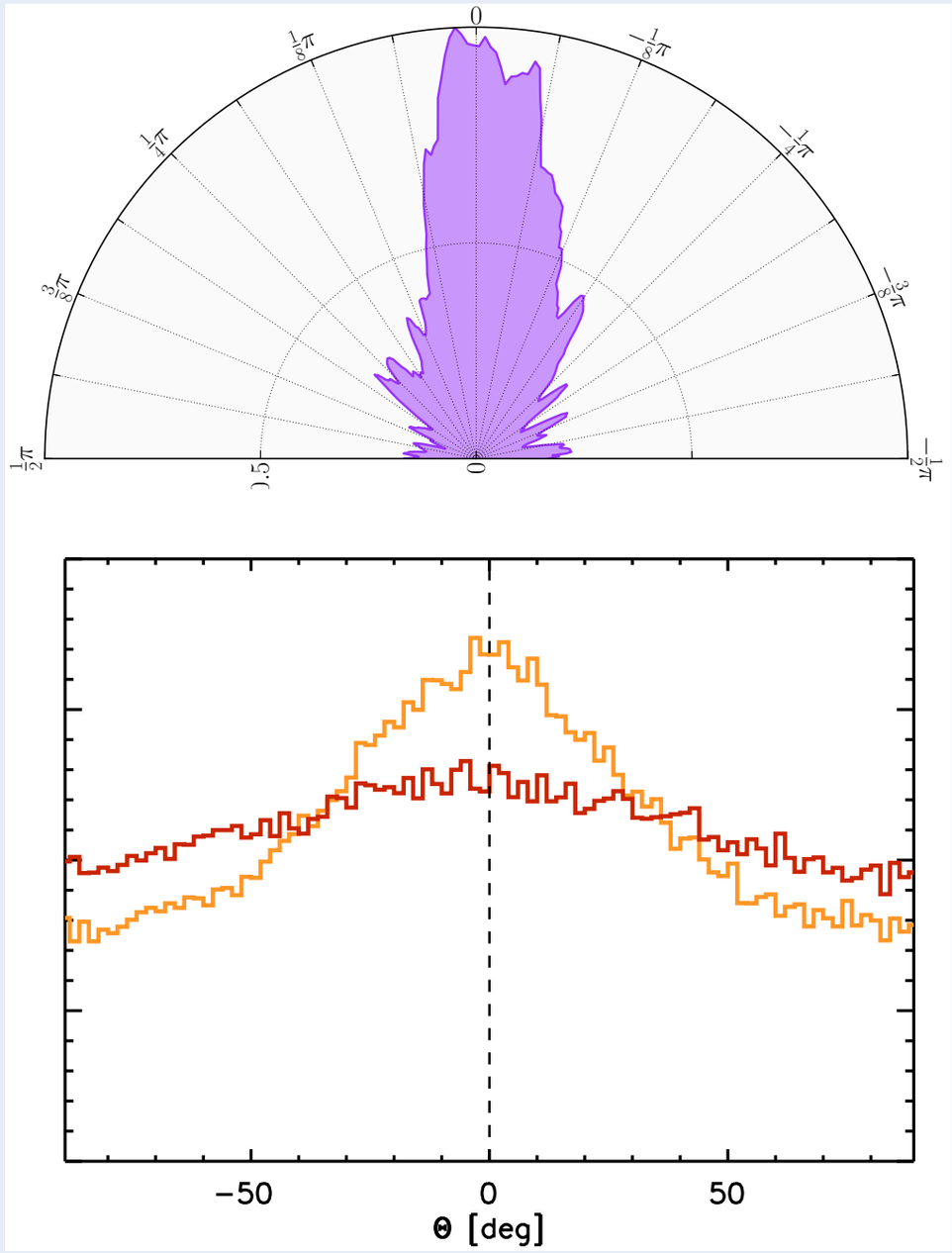
Not all "filaments" are the same! Choose (or design) a method appropriate to the hypothesis you wish to test!



The study of the interaction of B fields and gas structure requires measuring image phase info

Not all "filaments" are the same! Choose (or design) a method appropriate to the hypothesis you wish to test!

Low and very low column CNM linear features align with the B field especially a small scales



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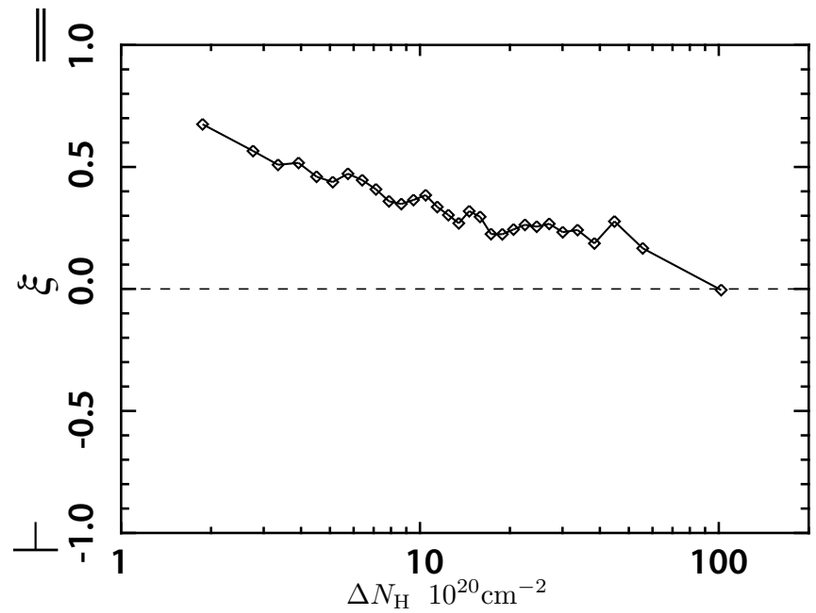

Low and very low column CNM linear features align with the B field especially a small scales

The alignment weakens as we approach the molecular regime, mimicking results at higher densities