Study of flare onset with high speed imaging observations at Hida observatory

-- A joint program led by STEL --

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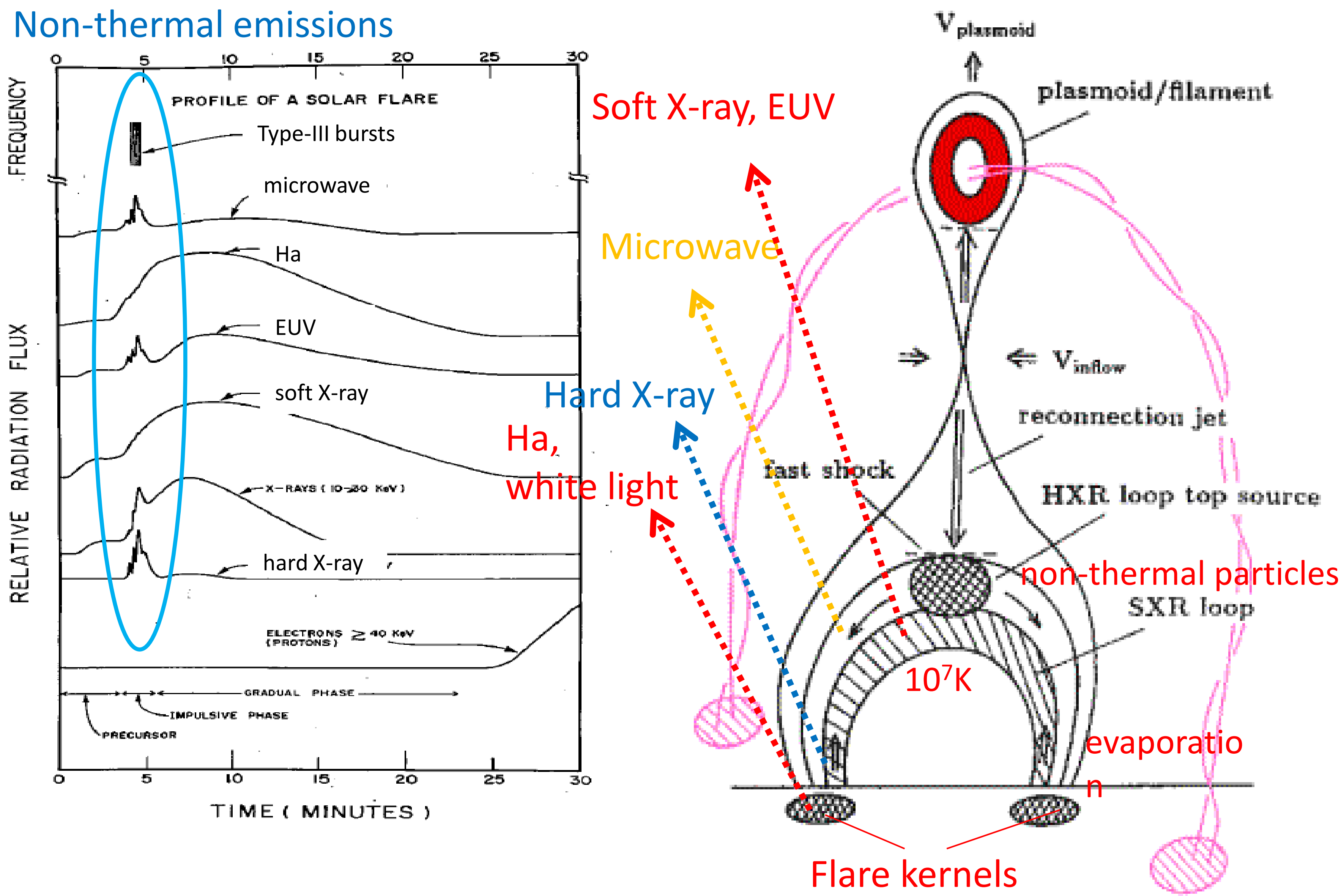
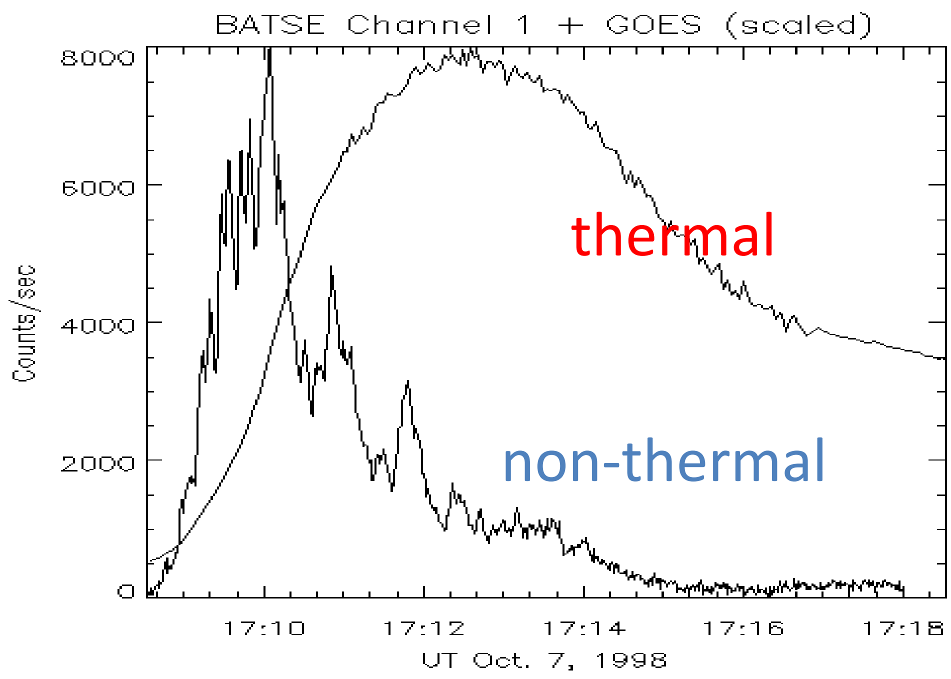
Outline

1. Introduction
   - Fine structures of solar flare
   - Flare ‘kernel’; foot points of flaring magnetic fields
   - Motivation for high speed flare imaging
2. Joint program of flare research by STEL and Hida observatory
   - Introduction to Hida observatory
   - High speed flare imager
   - (New vector magnetograph)
   - Initial data
   - Strategy for flare research
3. Summary

1. Introduction; Solar flare emissions



‘Neupert’ effect

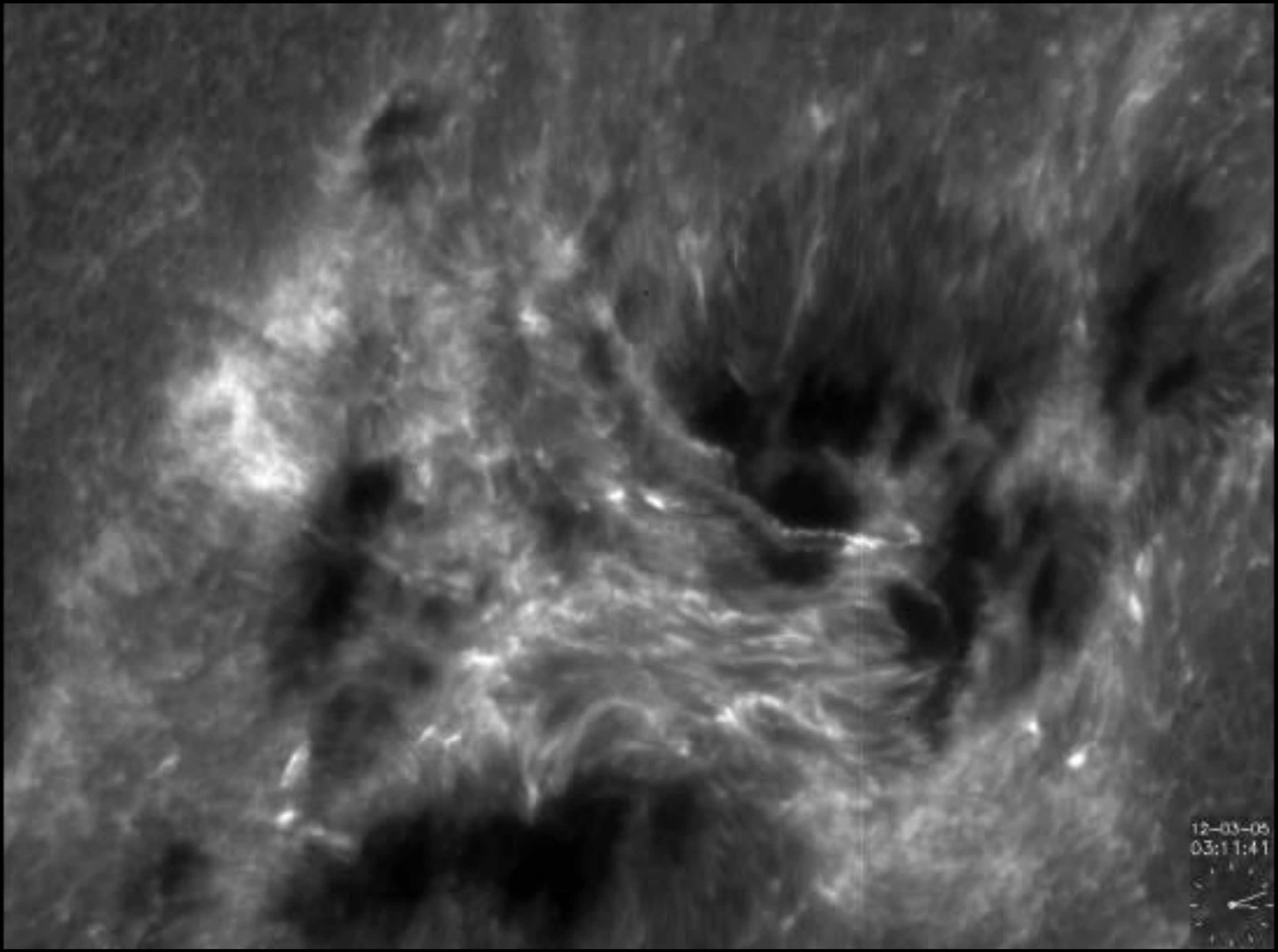


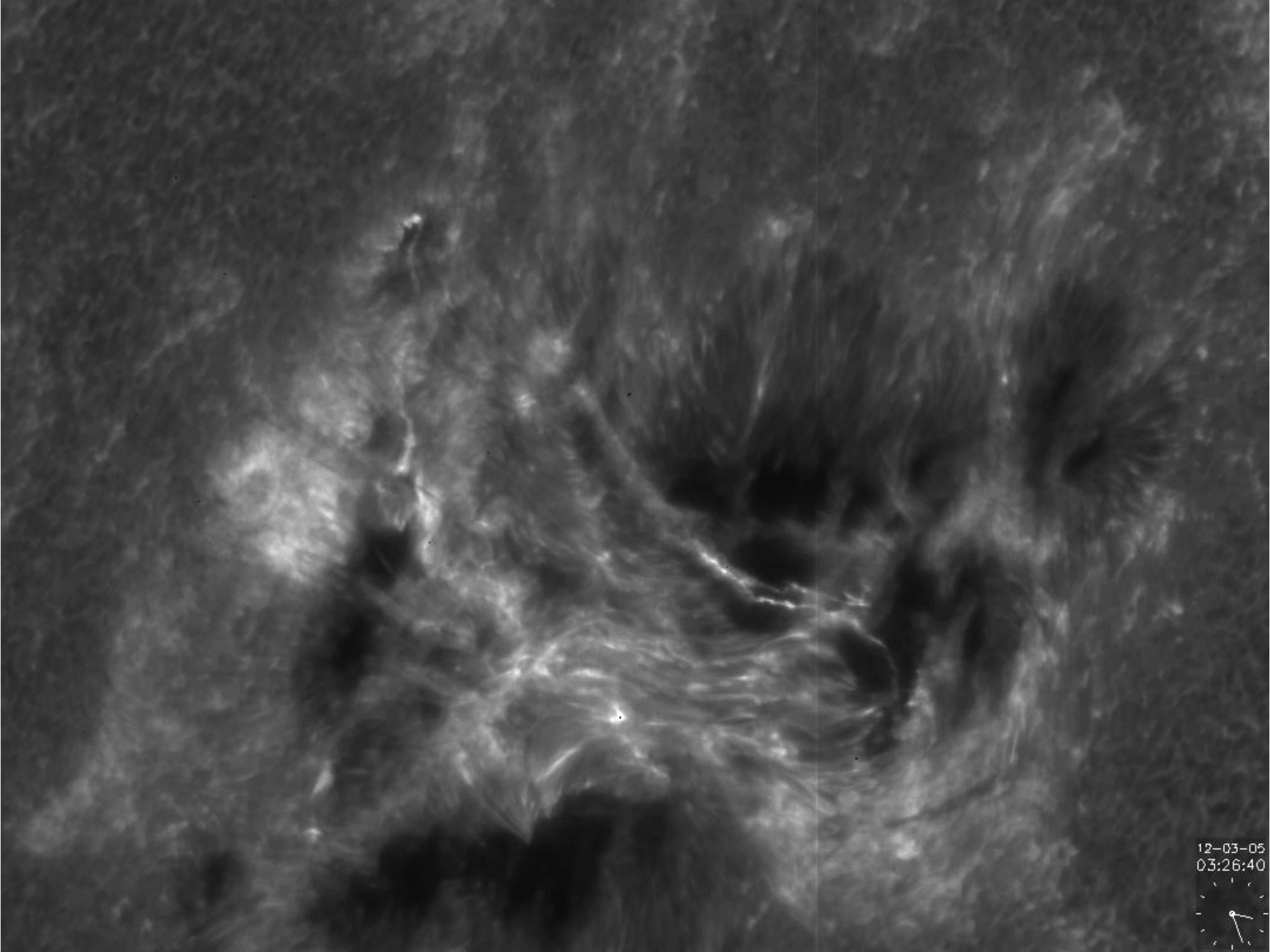
$$I_{\text{thermal}} \sim \int I_{\text{non-thermal}}\, dt$$

Thermal flare plasma is a by-product of the non-thermal particles

Particle acceleration is a primary ingredient of the solar flare.

Flare (X1.1) on 2012.3.5 by Hinode, CaII H

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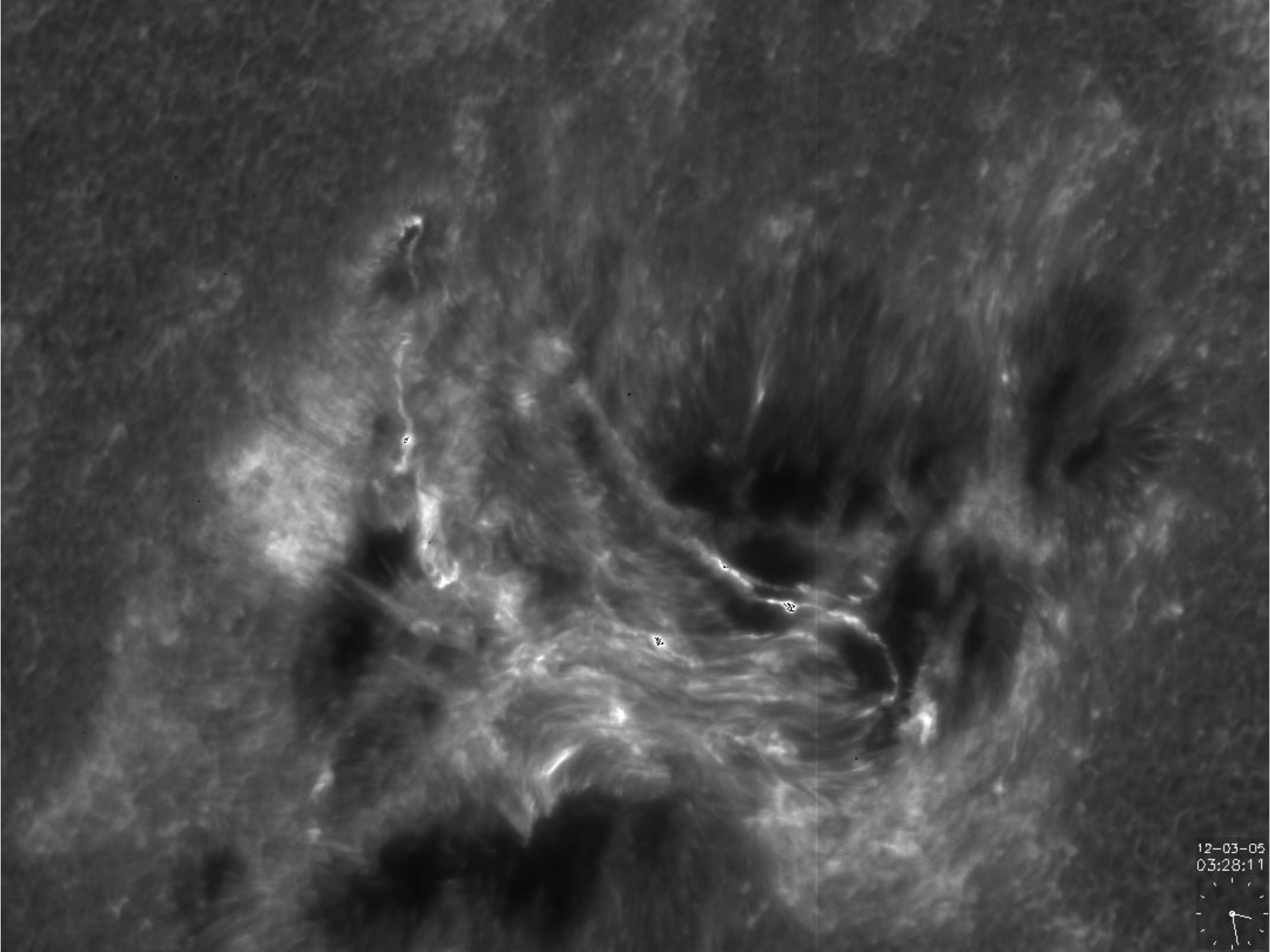
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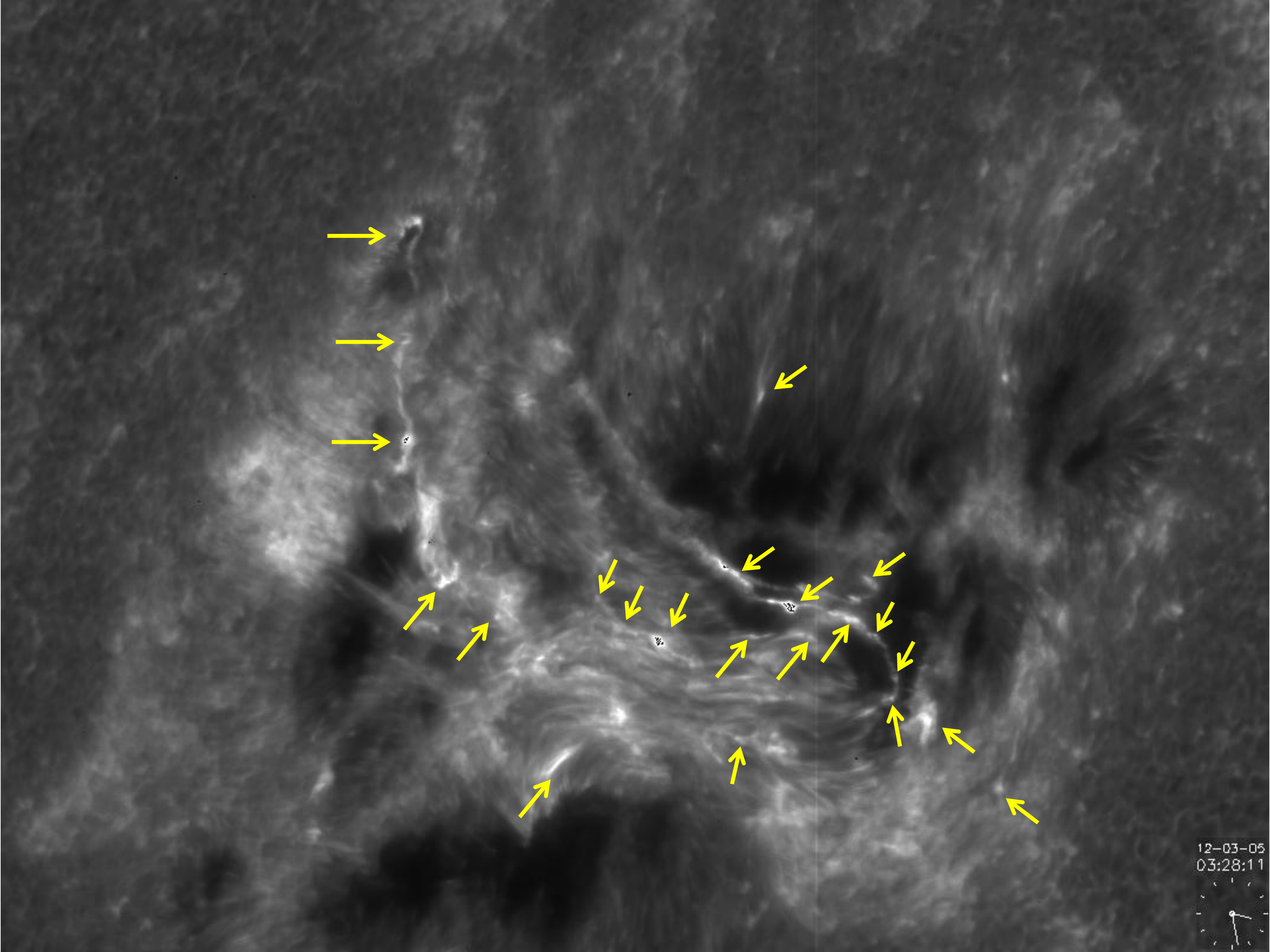
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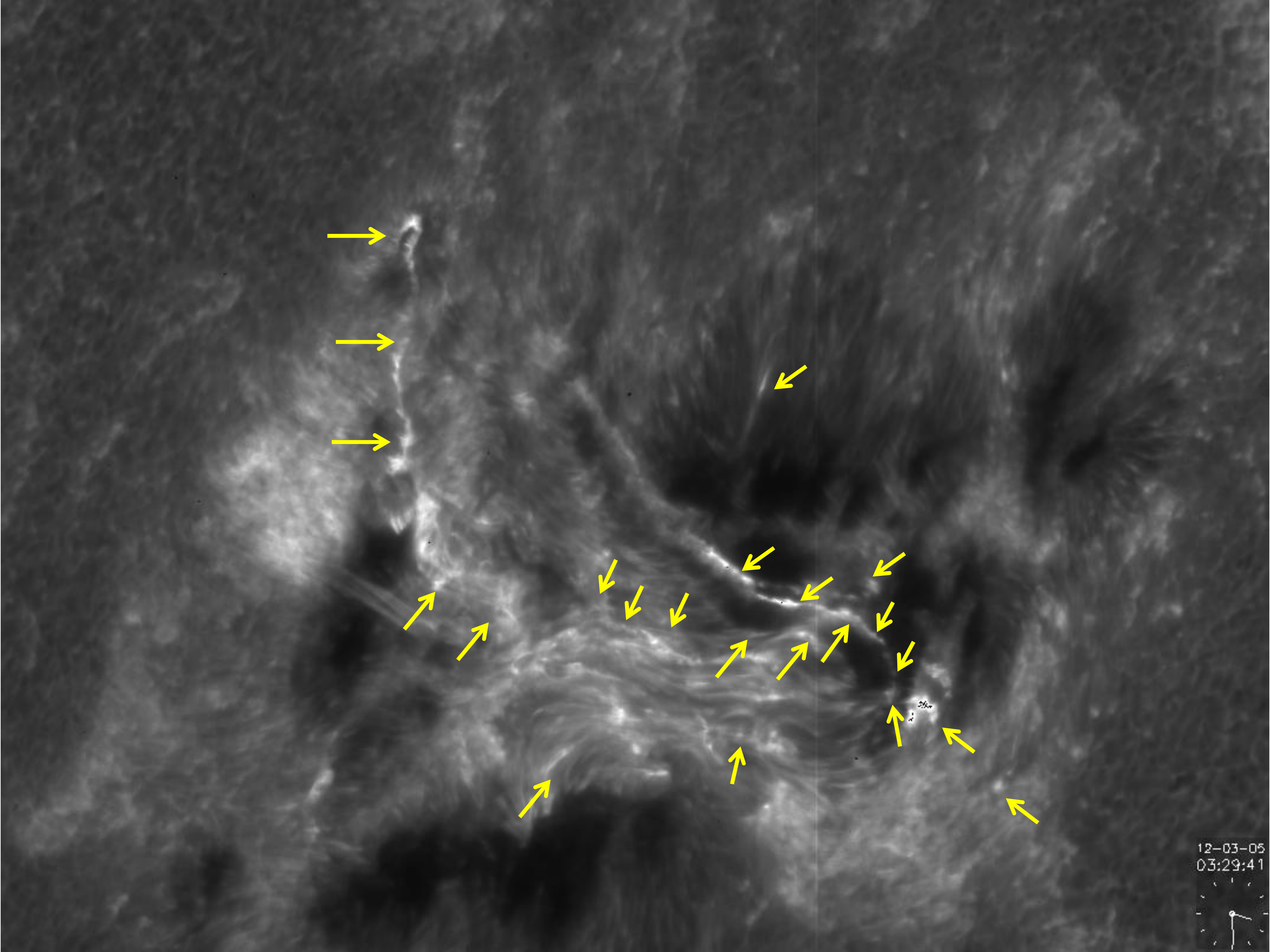
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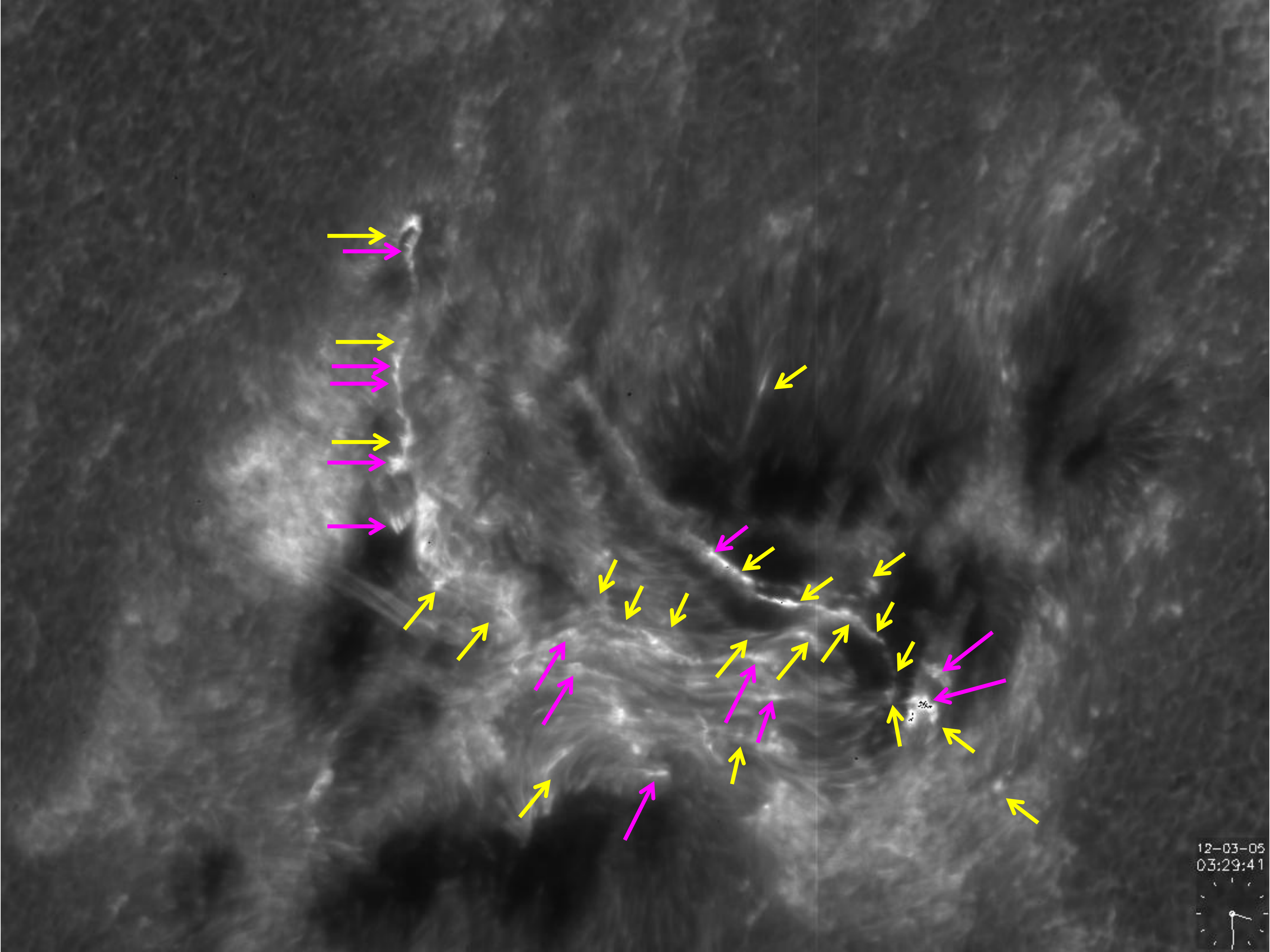
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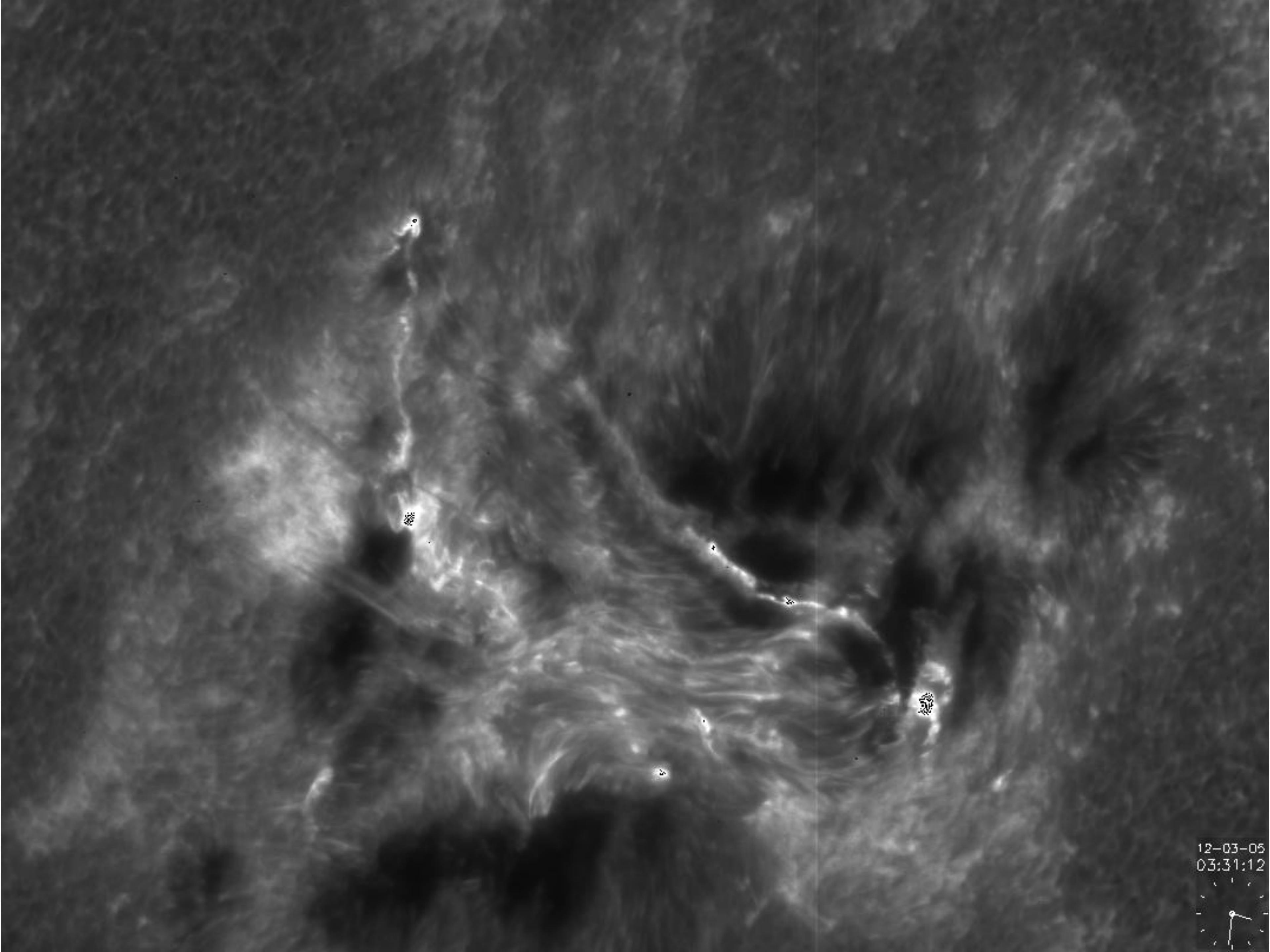
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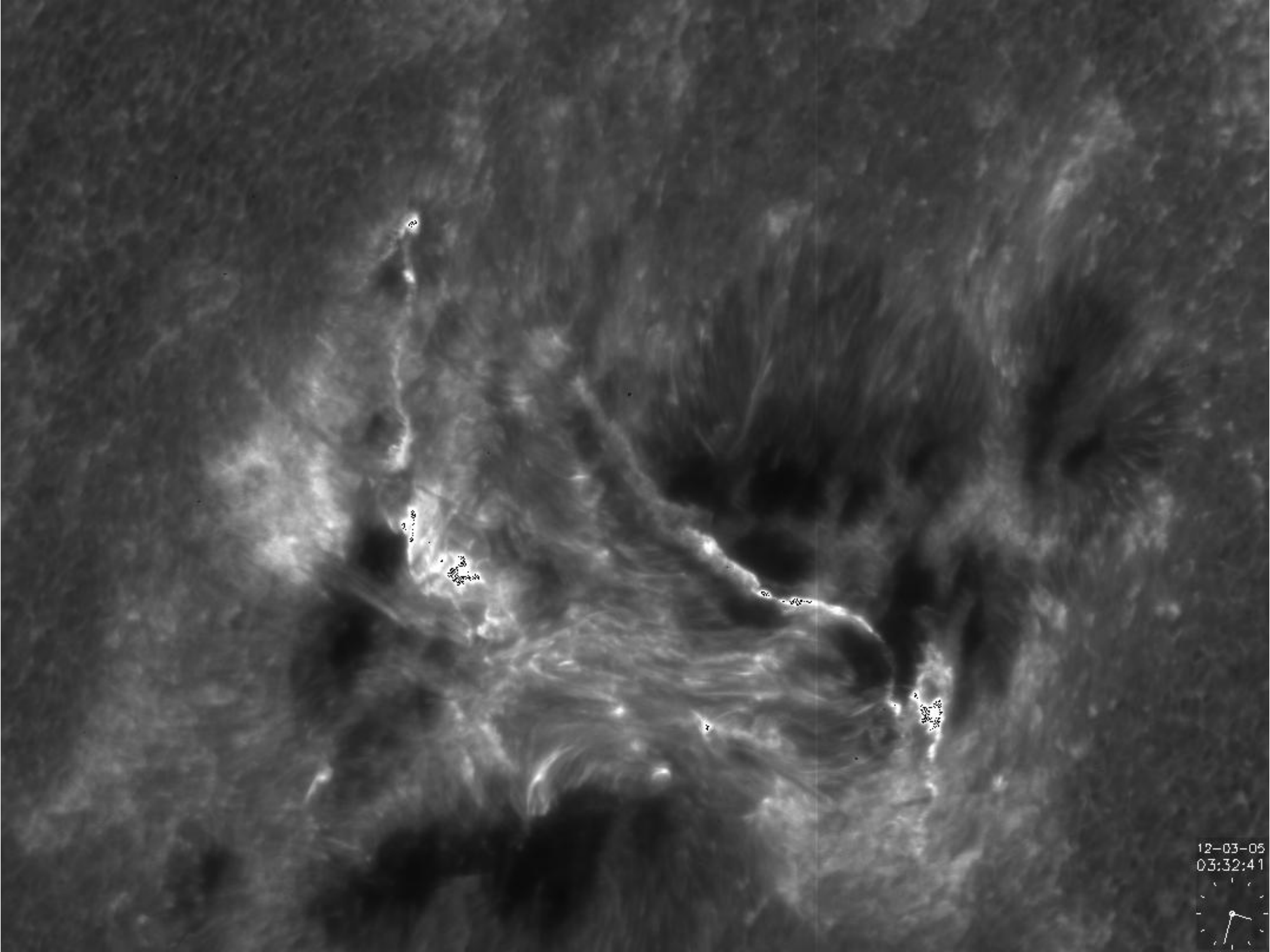
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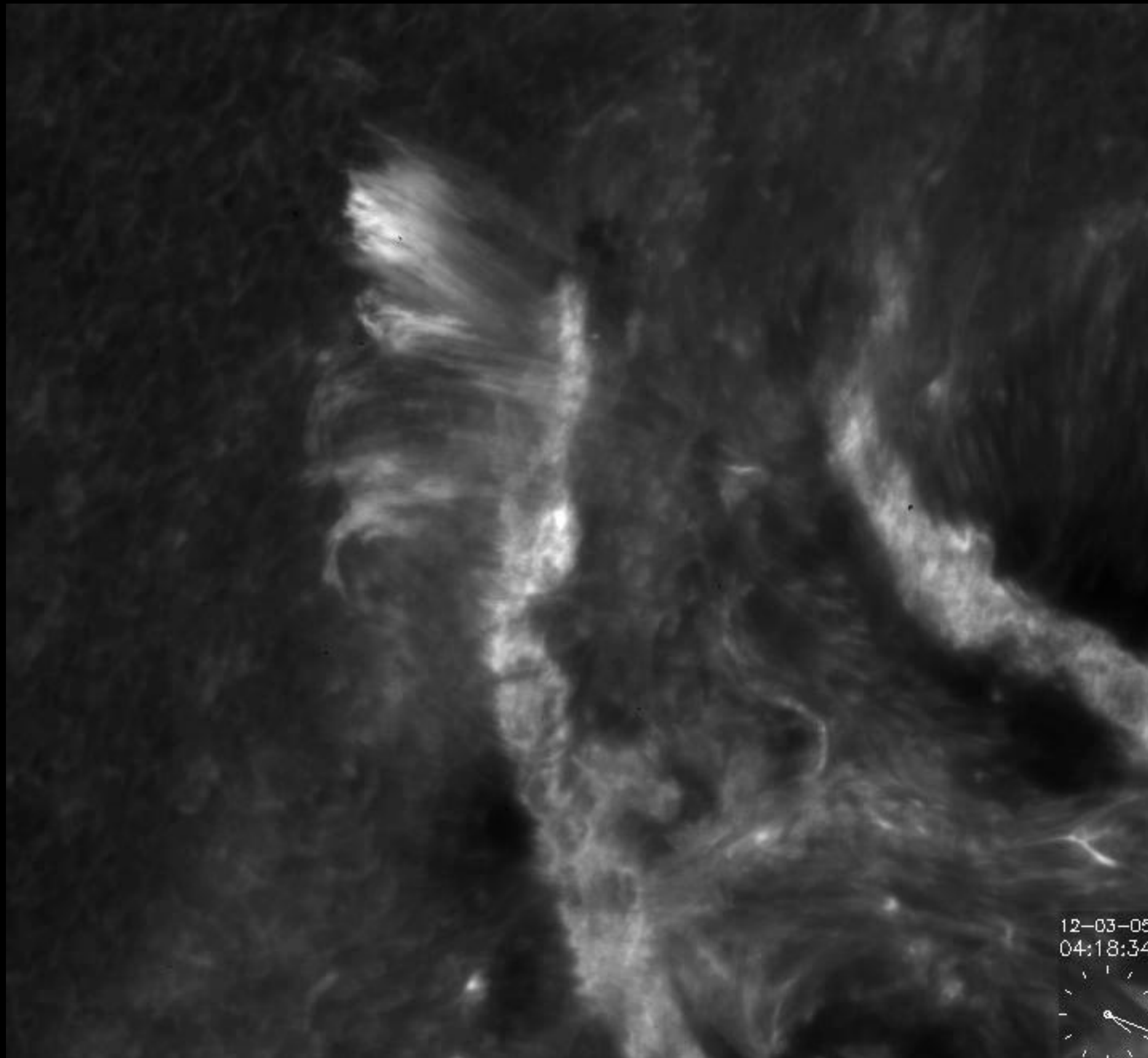
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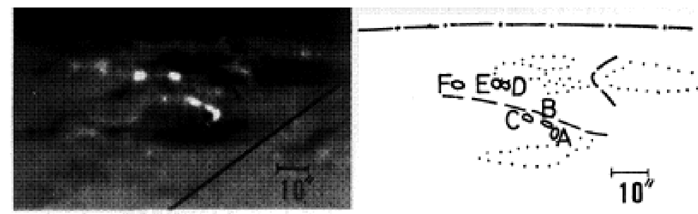
04:18:34

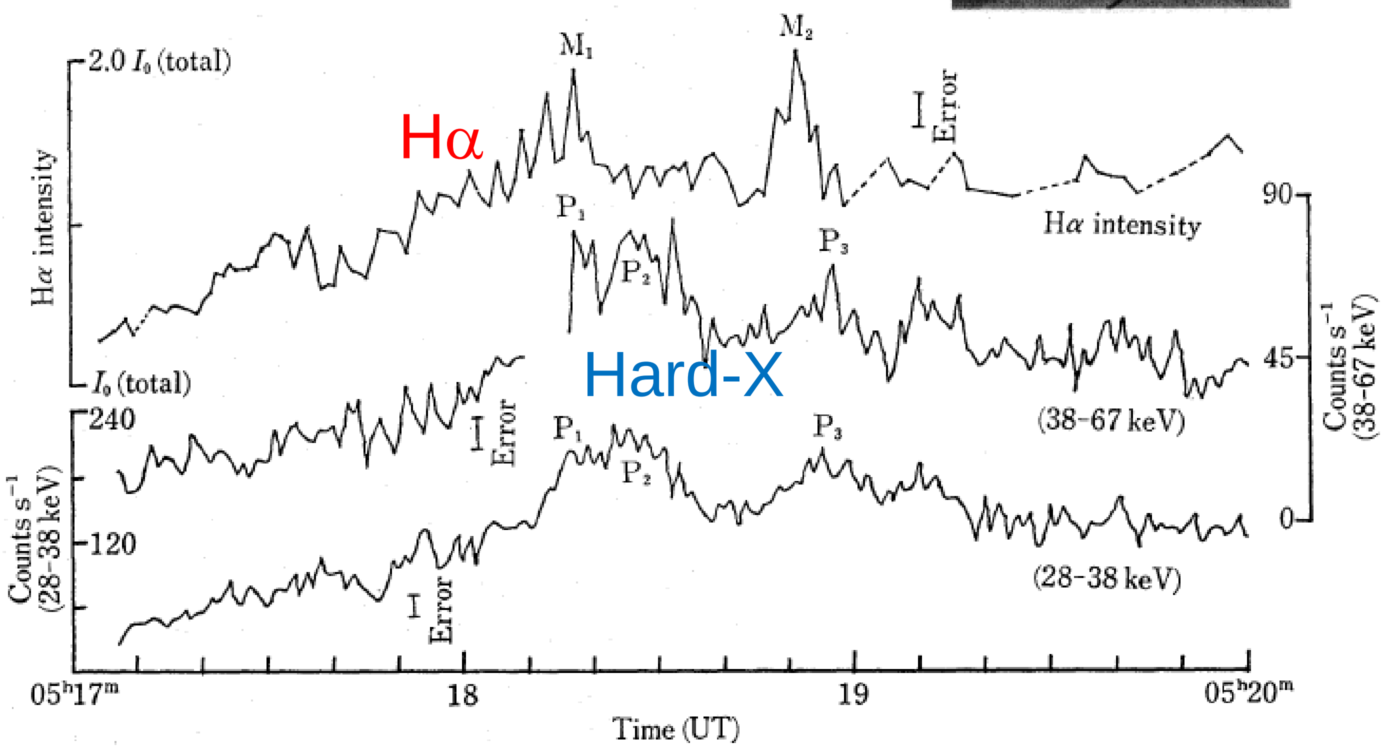
Previous works on flare kernel -1

Close relationship between Ha and hard X-ray emissions at the impulsive phase of a flare

Kurokawa etal, 1988, PASJ, 40, 357



Time coincidence ≤ 1sec



➔ Flare kernels are excited by non-thermal electrons

Previous works on flare kernel -2

Progressive brightening observed in the wing of H-alpha line

Kawaguchi etal, 1982, Solar Physics, 78, 101

Flares consist of multiple loop system that are activated progressively.

Propagation speed
190 ~ 970km/s

➔ Flare kernels provide a mean to investigate the dynamic evolution of the flaring loop system

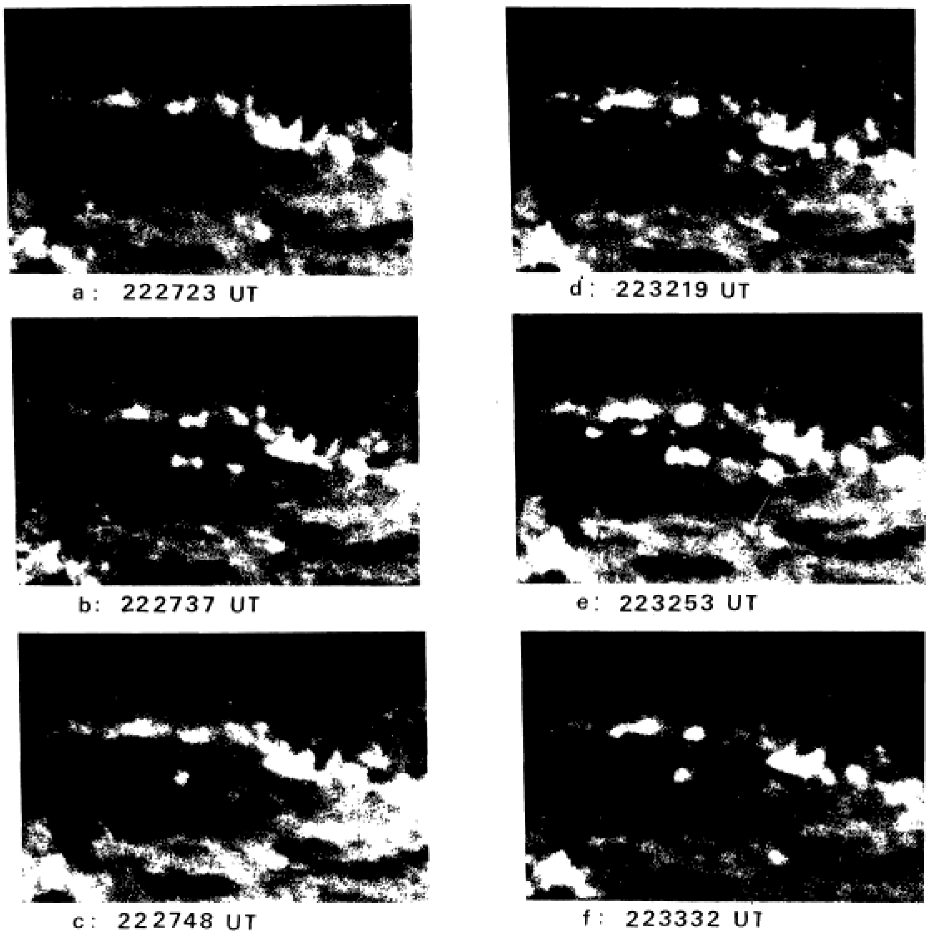


Fig. 1. Progressive brightenings observed in Hida Observatory. Pictures in (a), (b), and (c) belong to the first brightening and in (d), (e), and (f) to the second. In (b) and (e), one sees the several bright points in line. The upper and lower pictures show the active region just before and after the occurrence of the brightening, respectively.

Previous works on flare kernel -3

Evolution of Conjugate Footpoints inside Flare Ribbons during a Great Two-Ribbon Flare on 2001 April 10

Asai etal, 2003, ApJ, 586, 624

Simultaneity of flare kernel brightening tells conjugate footpoints of a flare loop

Flare kernels provide a mean to investigate the connectivity of flare loop system

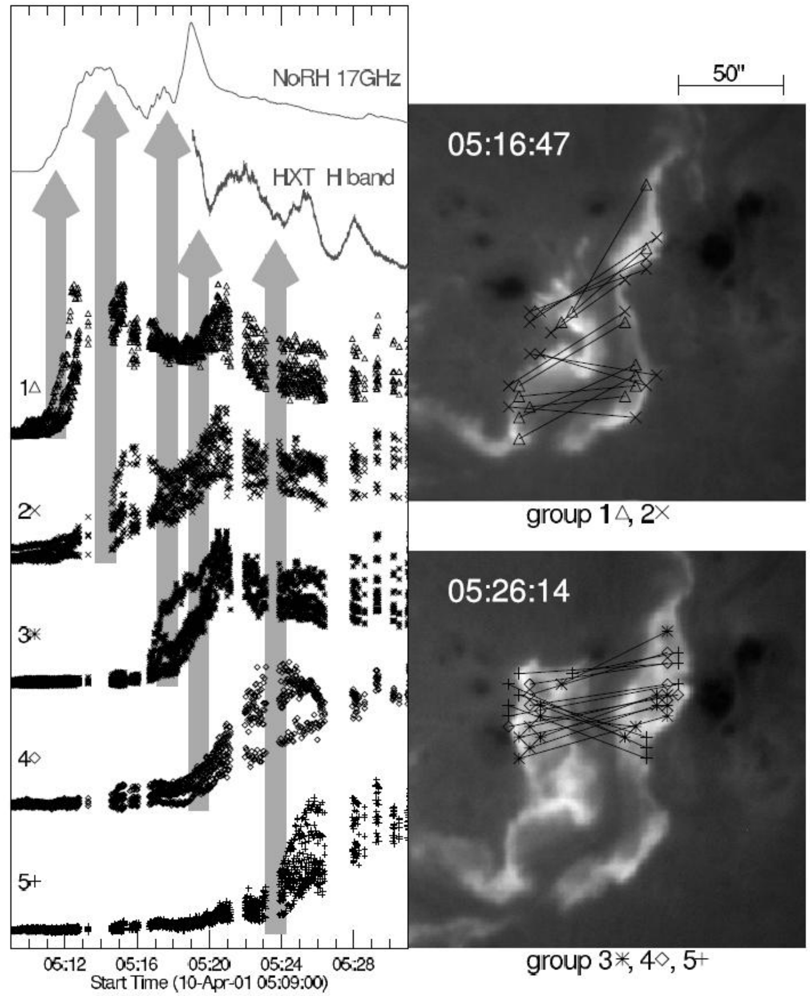


FIG. 5.—Temporal and spatial evolutions of the pairs of the Hα conjugate footpoints. *Left panel*: Light curves (*scaled arbitrarily*). The top two dark gray lines show microwave and hard X-ray fluxes, and the other curves are for each Hα group as numbered at the left side. They are plotted with different symbols for each group, as shown on the left. Light gray broad vertical arrows show rough brightening times of each group. *Right panels*: Hα images marked with pairs of the Hα conjugate footpoints. *Top panel*: Groups 1 and 2. *Bottom panel*: Groups 3, 4, and 5. Celestial north is up, and west is to the right. The marks are the same as those of the time profiles in left panel.

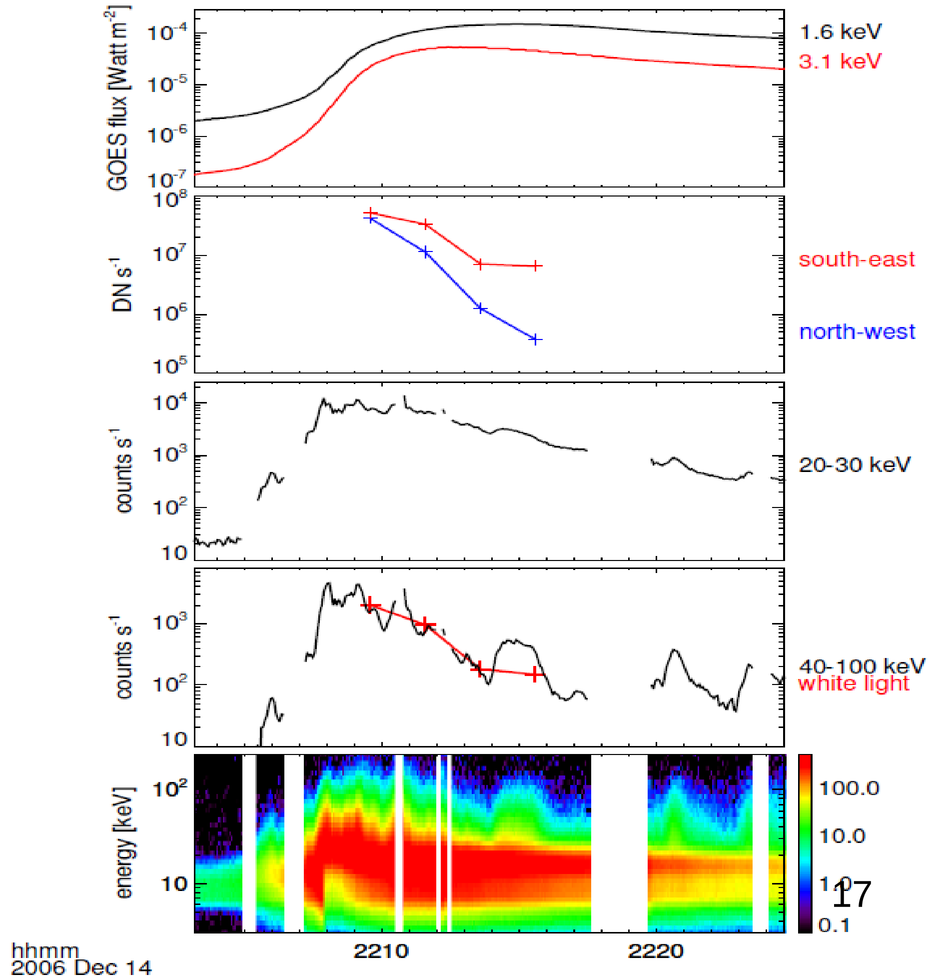
Previous works on flare kernel -4

G-band and Hard X-ray Emissions of the 2006 December 14 Flare Observed by Hinode/SOT and RHESSI

Watanabe,K. etal, 2010, ApJ, 715, 651

white light emission has consistent energy with >40keV electrons

Close relation between white light kernels and non-thermal electrons



Previous works on flare kernel -5

Ha red asymmetry of solar flares

Ichimoto & Kurokawa, 1984, SolPys, 93, 105

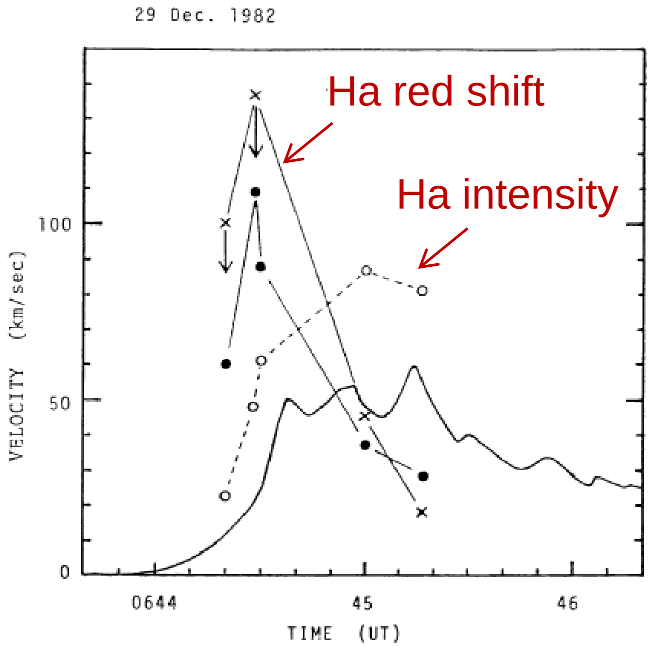


Fig. 6c.

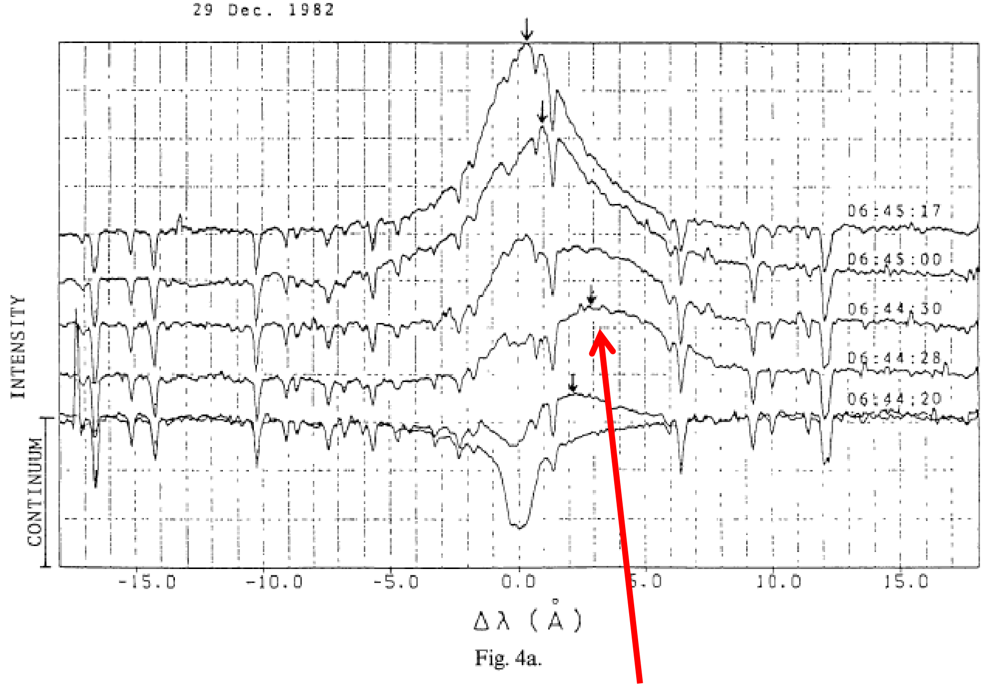


Fig. 4a.

Red-shifted Hα profiles at the onset of a flare kernel

Previous works on flare kernel -5

Ha red asymmetry of solar flares

Ichimoto & Kurokawa, 1984, SolPys, 93, 105

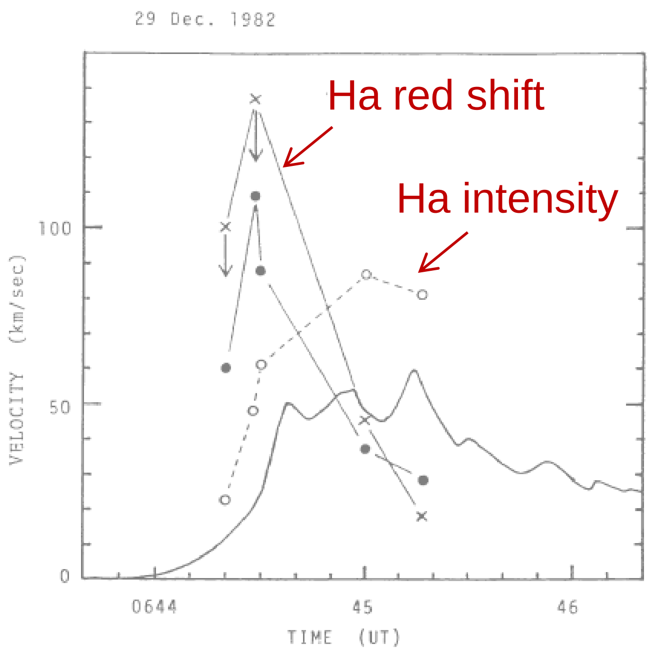
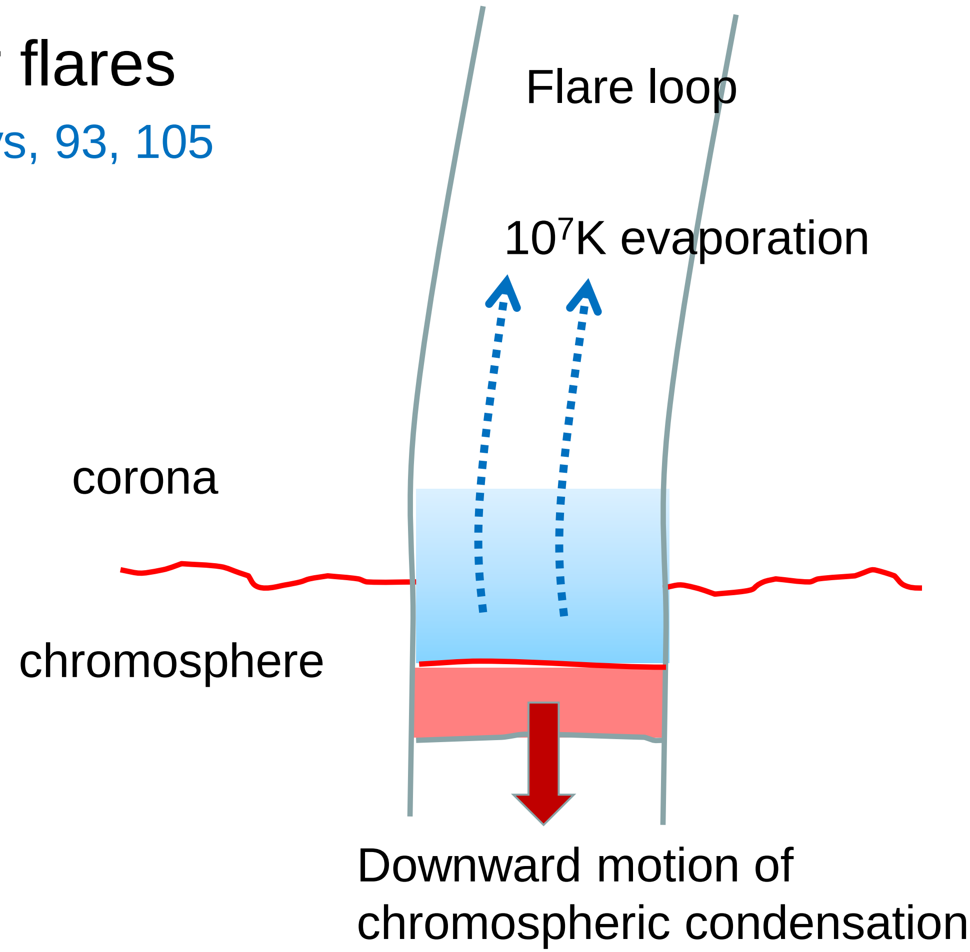


Fig. 6c.



Travel distance > 5000km > thickness of chromosphere

➔ unresolved structures in flare kernels

Fine structures of flare

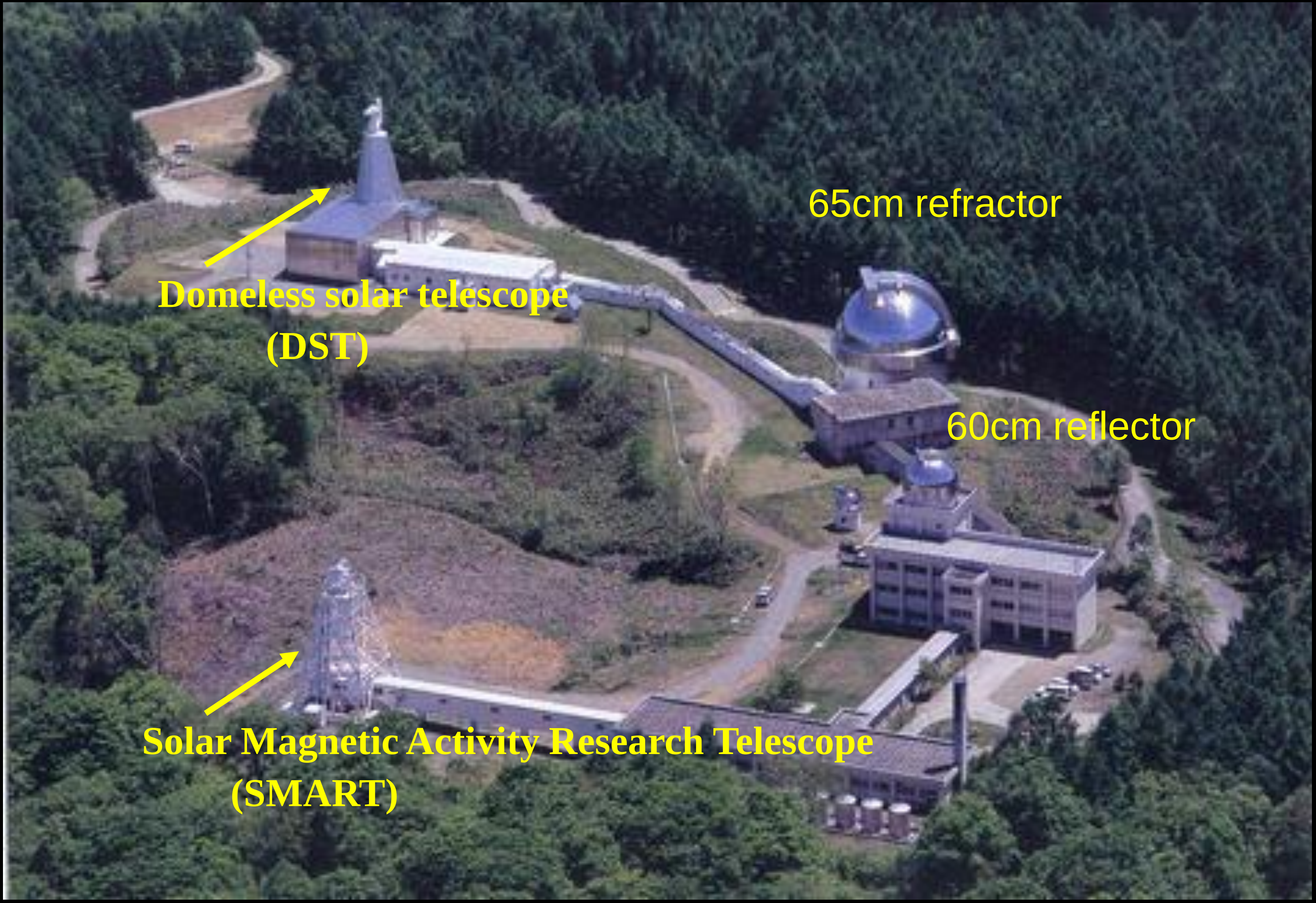
- Flares consist of numerous elementary non-thermal processes that make spatial and temporal fine structures of flares.
- They change rapidly in time scale of a second.
- Flare kernels provides us a clue to study spatial and temporal evolution of the non-thermal events and flare loop system.

➔ Need for high speed / high resolution imaging observations of flare kernals

2. Joint program for flare research by STEL and Hida observatory

Hida Obs.
Altitude ～1300m

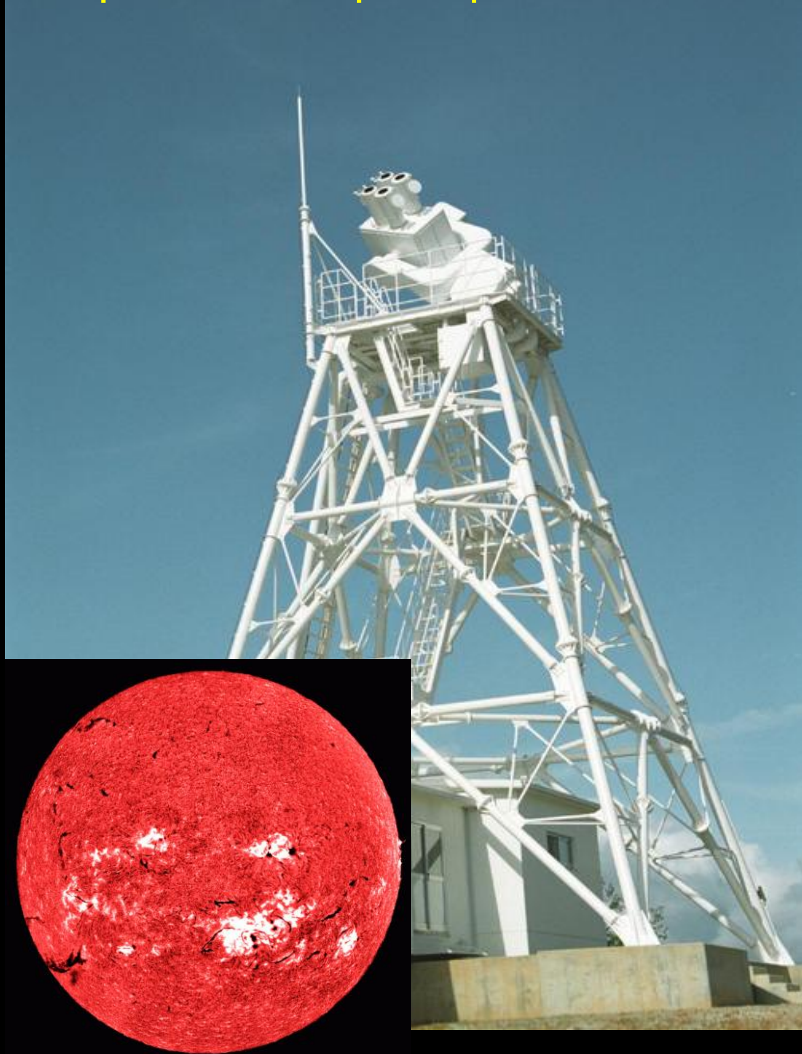
Hida Observatory



Solar telescopes at Hida Obs.

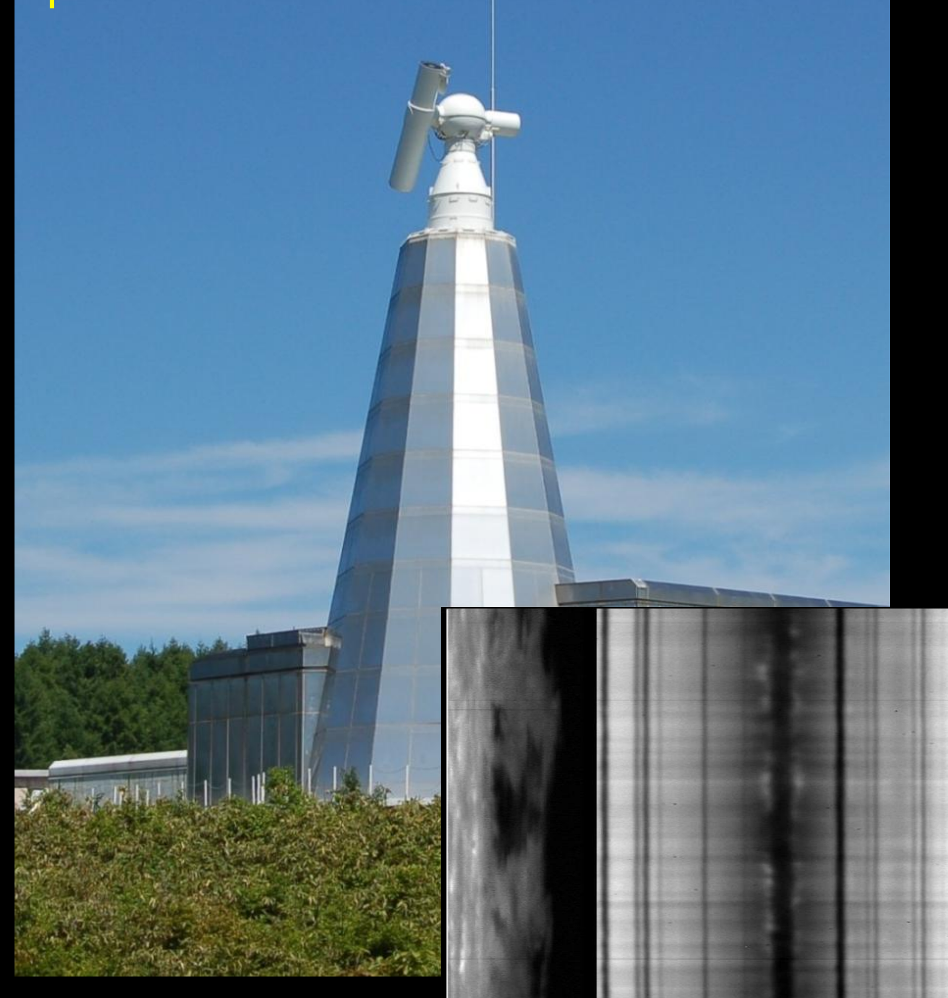
SMART

20-25cm, Full / partial disk imagers
→ patrol of eruptive phenomena

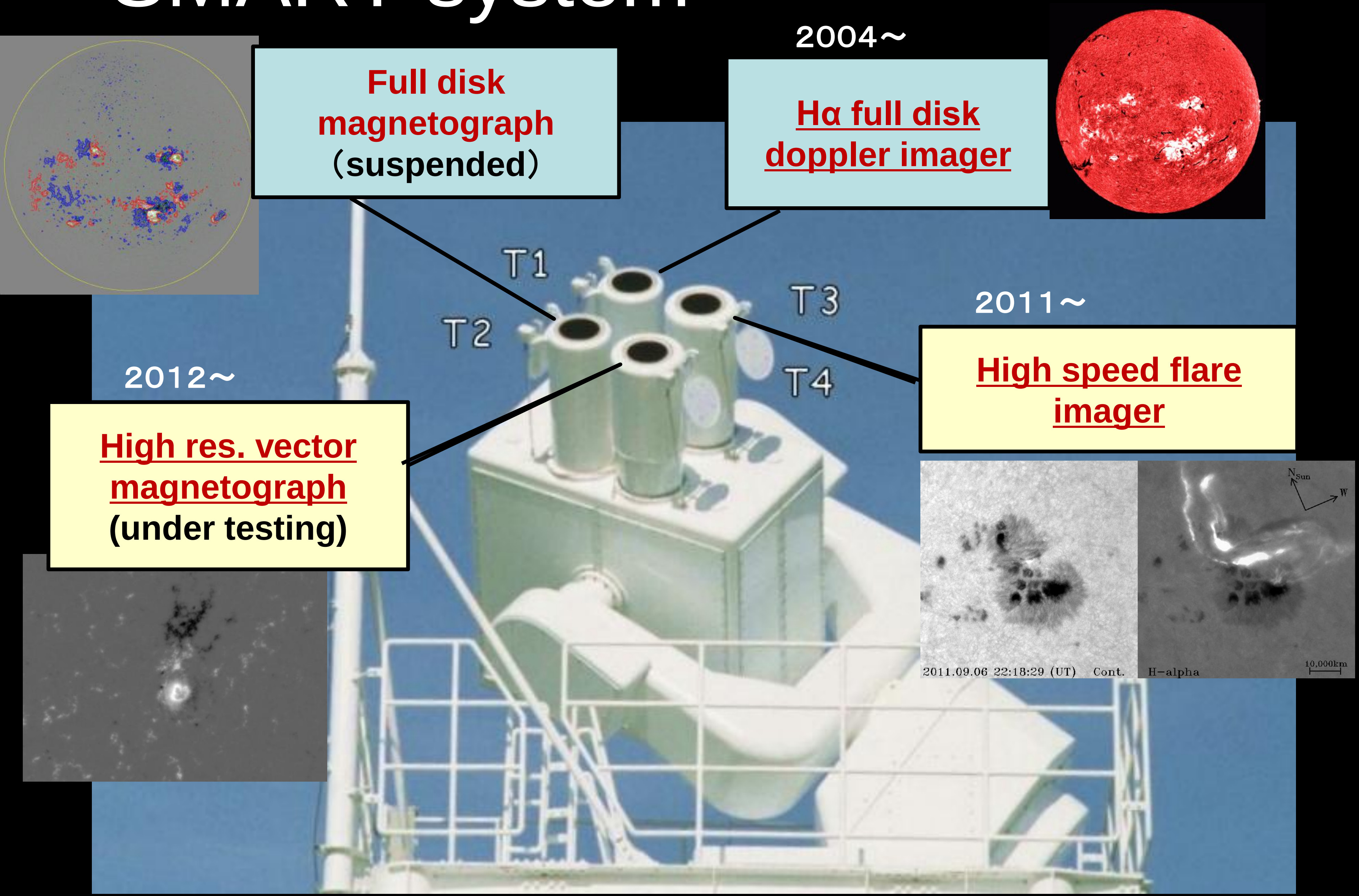


Domeless Solar Telescope

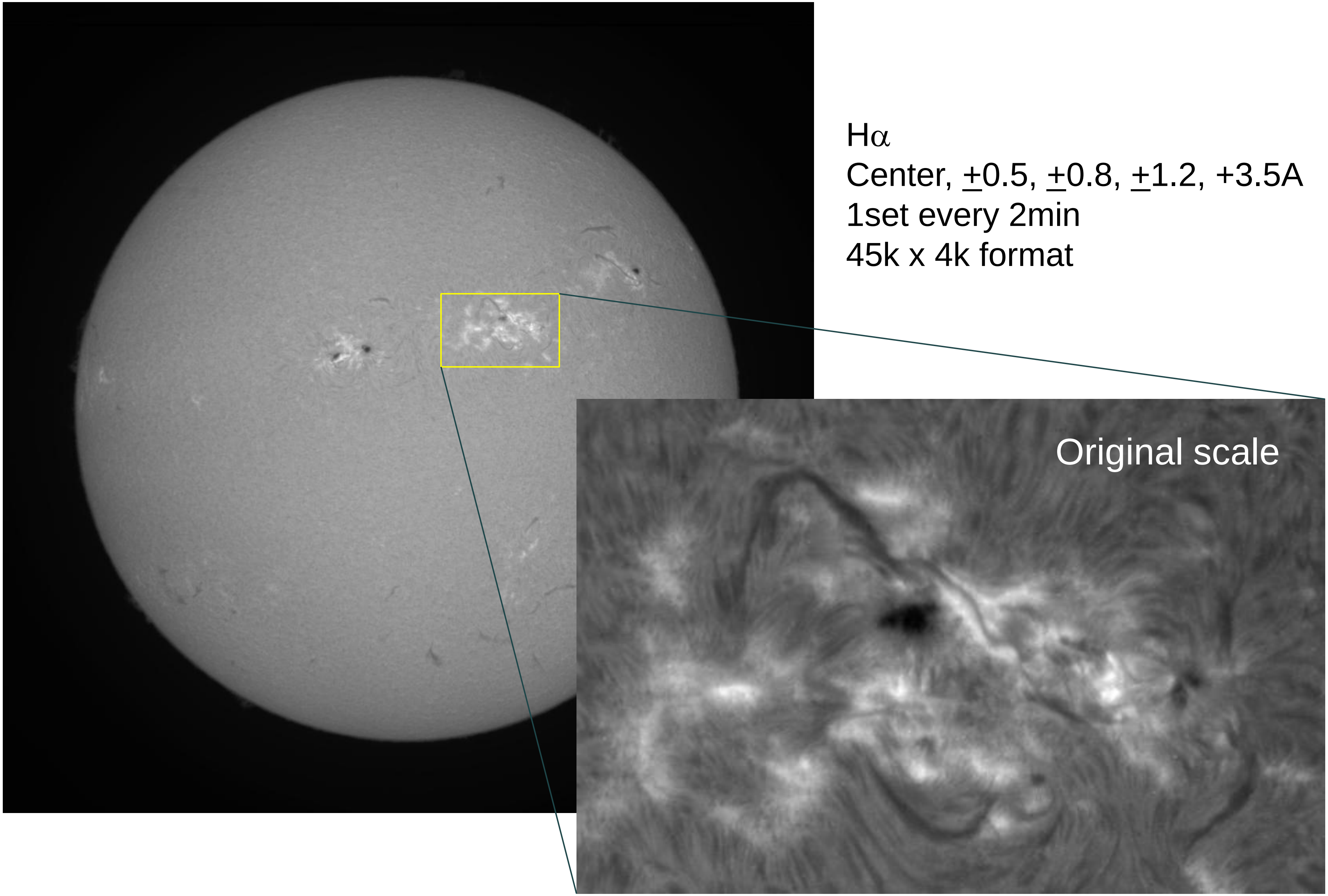
60cm, High resolution spectroscopy
→ Detailed diagnosis of plasma process



SMART system



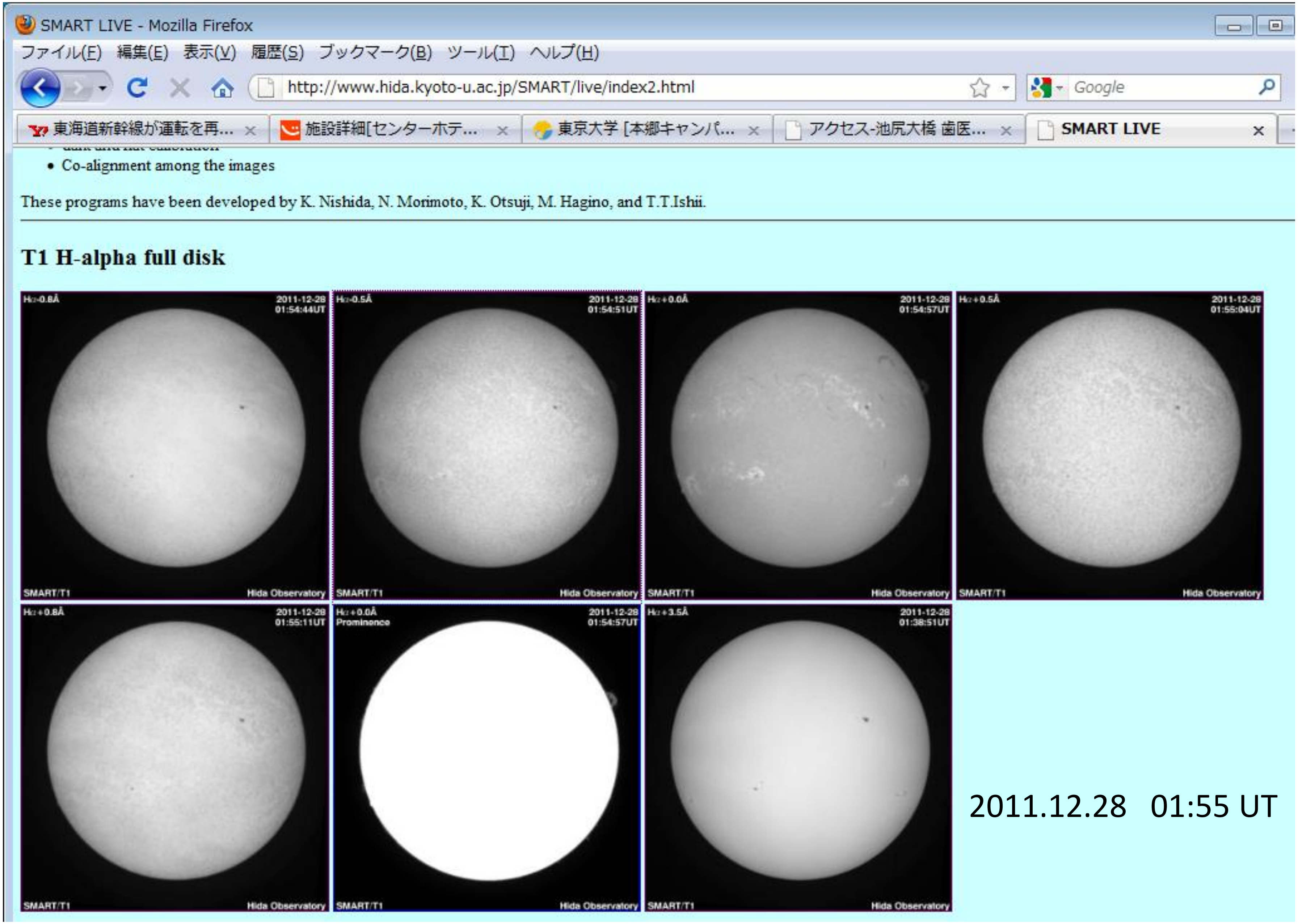
SMART H-alpha center (2011.08.03)



Hα
Center, ±0.5, ±0.8, ±1.2, +3.5A
1set every 2min
45k x 4k format

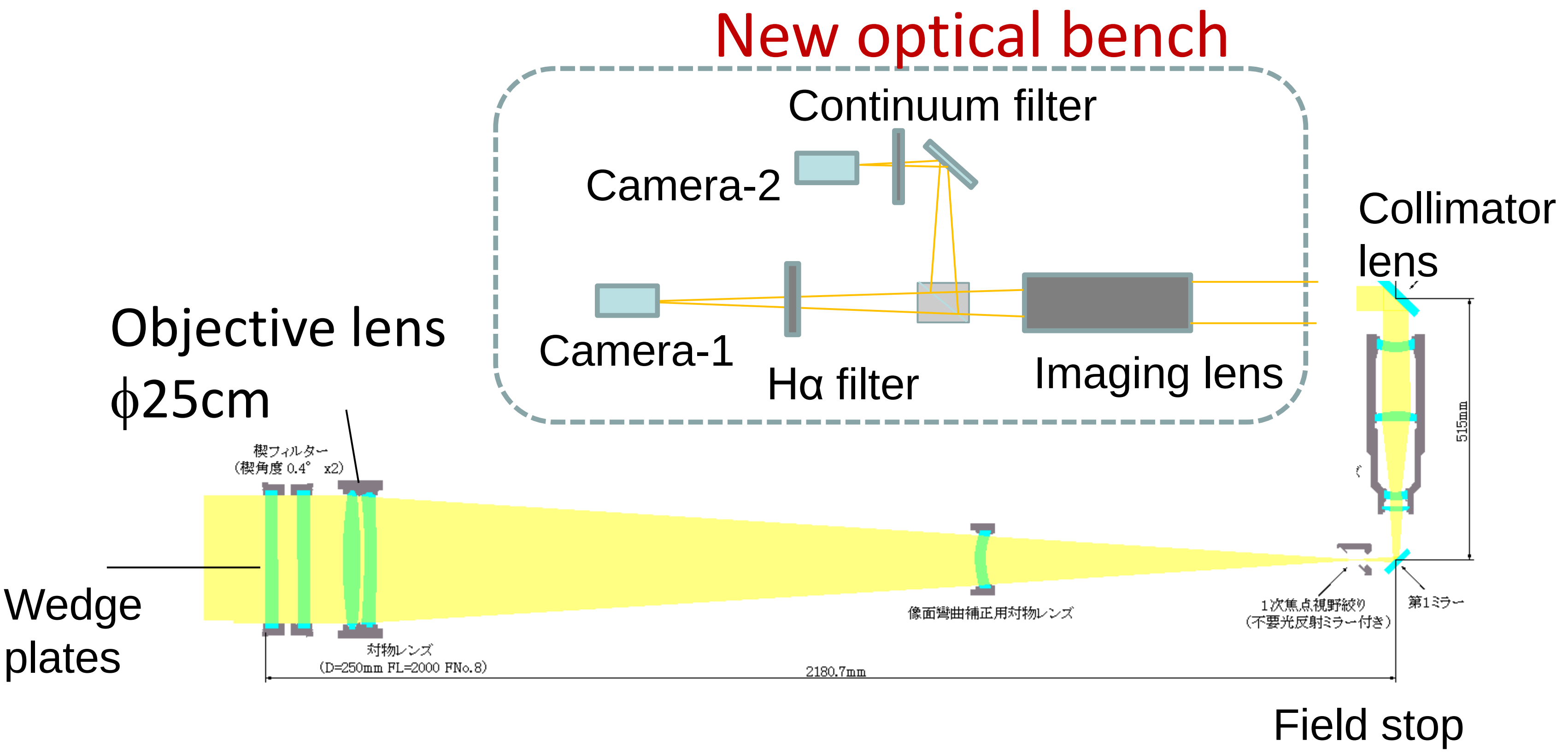
Data open on Web.

http://www.hida.kyoto-u.ac.jp/SMART/



High speed flare imager (HSFI)

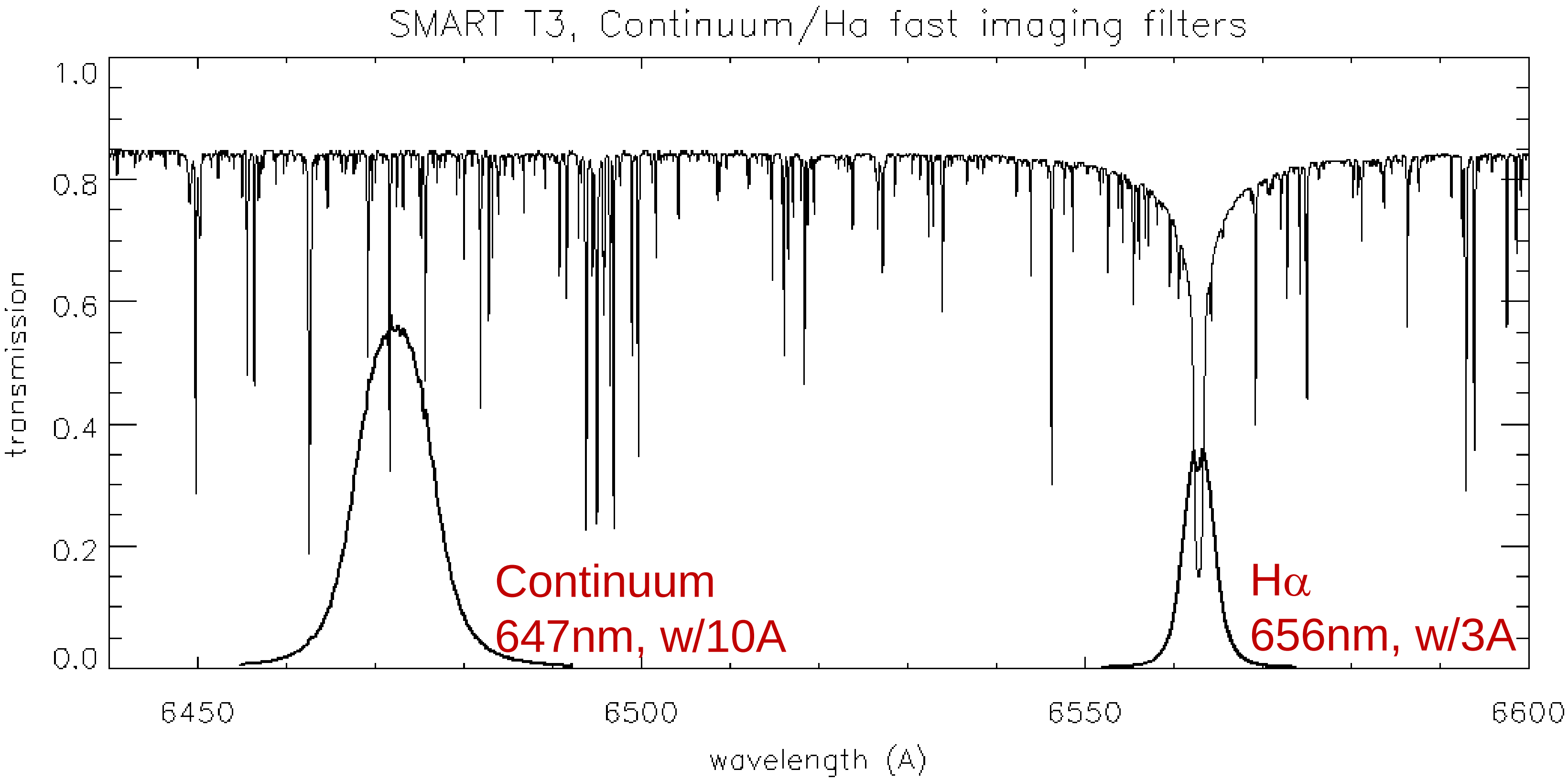
Optical layout



Developed by the joint research program of the STEL, Nagoya-U, 2011

“Study of particle acceleration in solar flares with a high speed imaging observation in visible light“

Transmission profiles of continuum and Hα filters



Integrated Ha emission over the wavelength

Basic features

Spatial resolution :	0.6” (0.215”/pix)
FOV :	344”x258” (1600x1200 pix)
Exposure time :	0.1 – 0.2msec (freeze seeing)
Frame rate :	25 frame /sec
Data rate :	192 MB/sec, ~7 TB/day

Data archive :

during a event of interest – all data are stored

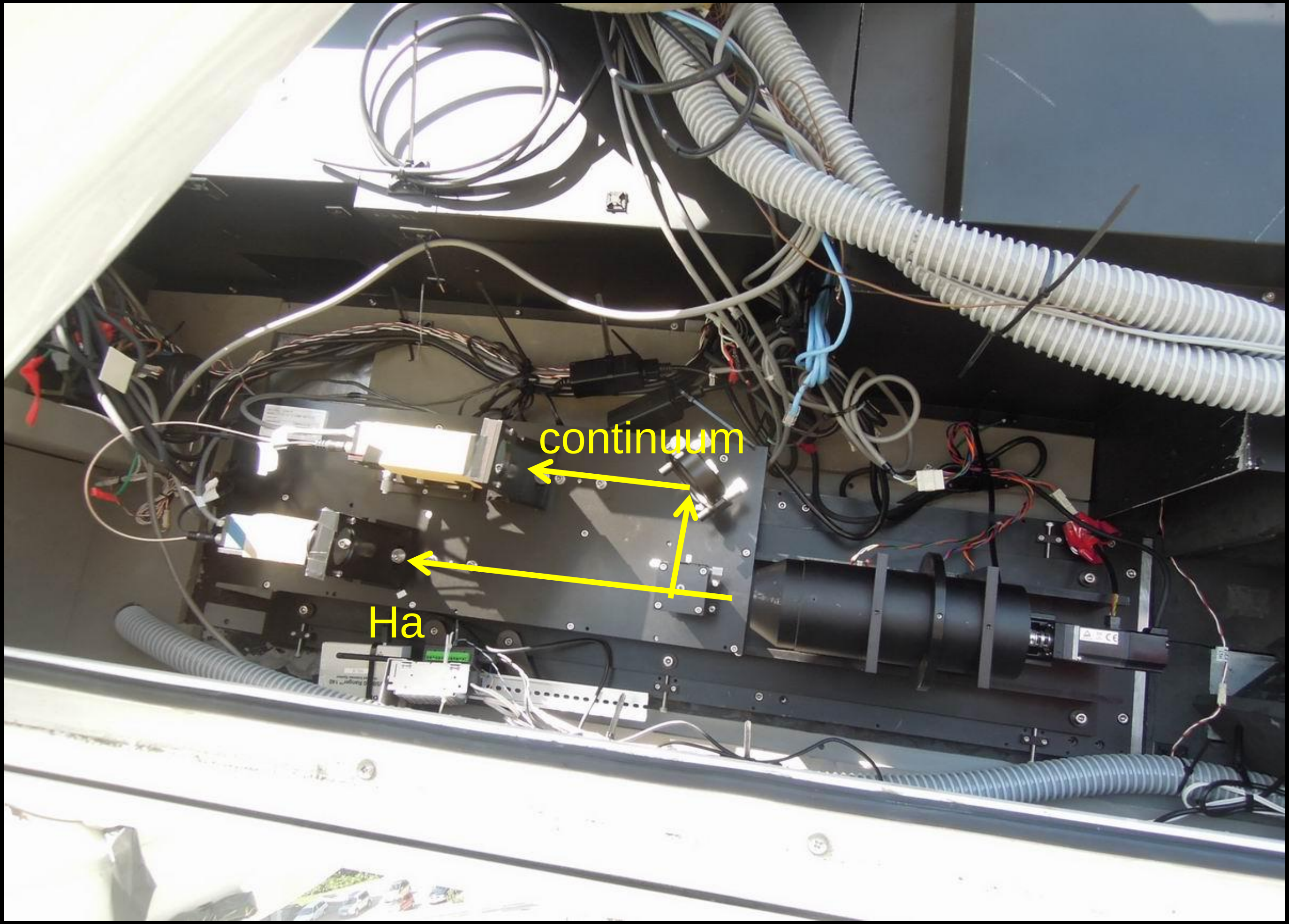
other periods – 1 set of images per every 5sec is stored after frame selection

Observation features

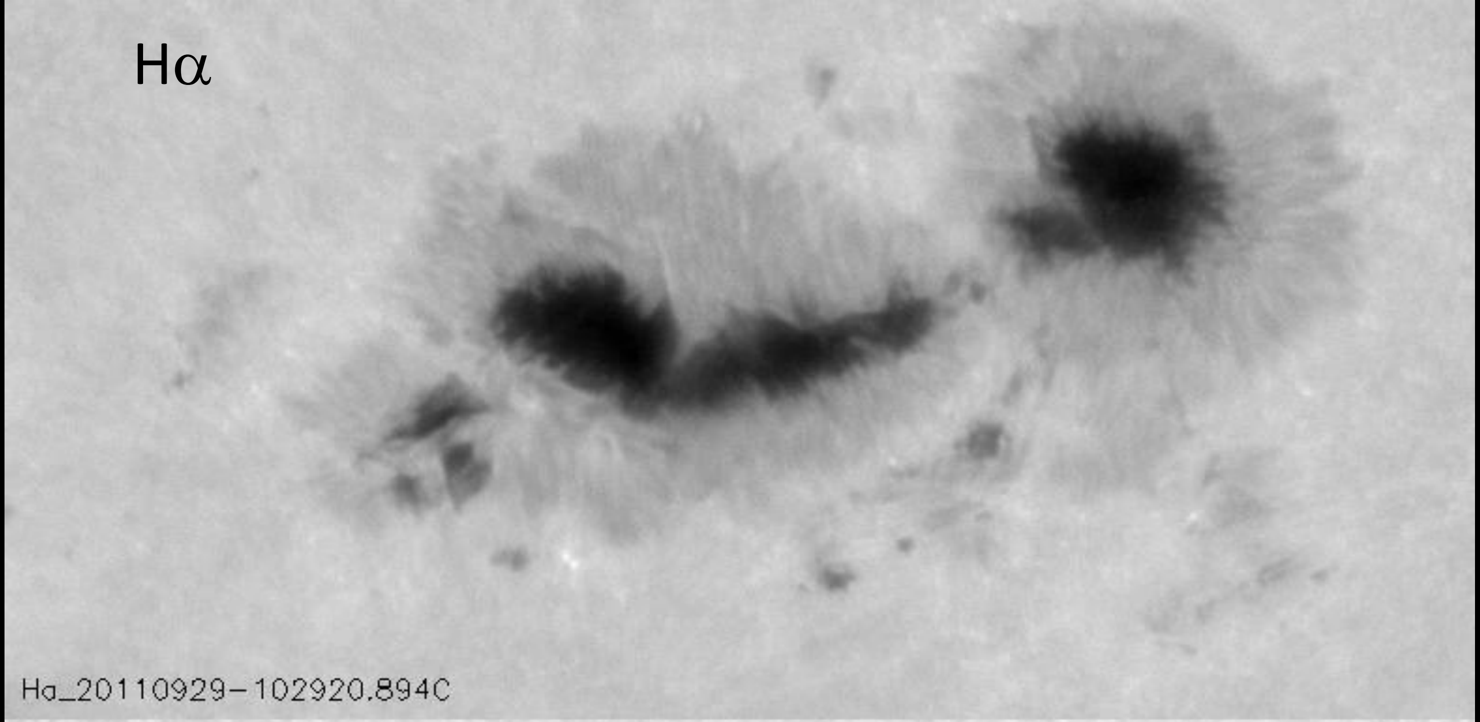
in comparison with other instruments

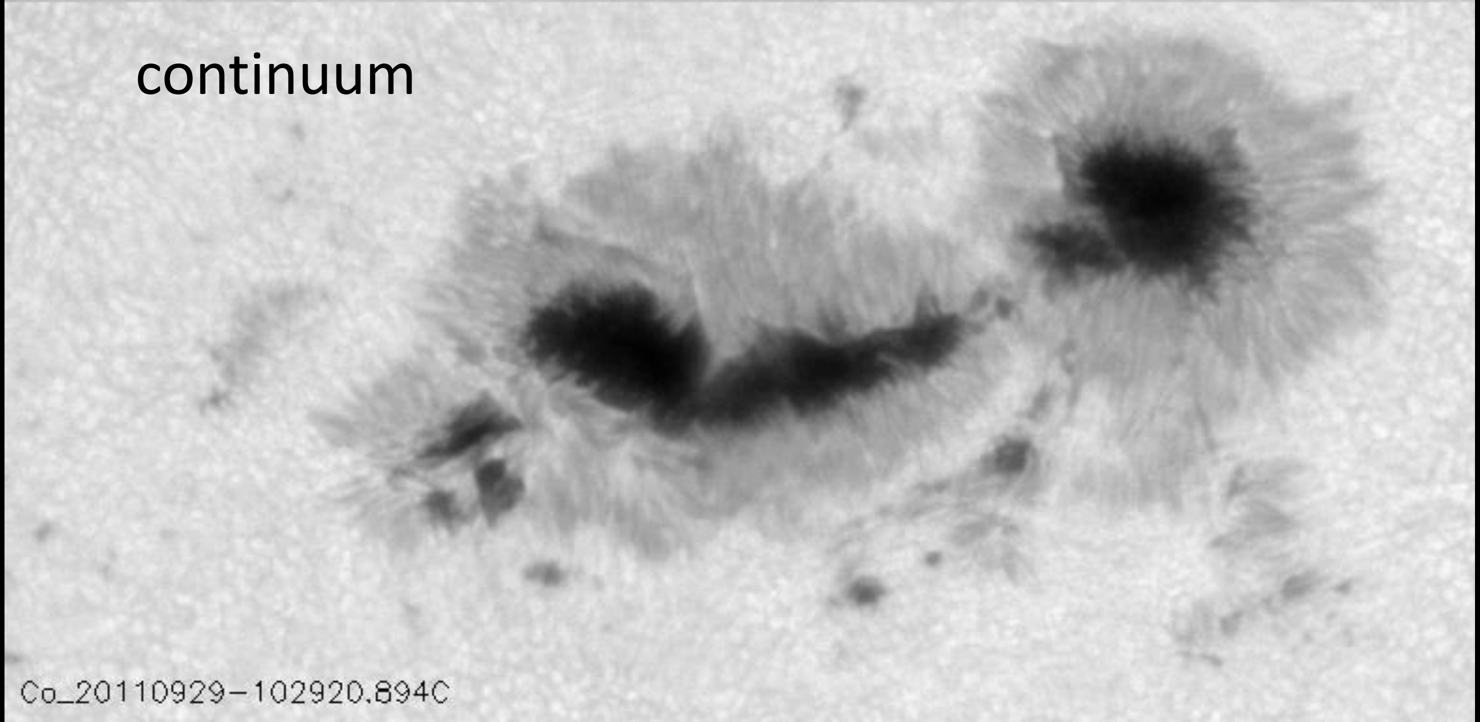
	BFI/Hinode	AIA/SDO	SMART-HSFI
Spatial resolution	0.2”	1.2”	0.6〜2”
Field of view	< 220”x110”	full disk	344”x258”
accuracy	10^{-2}	10^{-2}	10^{-2}
wavelength	CaH/ conti.	EUV/conti.	Hα/conti.
Time resolution	~20sec	12sec	0.04 sec
Time coverage	24hr/day	24hr/day	0〜10hr/day

Optical bench

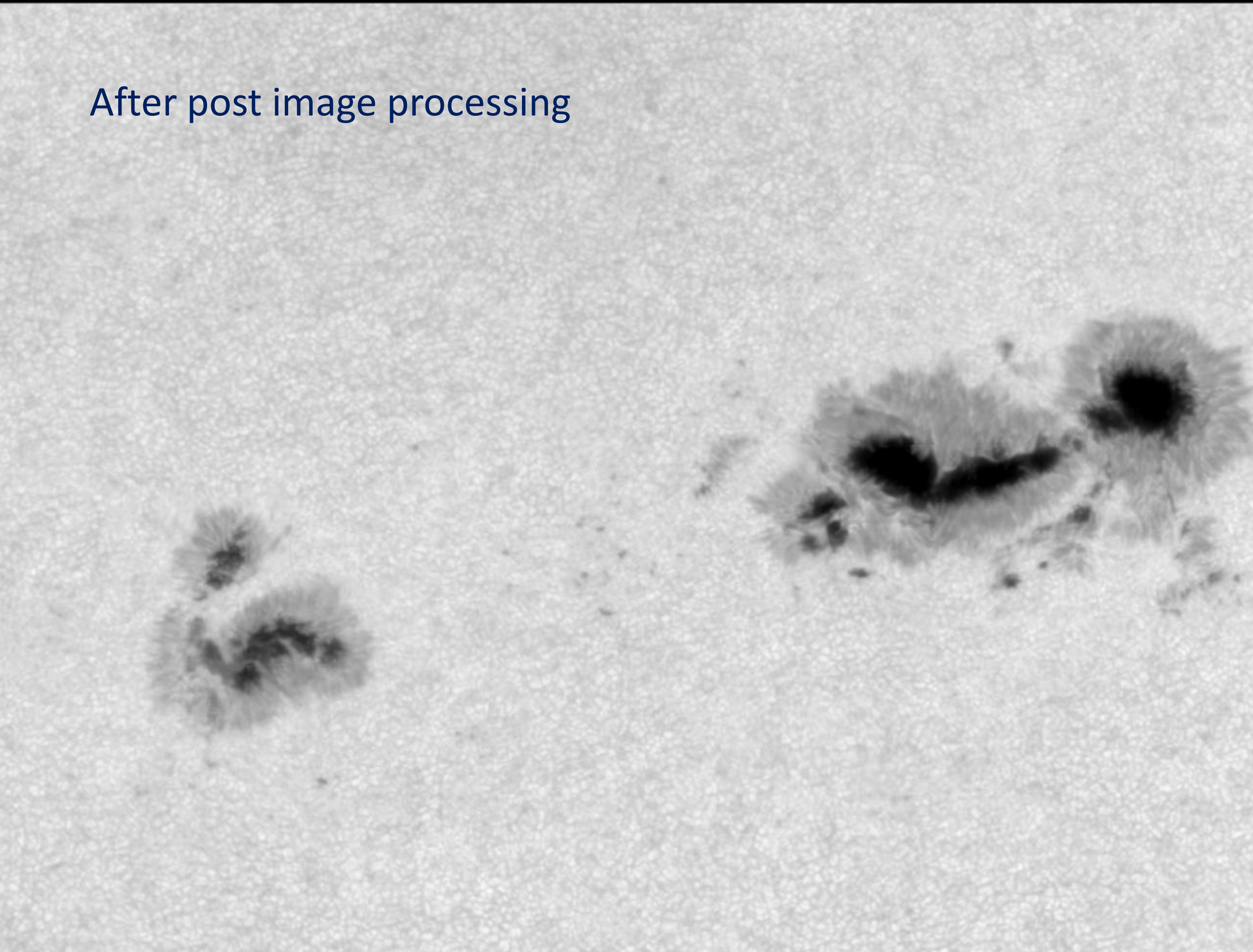


First light on 2011.8.17

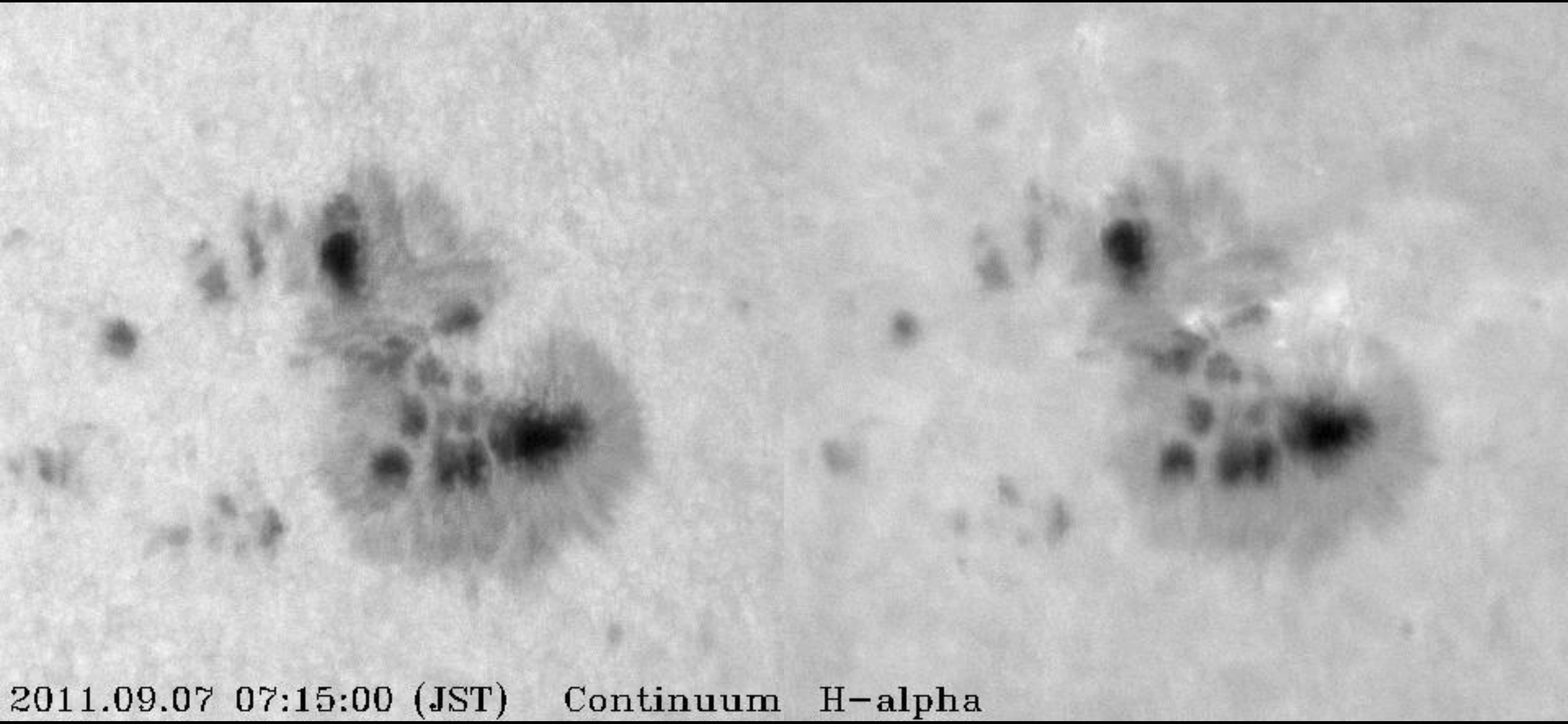

Hα
Ha_20110929-102920.894C


continuum
Co_20110929-102920.894C

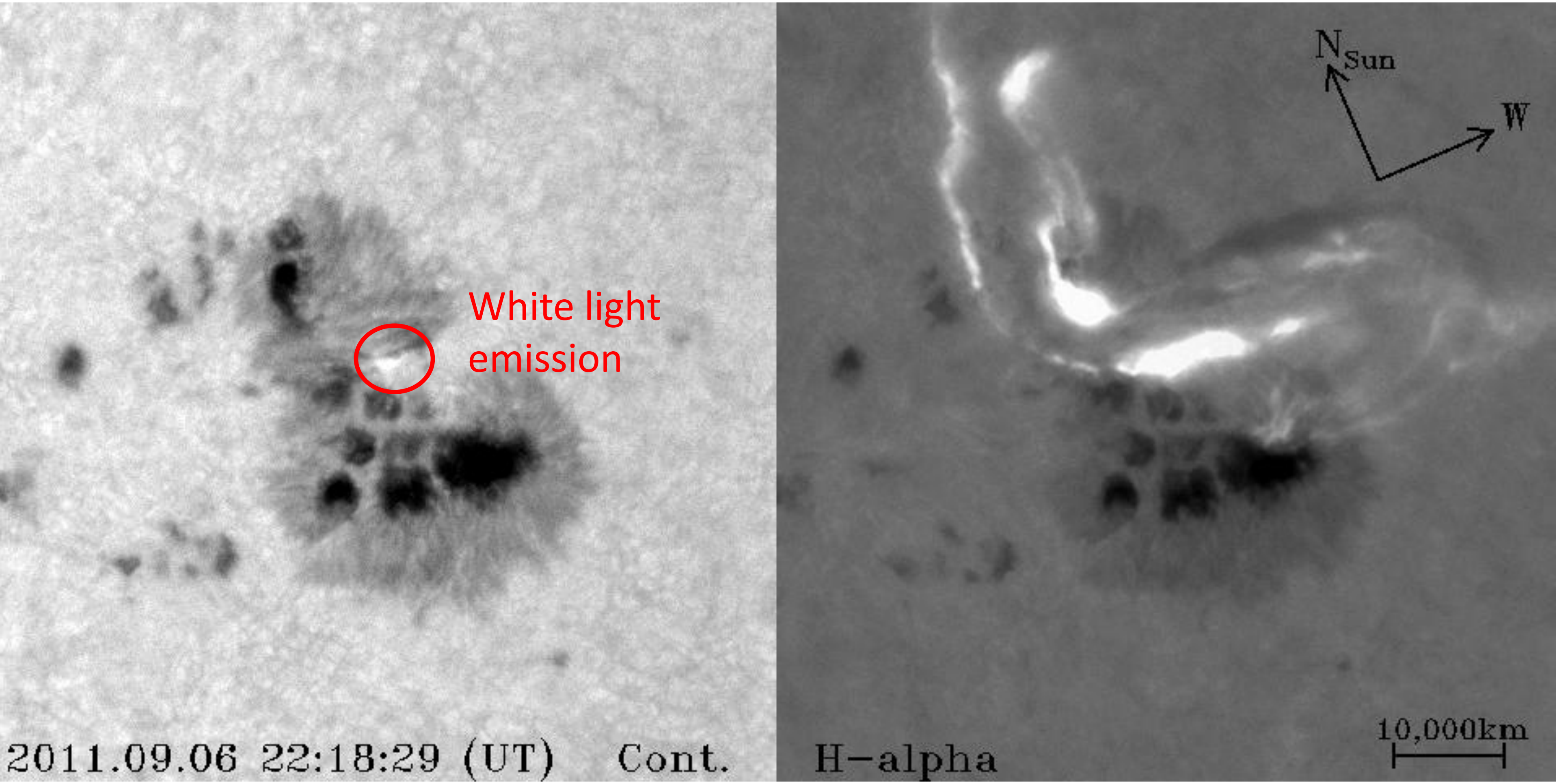
After post image processing



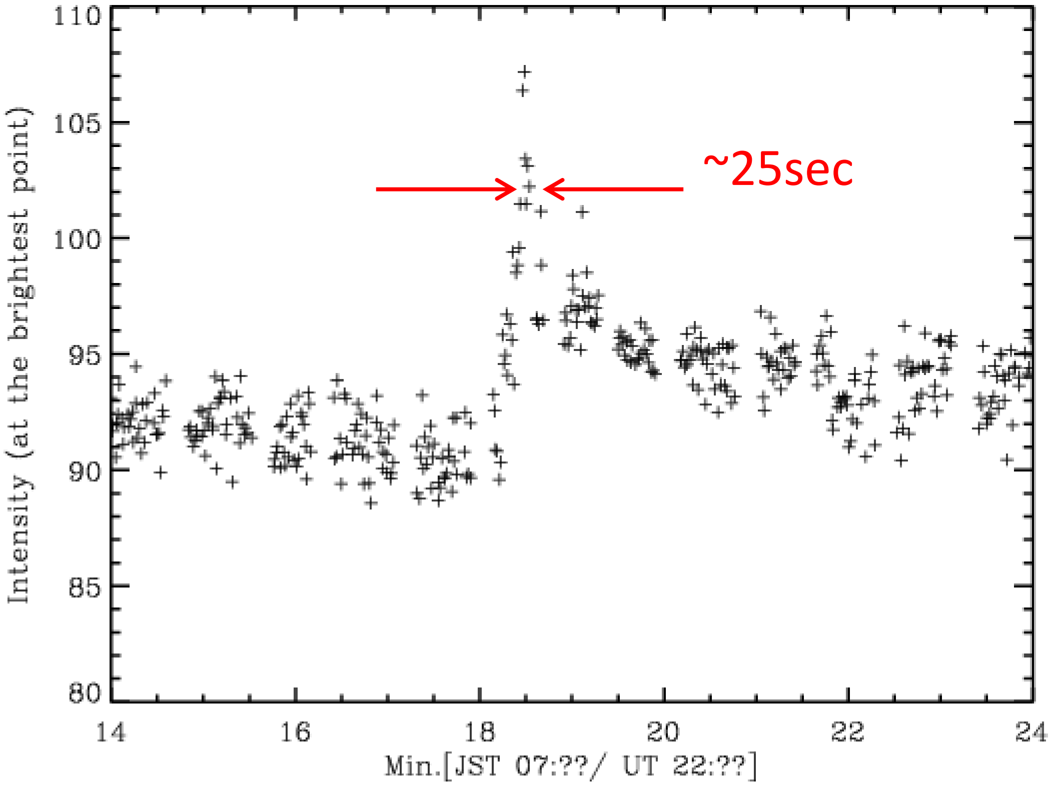
White light flare on 6 Sep.2011



White light flare on 6 Sep.2011

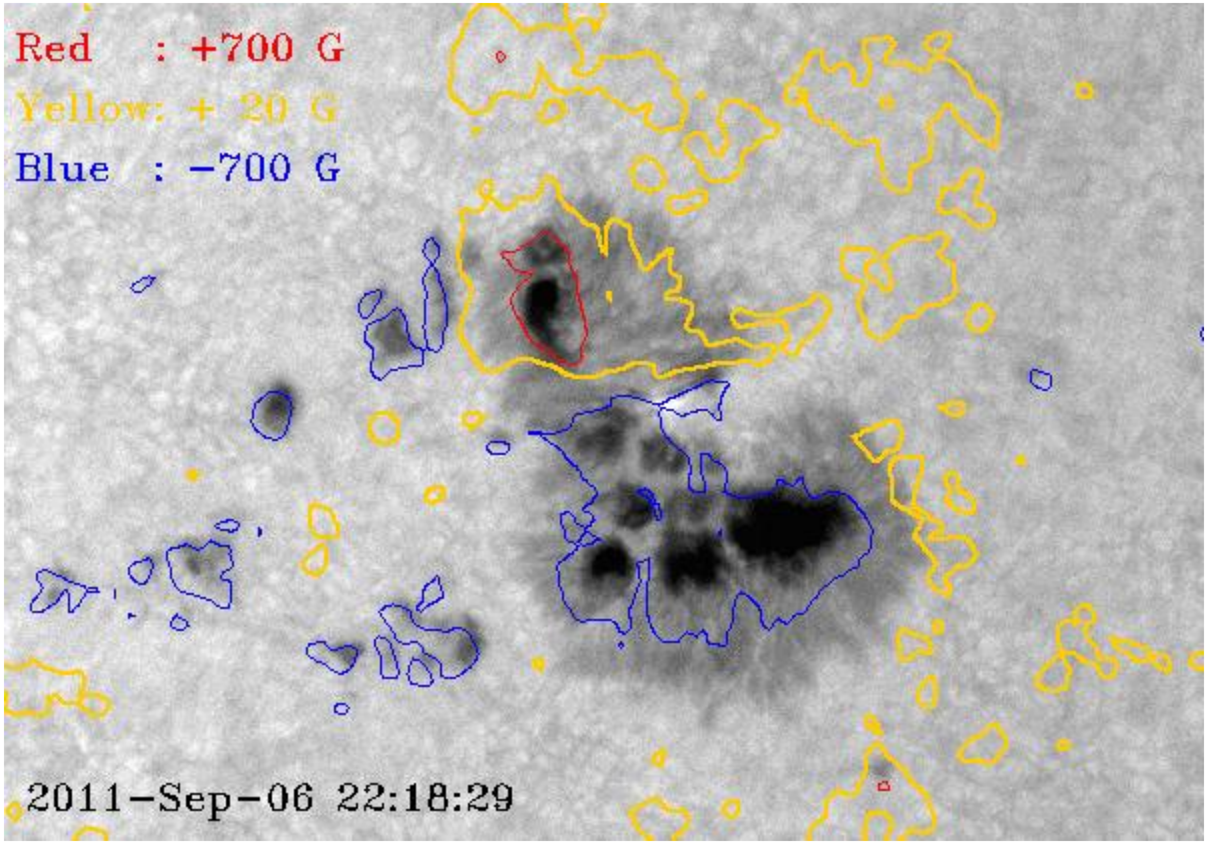


Light curve of white light flare

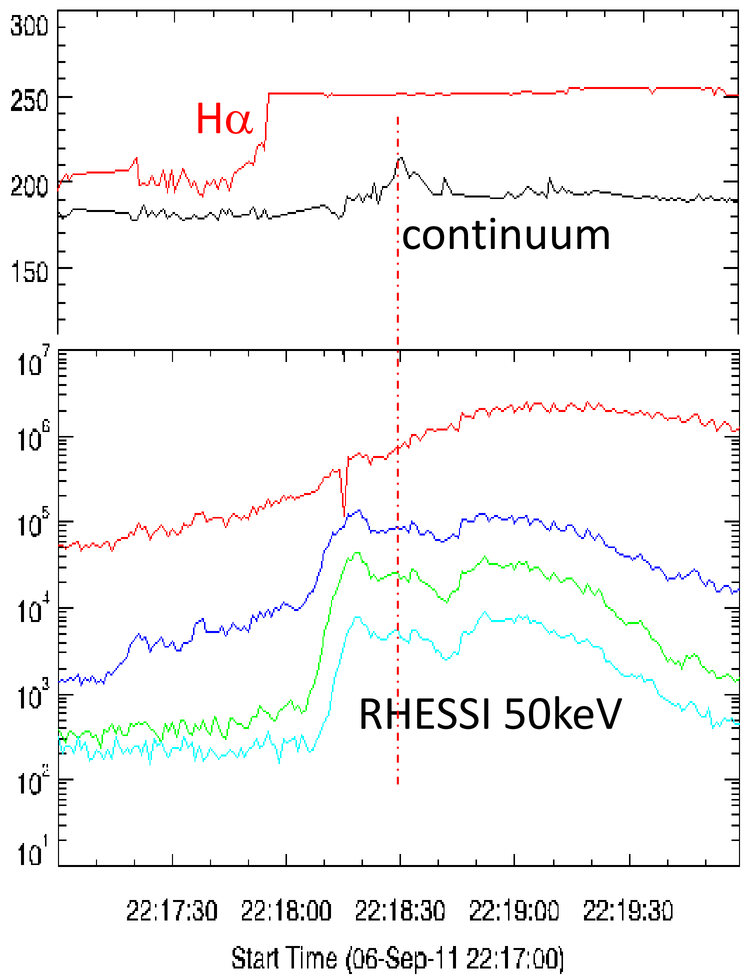


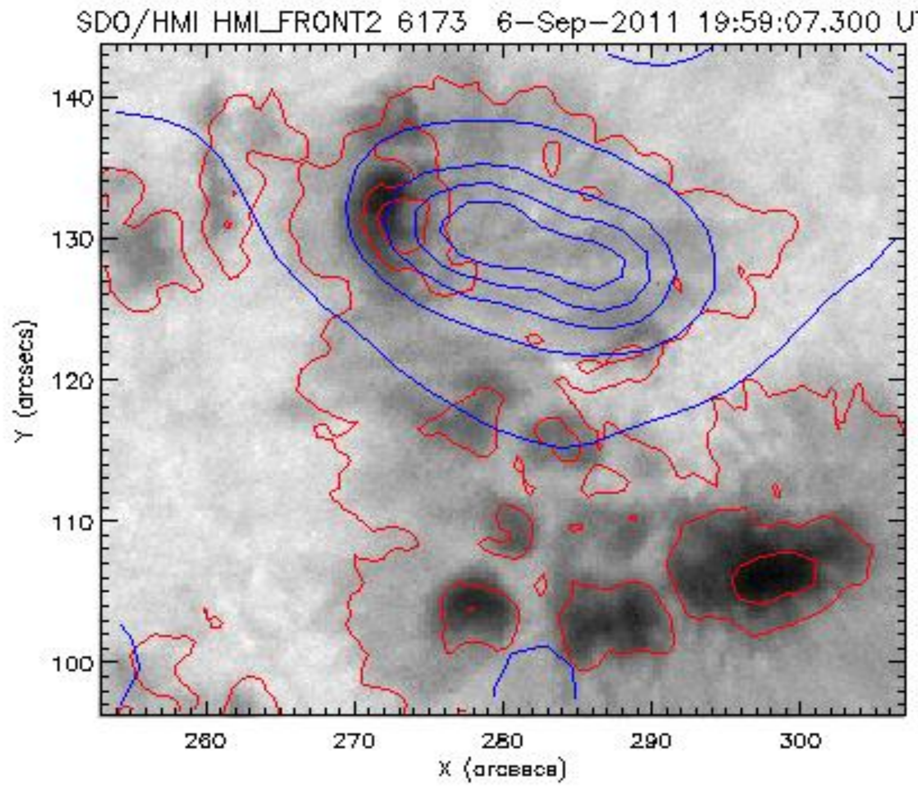
X2.1 flare on Sep. 06, 2011

（SMART / T3 Continuum, HMI magnetic field)



Comparison with HXR emission





- Ha brightening proceeds continuum by 40sec
- HXR peak proceeds continuum by 10sec
- HXR source is ~10arcsec apart from the continuum kernel

Eruptive flare, 2011.9.7

Hα

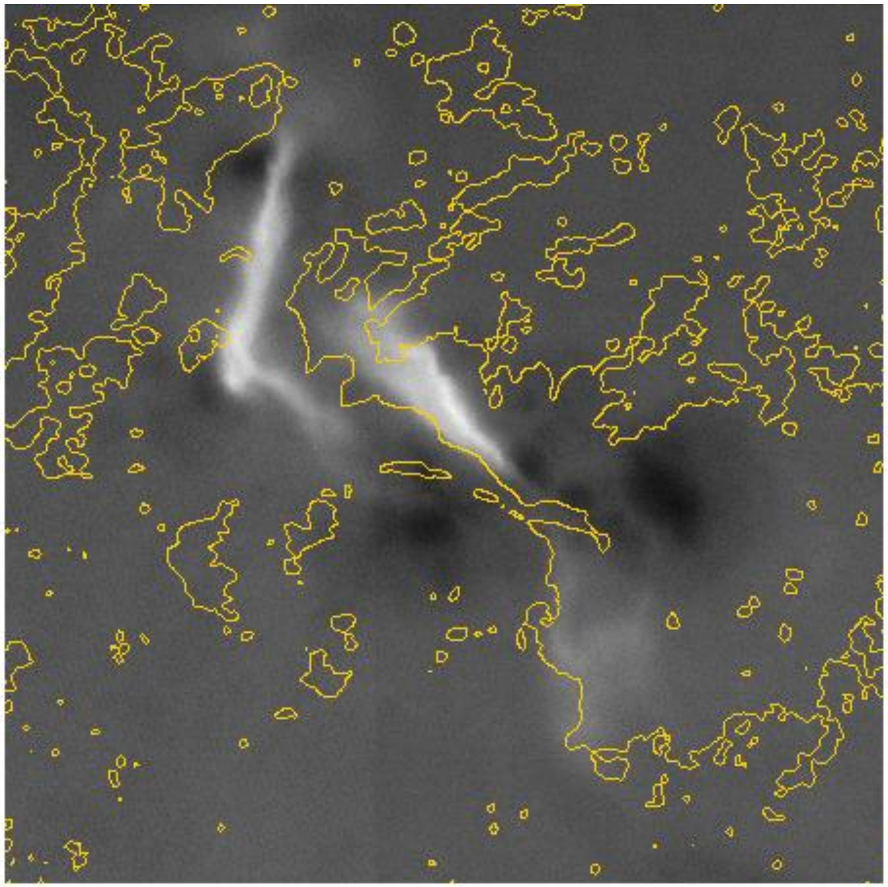
Conti.

Eruptive flare, 2011.9.7

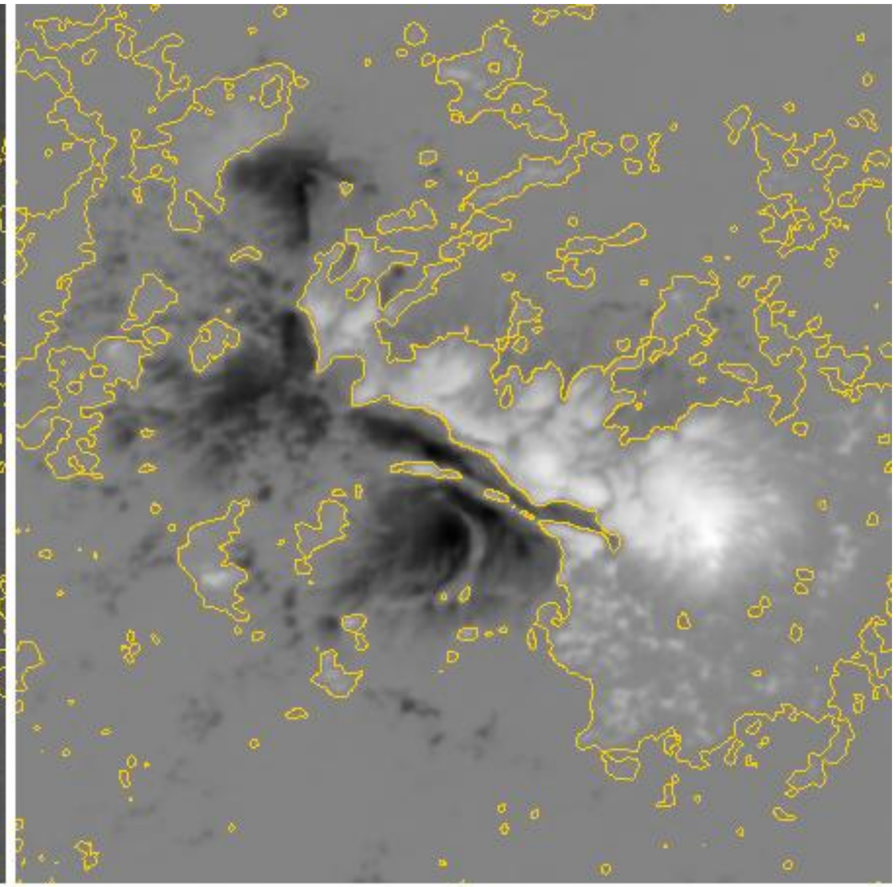
Hα

Conti.

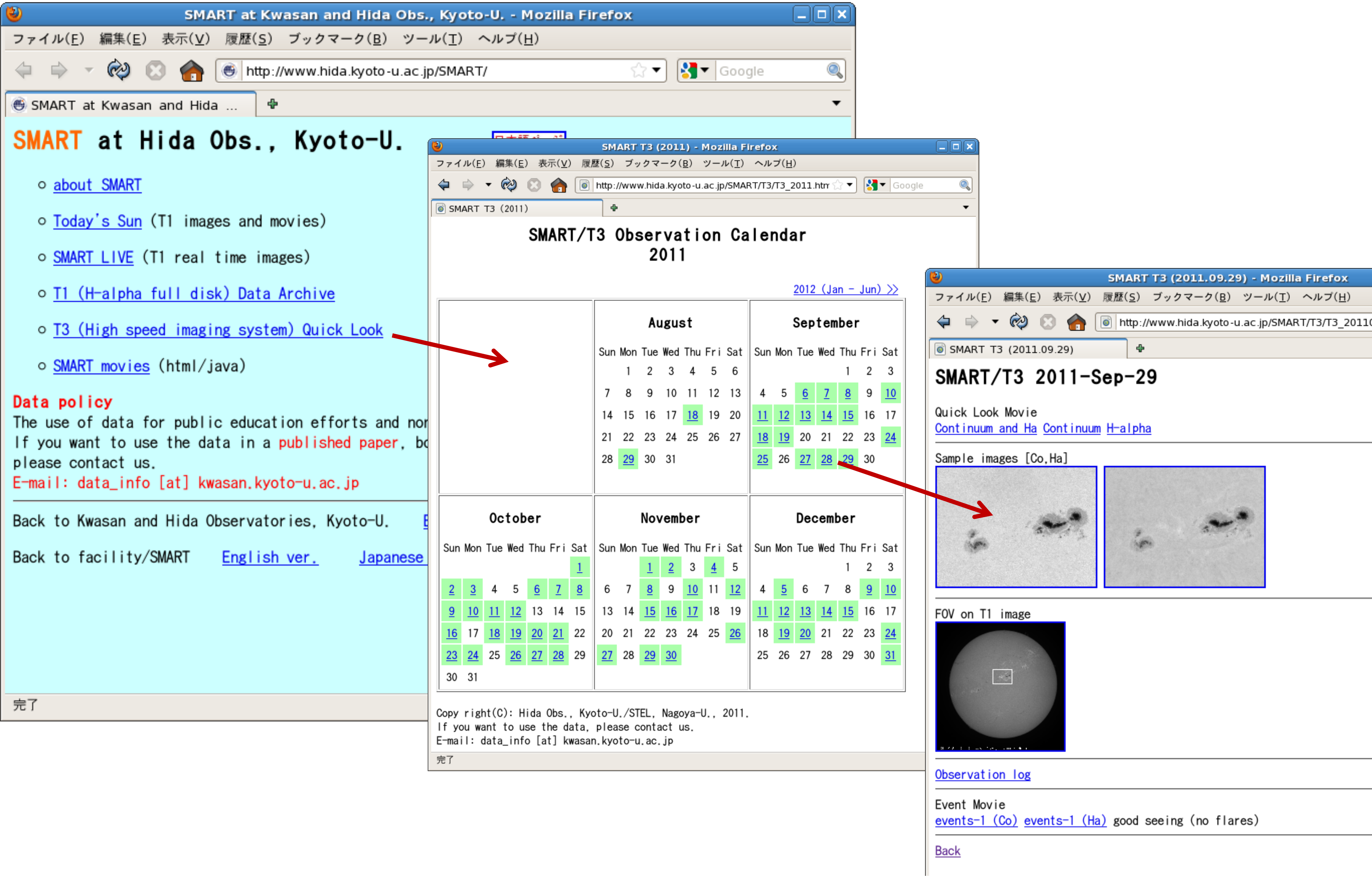
Flare (X5.4) on 2012.3.7



T3 Ha 2012-Mar-07 00:21:38.371

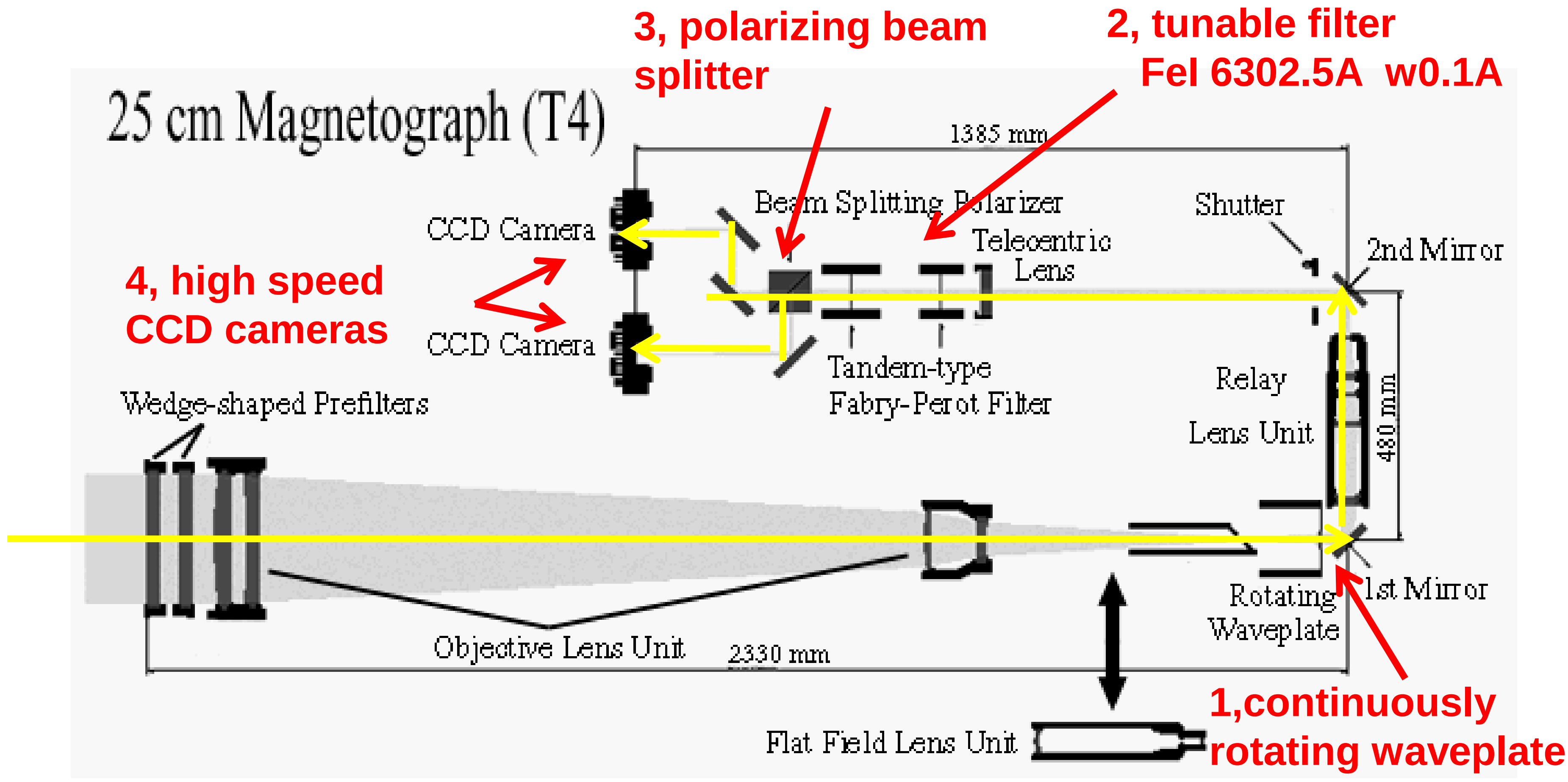


HMI 2012-Mar-07 00:12:00/00:24:00



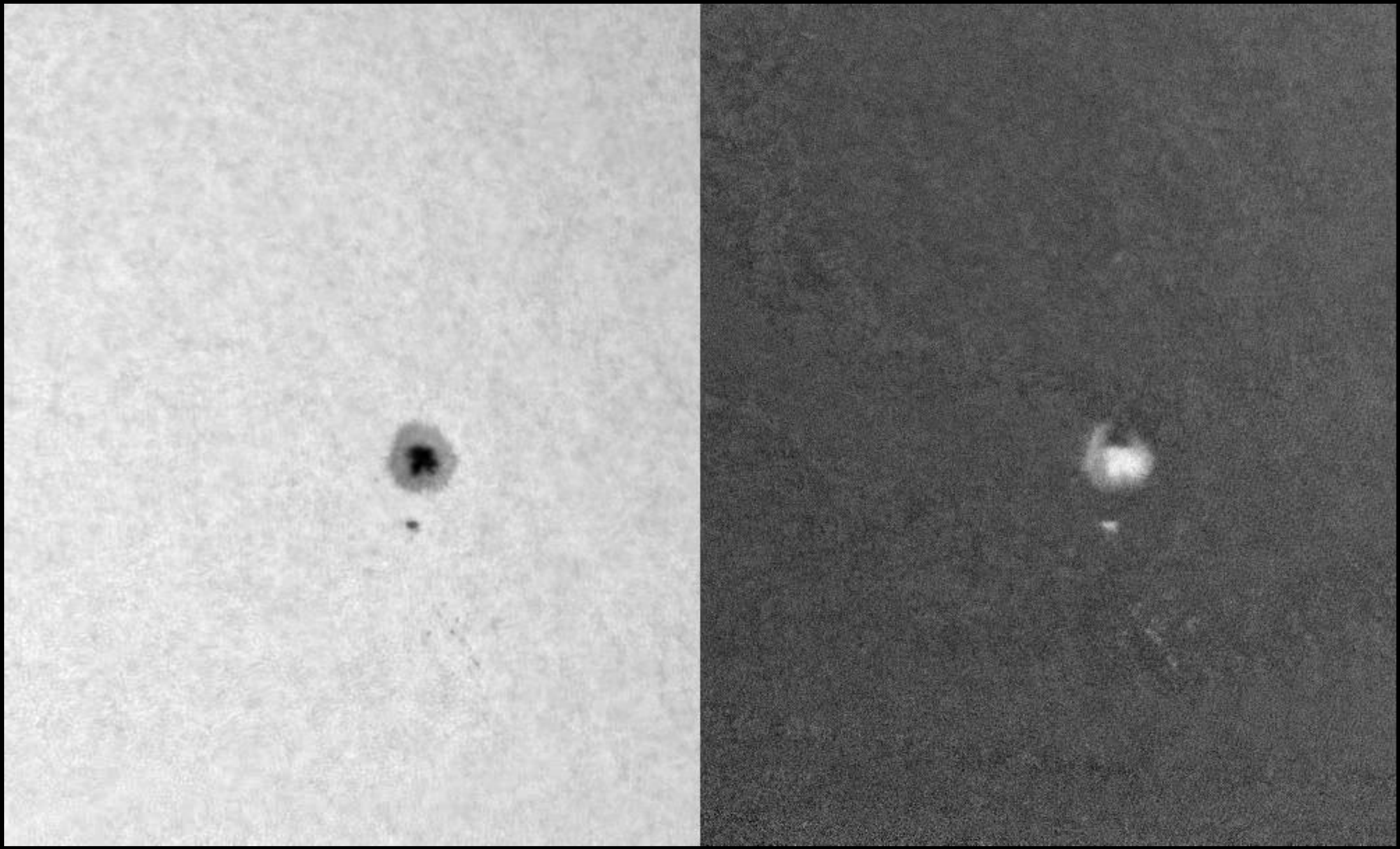
Data is open at http://www.hida.kyoto-u.ac.jp/SMART

SMART T4 new vector magnetograph



The coefficients *a,b,c,d* are the function of wave plate

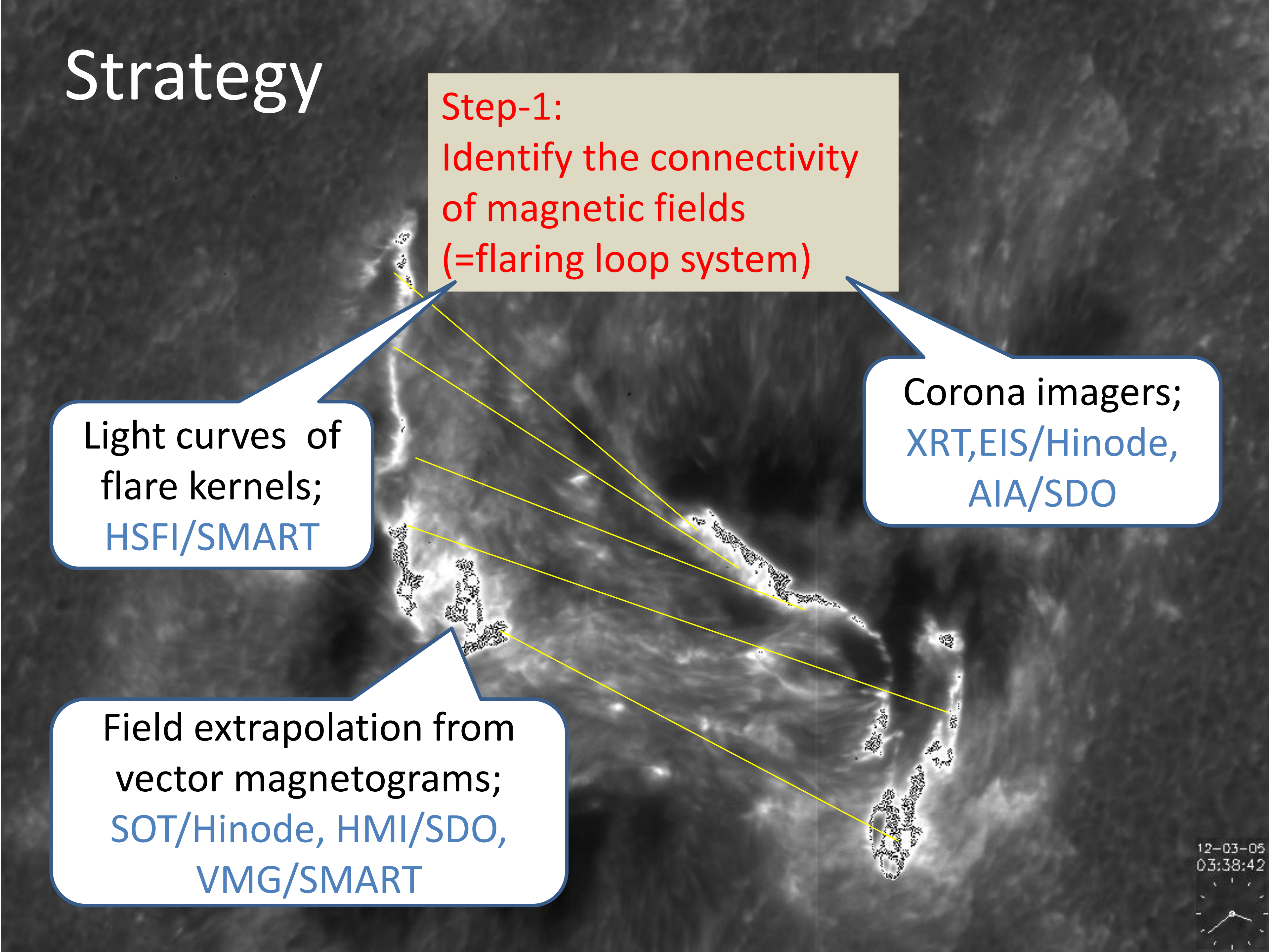
SMART T4 first light



Features of SMART T4 magnetograph

	SP/Hinode	HMI/SDO	SMART/VMG
Spatial resolution	0.3”	1”	0.6～5”
Field of view	< 320”x160”	full disk	450”x340”
accuracy	10^{-3}	3×10^{-3}	3×10^{-4}
wavelength	full profile	6	4
Time resolution	1hr ~ 1day	12min	0.5～1min
Time coverage	24hr/day	24hr/day	0～10hr/day

Strategy



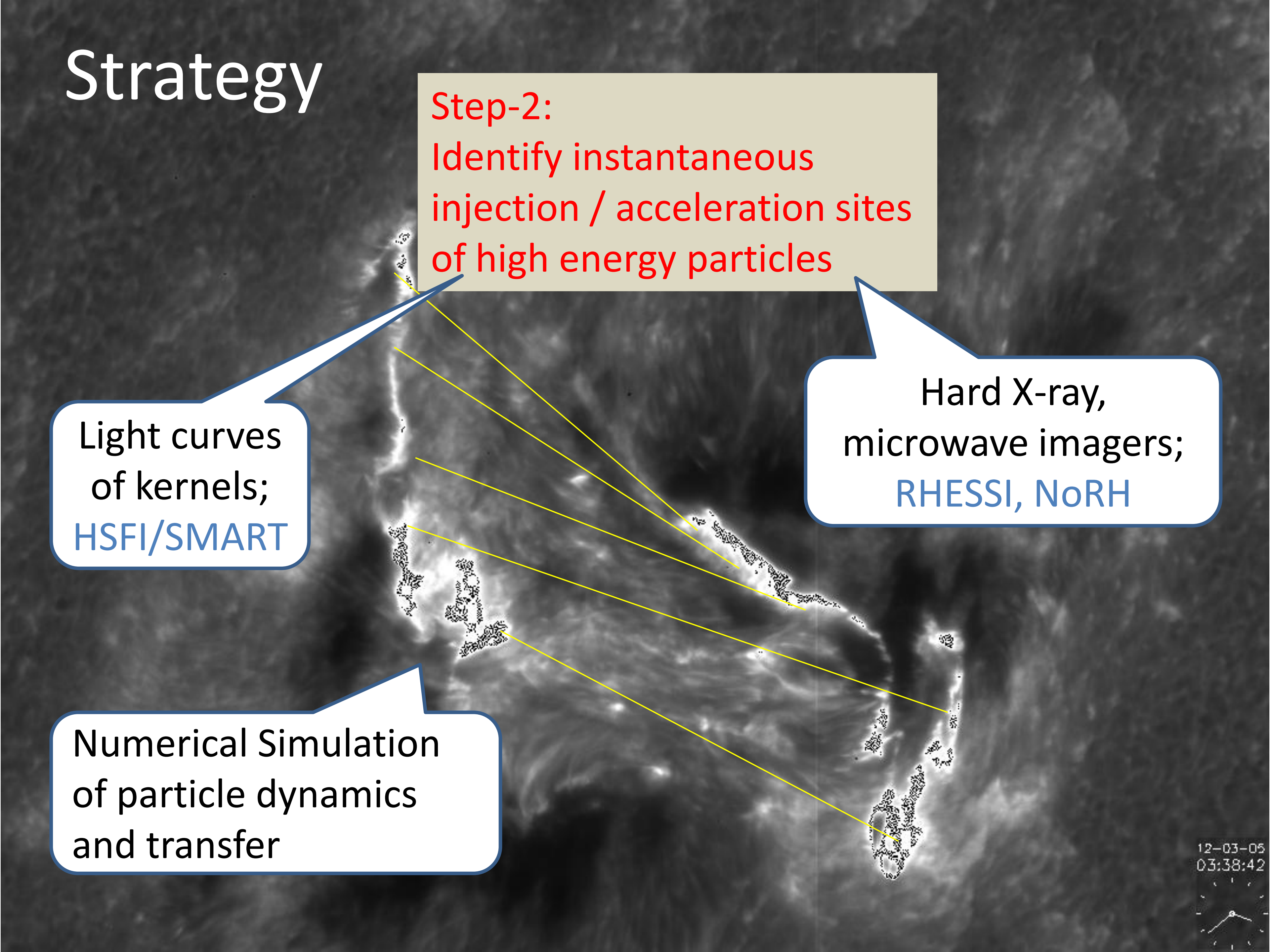
Step-1:
Identify the connectivity of magnetic fields (=flaring loop system)

Light curves of flare kernels;
HSFI/SMART

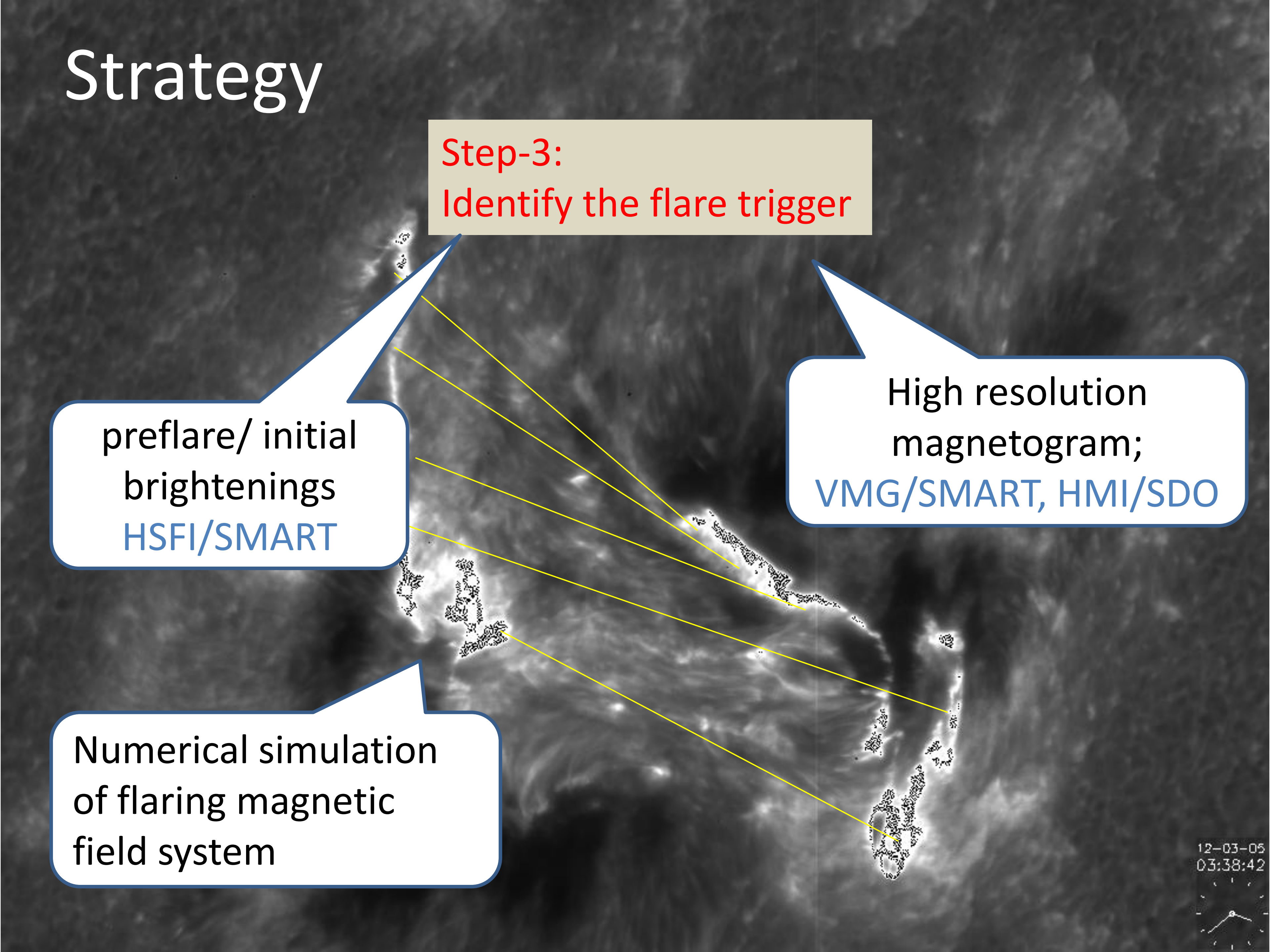
Corona imagers;
XRT,EIS/Hinode,
AIA/SDO

Field extrapolation from vector magnetograms;
SOT/Hinode, HMI/SDO,
VMG/SMART

Strategy


Step-2:
Identify instantaneous injection / acceleration sites of high energy particles
Light curves of kernels; HSFI/SMART
Hard X-ray, microwave imagers; RHESSI, NoRH
Numerical Simulation of particle dynamics and transfer
12-03-05
03:38:42

Strategy



Step-3:
Identify the flare trigger
preflare/ initial brightenings
HSFI/SMART
High resolution magnetogram;
VMG/SMART, HMI/SDO
Numerical simulation of flaring magnetic field system
12-03-05
03:38:42

3. Summary (1)

The High Speed Flare Imager (HSFI) is now in regular operation at Hida Observatory
Four X-class flares (out of 9) have been observed since its first light on 2011.8.17

The system aims to diagnose the spatial / temporal evolution of high energy particles and trigger mechanism of the solar flare by capturing rapid evolution of flare kernels, and to find a path for better flare prediction.

The data are available on http://www.hida.kyoto-u.ac.jp/SMART/T3/.

3. Summary (2)

Joint program of STEL for
“Study of onset mechanism of solar flares with high resolution imaging observations and numerical modeling” is in progress.

Task;

- High speed imaging by SMART
- Vector magnetogram by SMART
- Flare kernel analysis
- NoRH, RHESSI analysis
- SDO/HMI & SMART magnetogram analysis
- SDO/AIA, EIS/XRT analysis
- SOT-G/Hinode analysis
- Magnetic field / flare modeling
- Modeling of high energy particle

Collaborators;

Ichimoto, Ishii, Nakatani (Kyoto-U)
Nagata, Morita (Kyoto-U)
Kawate, Ishii (Kyoto-U)
Masuda (STEL)
Yoshinaga, Morita (Kyoto-U)
Asai (Kyoto-U)
Watanabe,K (ISAS)
Kusano, Yamamoto (STEL)
Minoshima (JAMSTEC)
Yokoyama (Tokyo-U)

Thank you for attention.

計画概要:
フレア粒子加速の総合的研究

フレアカーネルの高速撮像観測　→ 磁力線の接続、フレアループの連鎖

光球磁場観測＋モデリング　ー、不安定点

EUV、軟X線観測　変化

電波、硬X線観測　布、スペクトル

➔ 磁場の繋がりは整合し
➔ 高エネルギー粒子の注　搬

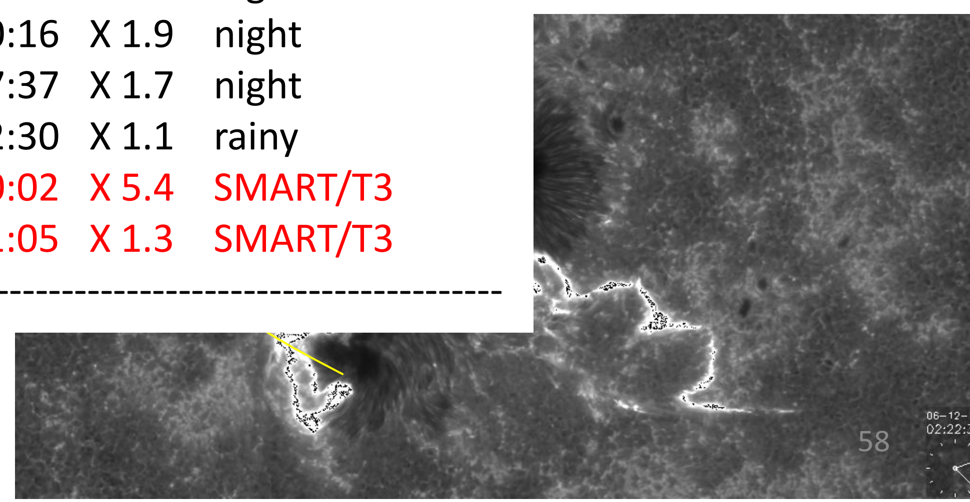
粒子輸送モデリング

➔ 粒子加速領域特定

➔ 粒子加速メカニズム

4 X-class flares (out of 9) were observed since the first light on 2011.8.17

Date	start		
110906	22:12	X 2.1	SMART/T3
110907	22:32	X 1.8	SMART/T3
110922	10:29	X 1.4	night
110924	09:21	X 1.9	night
111103	20:16	X 1.9	night
120127	17:37	X 1.7	night
120305	02:30	X 1.1	rainy
120307	00:02	X 5.4	SMART/T3
120307	01:05	X 1.3	SMART/T3

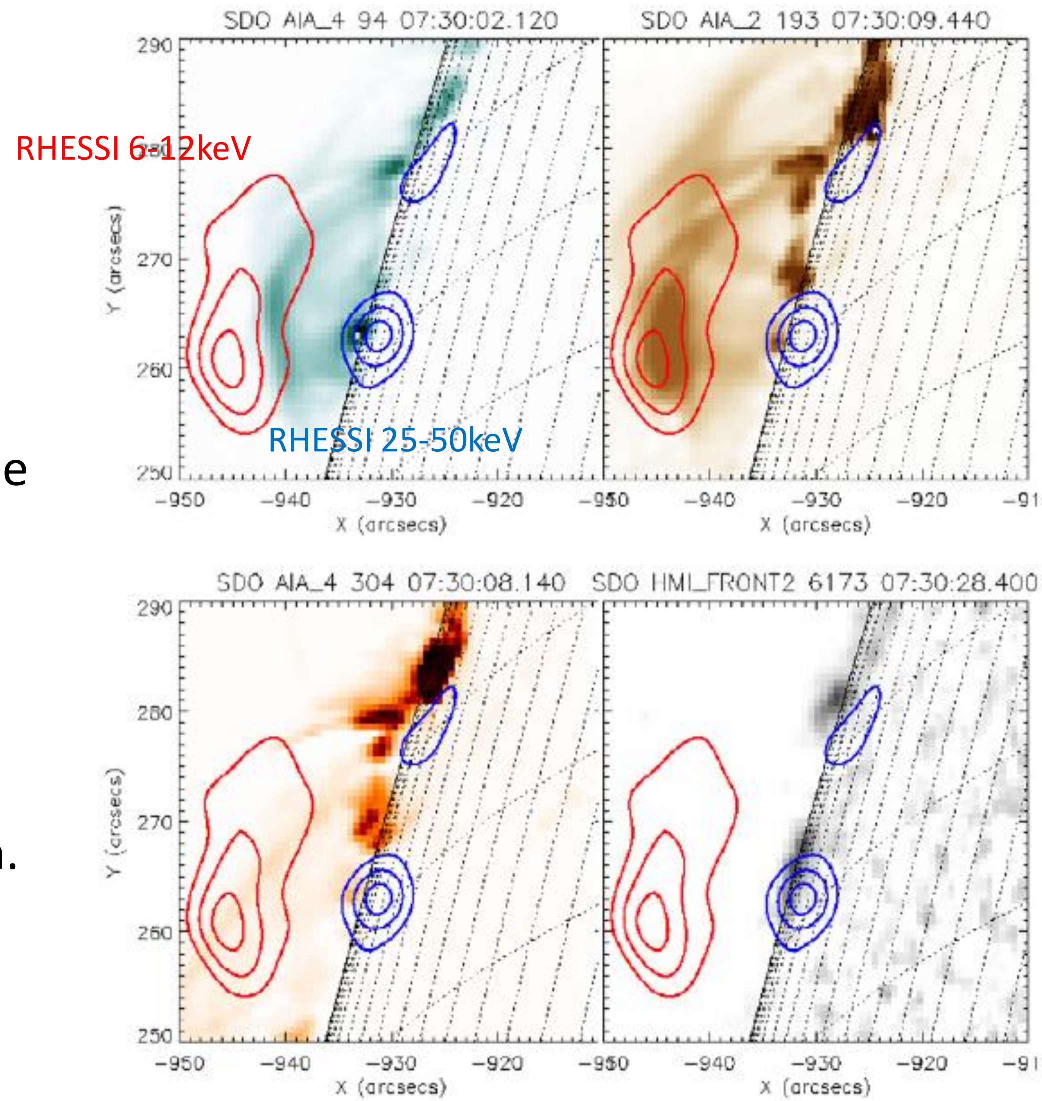


Height structure of X-ray, EUV, and white-light mission in a solar flare

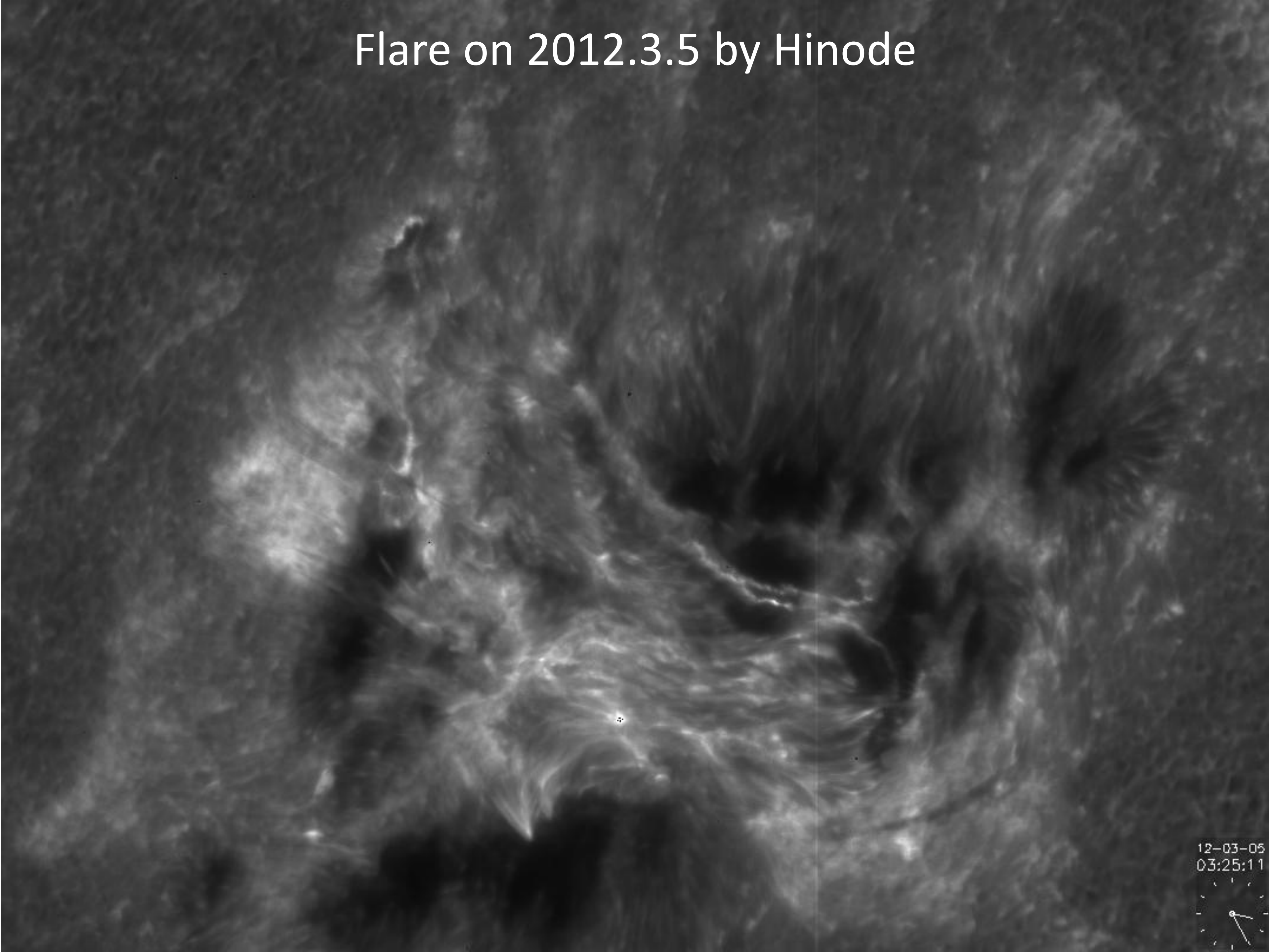
24 Feb. 2011

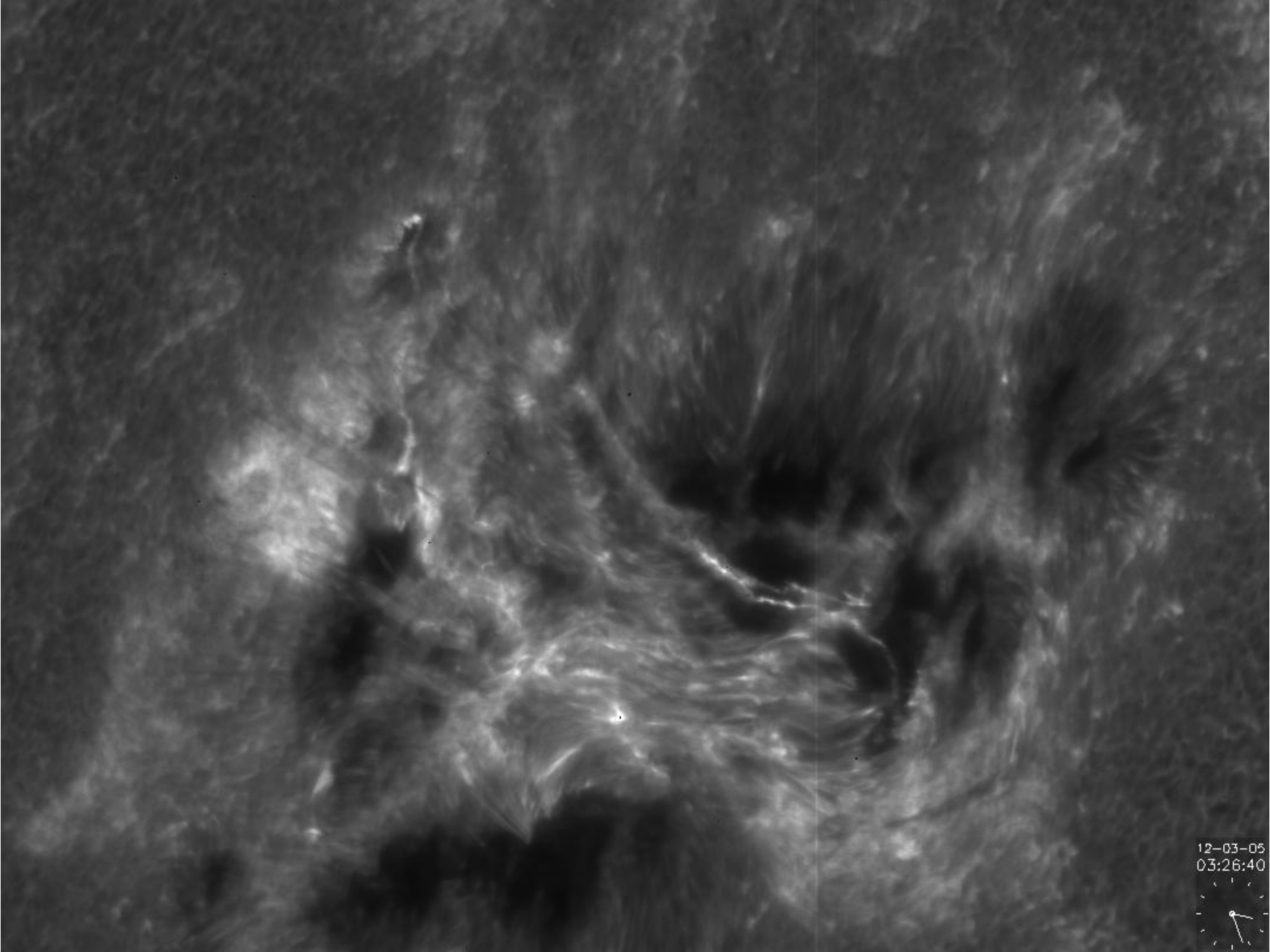
Battaglia and Kontar, 2011, A&A

The white-light continuum emission appears between the HXR and EUV emission, presumably in the transition between ionized and neutral atmospheres, implying that it consists of free-bound and free-free continuum emission.



Flare on 2012.3.5 by Hinode

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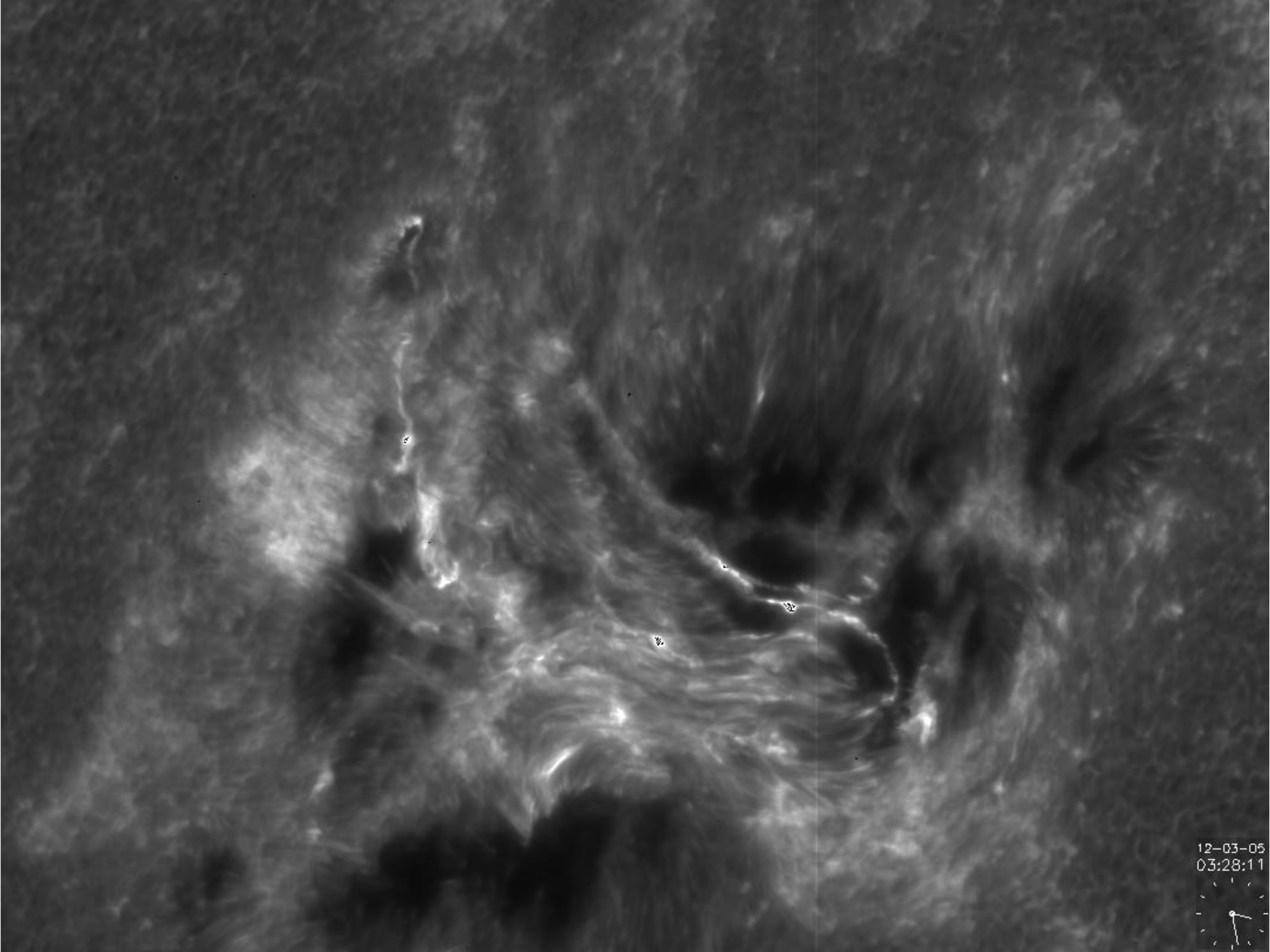
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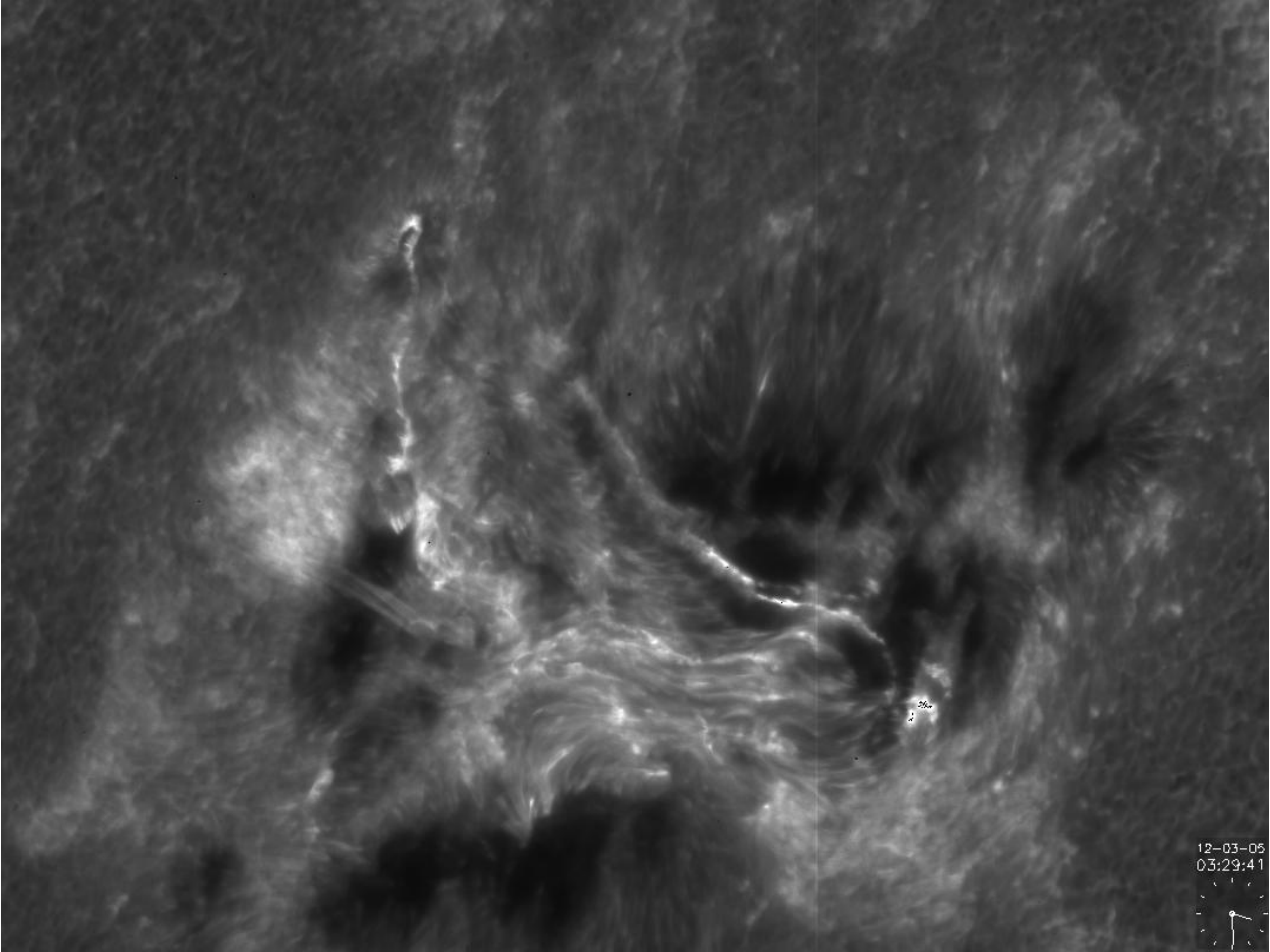
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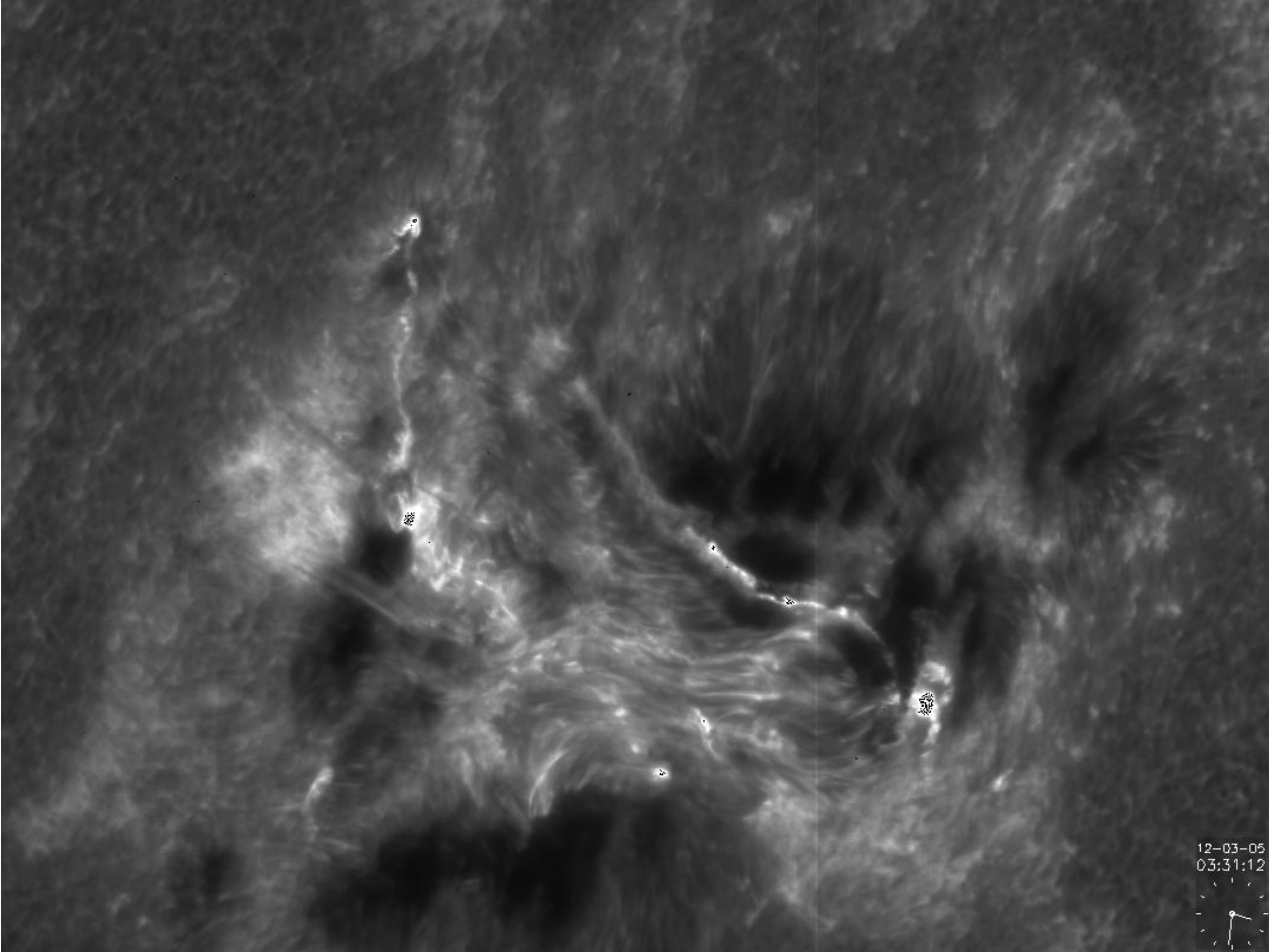
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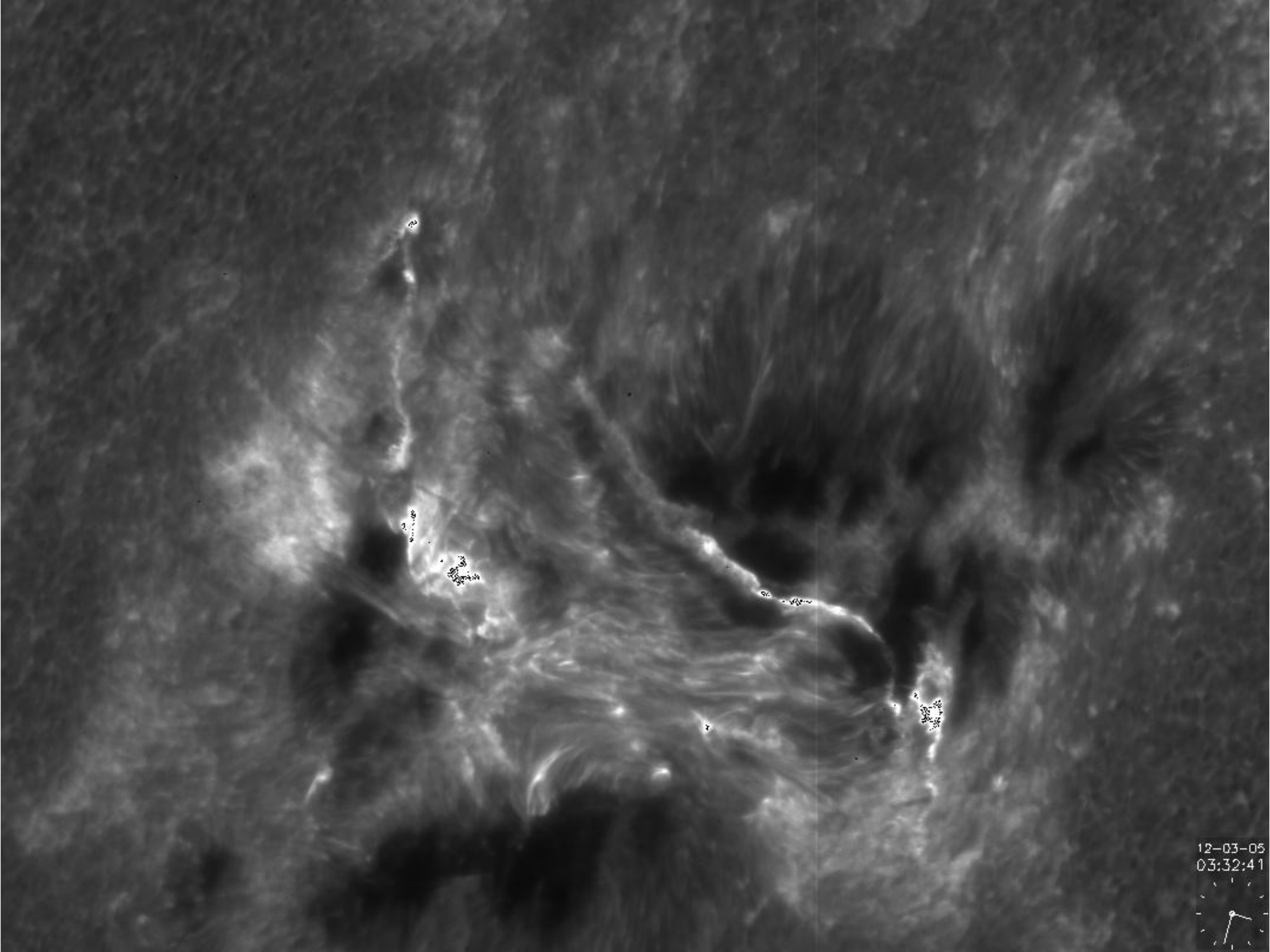
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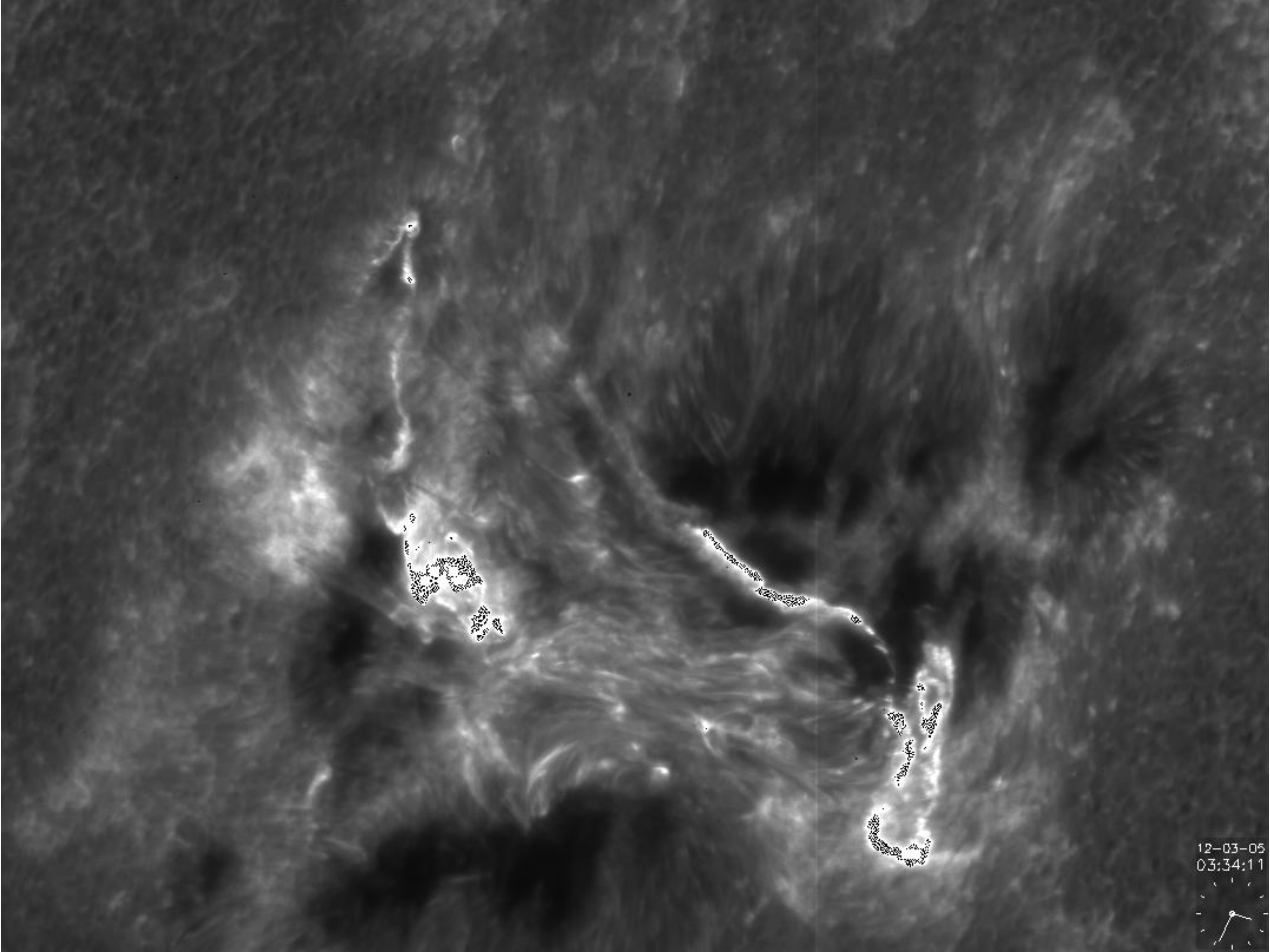
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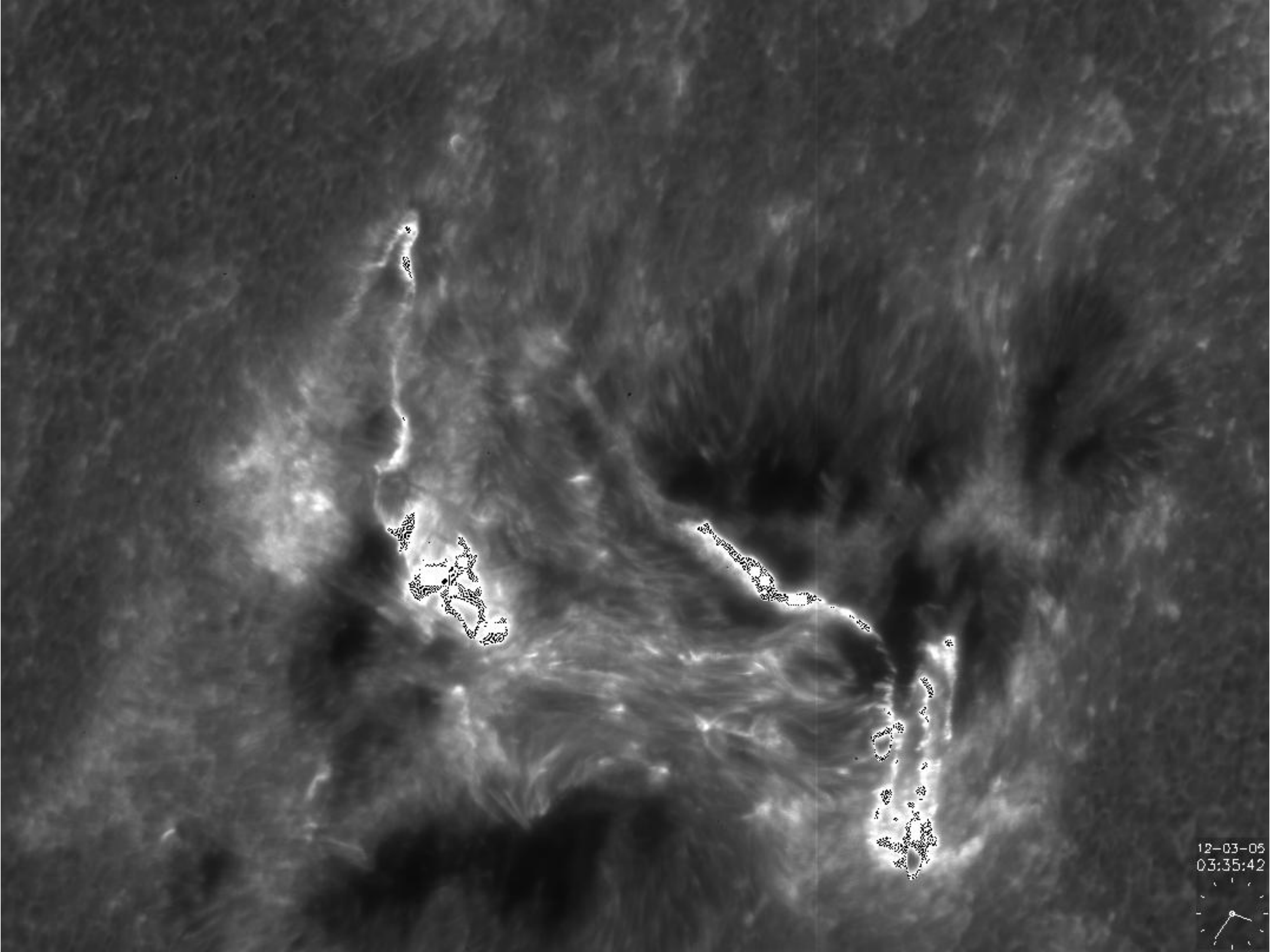
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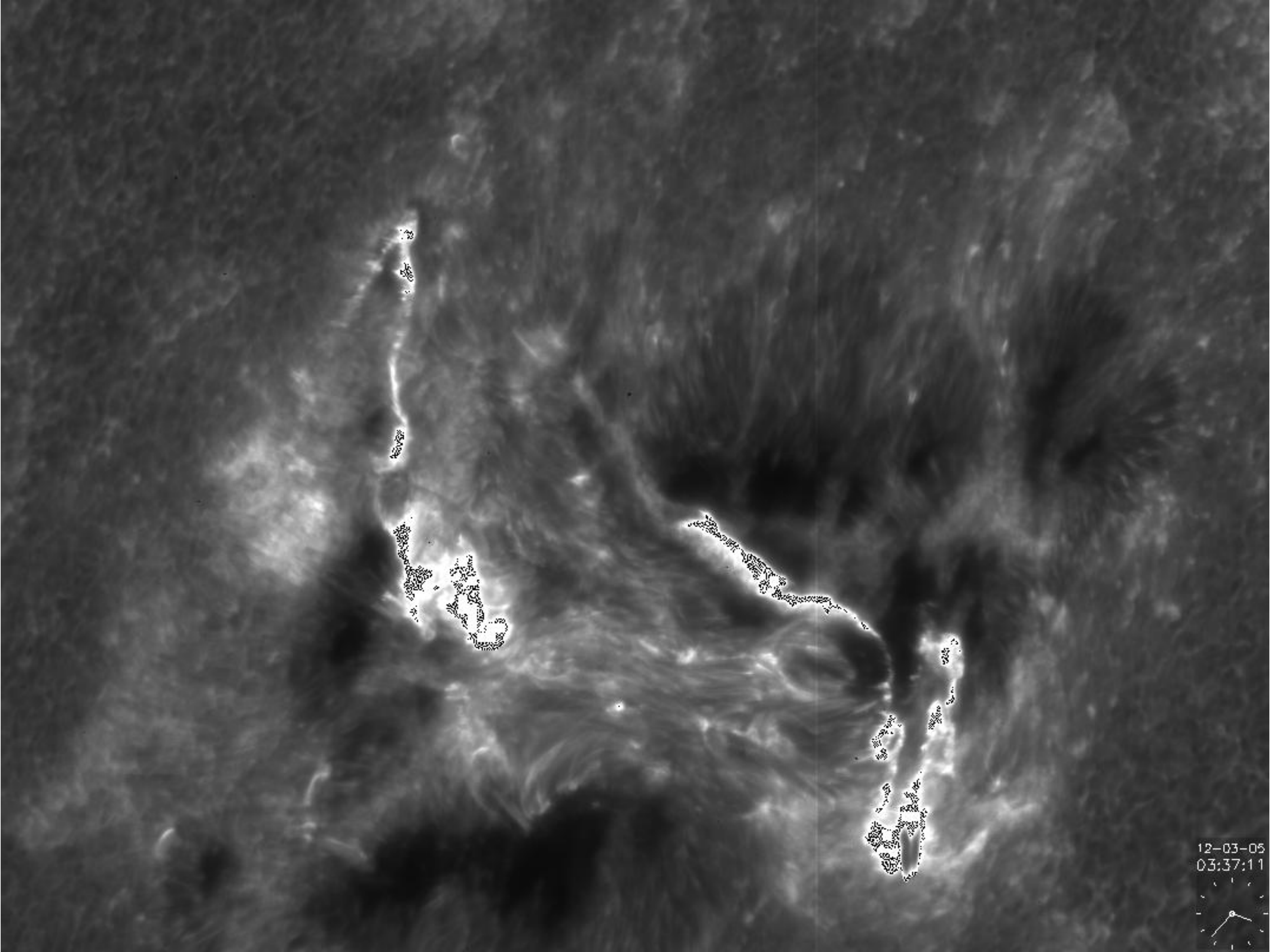
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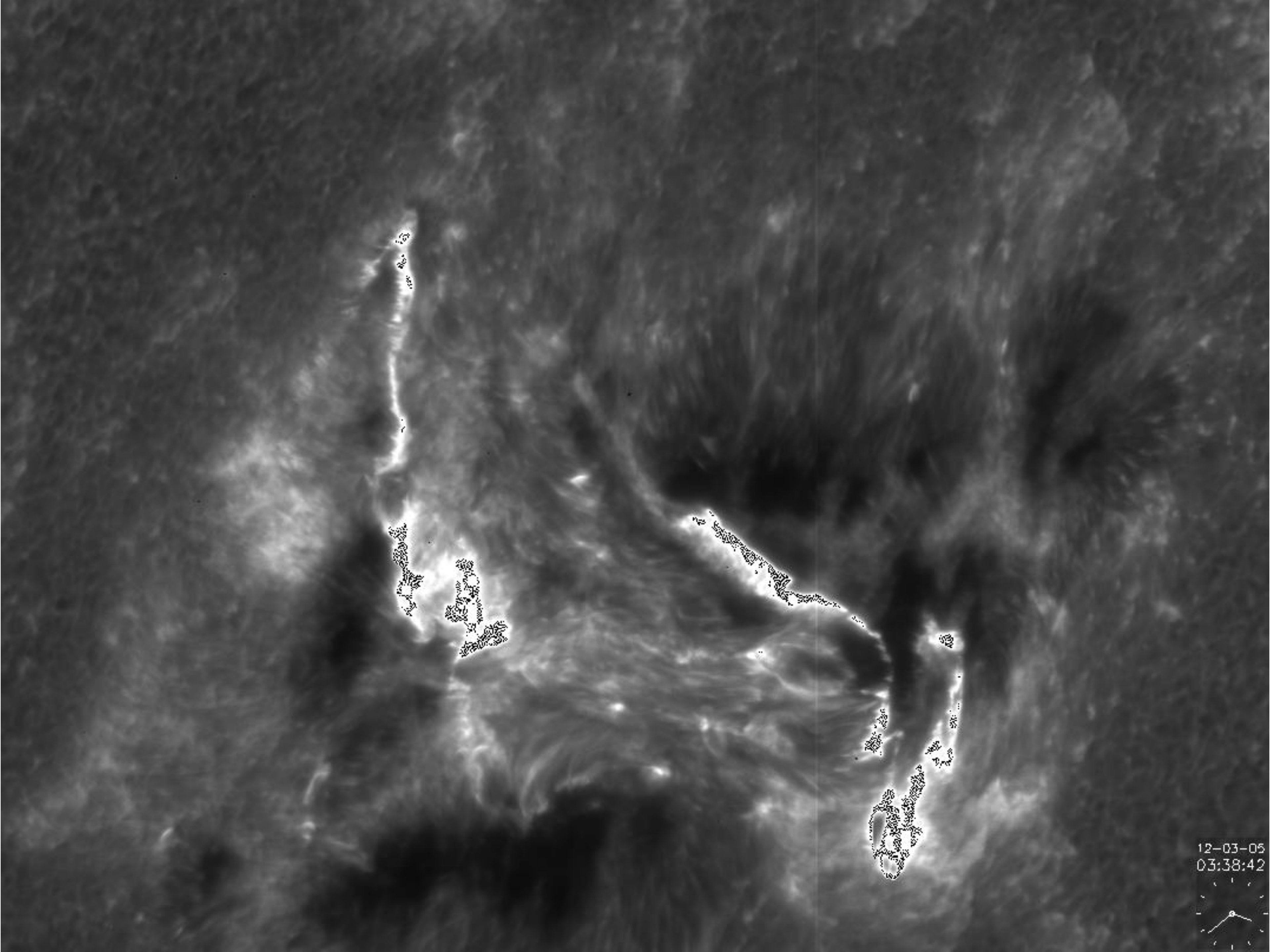
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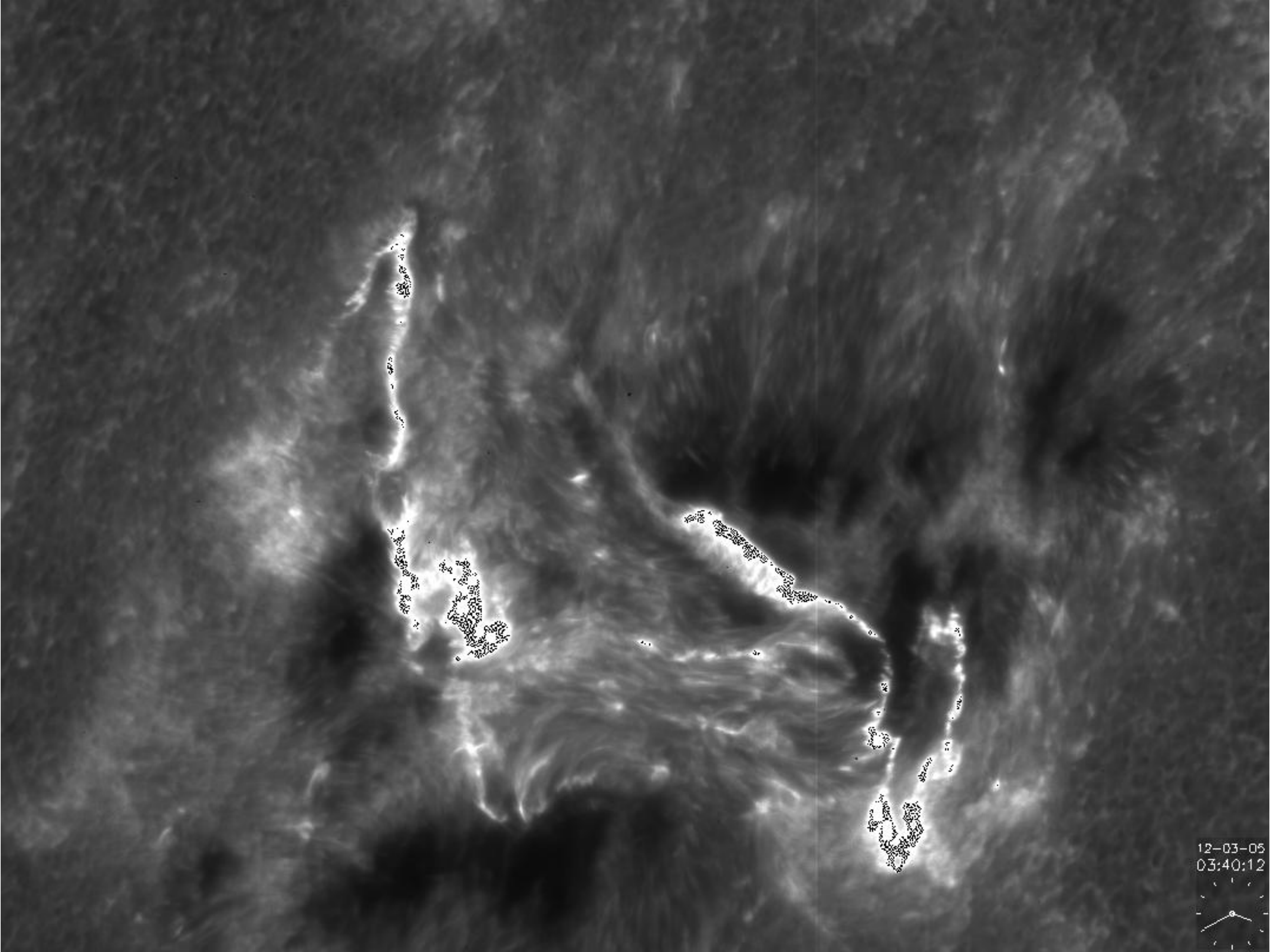
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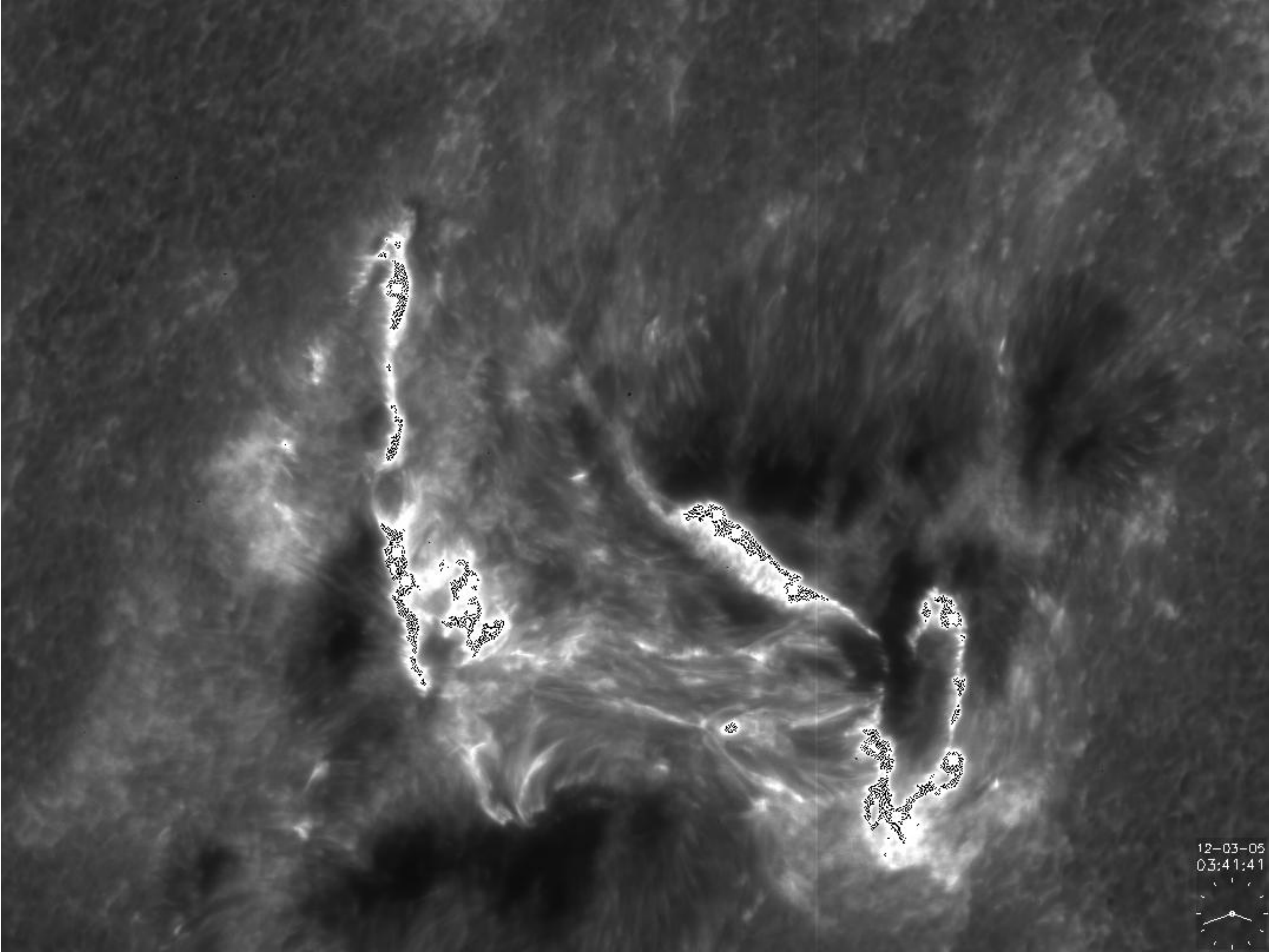
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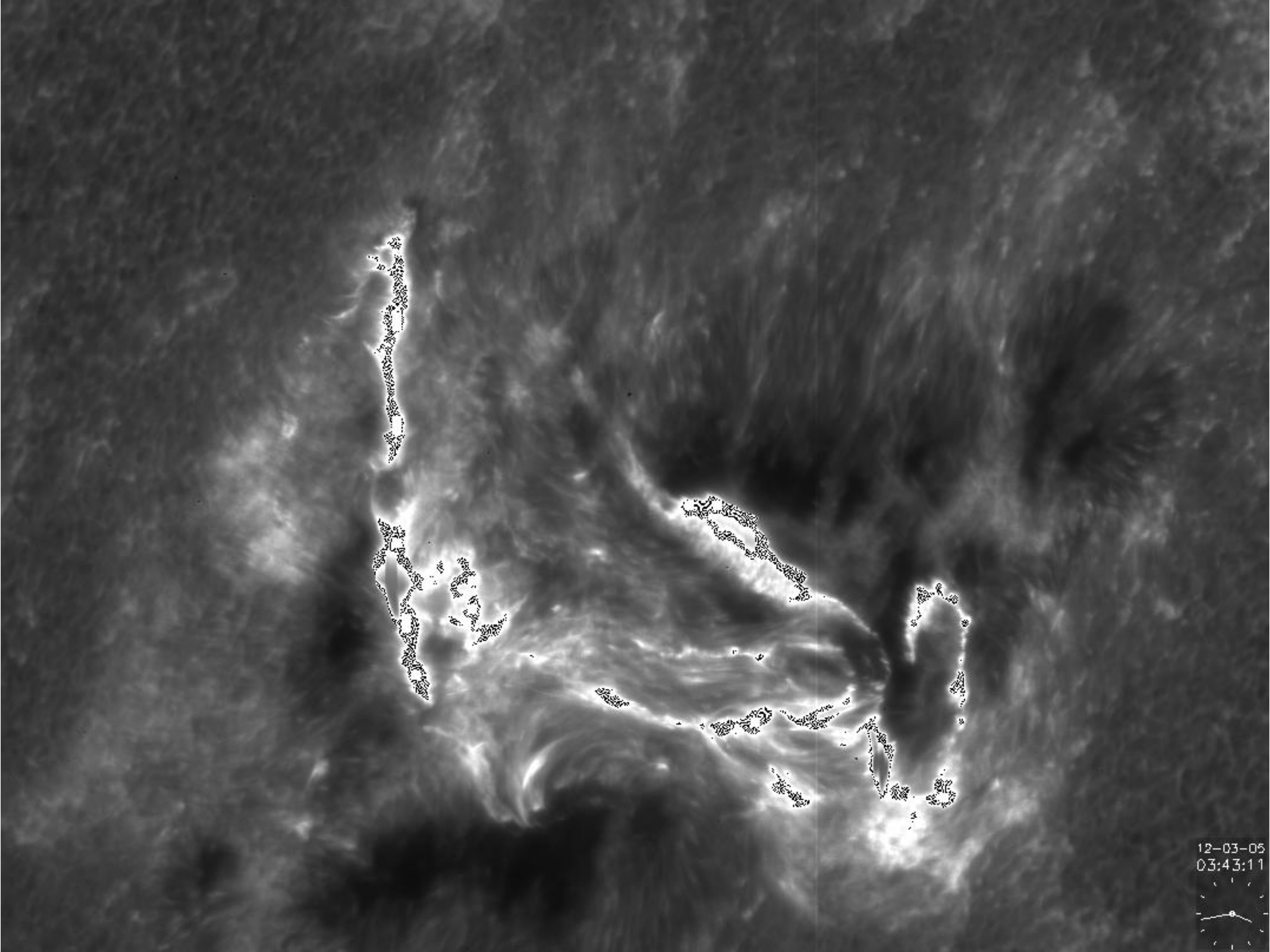
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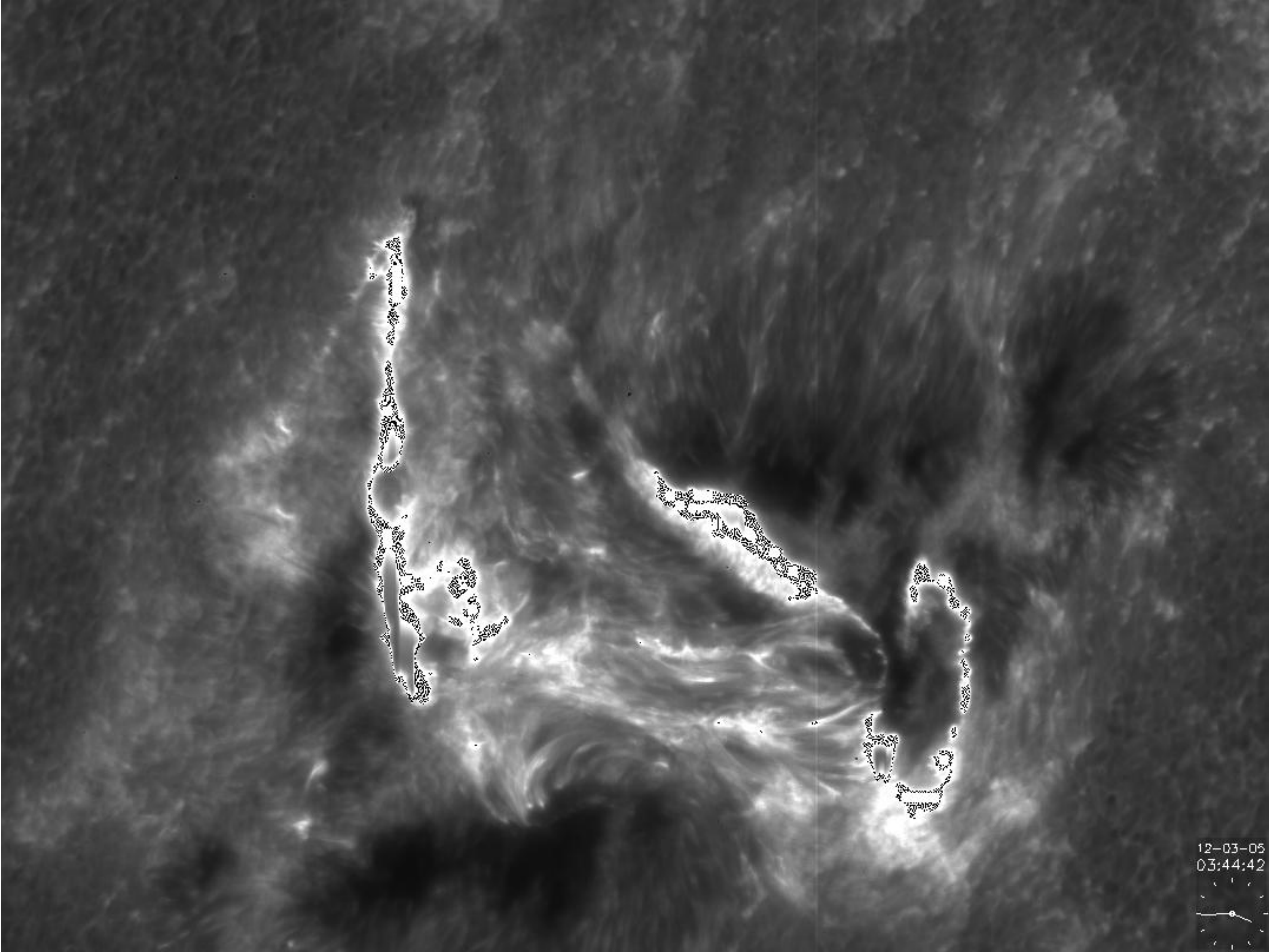

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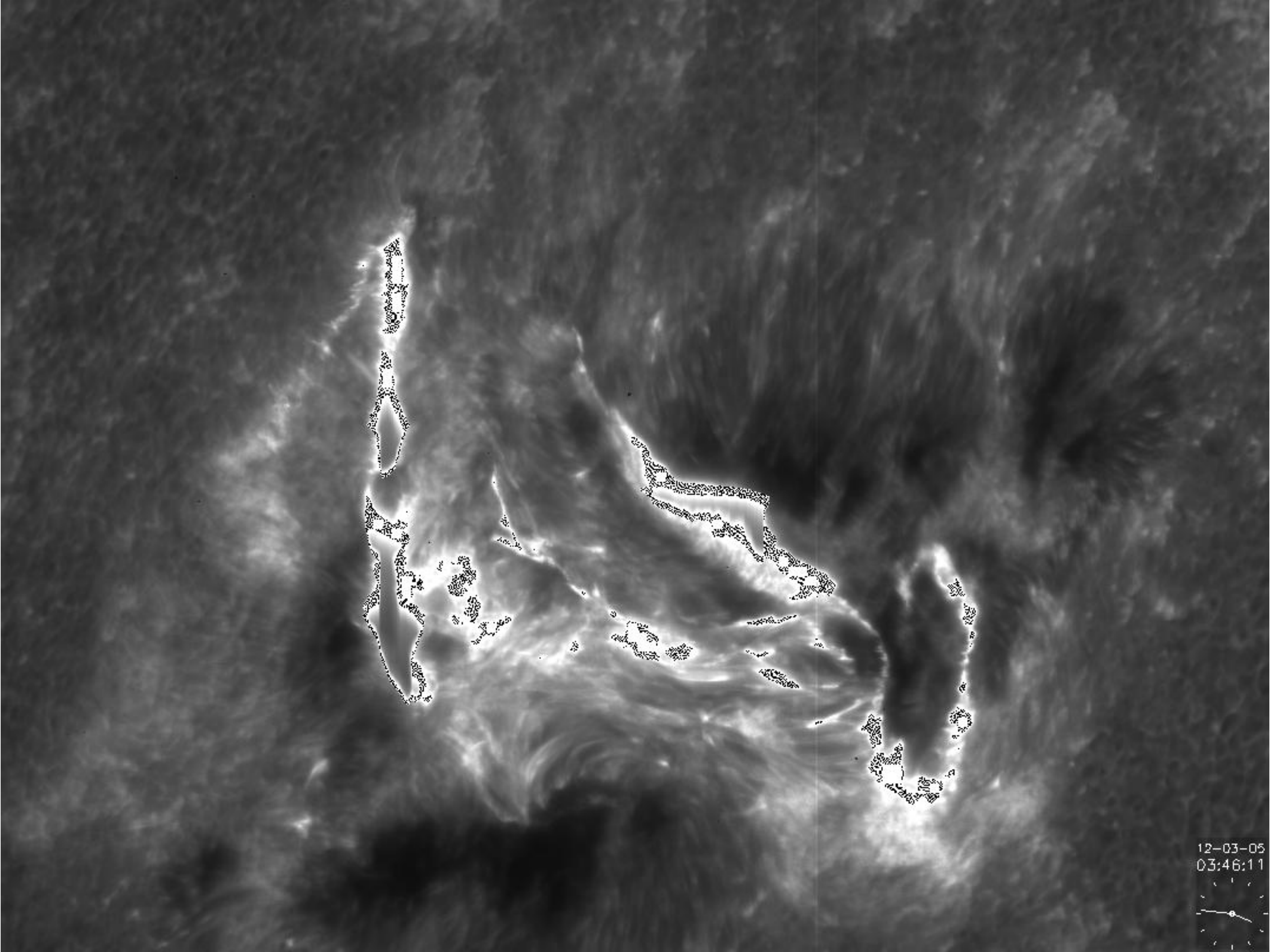
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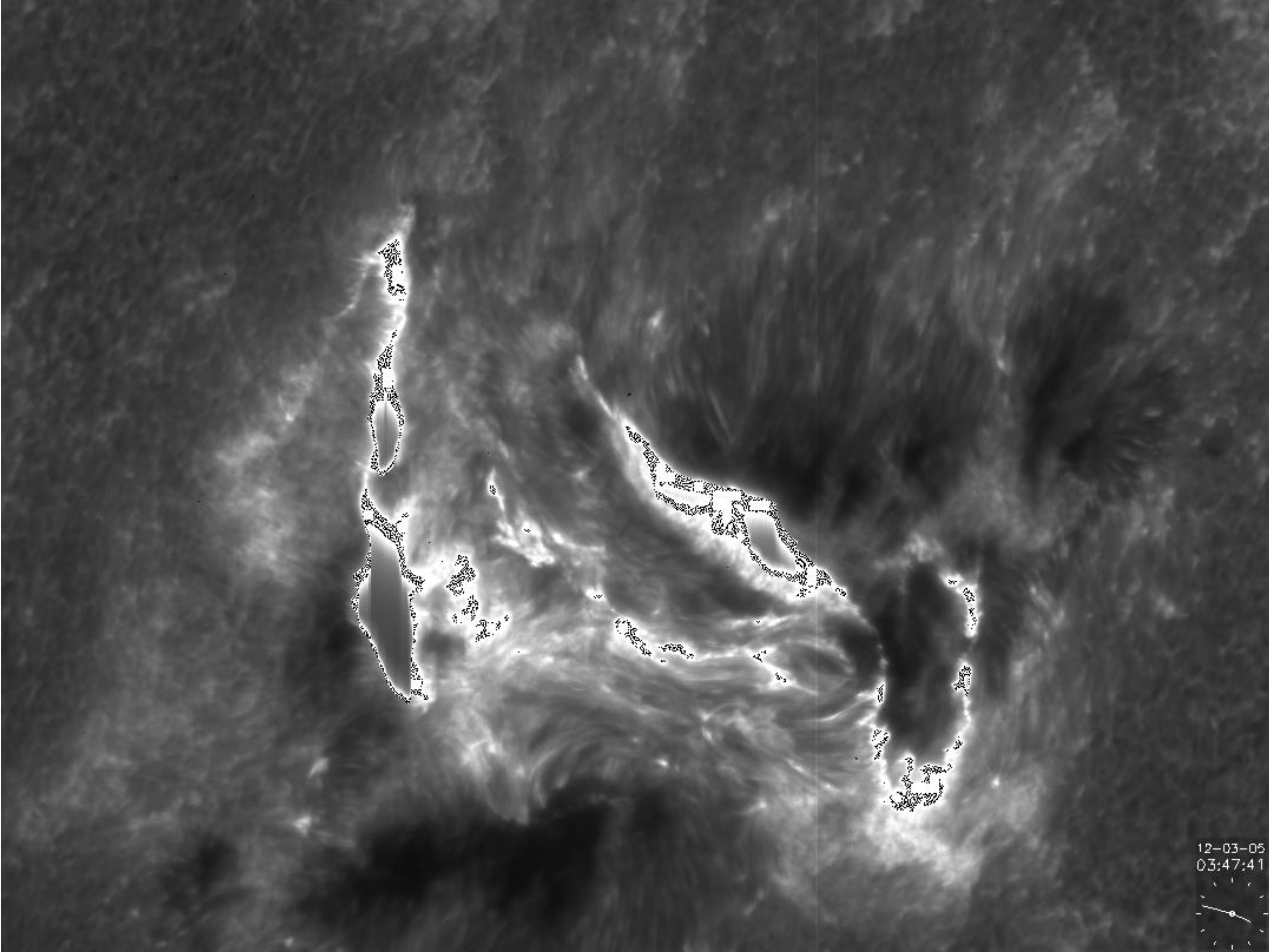
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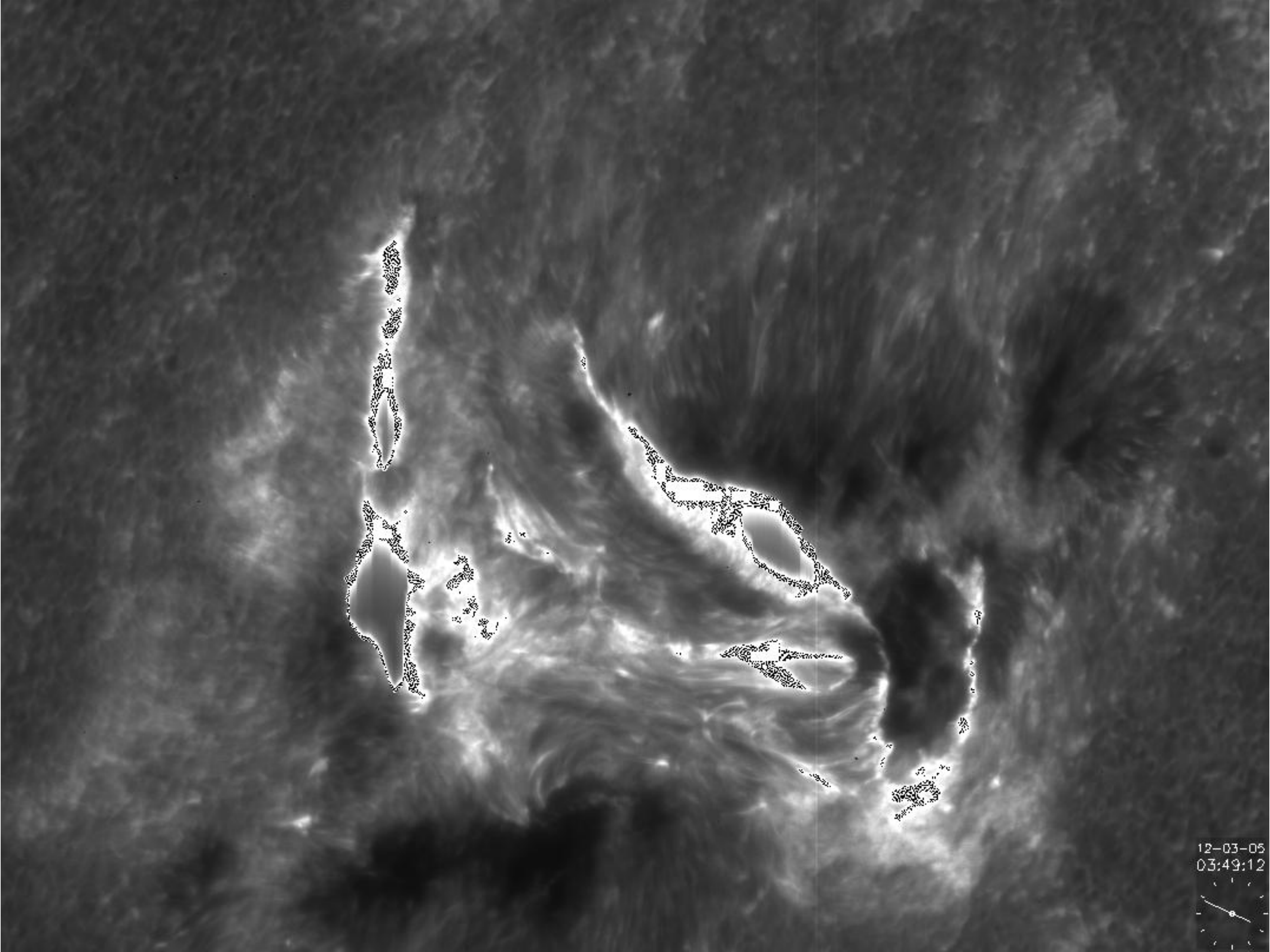
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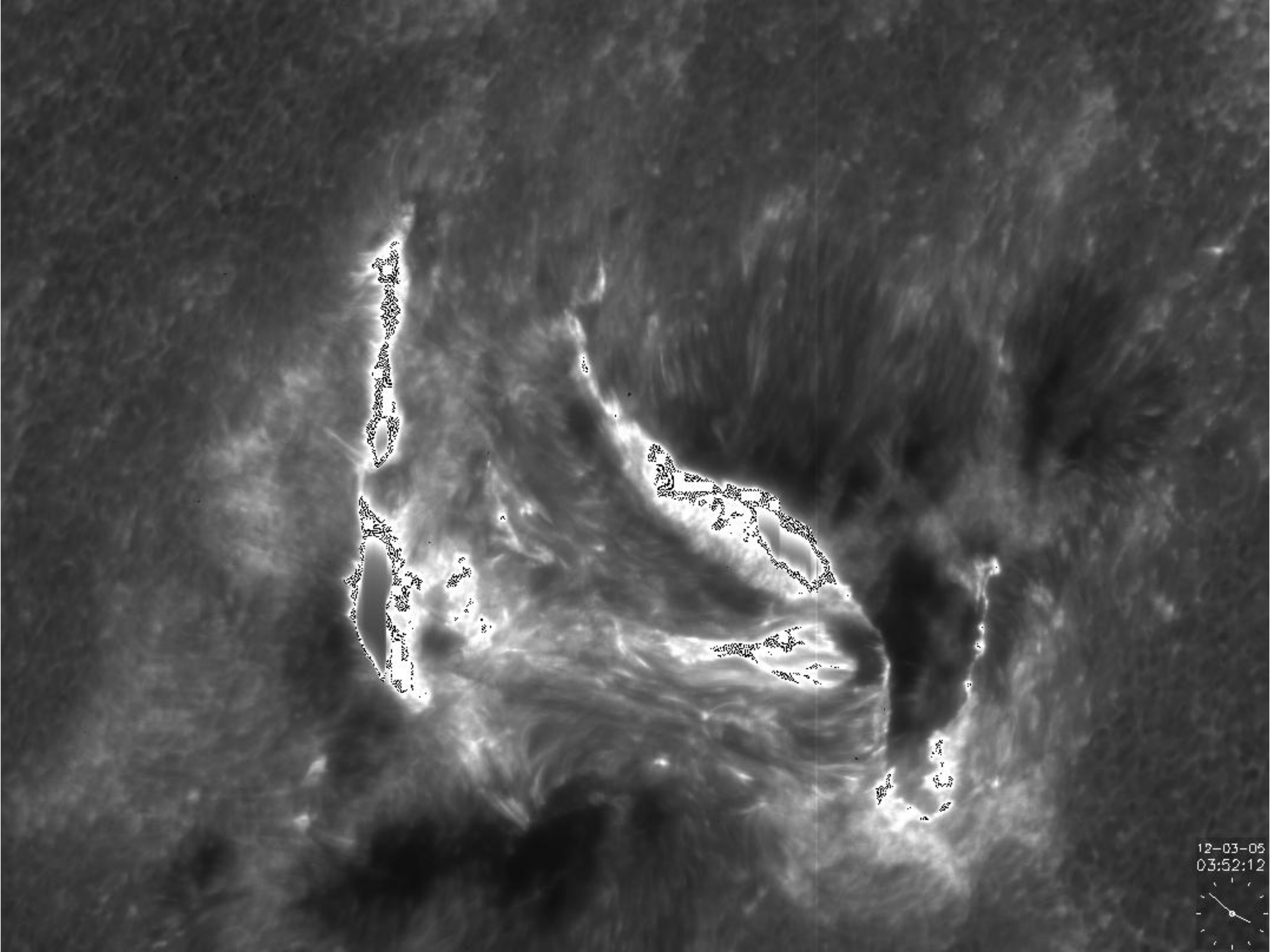
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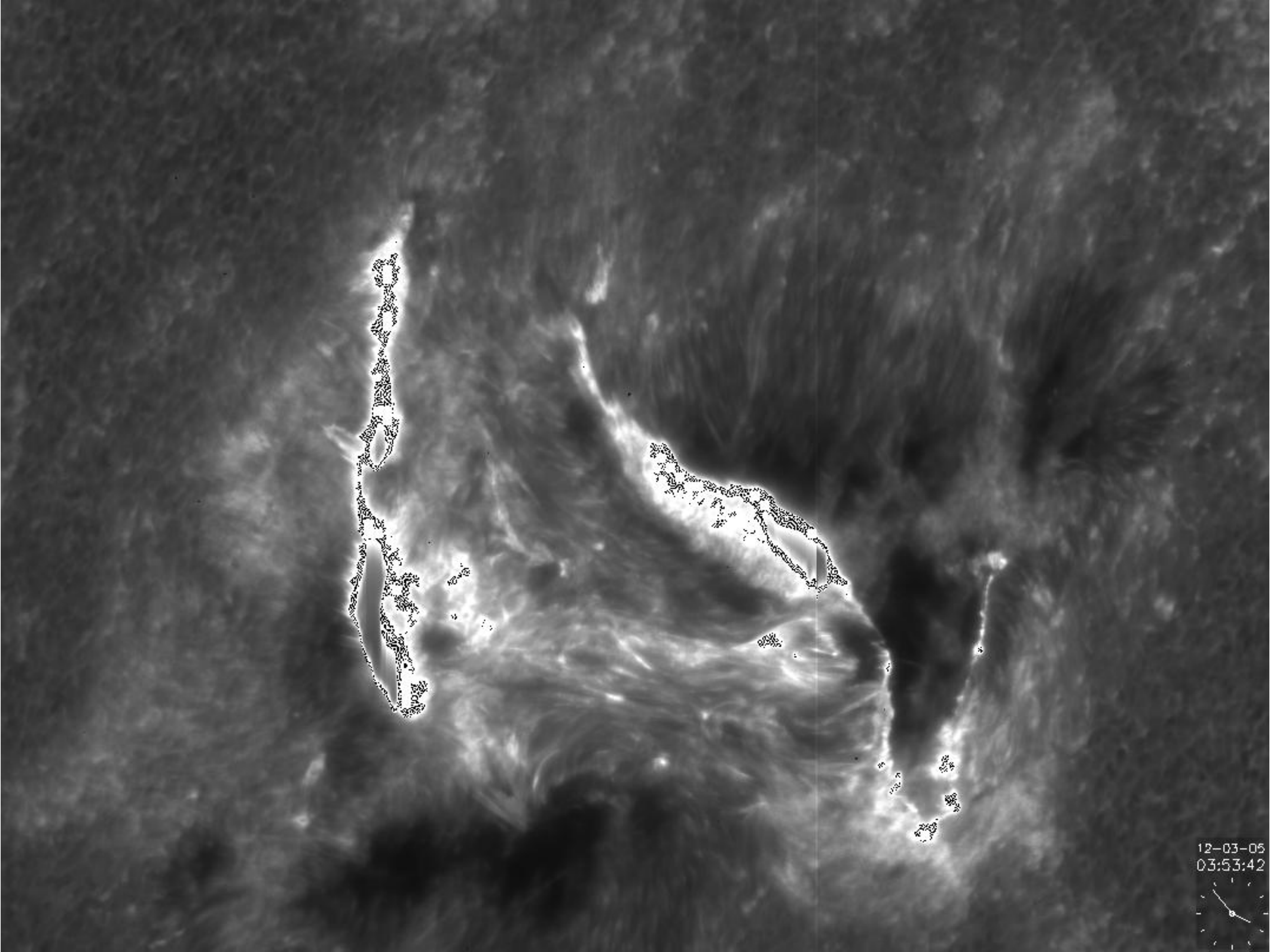
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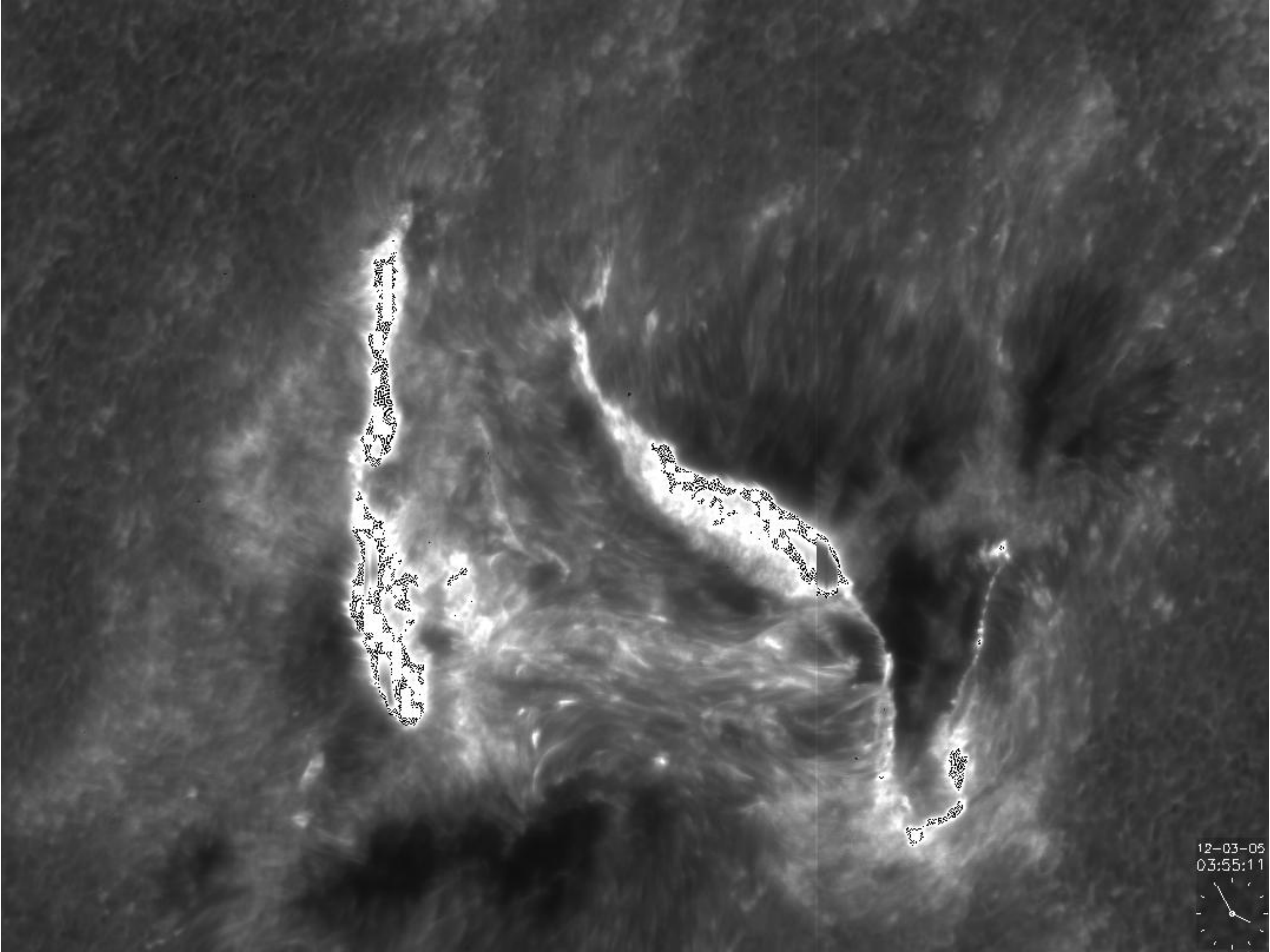
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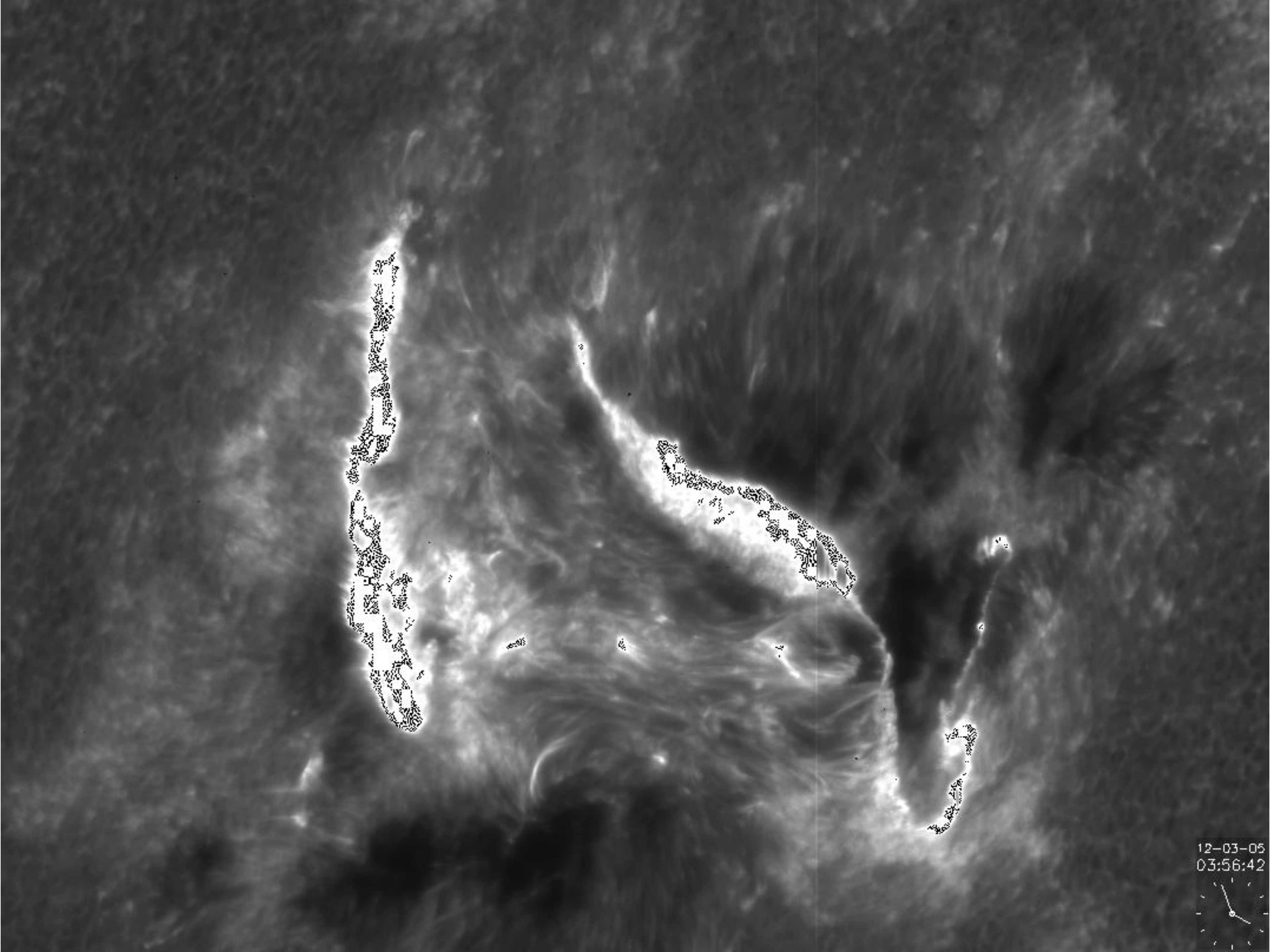
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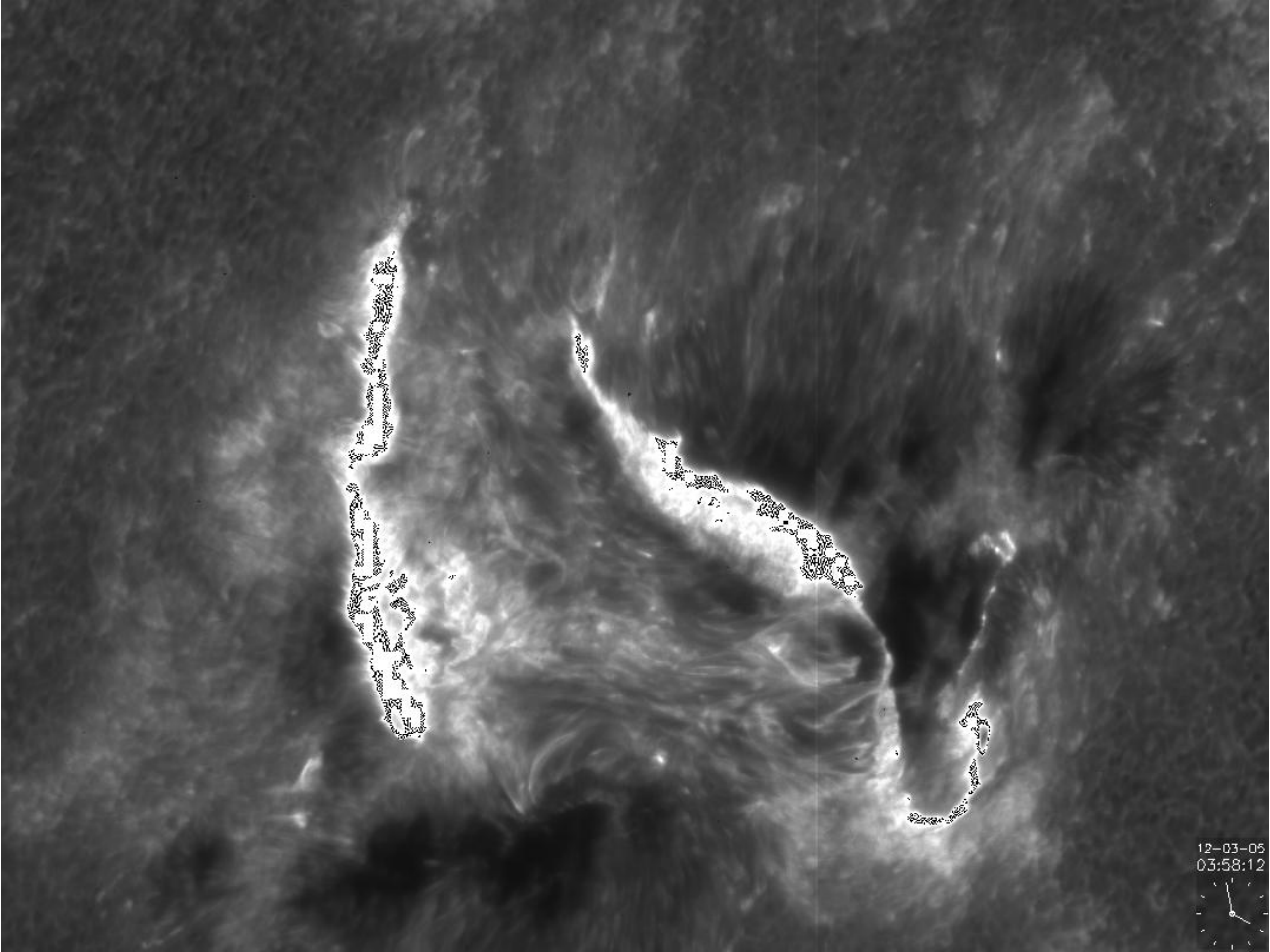
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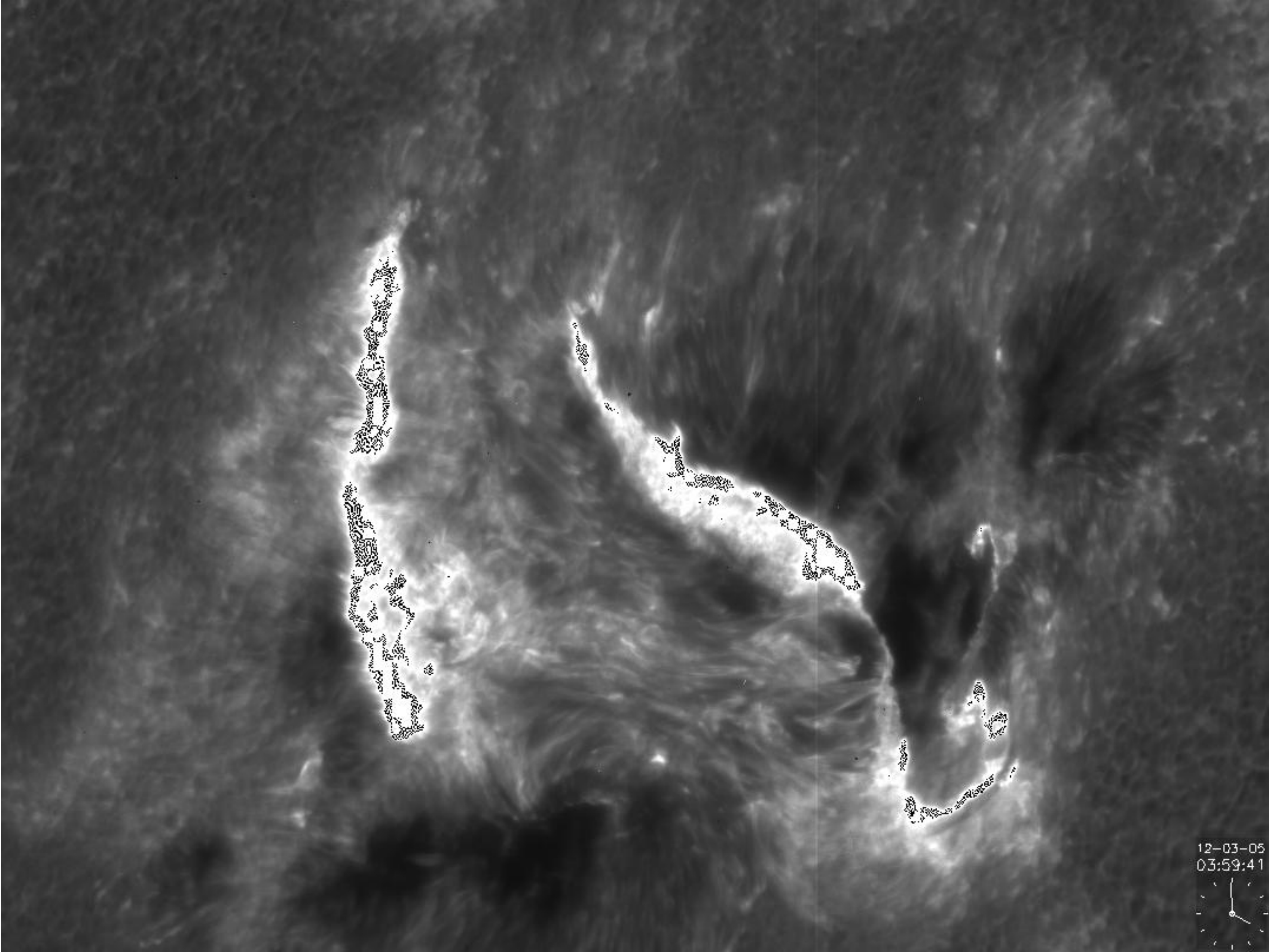
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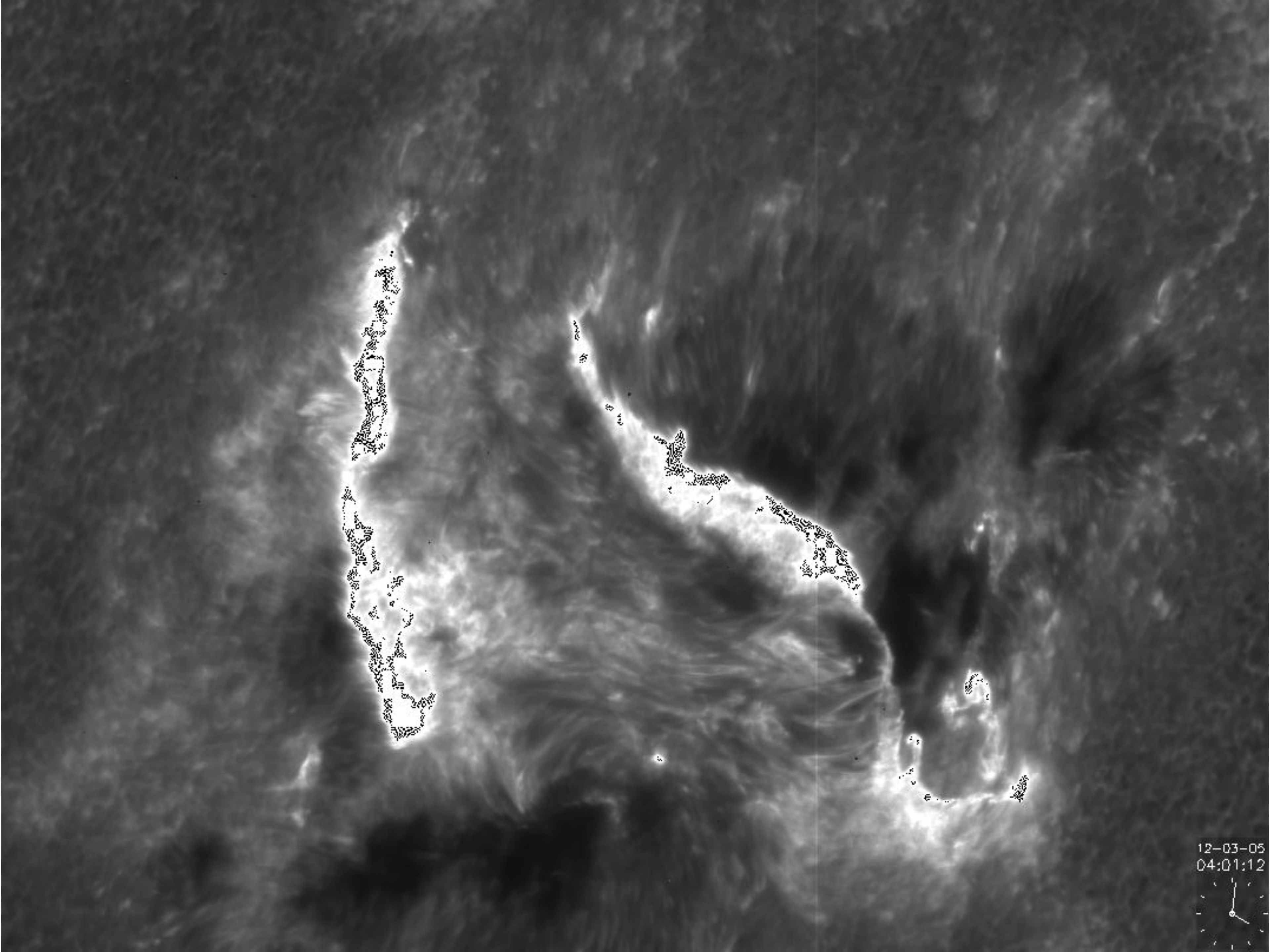
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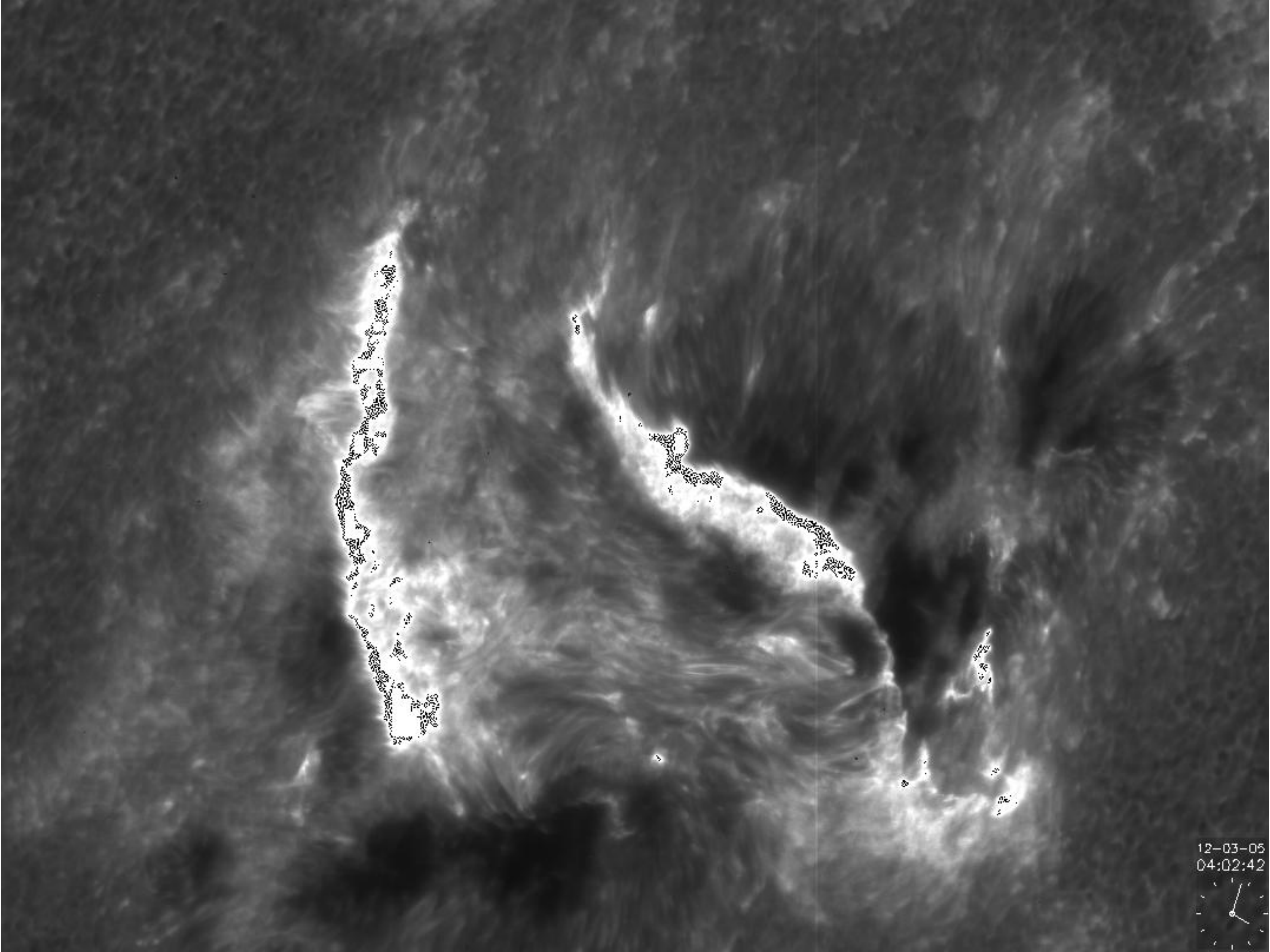
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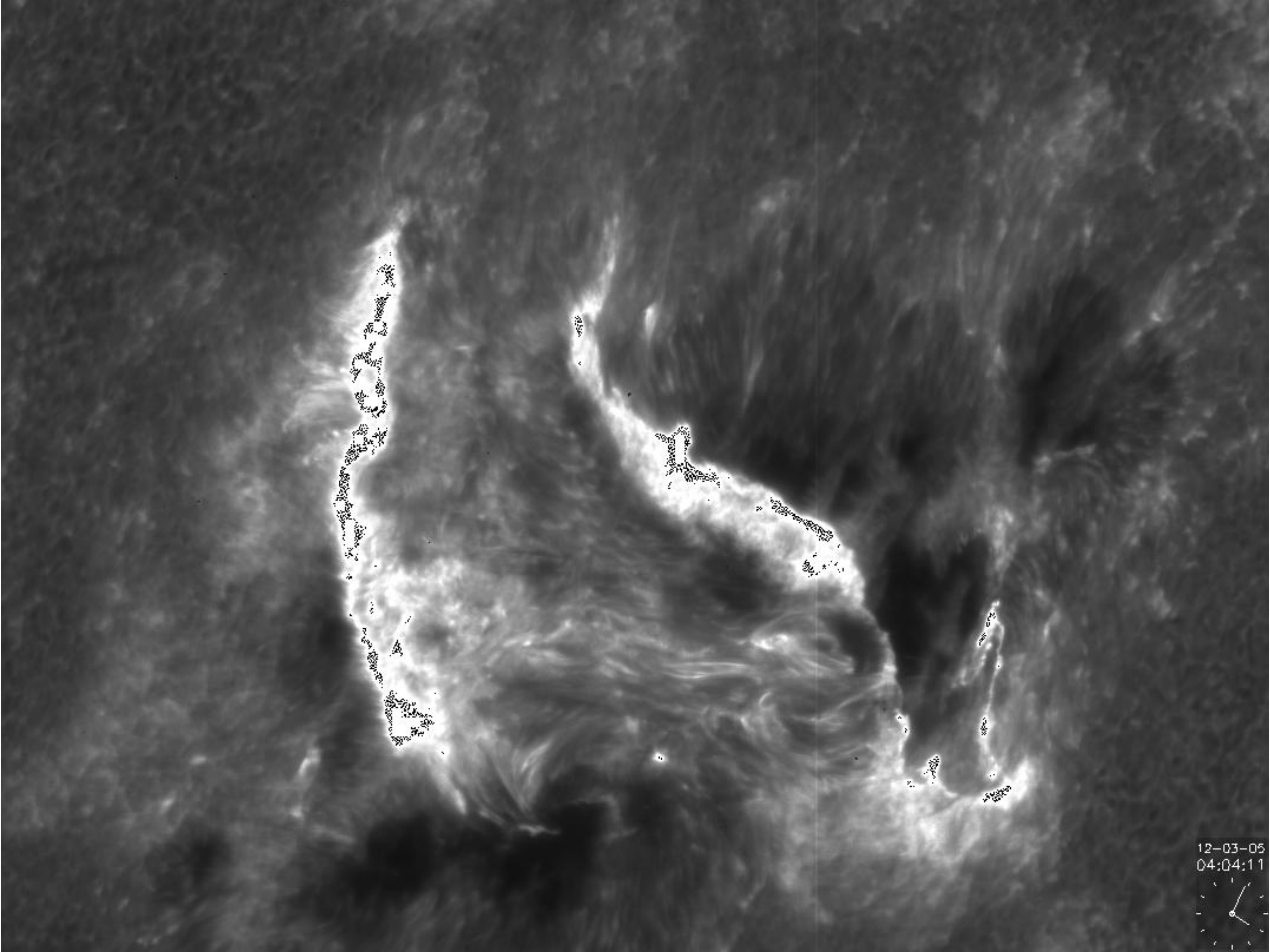
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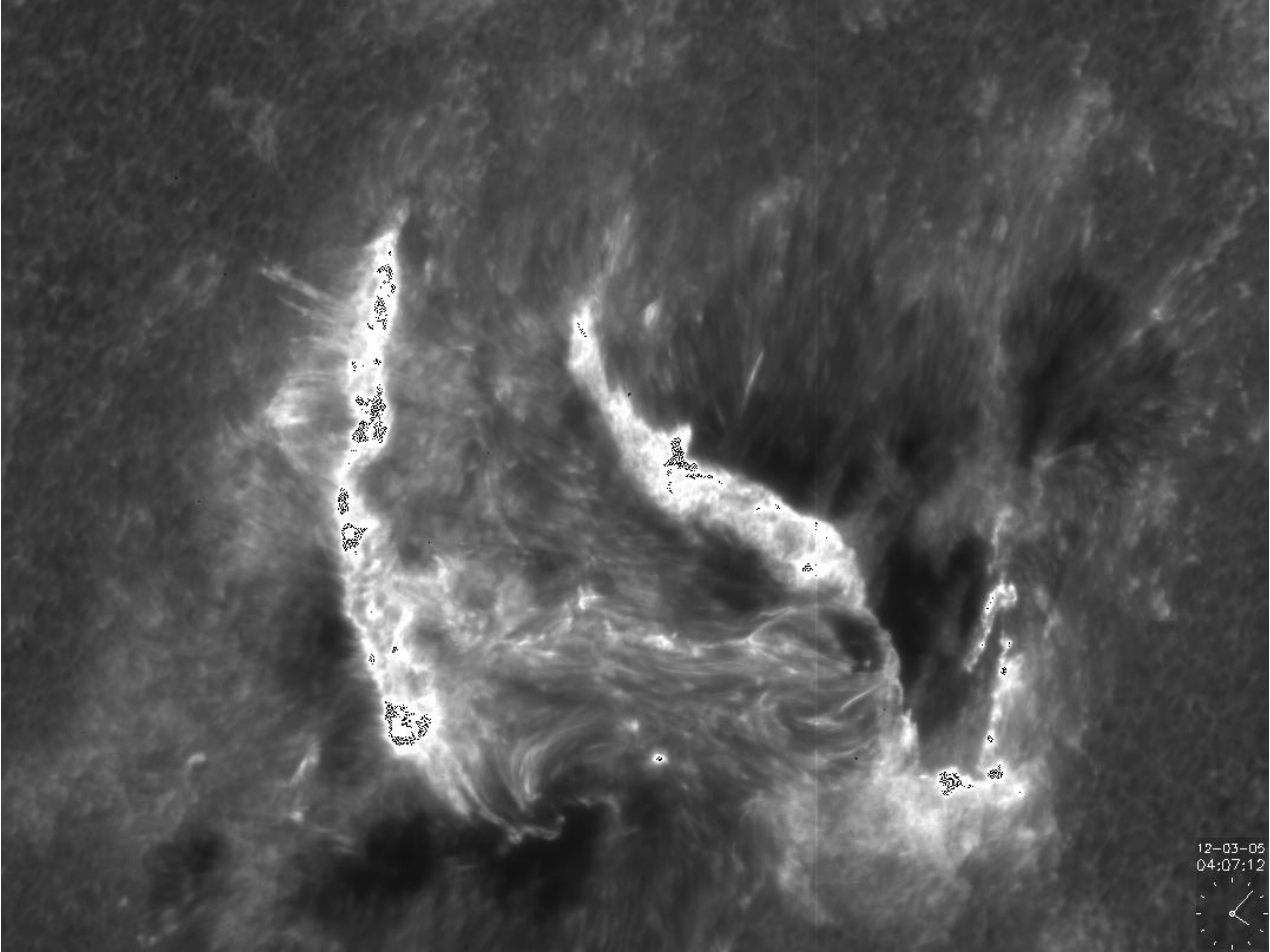
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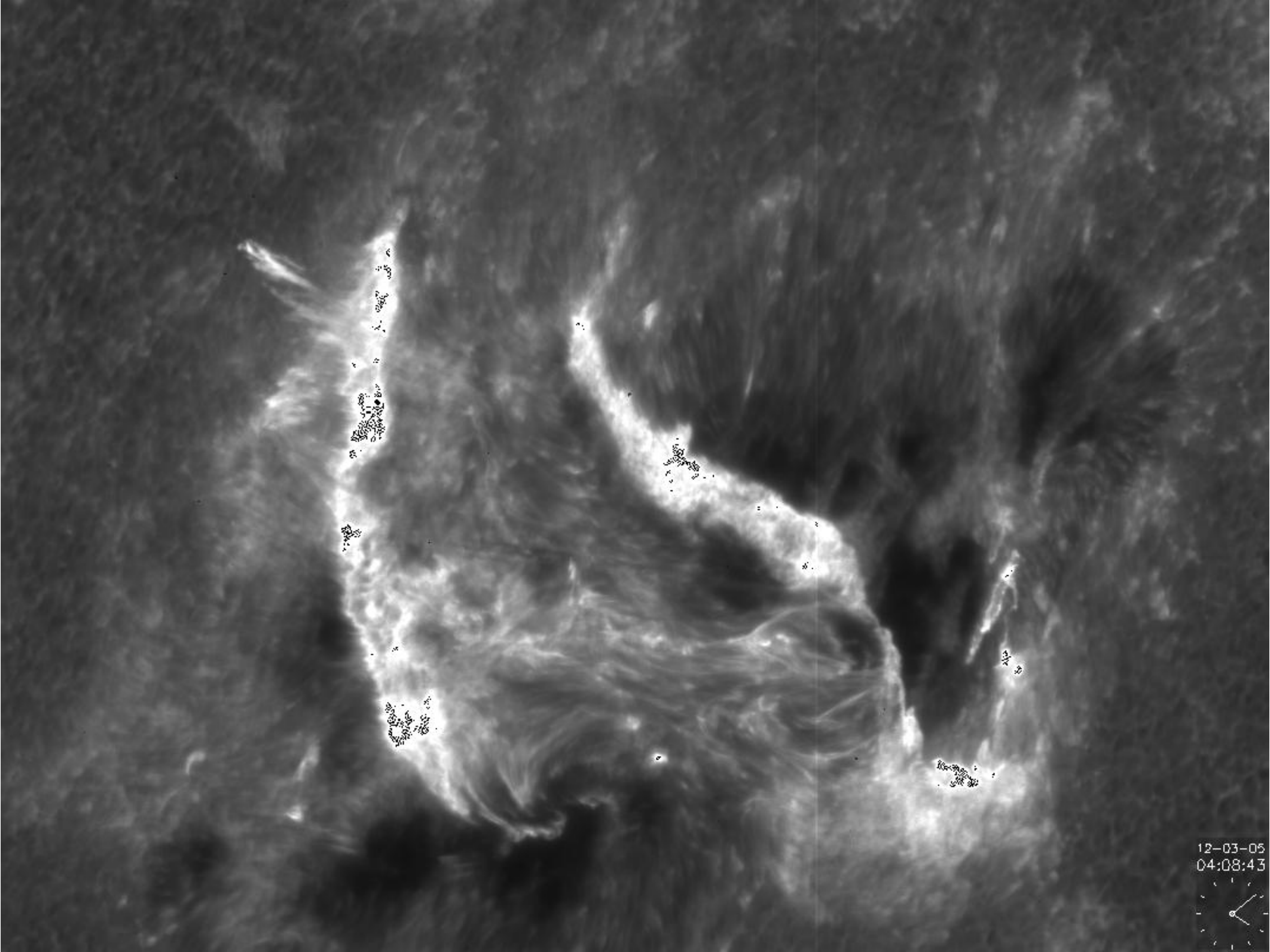
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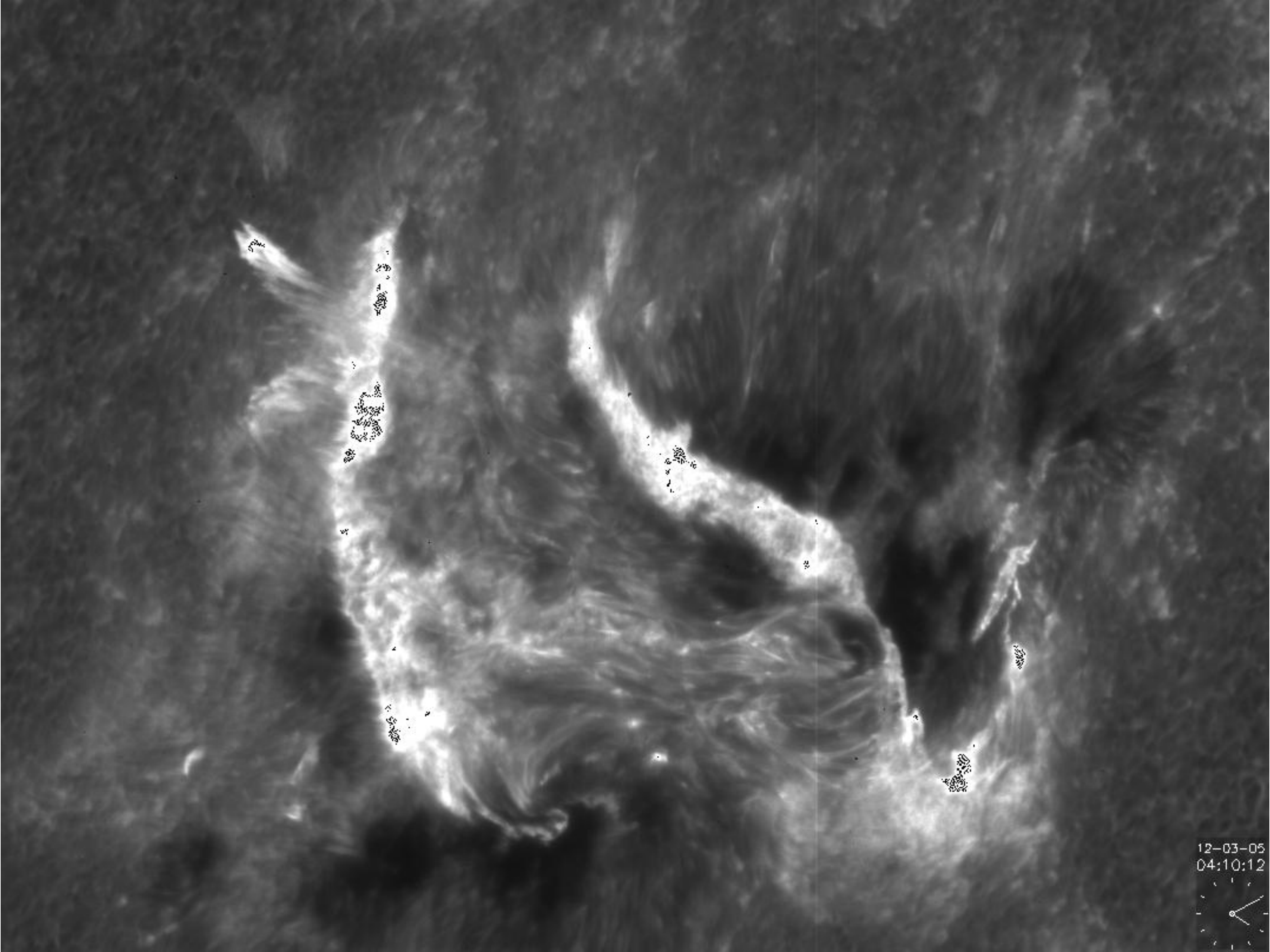
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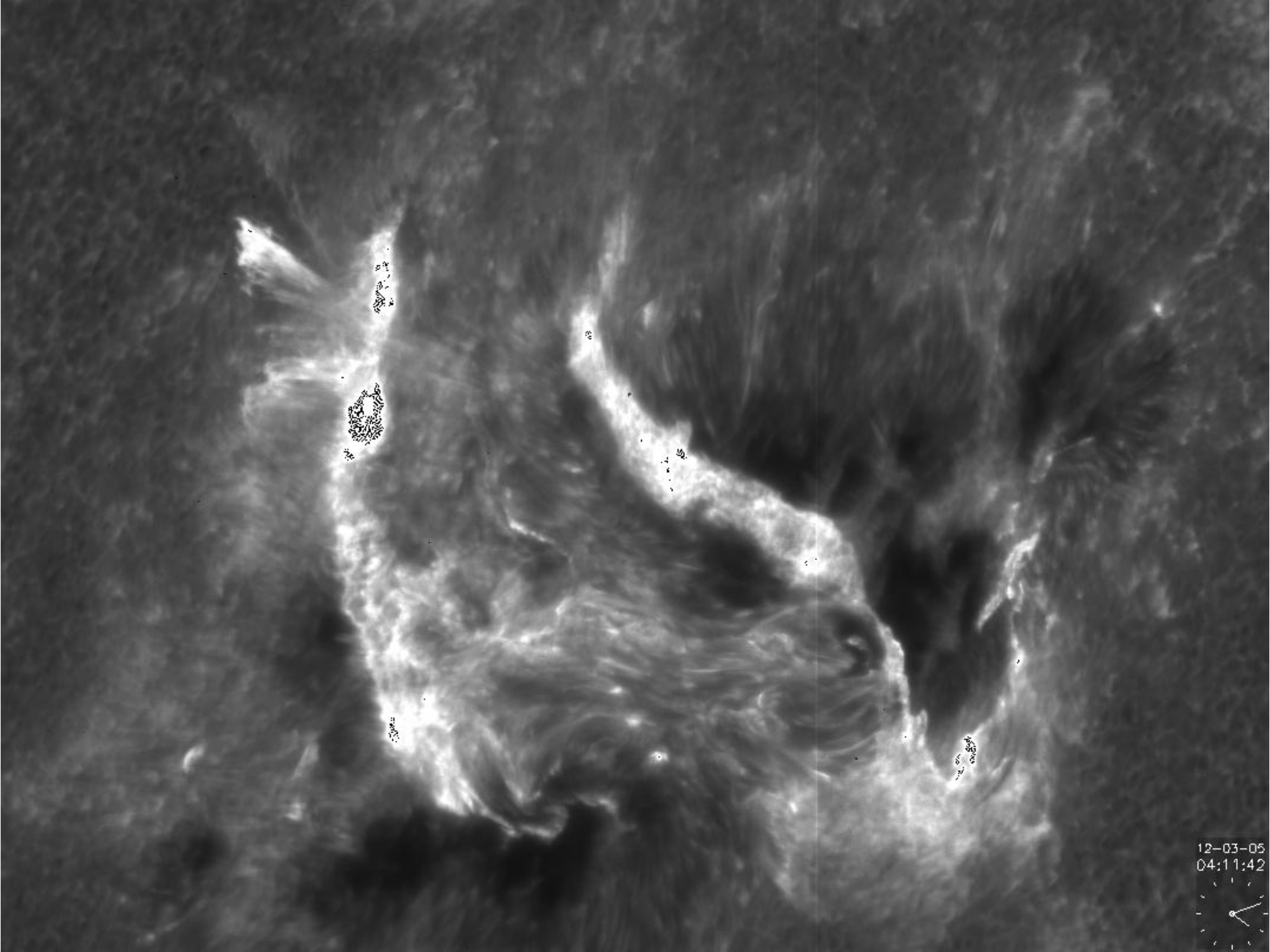
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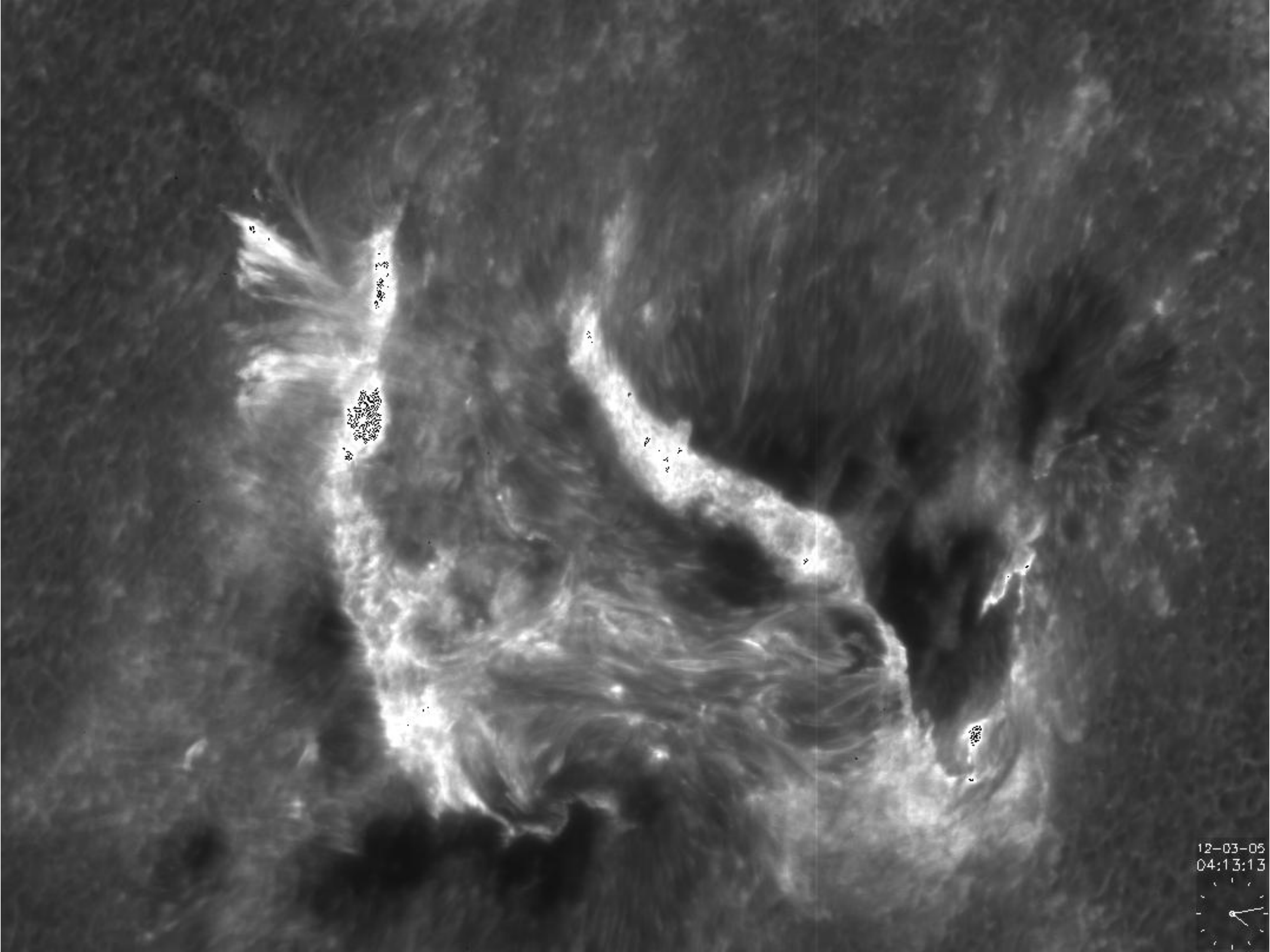
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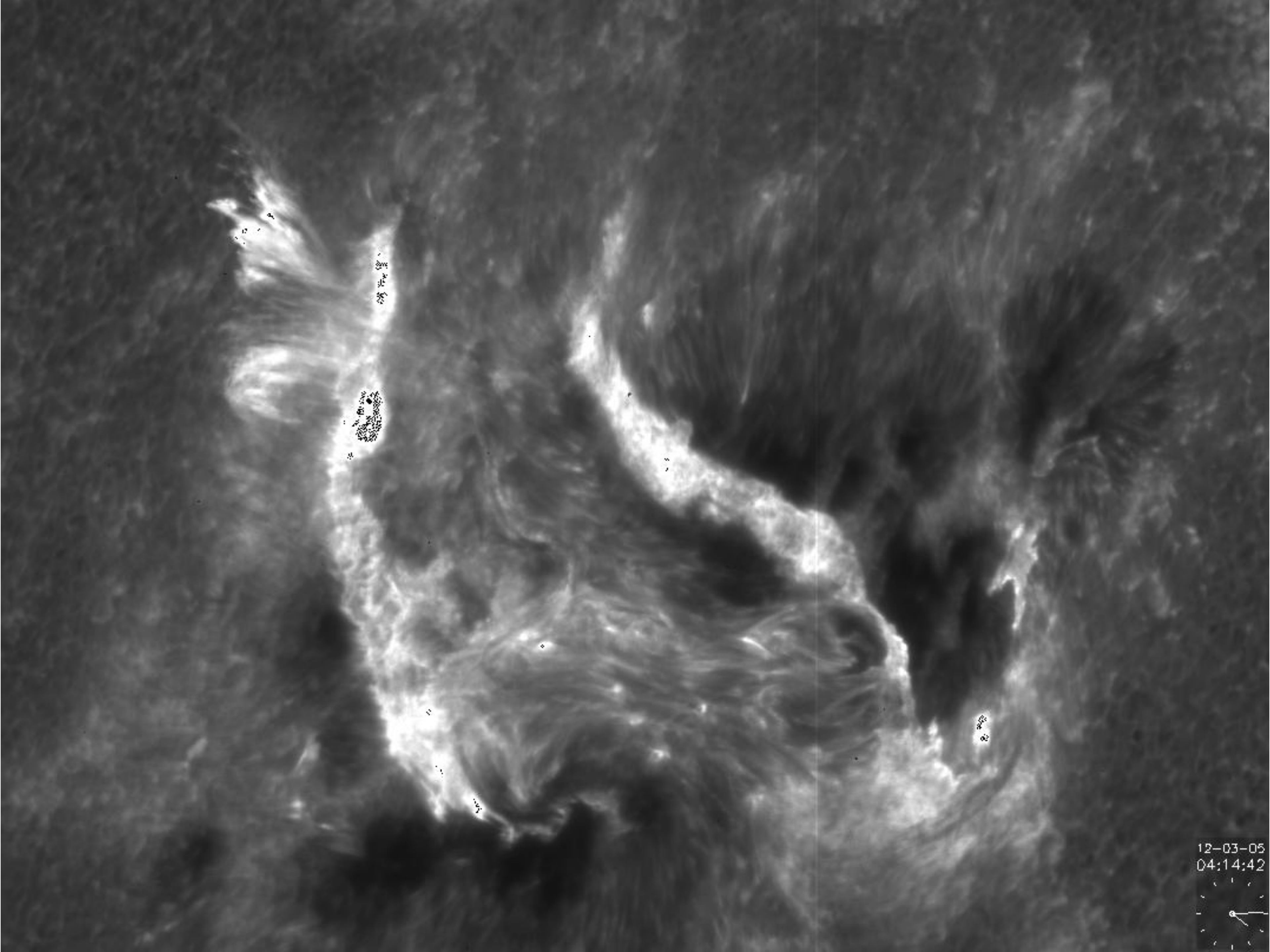
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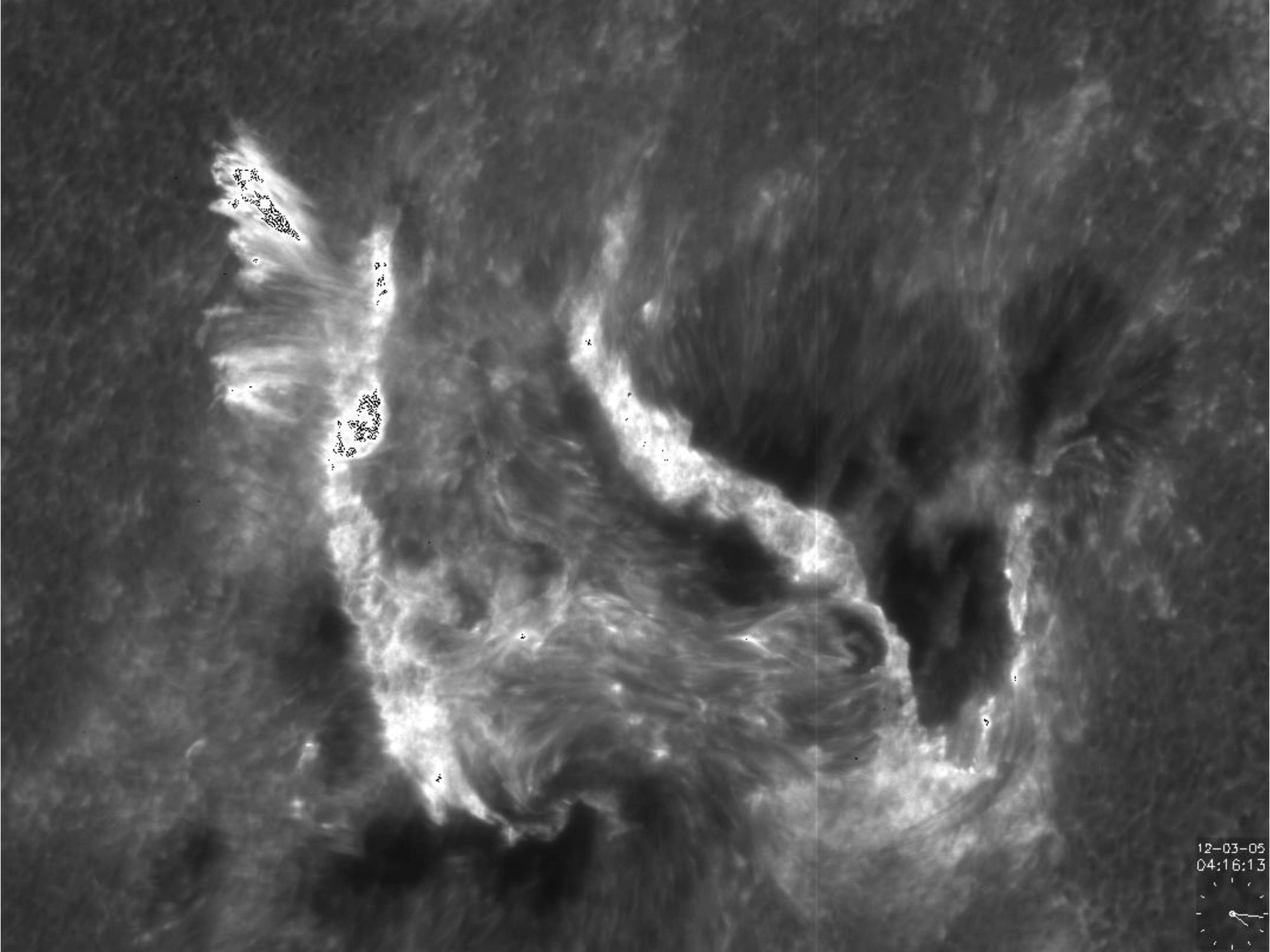
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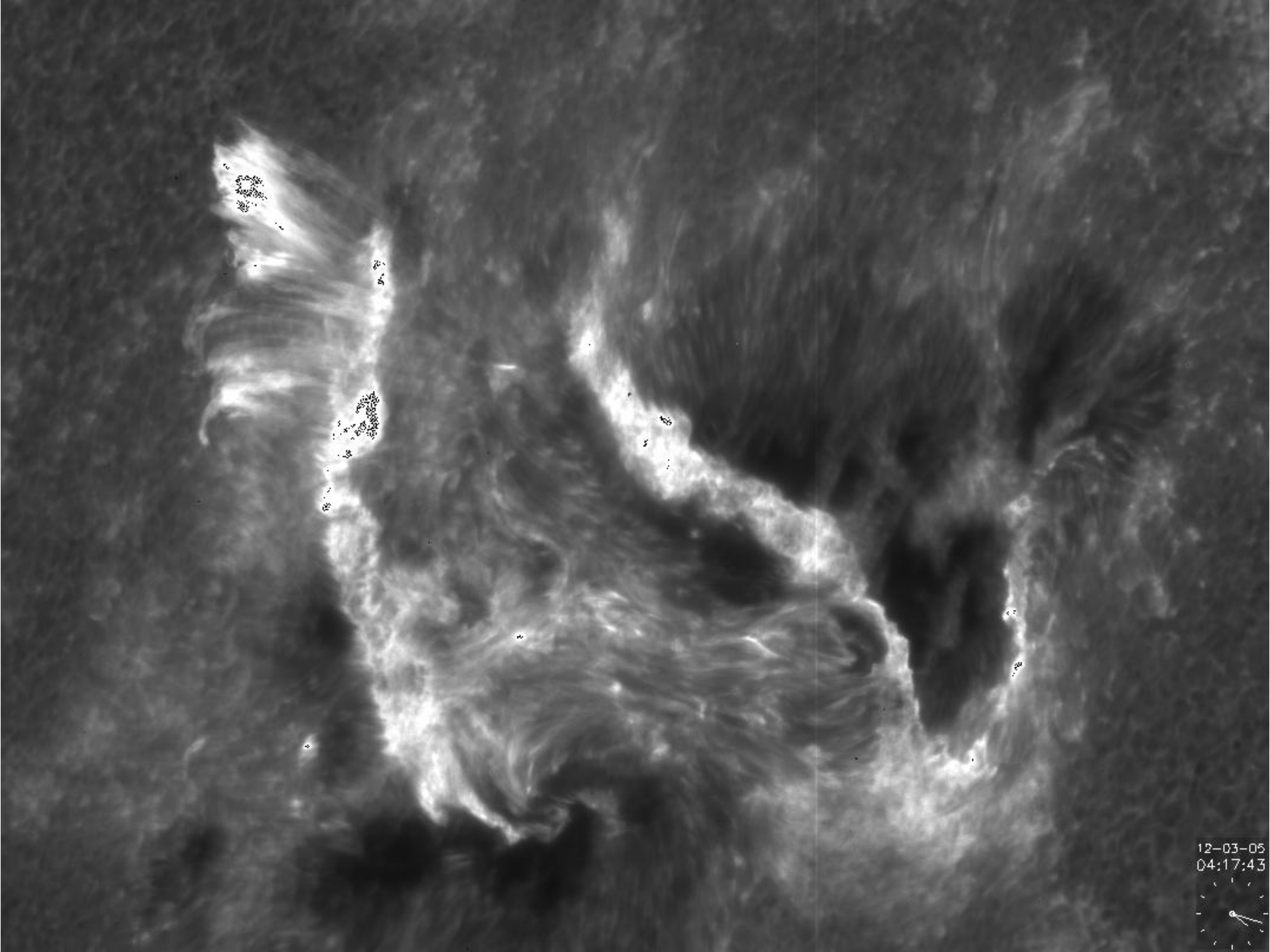
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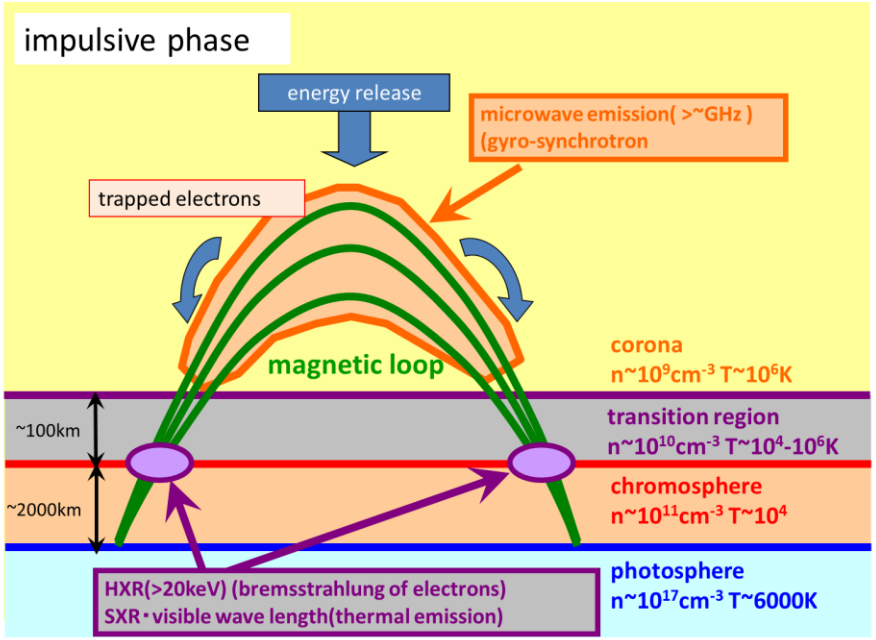
impulsive phase
energy release
microwave emission(>~GHz)
(gyro-synchrotron
trapped electrons
magnetic loop
corona
n~10^9cm^-3 T~10^6K
transition region
n~10^10cm^-3 T~10^4-10^6K
chromosphere
n~10^11cm^-3 T~10^4
photosphere
n~10^17cm^-3 T~6000K
~100km
~2000km
HXR(>20keV) (bremsstrahlung of electrons)
SXR・visible wave length(thermal emission)