# Chromospheric Magnetic Field Deduced from MHD Simulations

Mats Carlsson

Institute of Theoretical Astrophysics, University of Oslo

Pune, November 11 2014






ERC: Physics of the Solar Chromosphere

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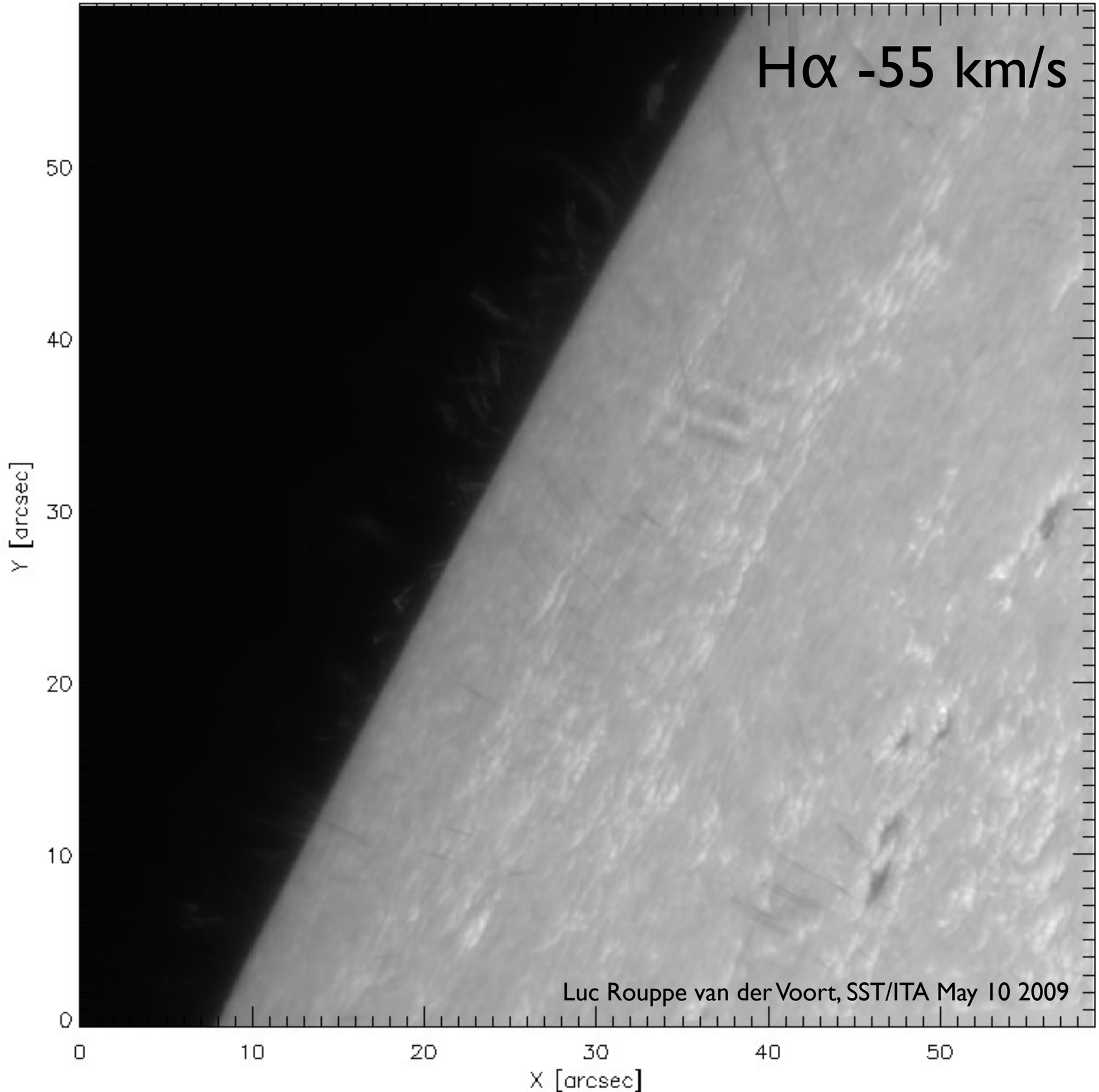
# Why is the chromosphere important?

- Coronal heating and mass balance
  - energy/mass go through chromosphere
  - chromosphere needs 10-100 times more energy
- $P_g/P_B = 1$
  - from forced B to force-free
  - wave mode conversion layer
- Ion-neutral effects
  - ionization degree $10^{-4}$ - 1
  - non-magnetized - magnetized

# Why is understanding the chromosphere difficult?

- Lack of diagnostics
  - from ground: (Na D, Mg b), H-alpha, Ca II, He 10830
  - from space: Mg II h & k, Ly α, UV-lines
- Weak signal in Stokes Q/U
- Difficult diagnostics
  - optically thick, NLTE, Hanle+Zeeman
- Complex physics
  - NLTE, many scale-heights, small & large spatial scales


Hα -55 km/s
Luc Rouppe van der Voort, SST/ITA May 10 2009
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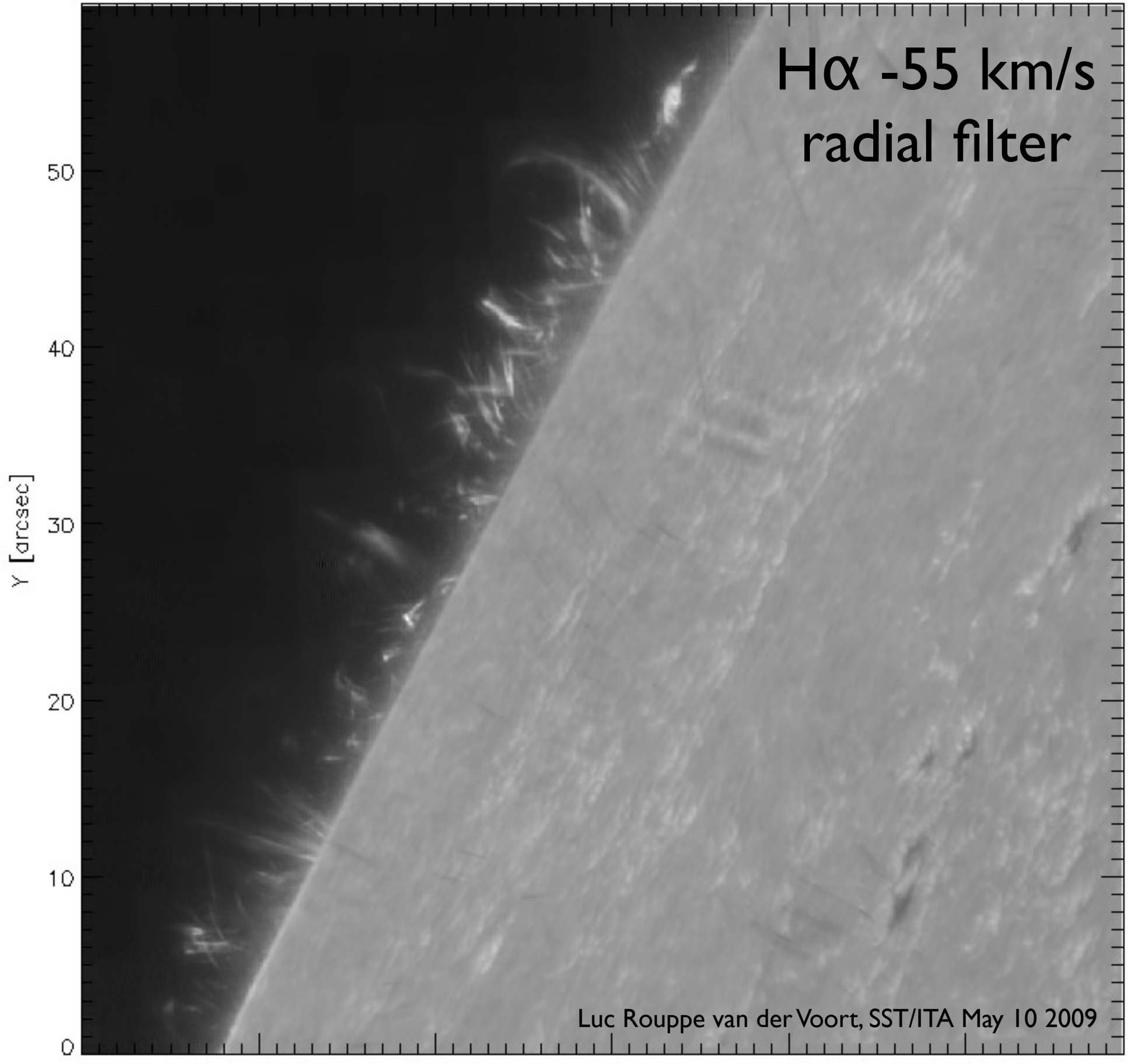
20
30
40
50


Hα -55 km/s
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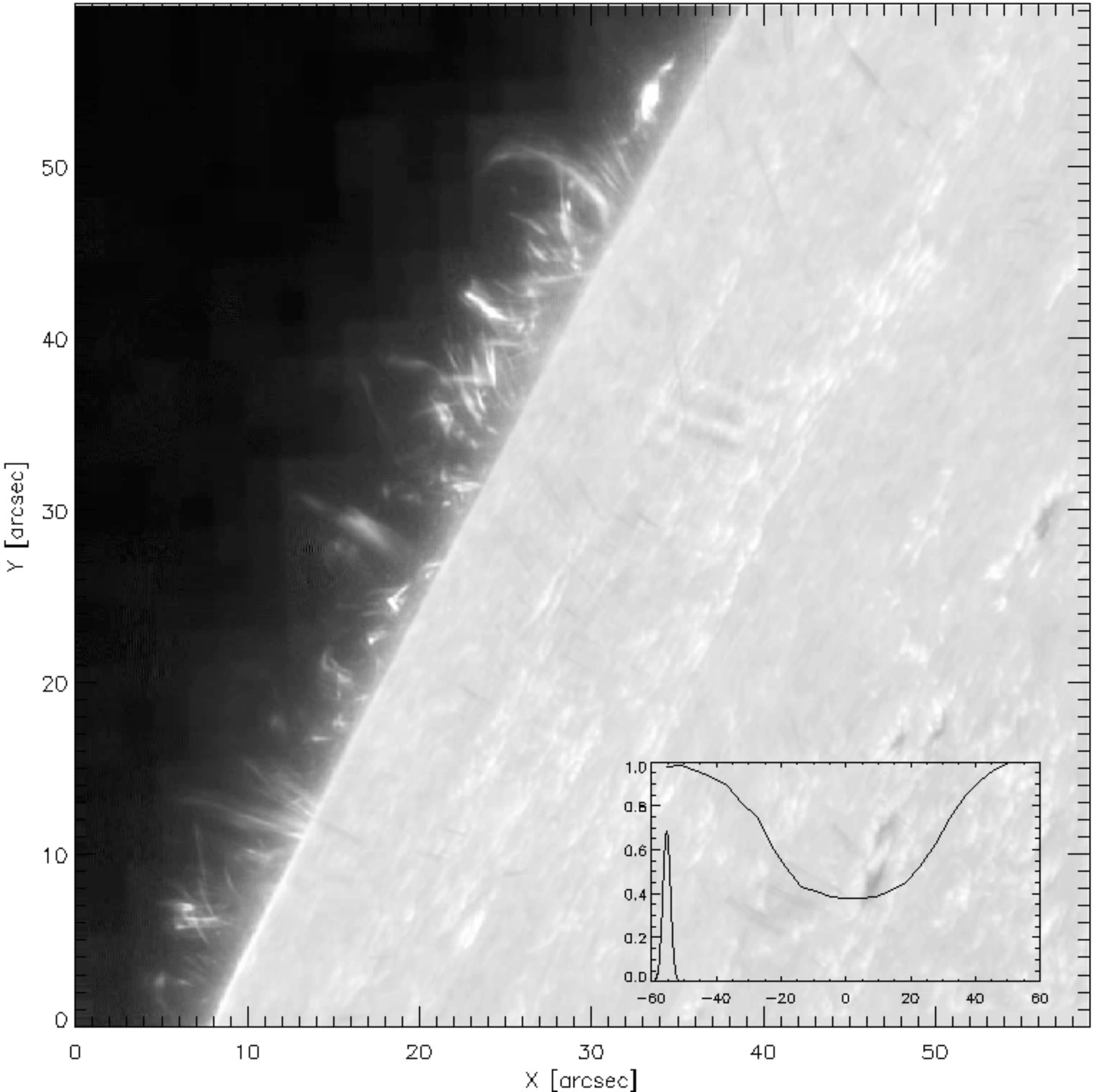
Luc Rouppe van der Voort, SST/ITA May 10 2009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−20
0
20
40
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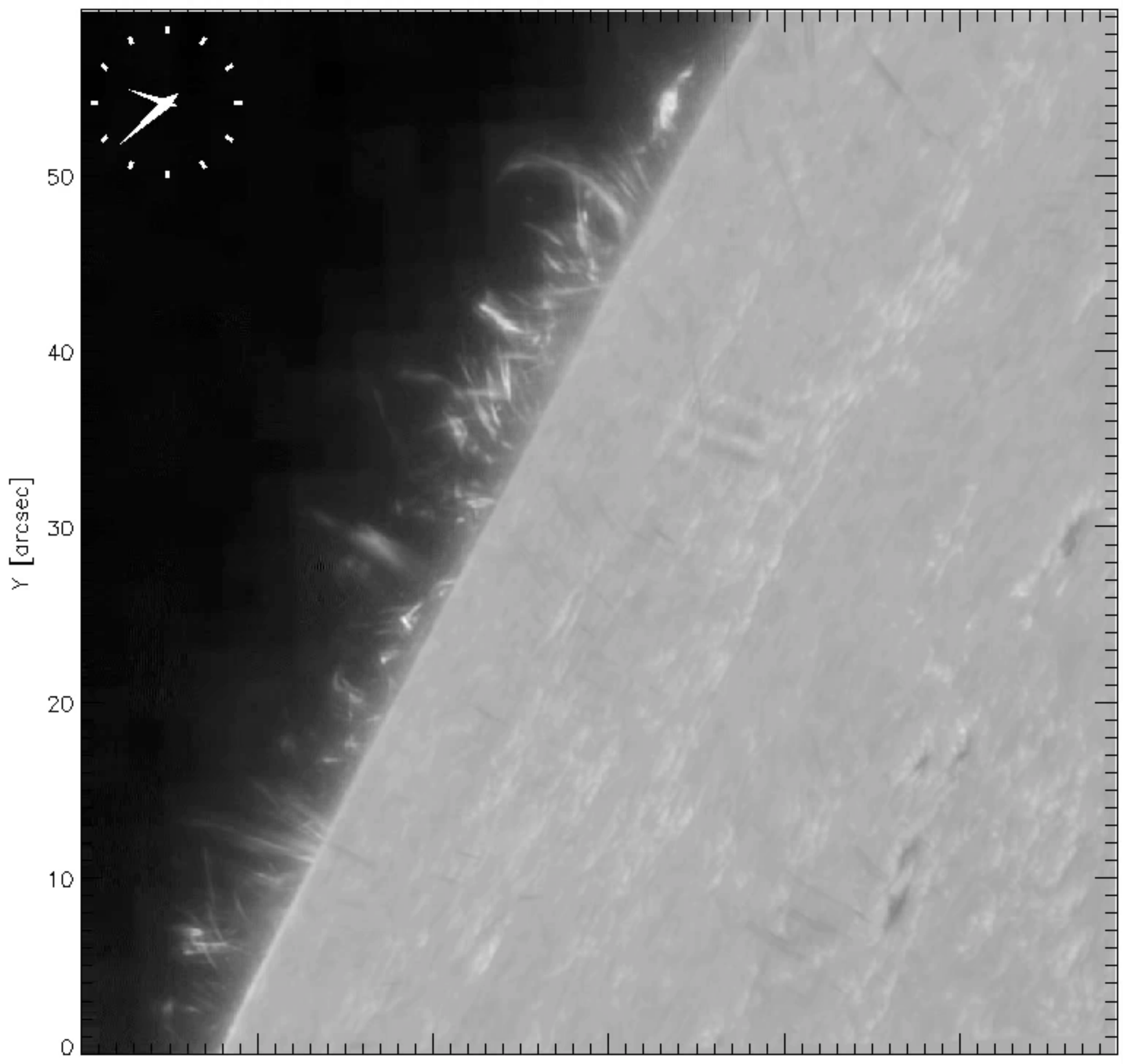
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30
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50
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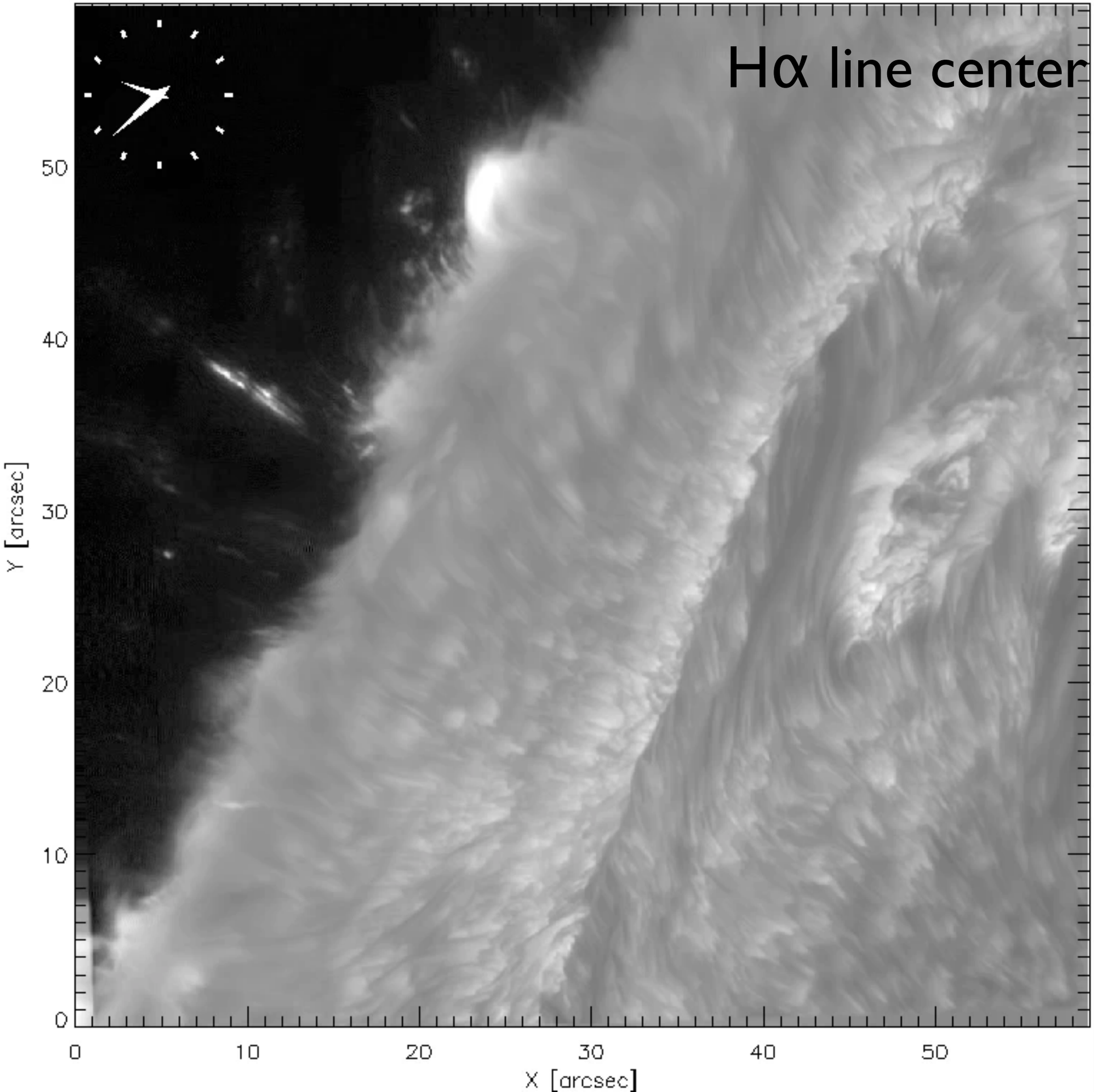
Hα line center
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10
20
30
40
50
X [arcsec]
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10
20
30
40
50

# BIFROST

Hansteen 2004, Hansteen, Carlsson, Gudiksen 2007, Sykora, Hansteen, Carlsson 2008, Gudiksen et al 2011

- 6th order scheme, with "artificial viscosity/diffusion"
- Open vertical boundaries, horizontally periodic
- Possible to introduce field through bottom boundary

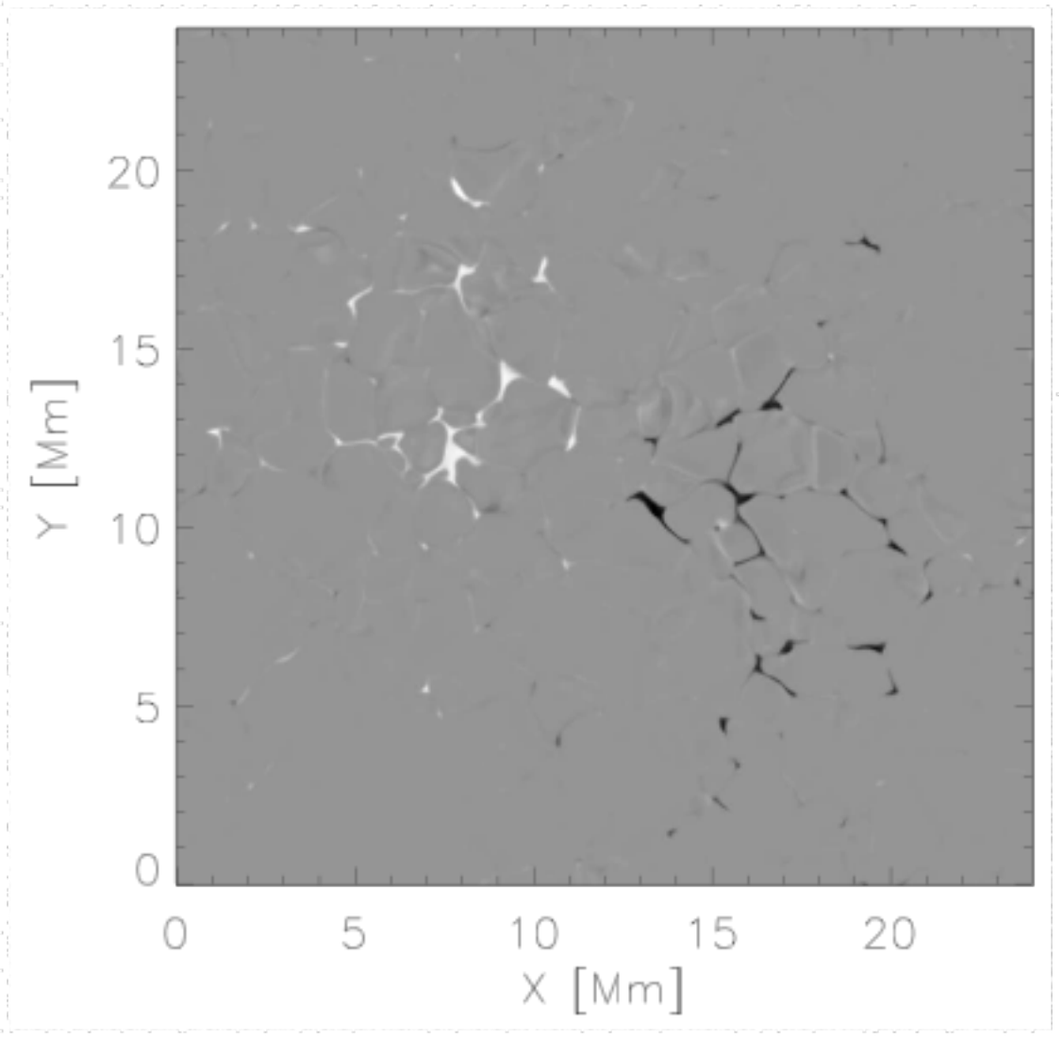
- "Realistic" EOS
- Detailed radiative transfer along 24 rays
  - Multi group opacities (4 bins) with scattering
- NLTE losses in the chromosphere, optically thin in corona

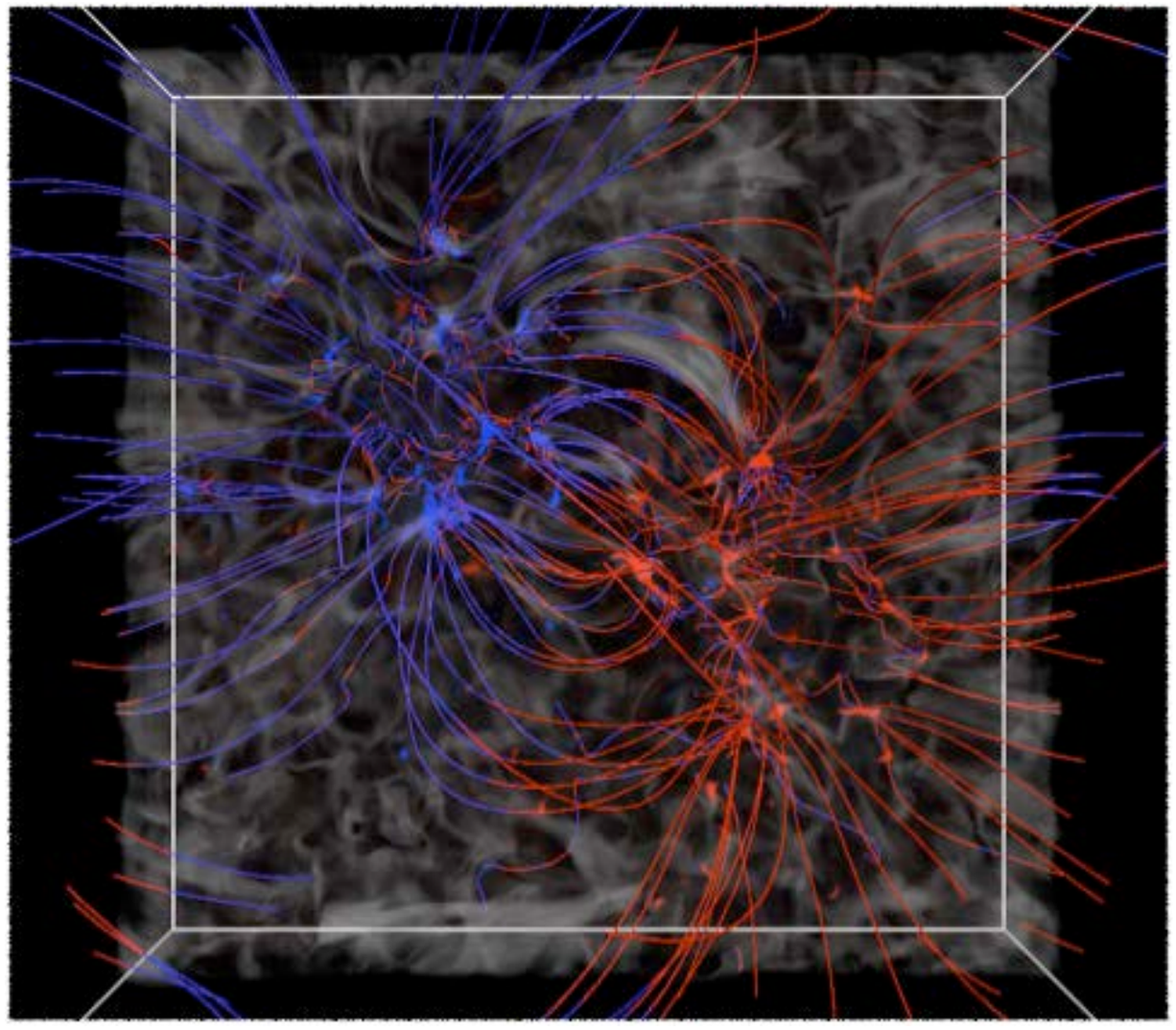
- Conduction along field lines
  - Operator split and solved by using multi grid method

- Non-equilibrium Hydrogen ionization

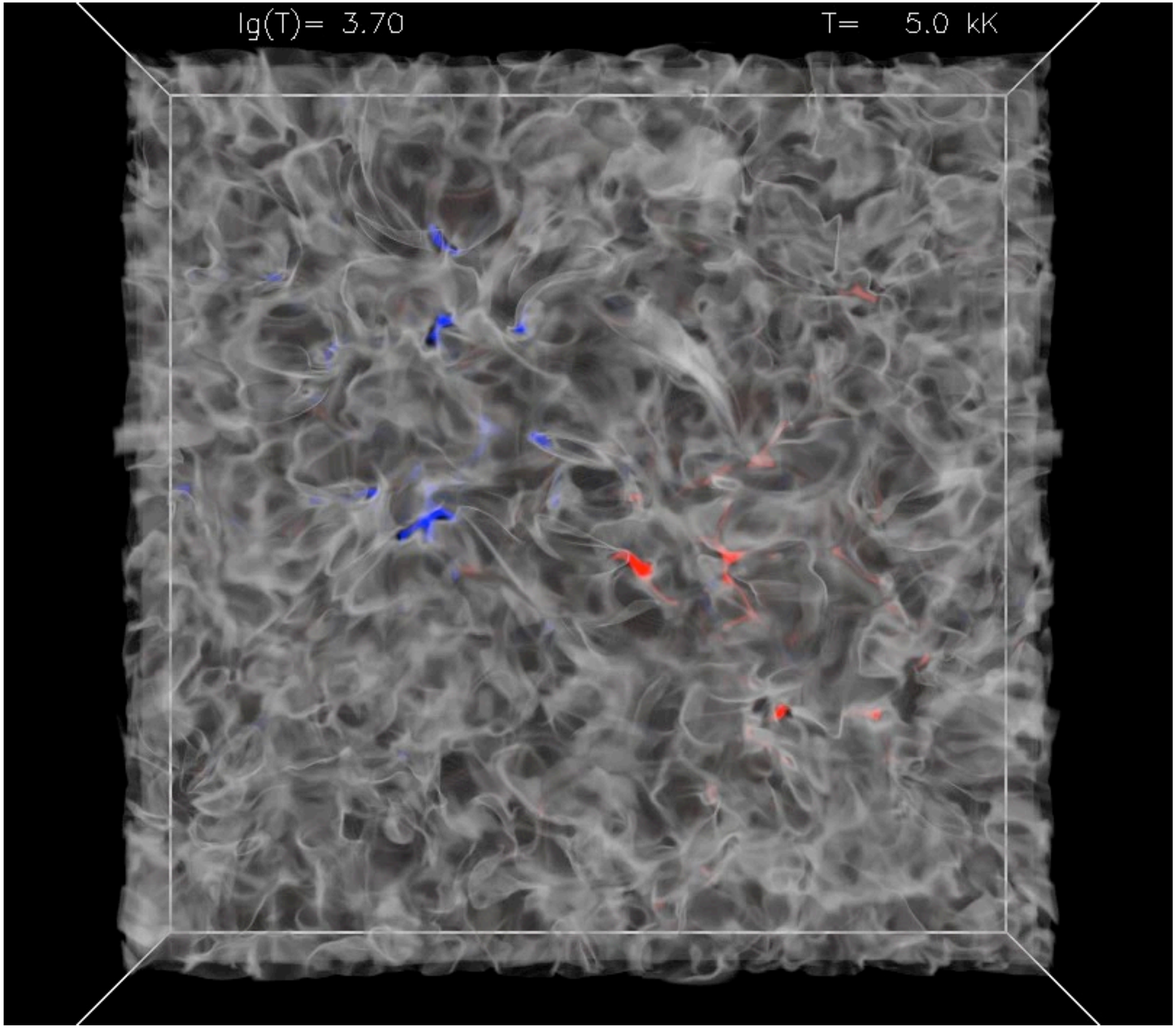
- Non-equilibrium Helium ionization
- Generalized Ohm's law

# Bifrost model



Made available at http://sdc.uio.no/search/simulations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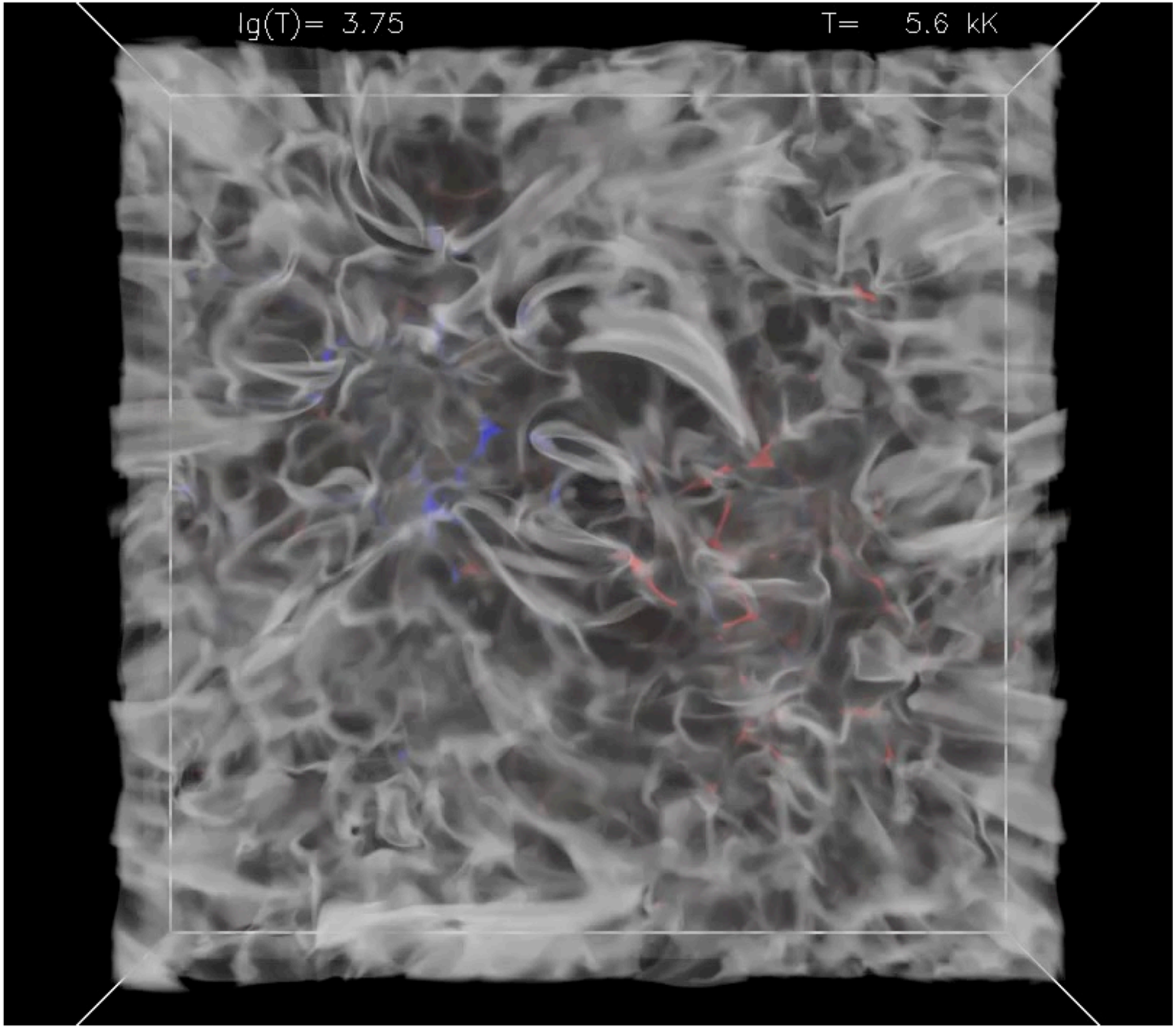
lg(T)= 3.75
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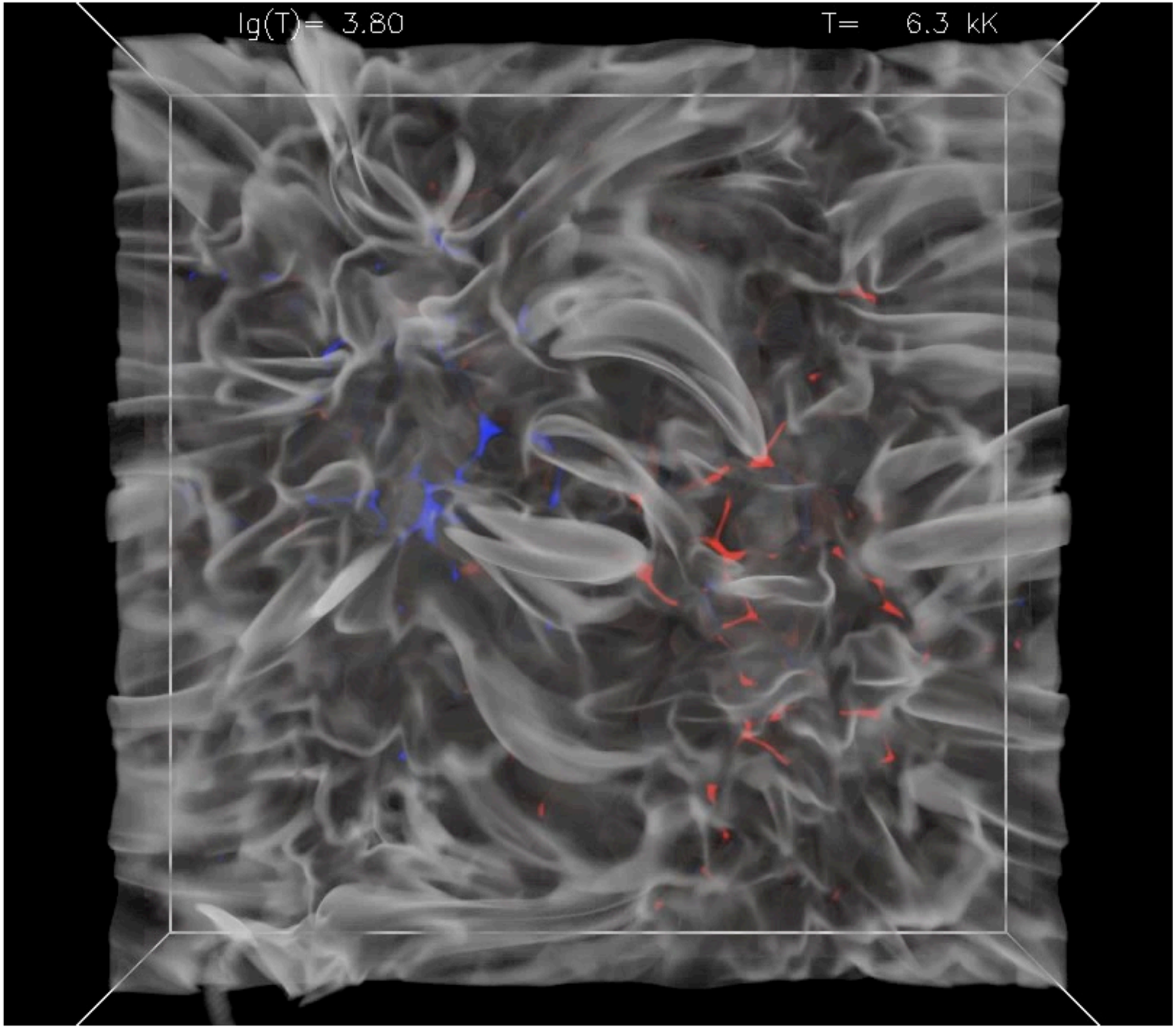
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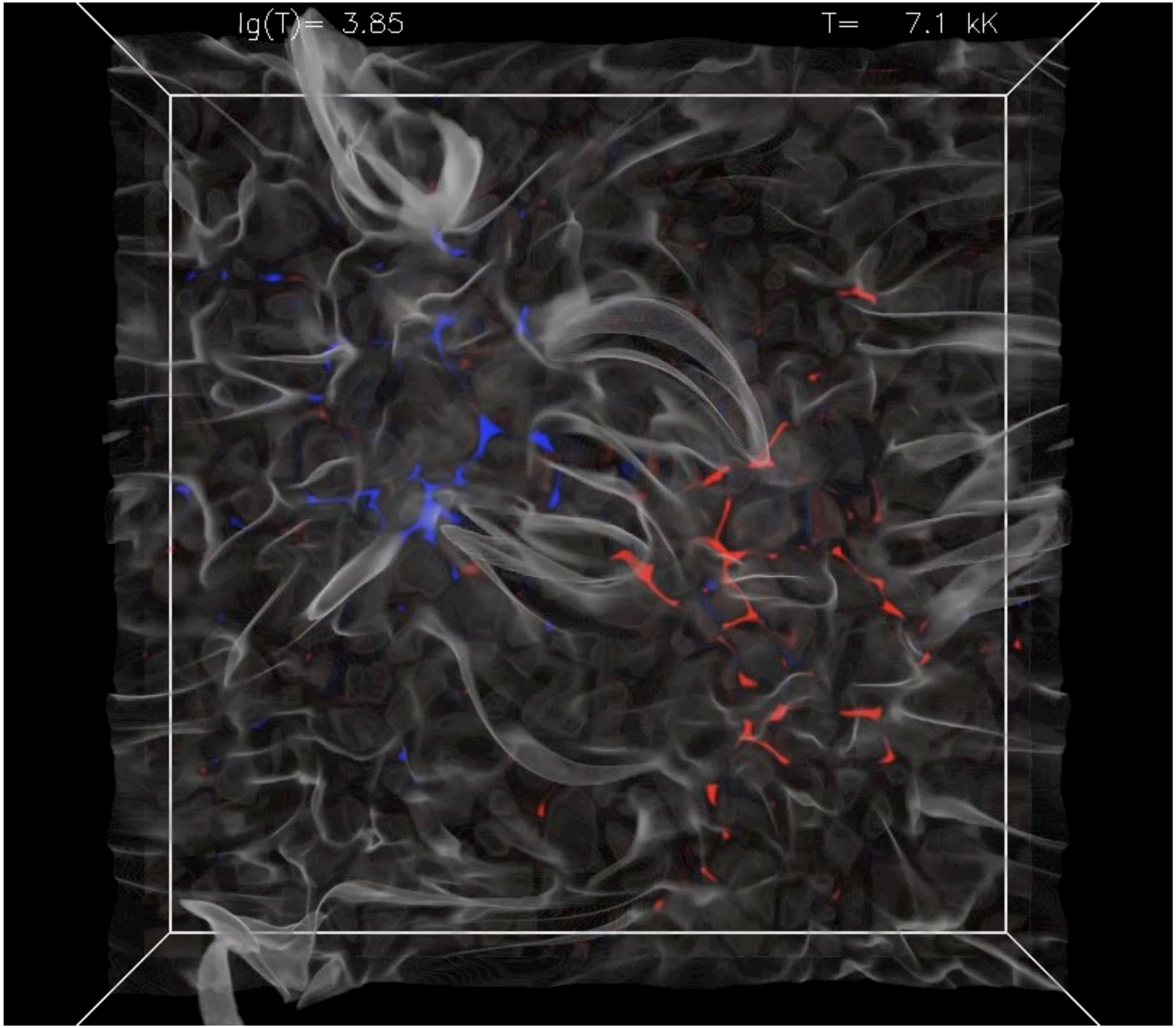
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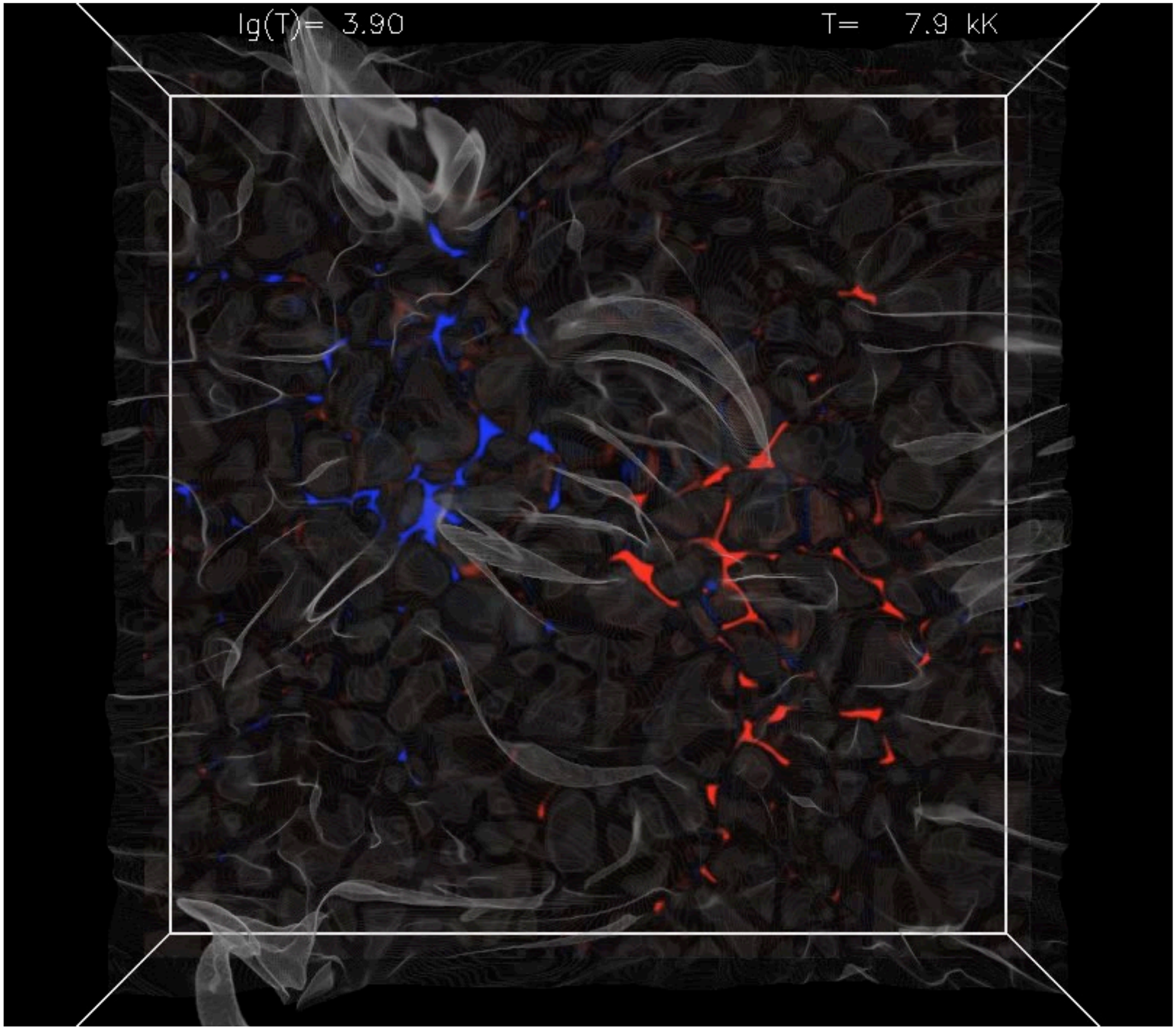
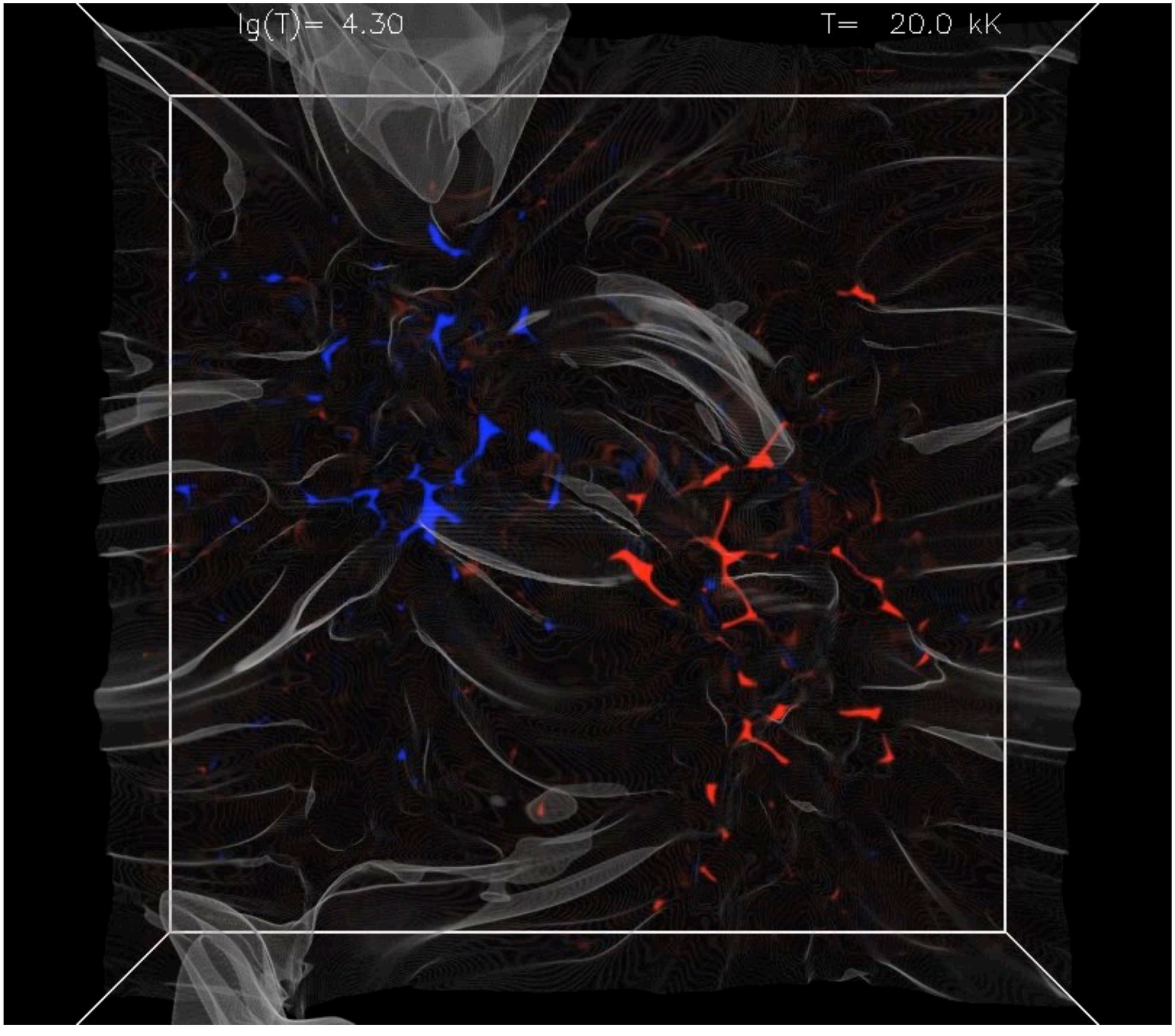

lg(T)= 3.90
T= 7.9 kK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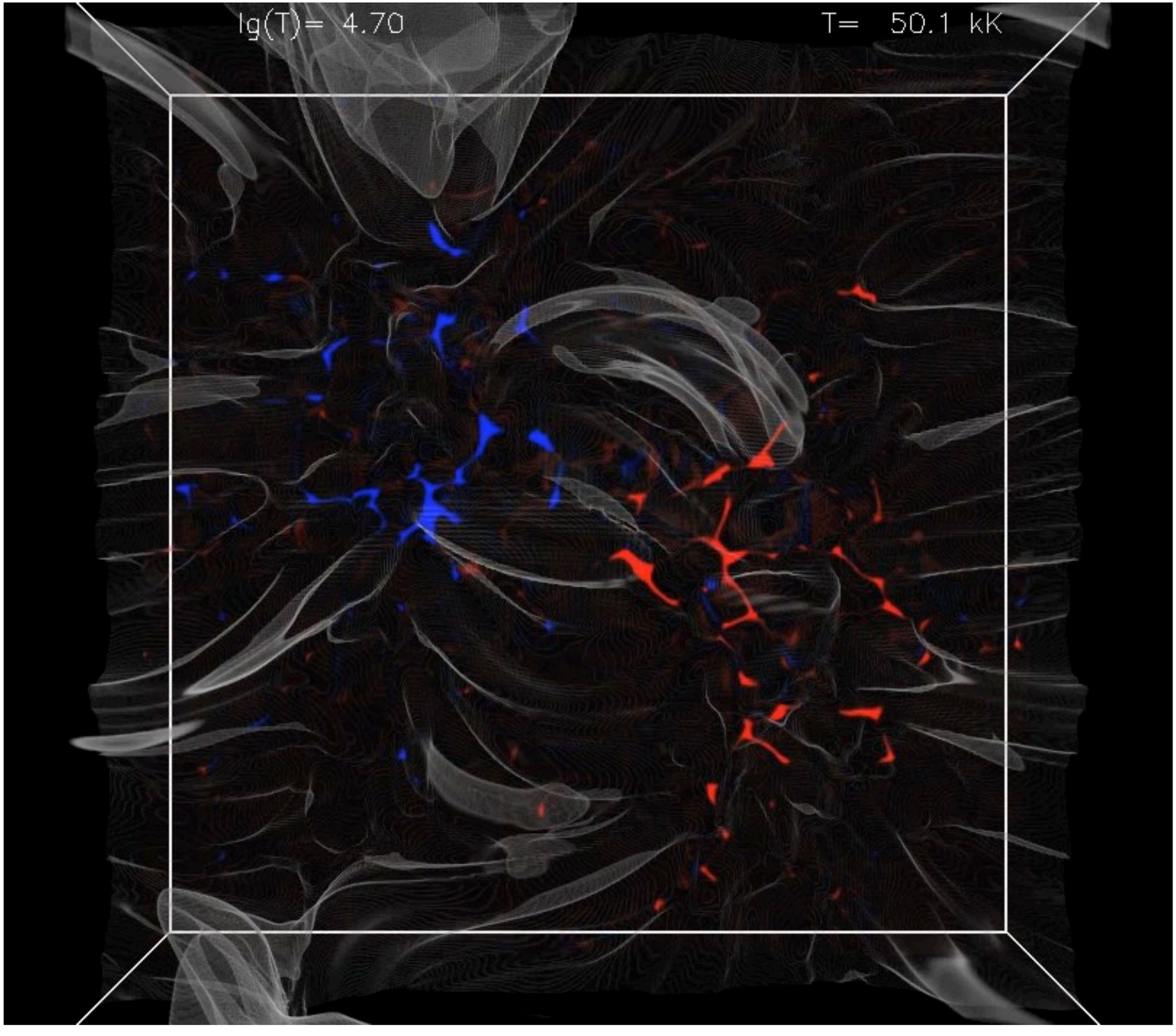
lg(T)= 4.70
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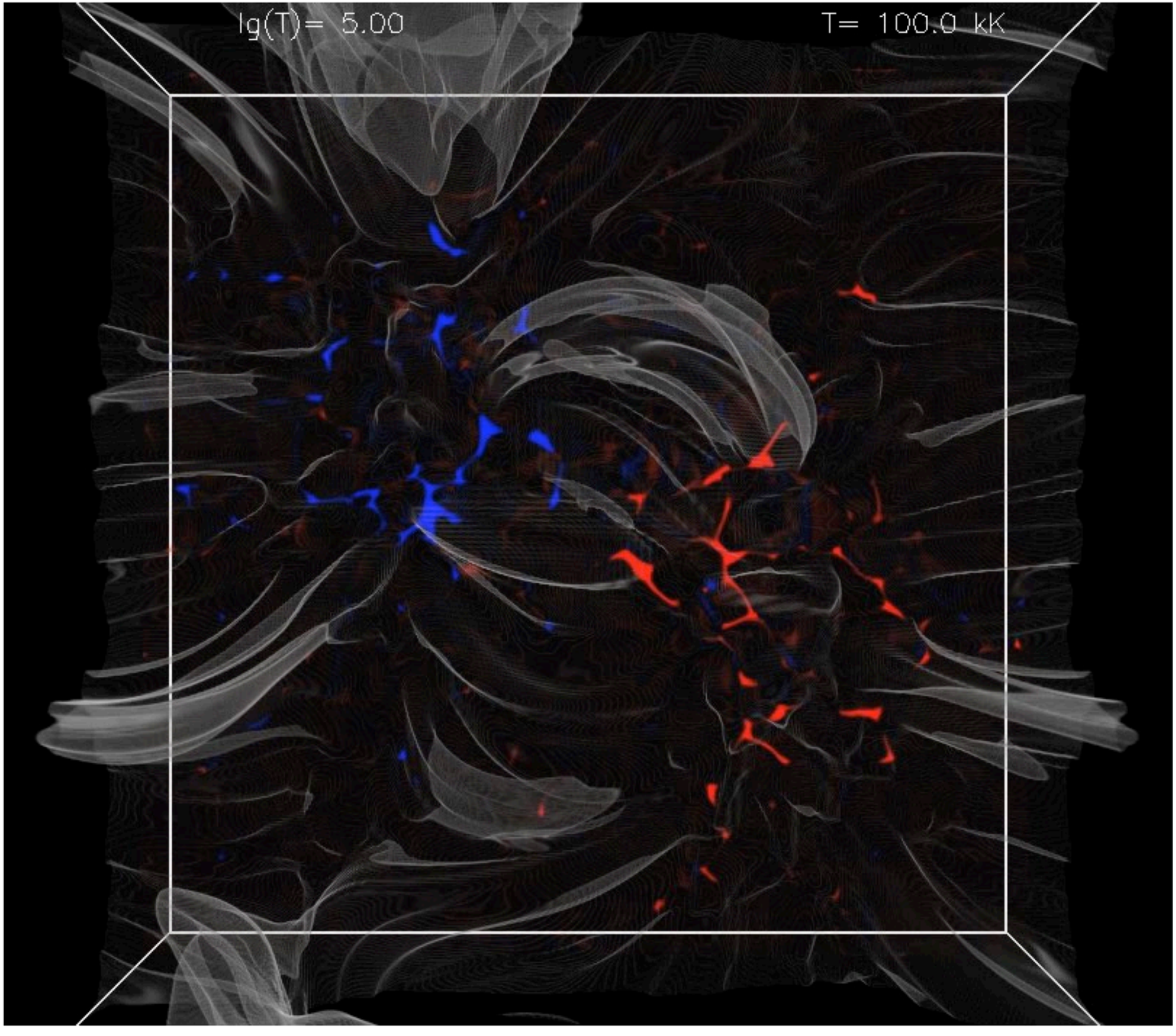
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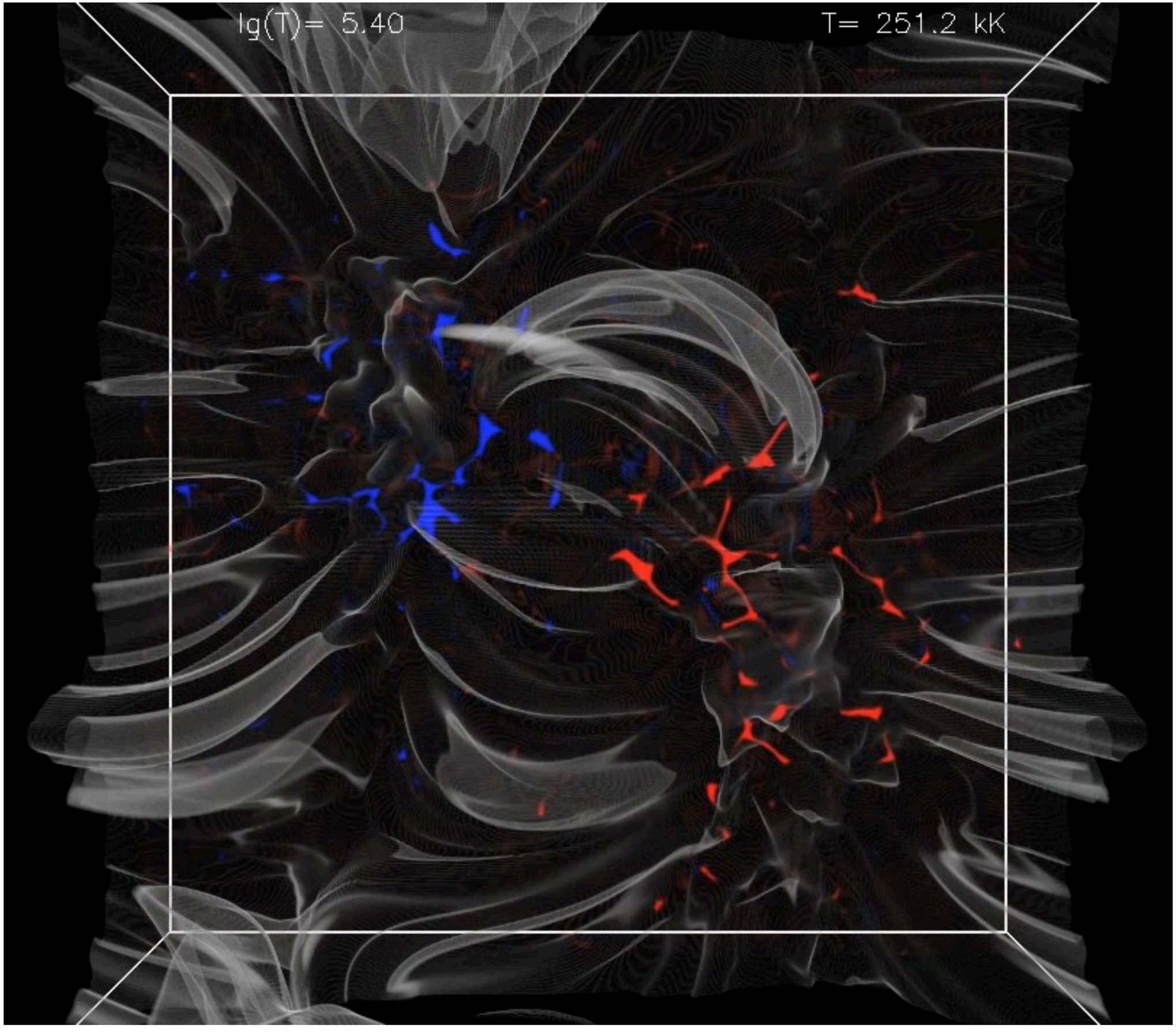
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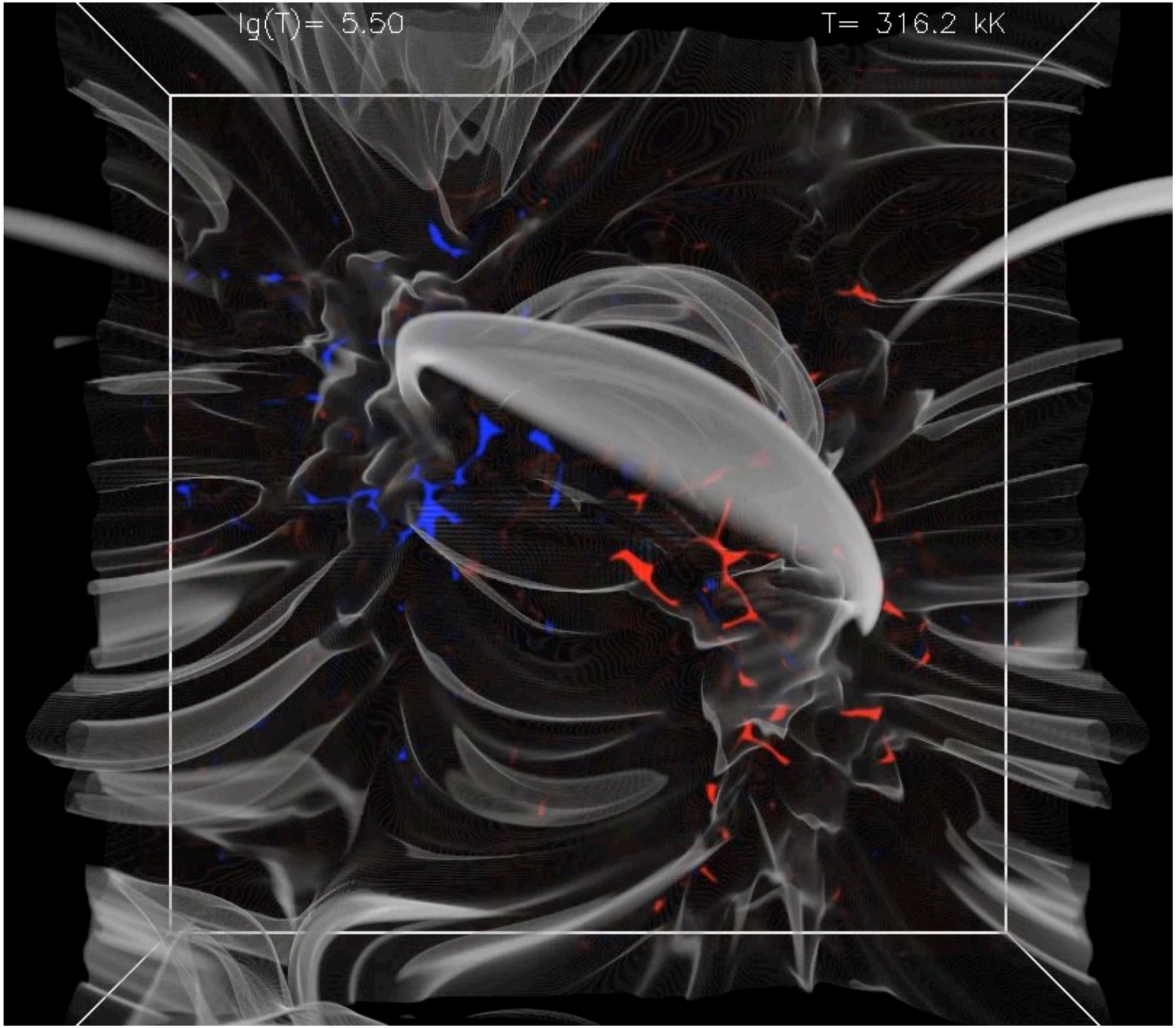
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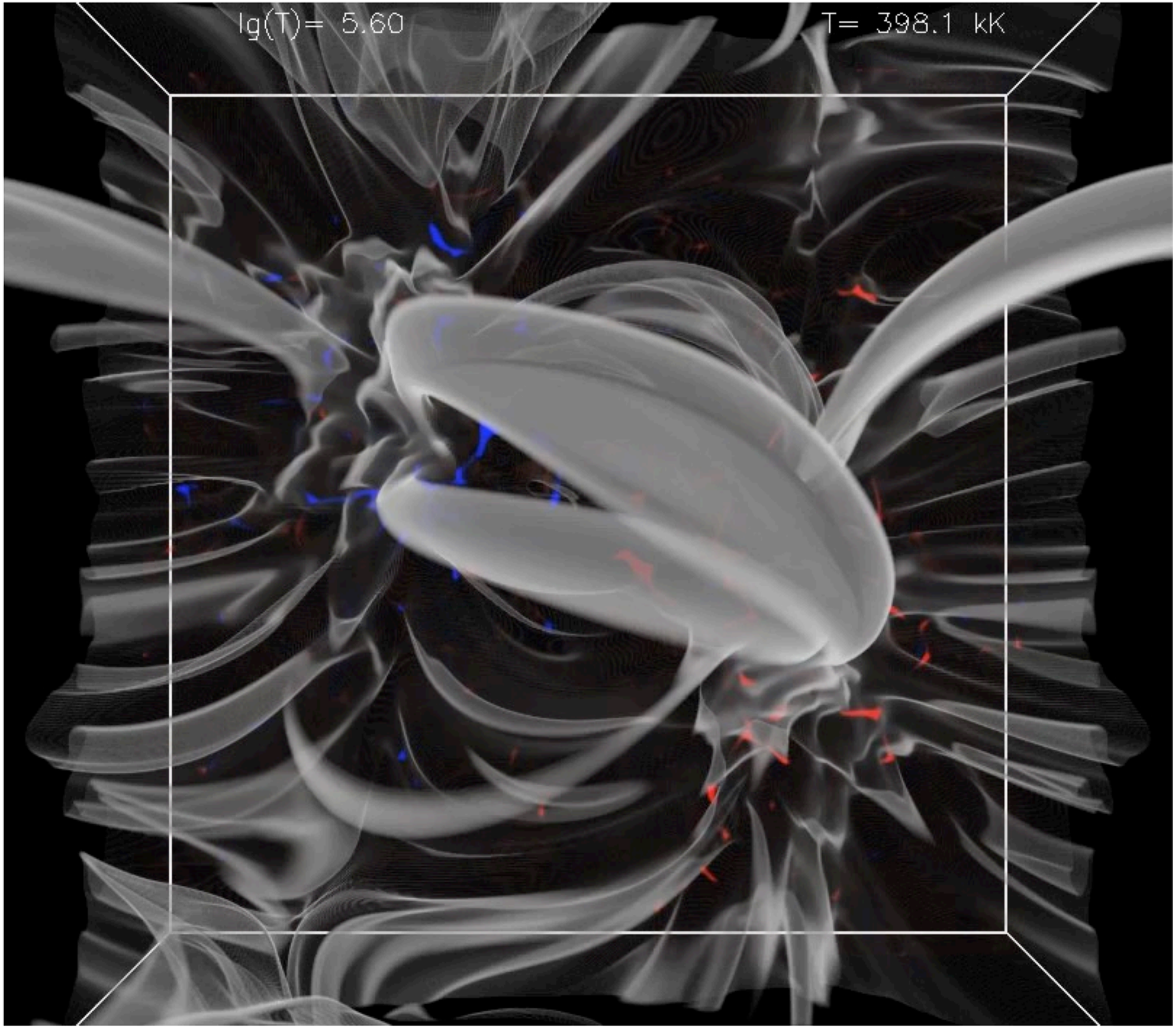
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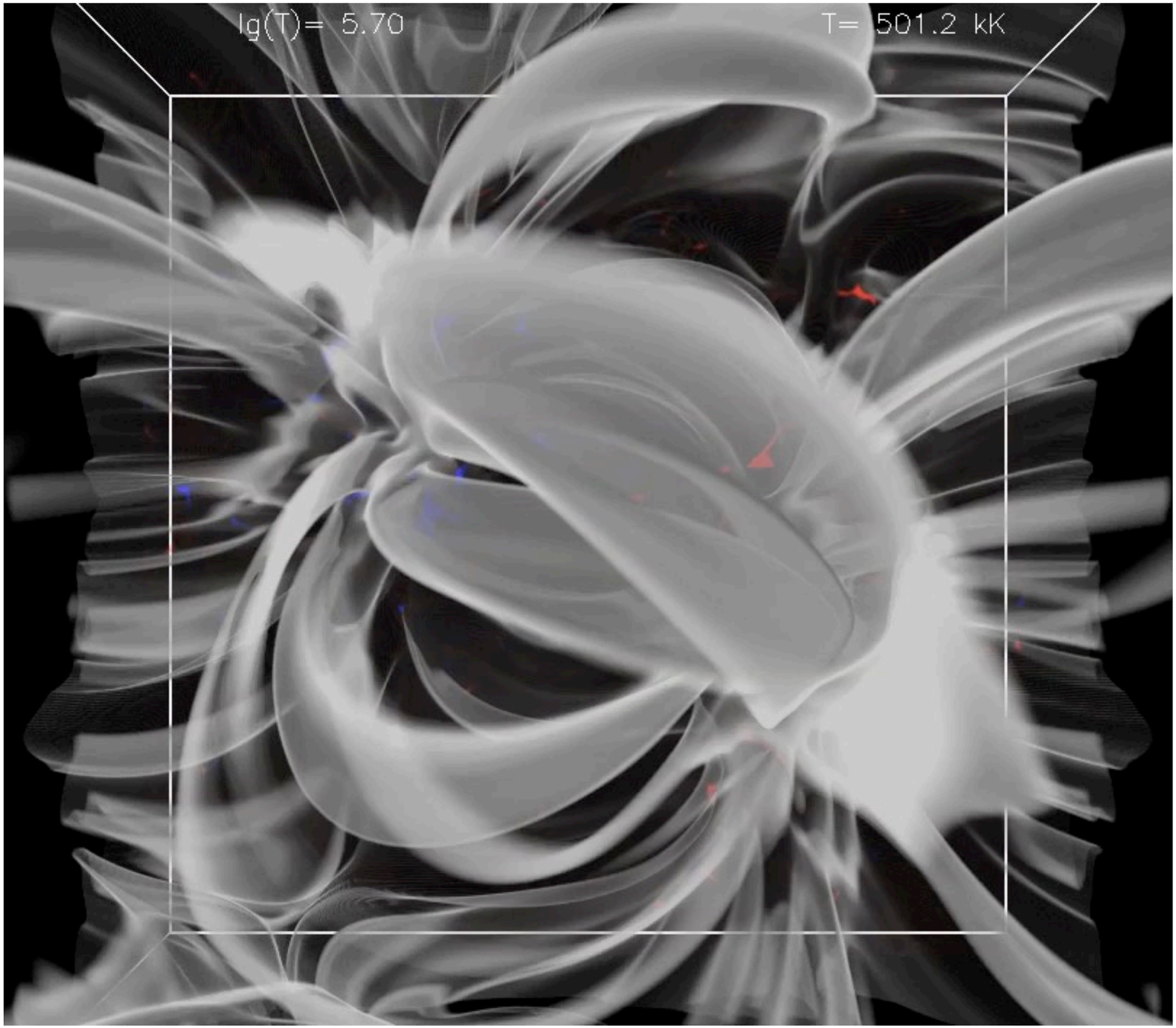
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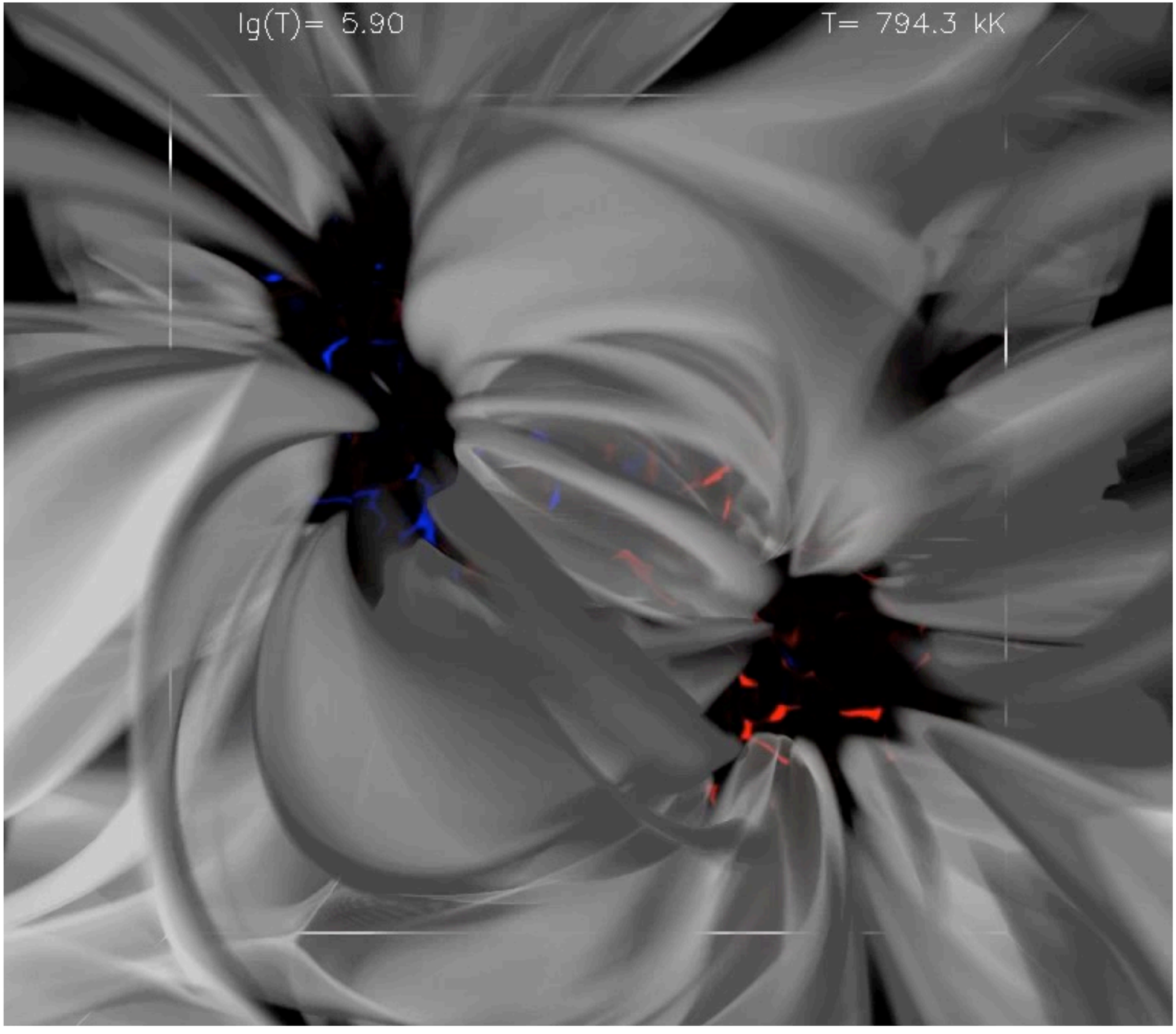
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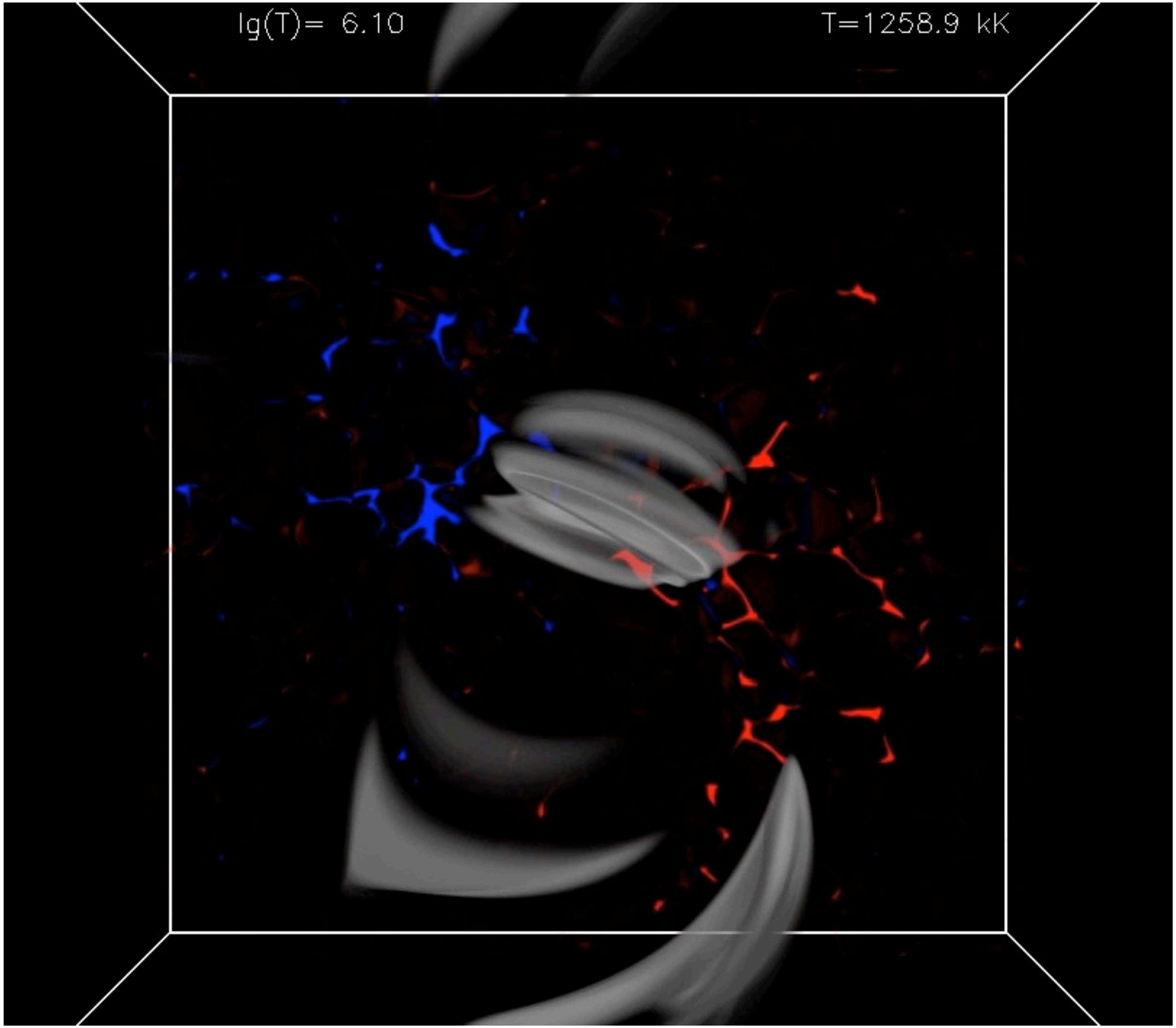
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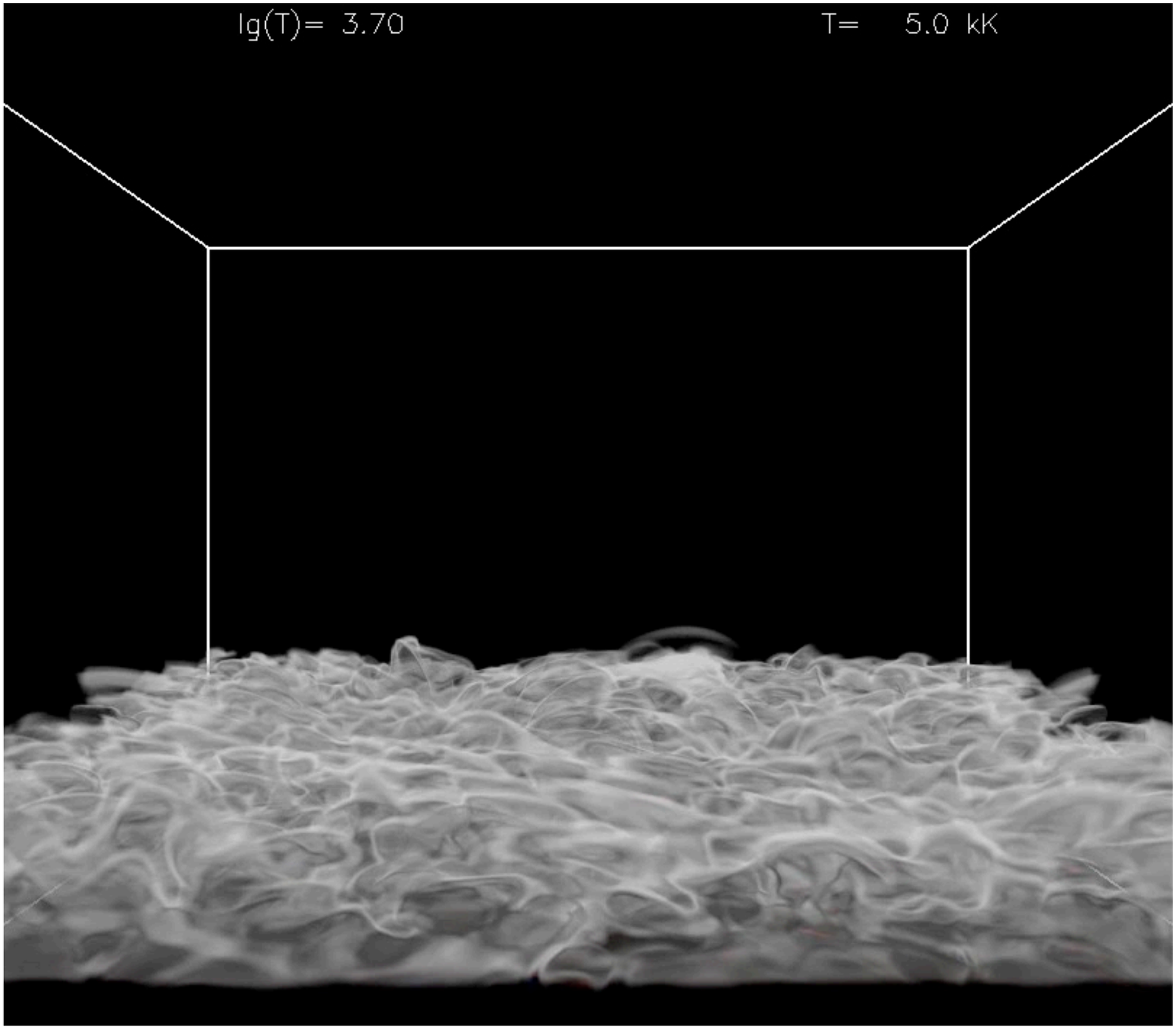
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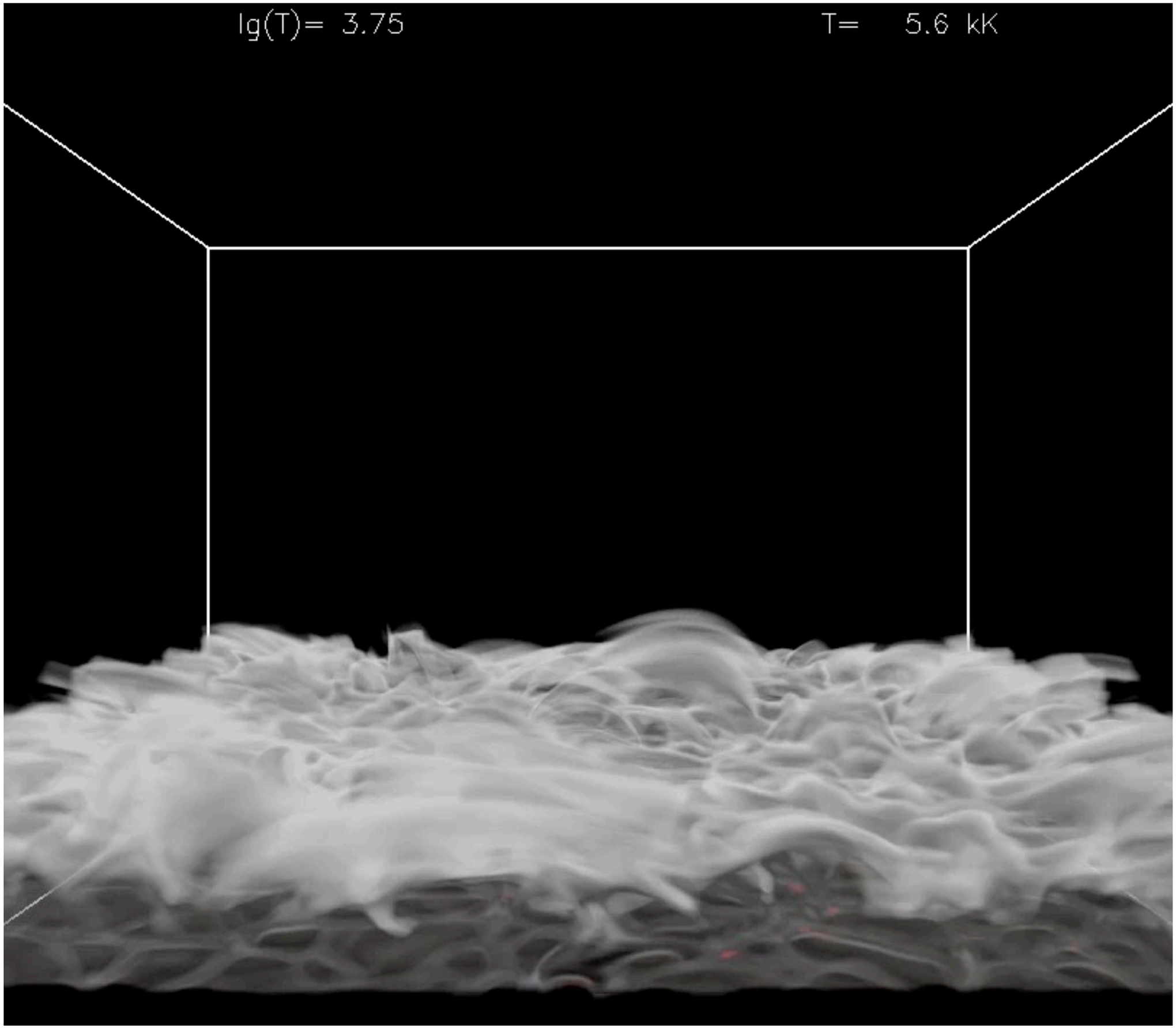
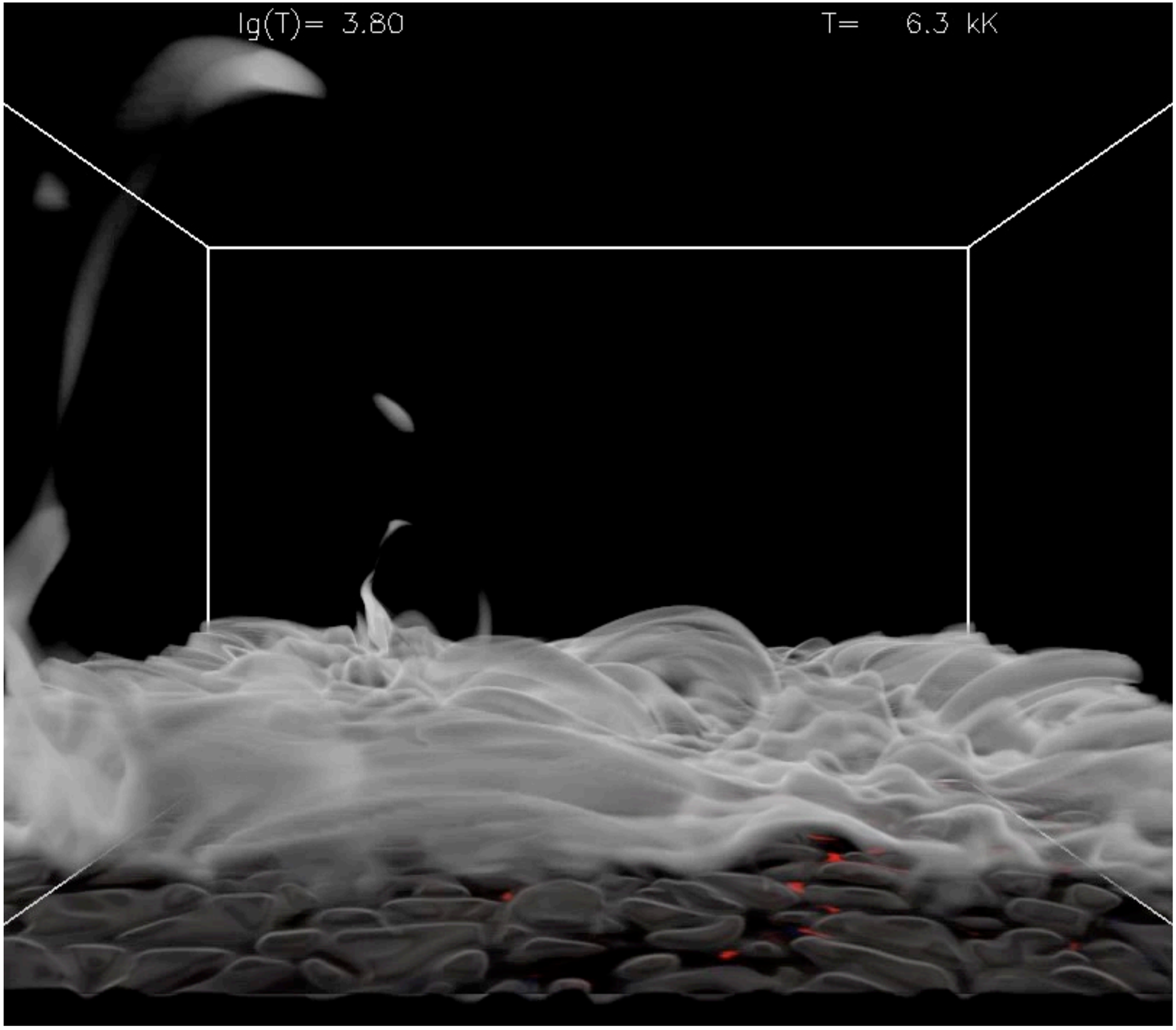

lg(T)= 3.75
T= 5.6 kK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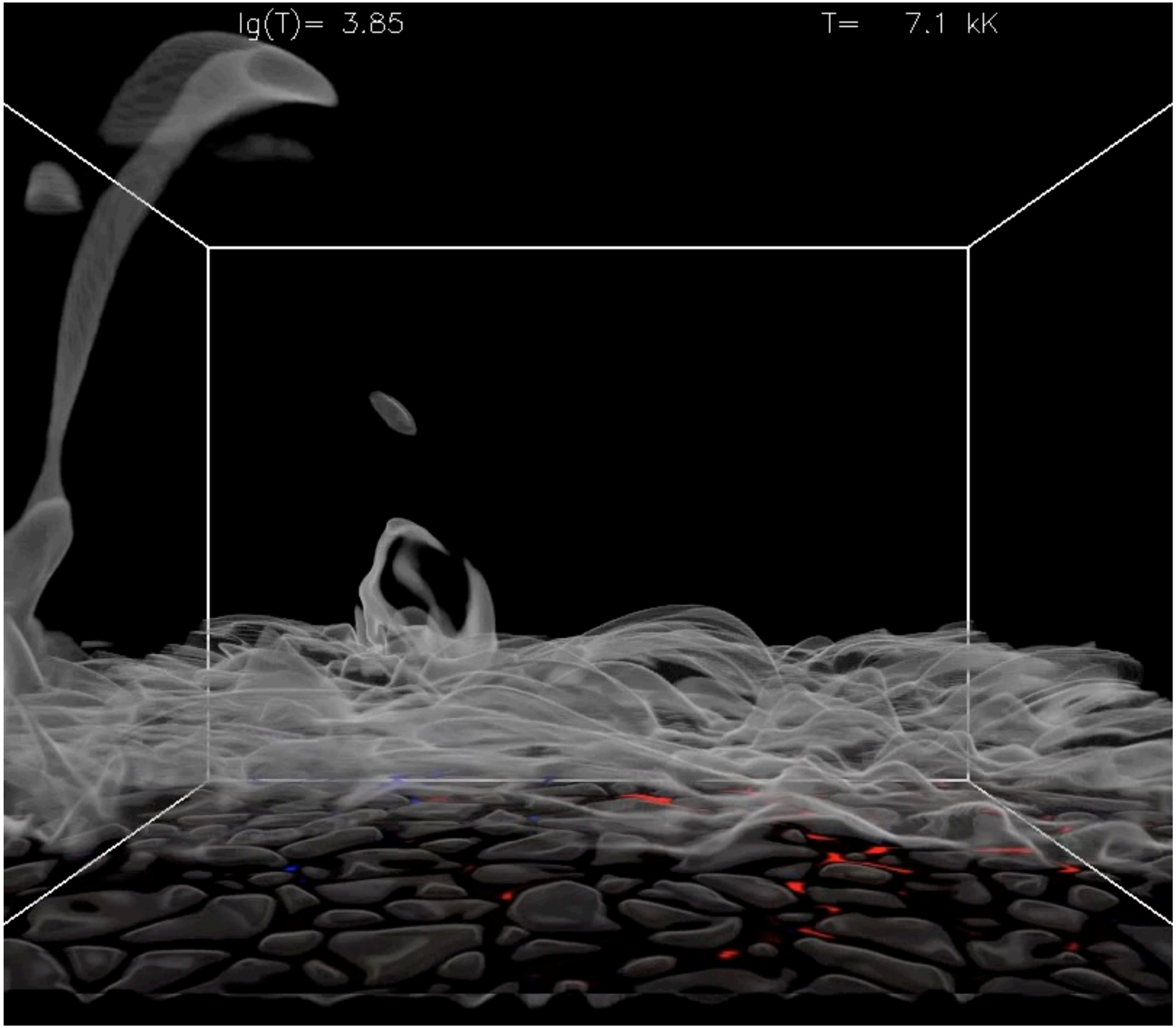
lg(T)= 3.85
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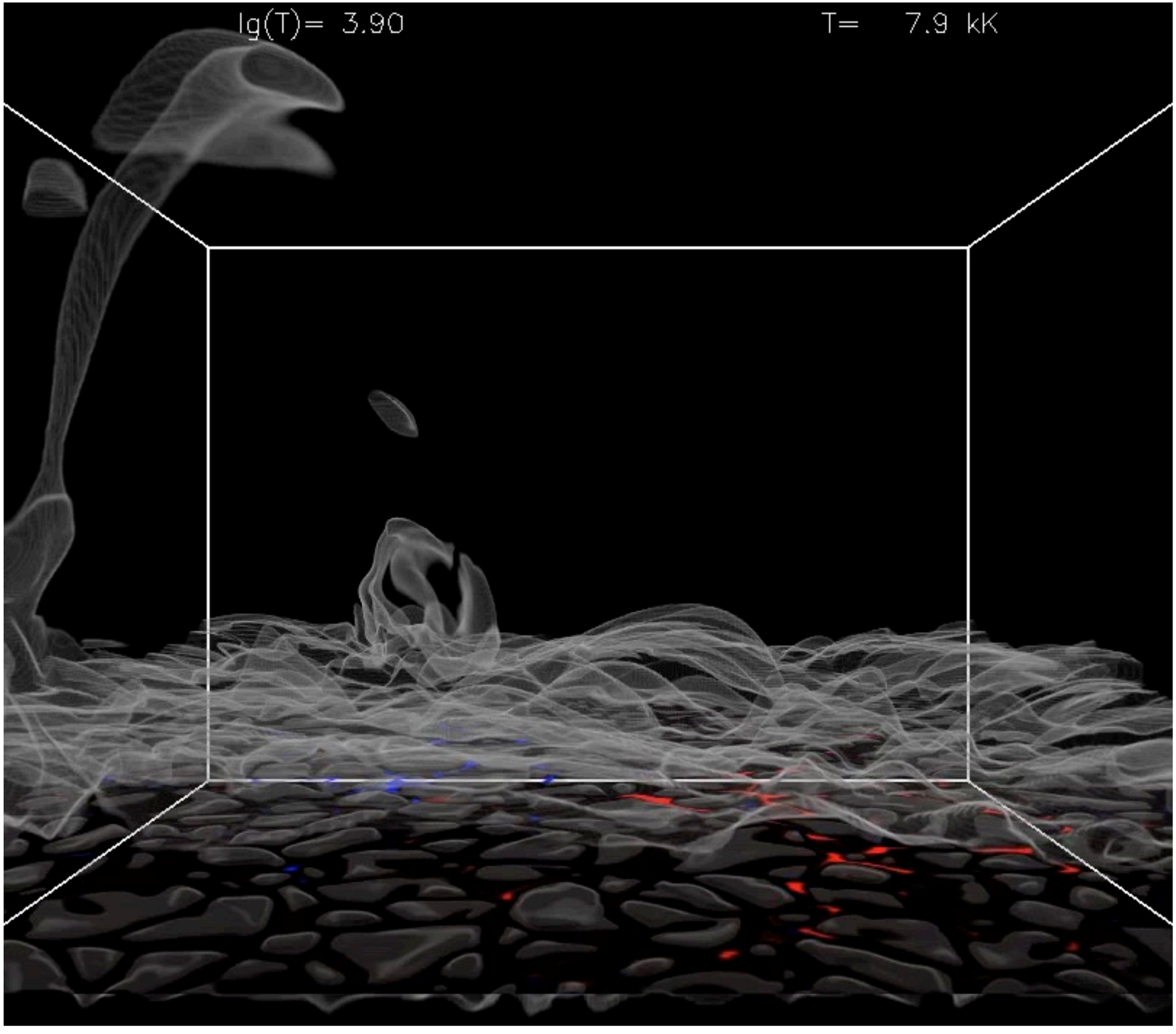
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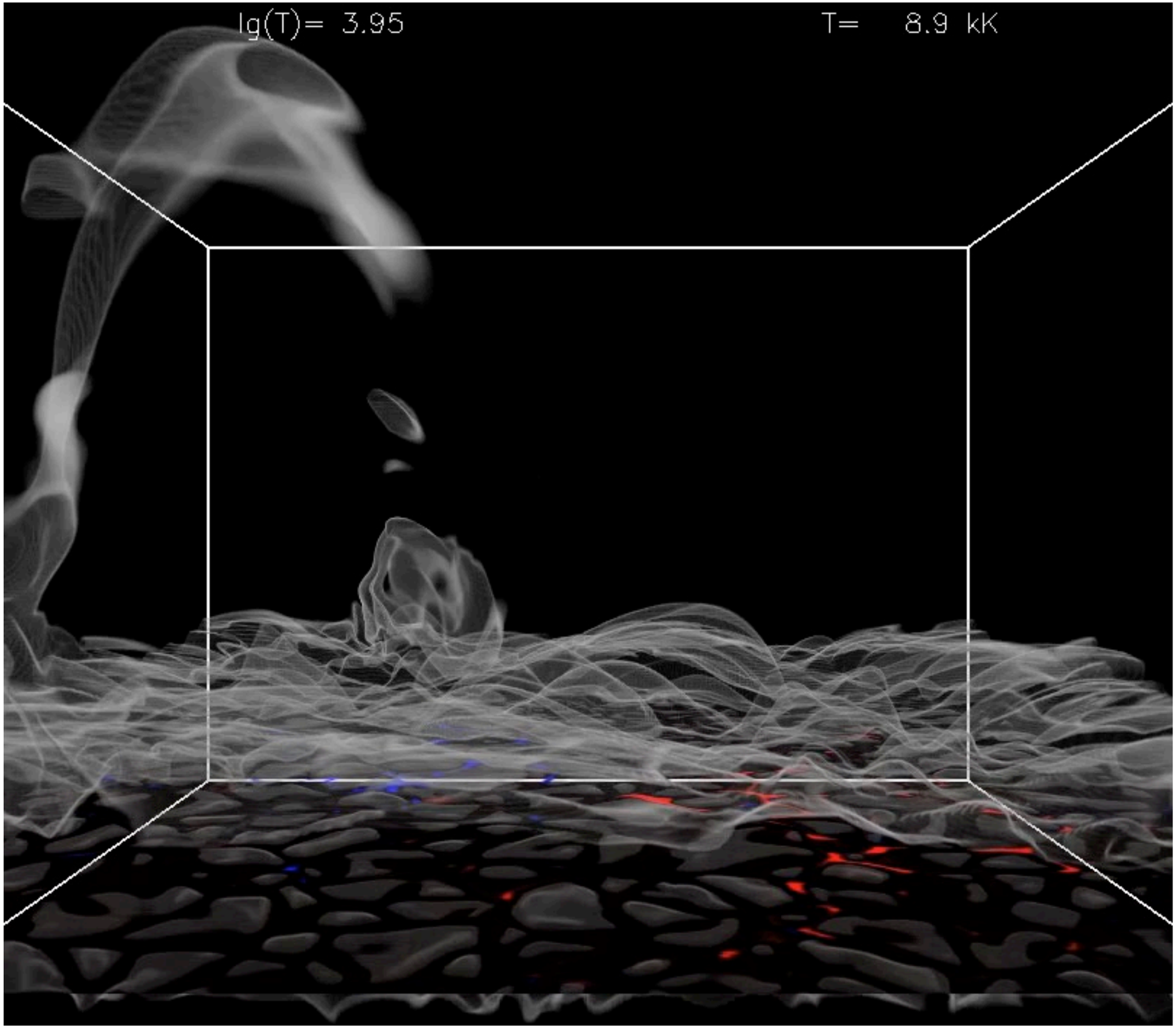
T= 7.9 kK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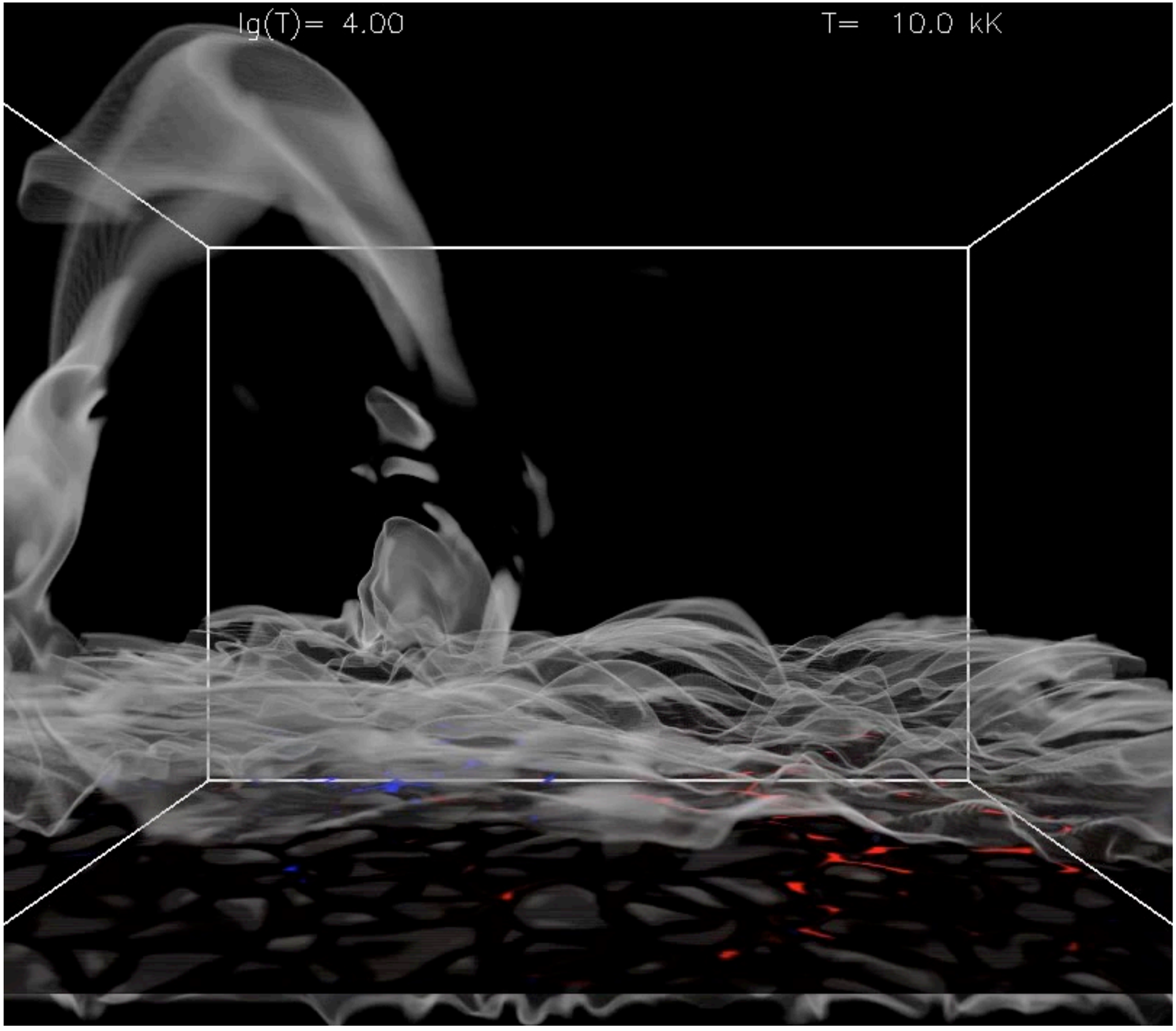
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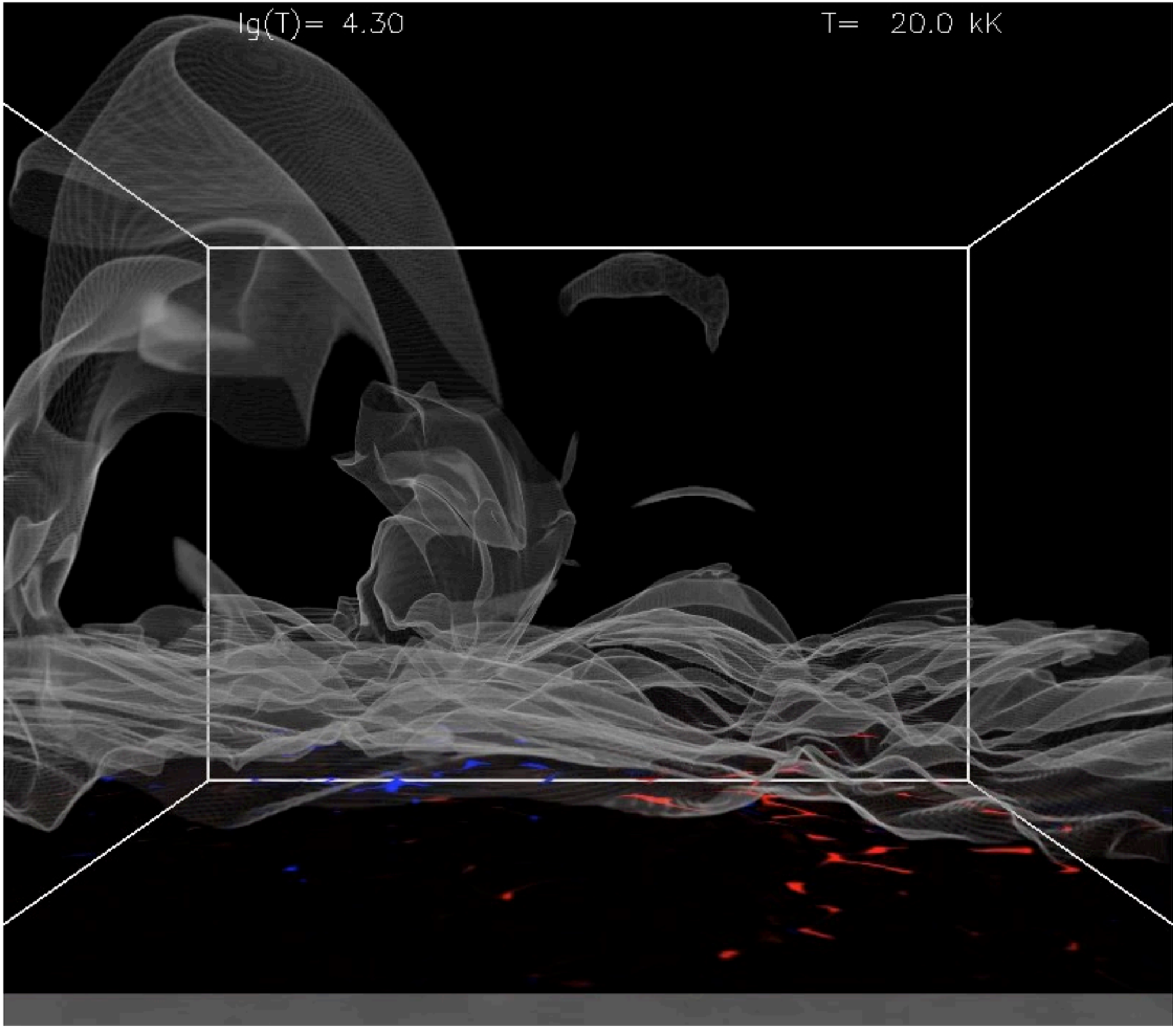
lg(T)= 4.30
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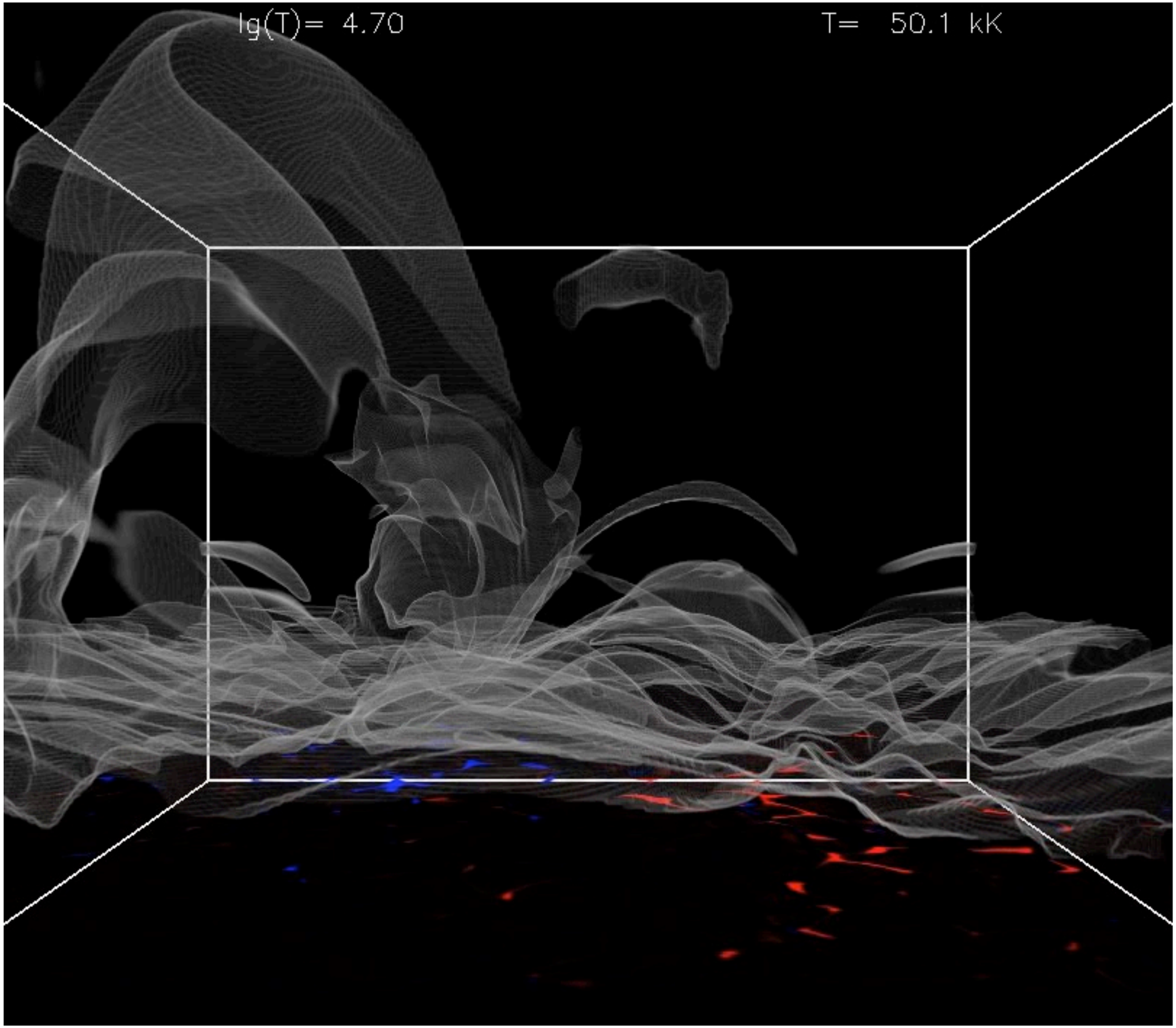
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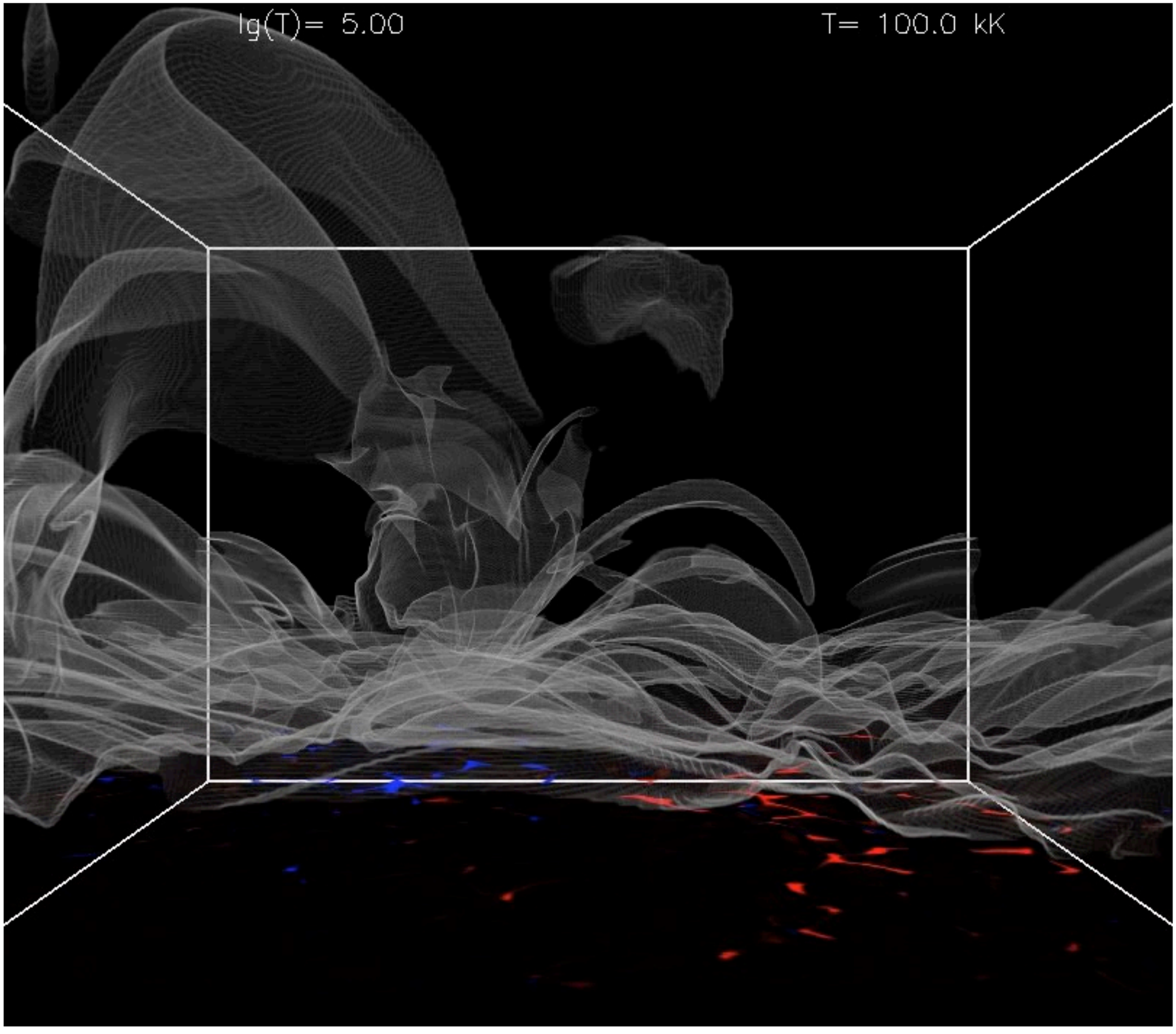
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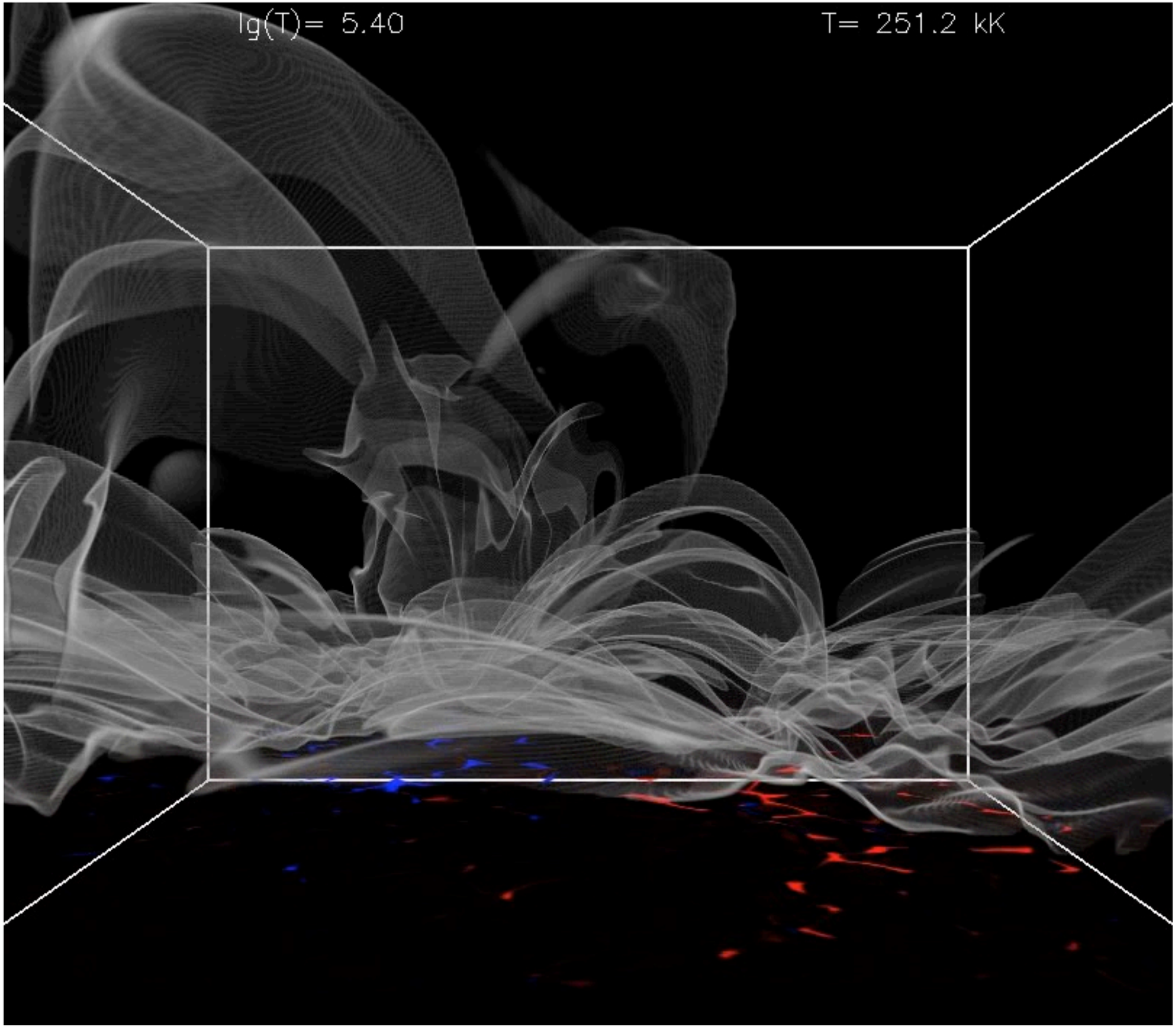
lg(T)= 5.40
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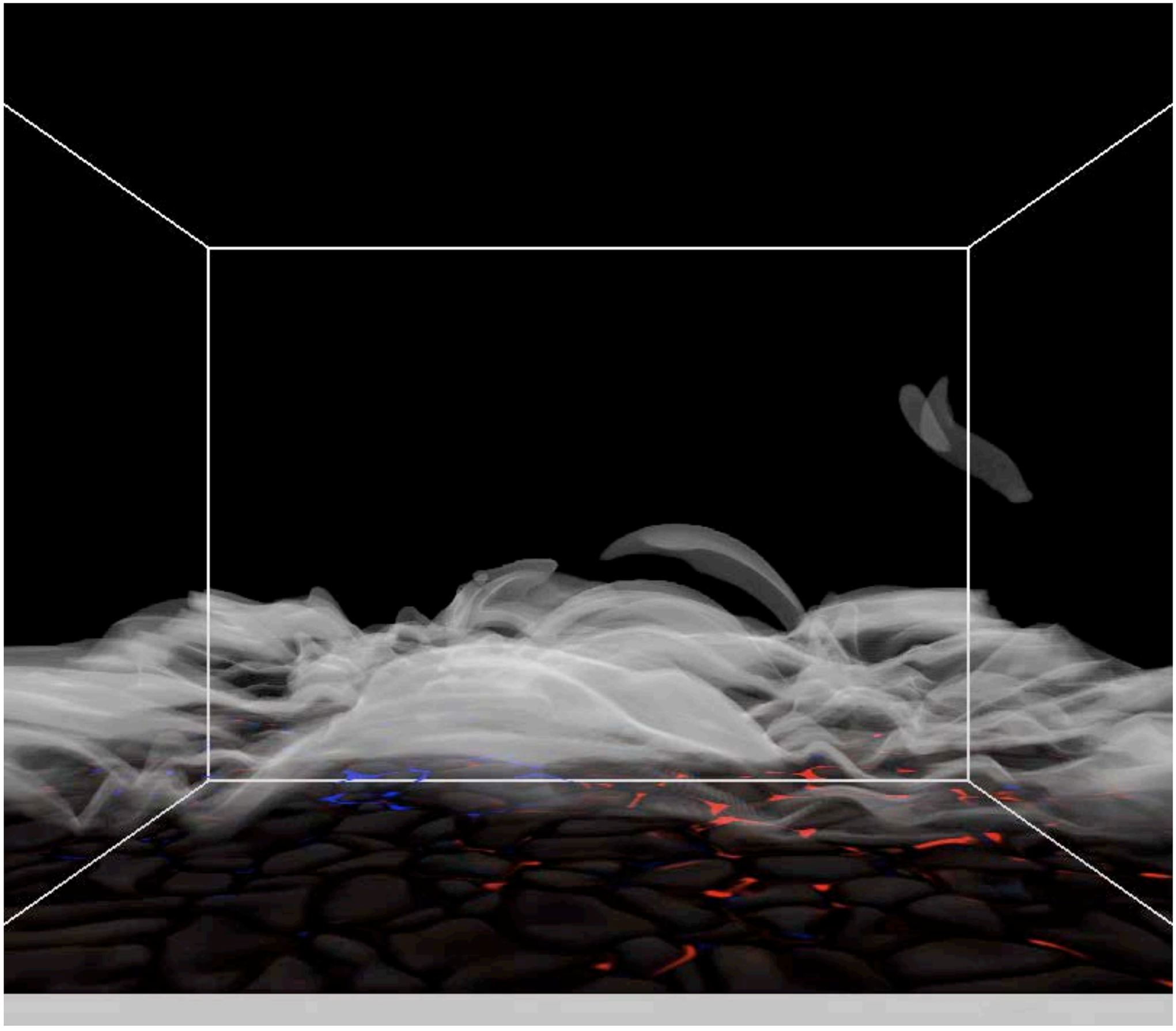
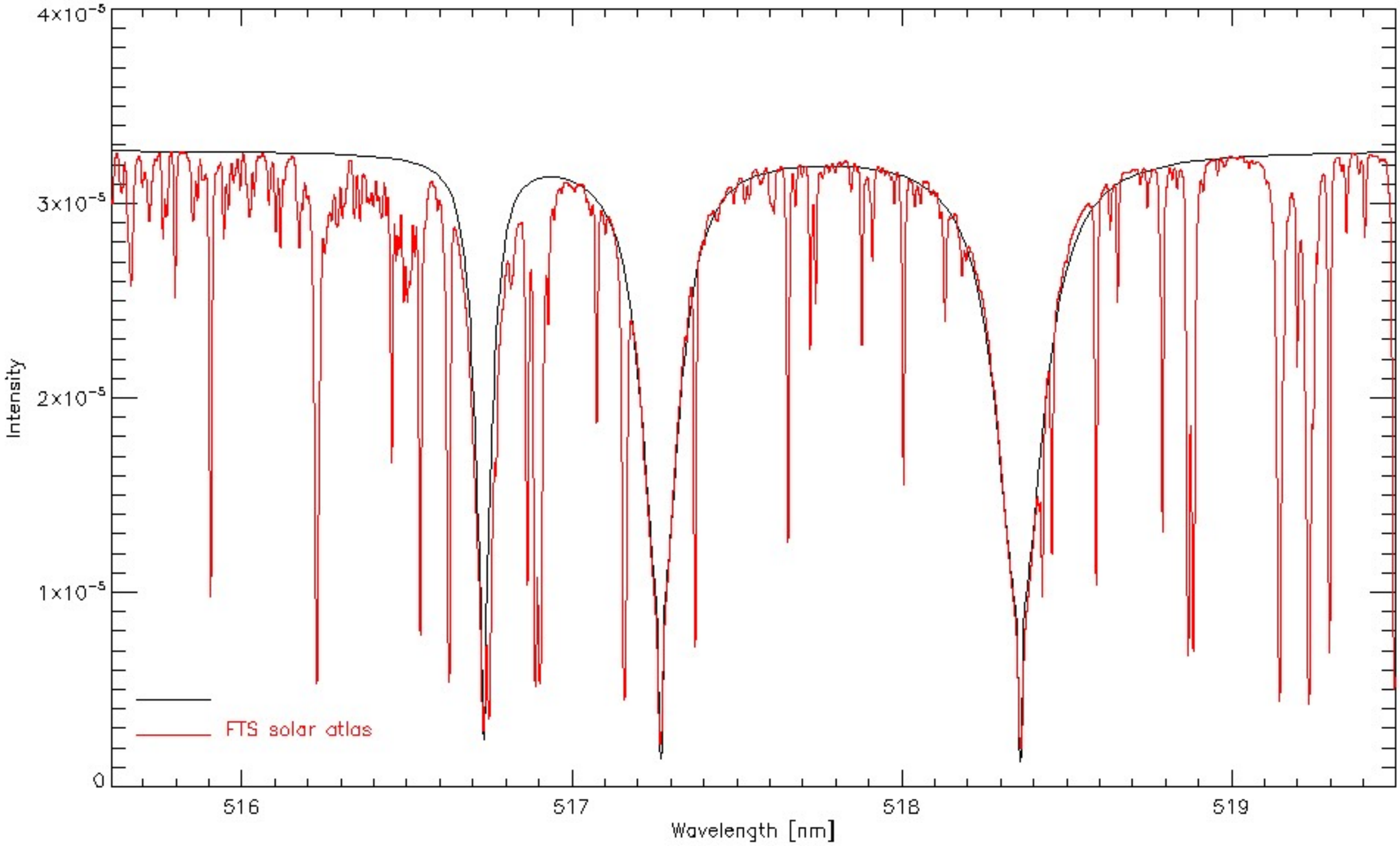
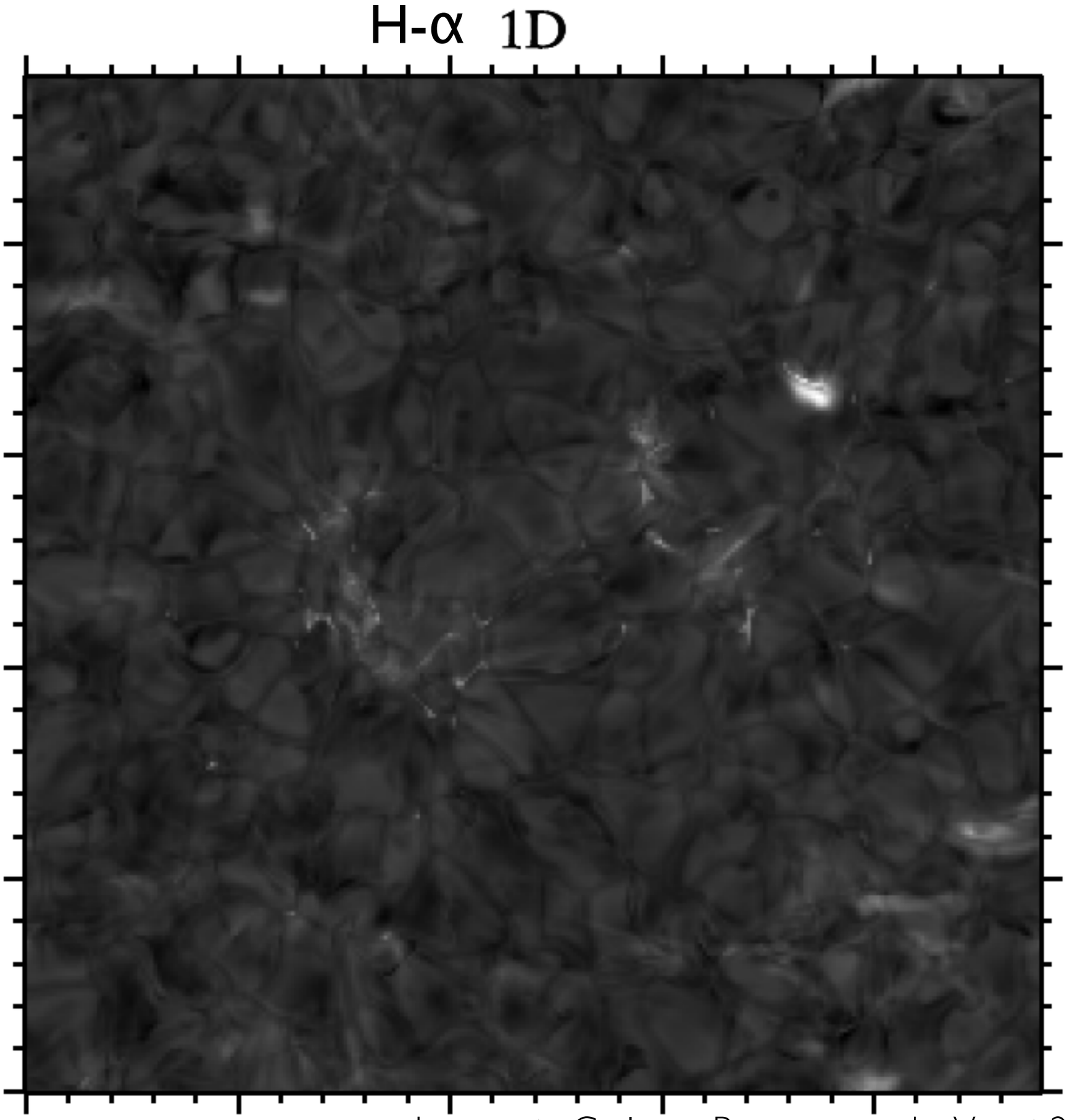
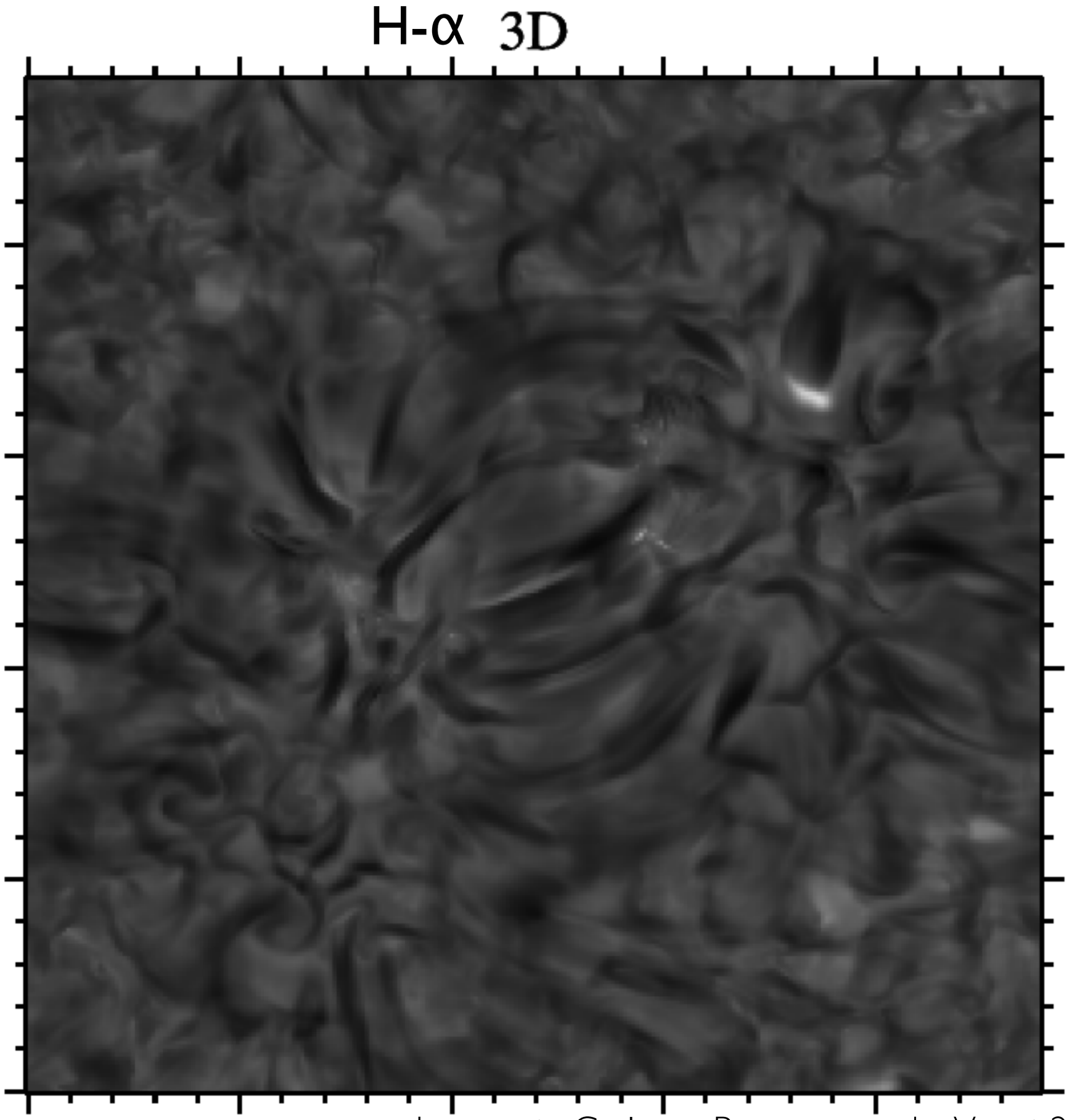


# Mg I b lines


4x10⁻⁵
3x10⁻⁵
2x10⁻⁵
1x10⁻⁵
0
Intensity
516
517
518
519
Wavelength [nm]
FTS solar atlas

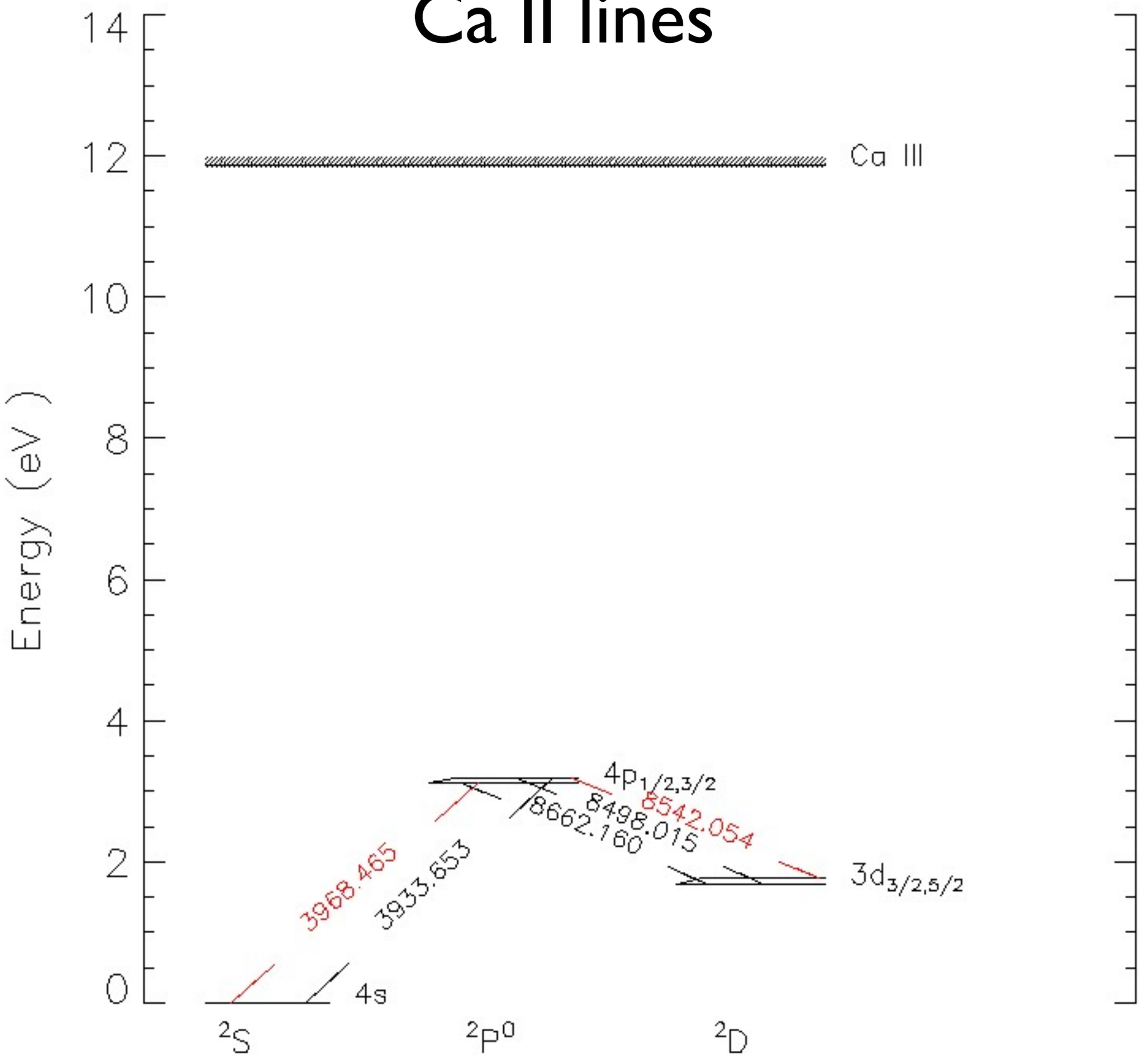



Leenaarts, Carlsson, Rouppe van der Voort 2012: ApJ 749, 136

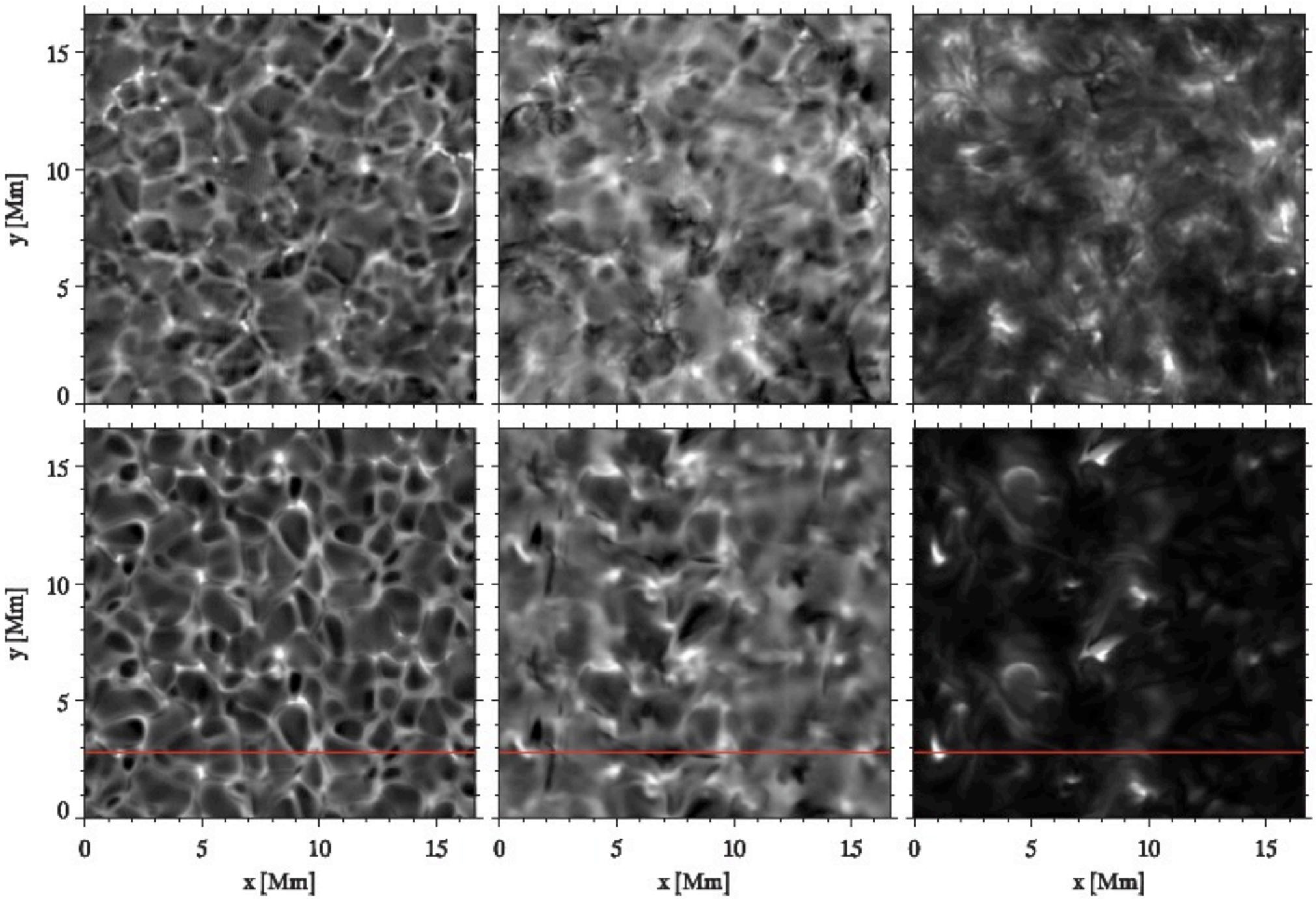



Leenaarts, Carlsson, Rouppe van der Voort 2012: ApJ 749, 136

# Ca II lines


14
12
10
8
6
4
2
0
Energy (eV)
Ca III
4p1/2,3/2
8662.160
8498.015
8542.054
3968.465
3933.653
3d3/2,5/2
4s
2S
2P0
2D

# 3D NLTE: Ca II 8542




SST/Crisp

Bifrost

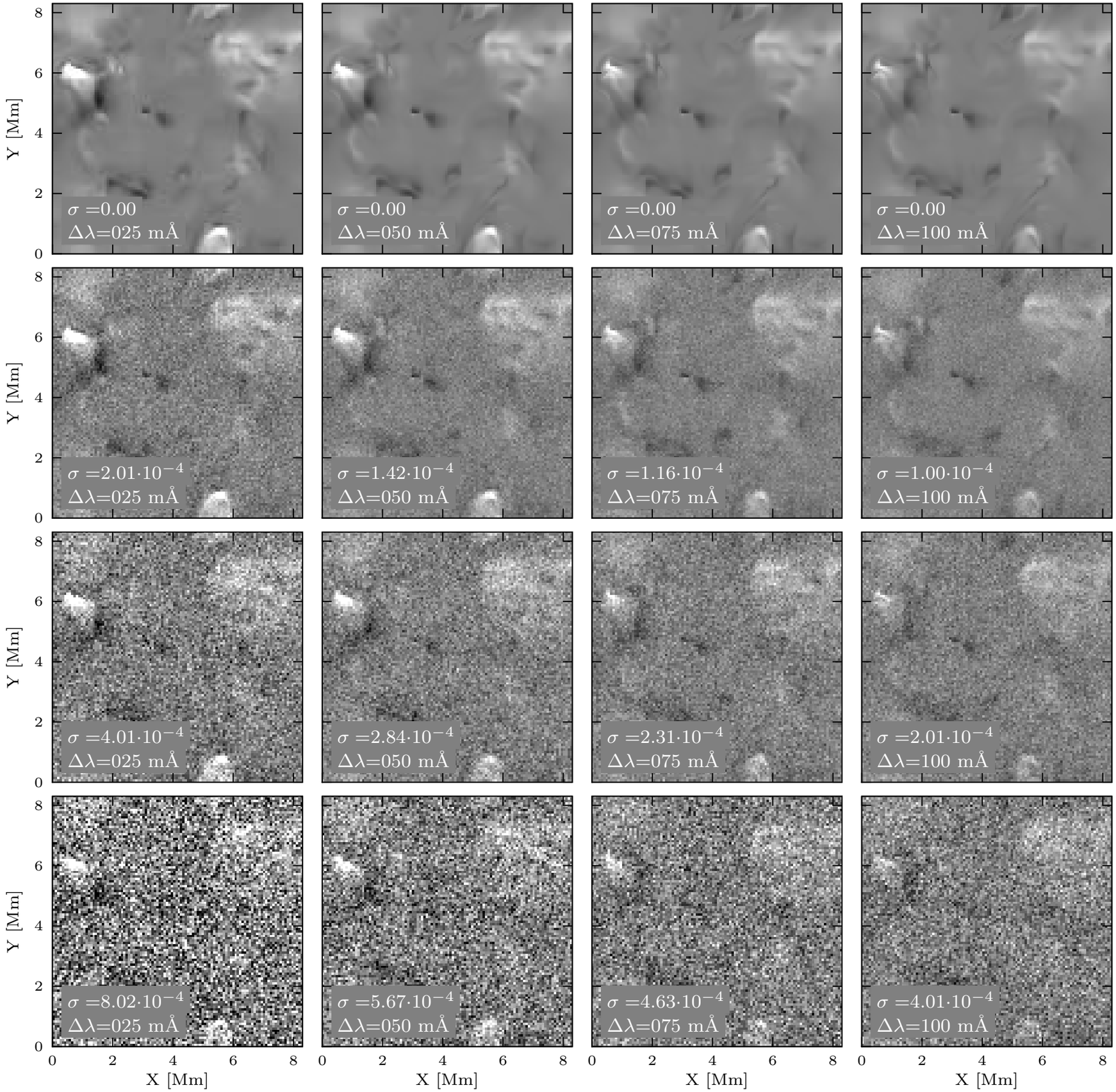
Leenaarts et al 2009: ApJ 694,L128

# 1.5 m telescope, 10% efficiency, 0.1” pixels

# Ca II 8542

Stokes Q

Original



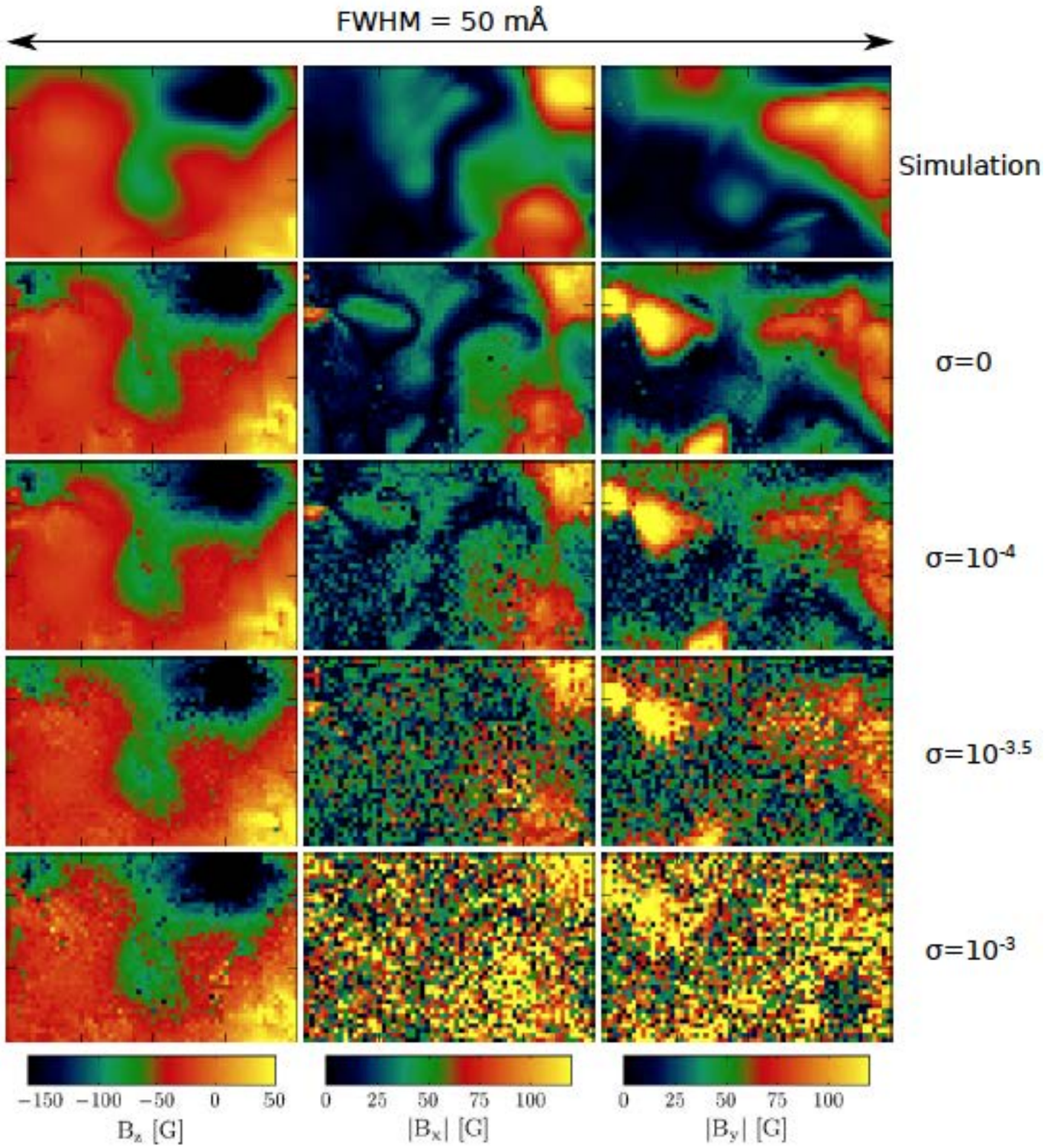

16s

4s

1s

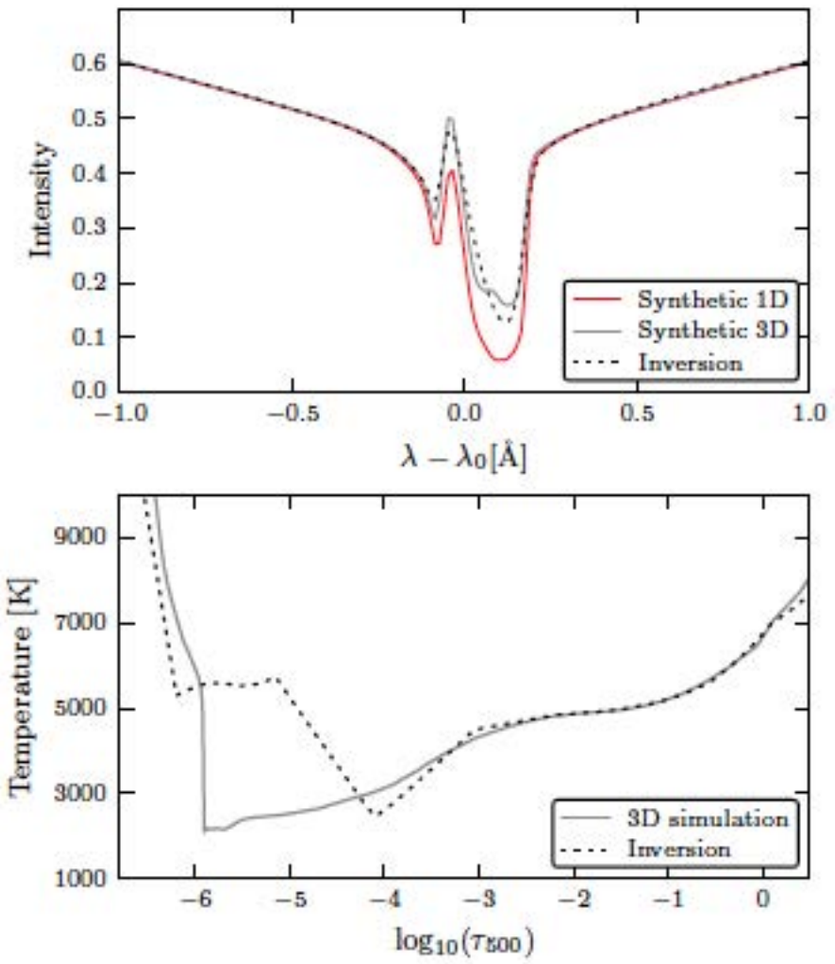
de la Cruz Rodriguez et al, 2012, A&A 543, A34

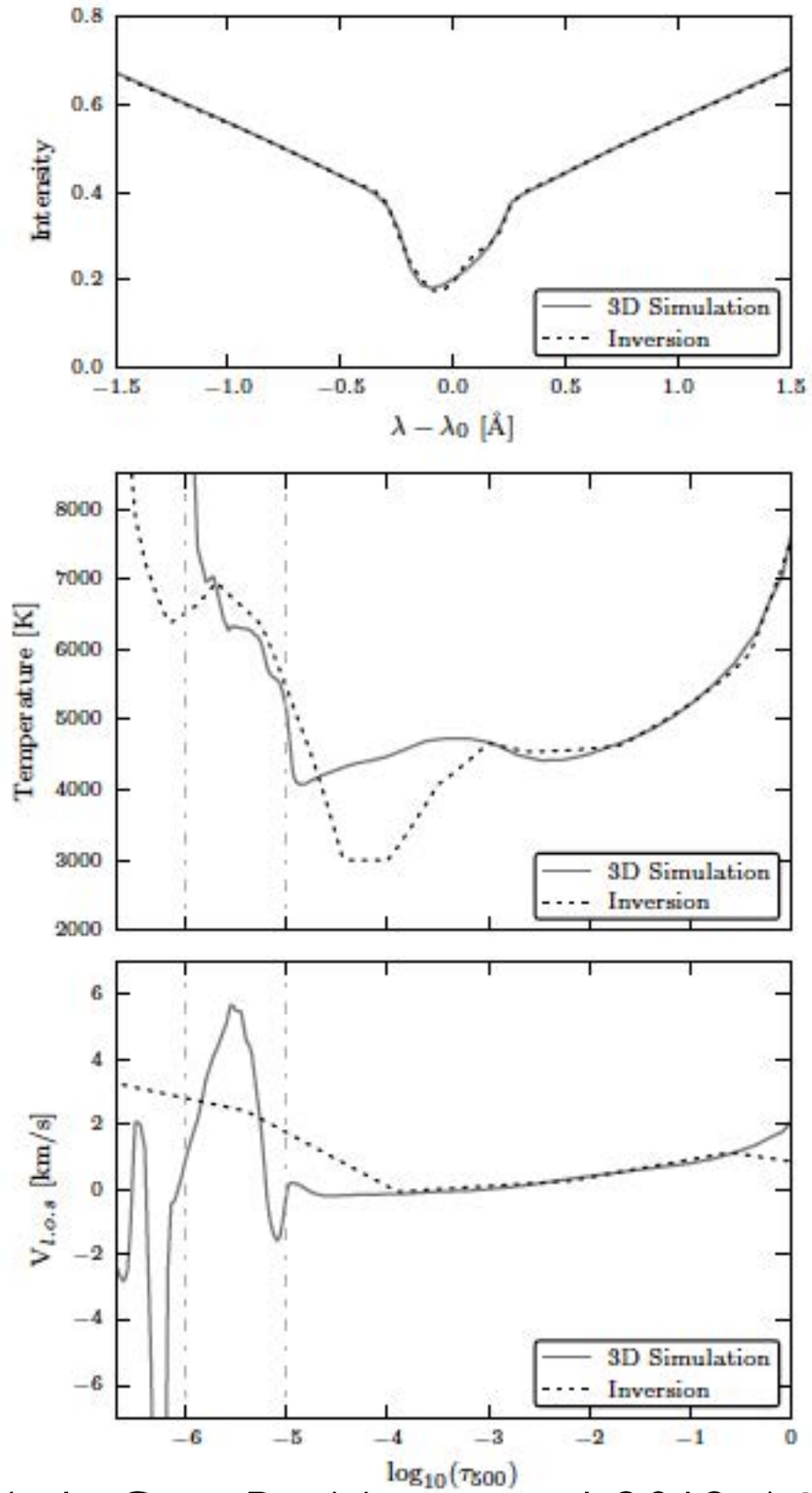
# Inversions with Nicole




de la Cruz Rodriguez et al, 2012, A&A 543, A34

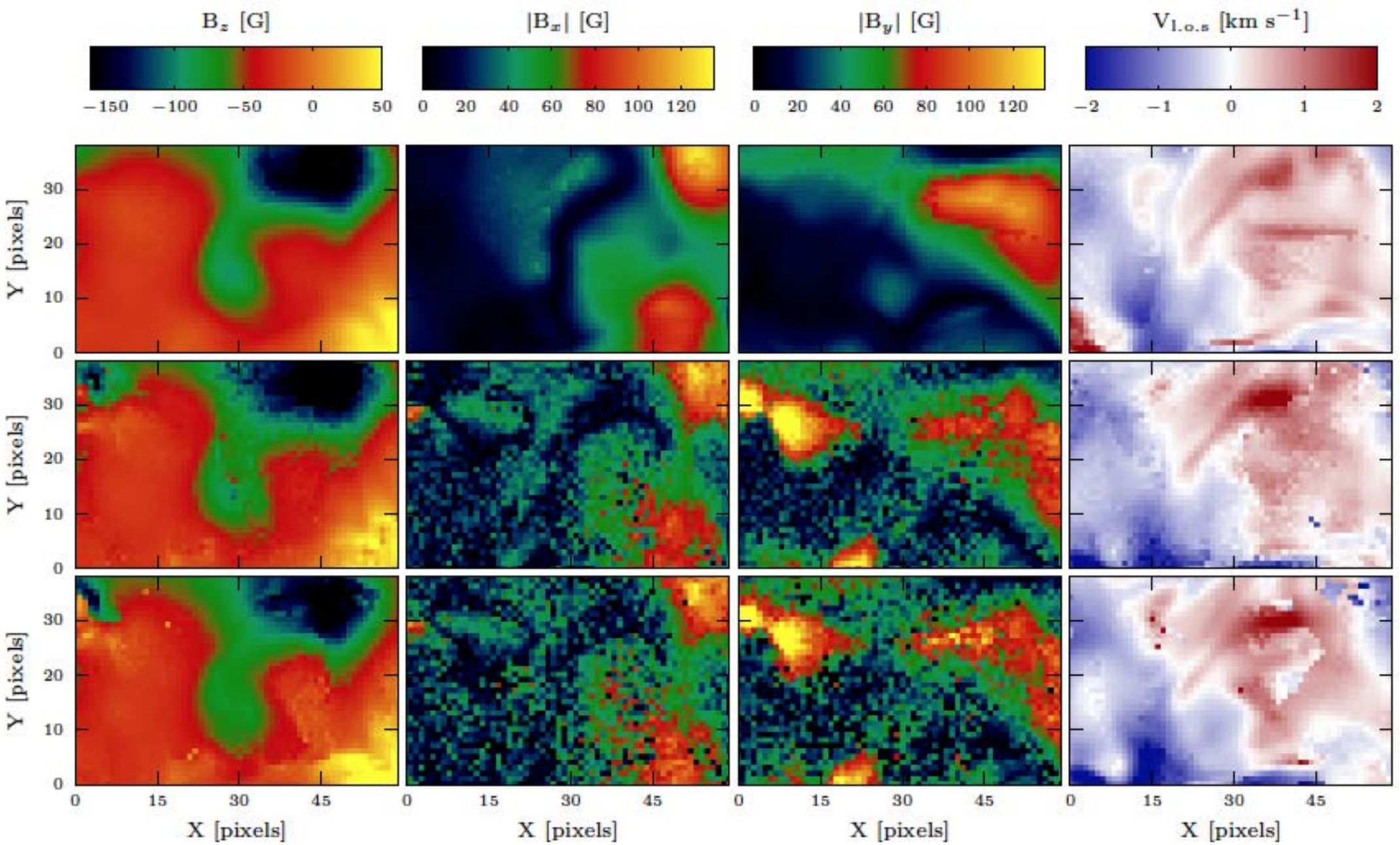
# Inversions with Nicole




de la Cruz Rodriguez et al, 2012, A&A 543, A34

# Inversions with Nicole



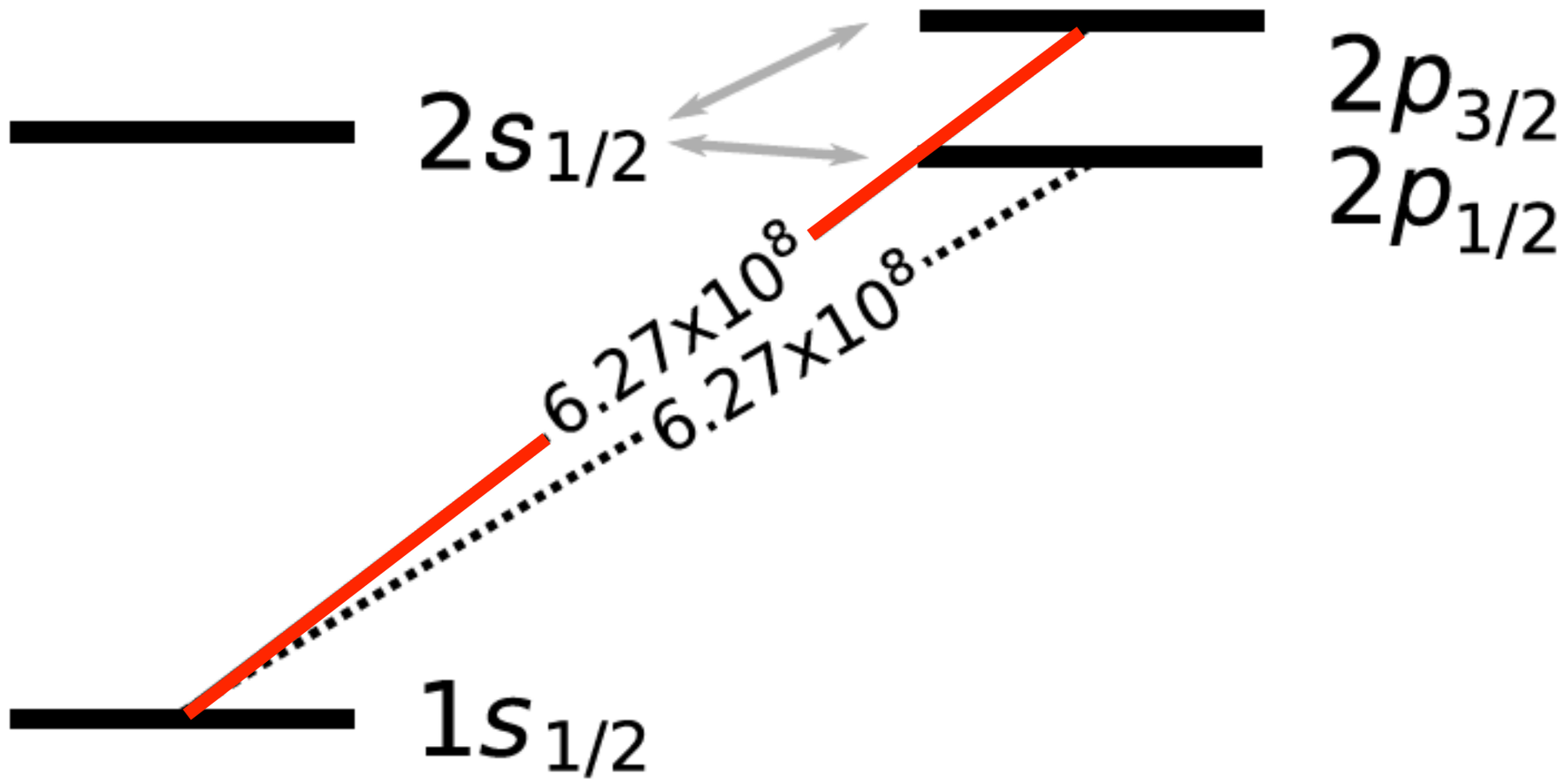

Sim

NLTE

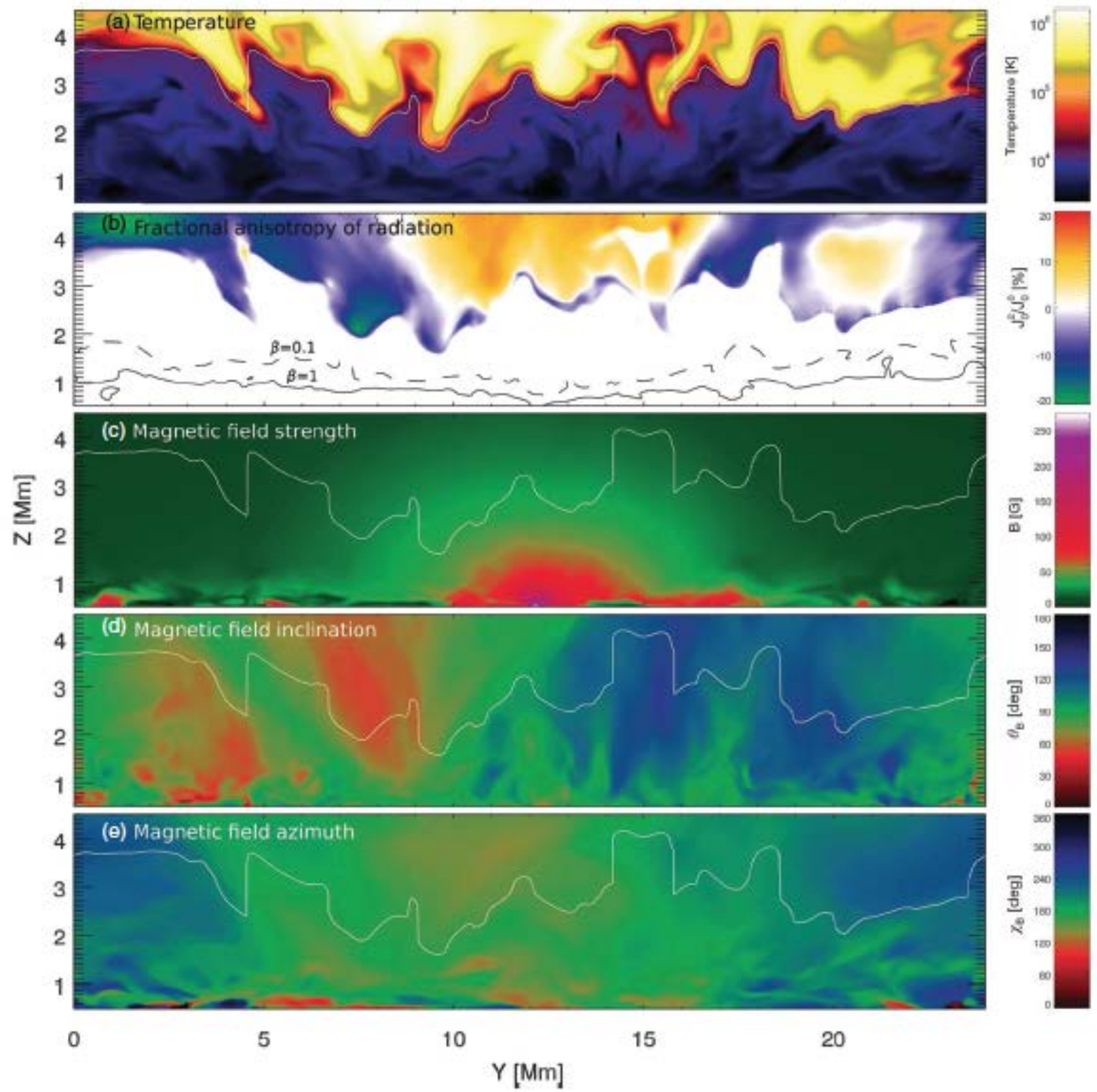
LTE

de la Cruz Rodriguez et al, 2012, A&A 543, A34

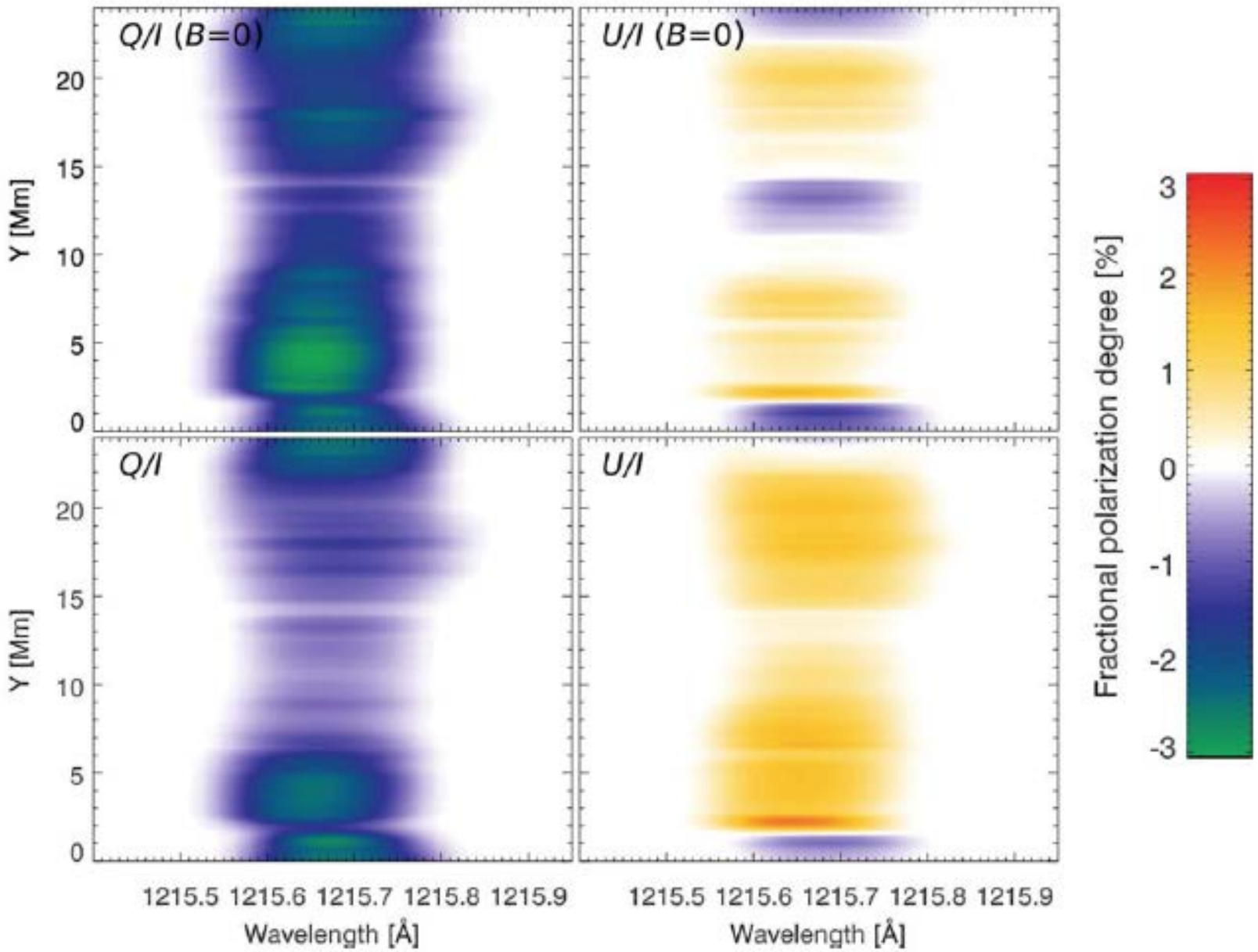
# Ly-alpha



# Ly-alpha diagnostics

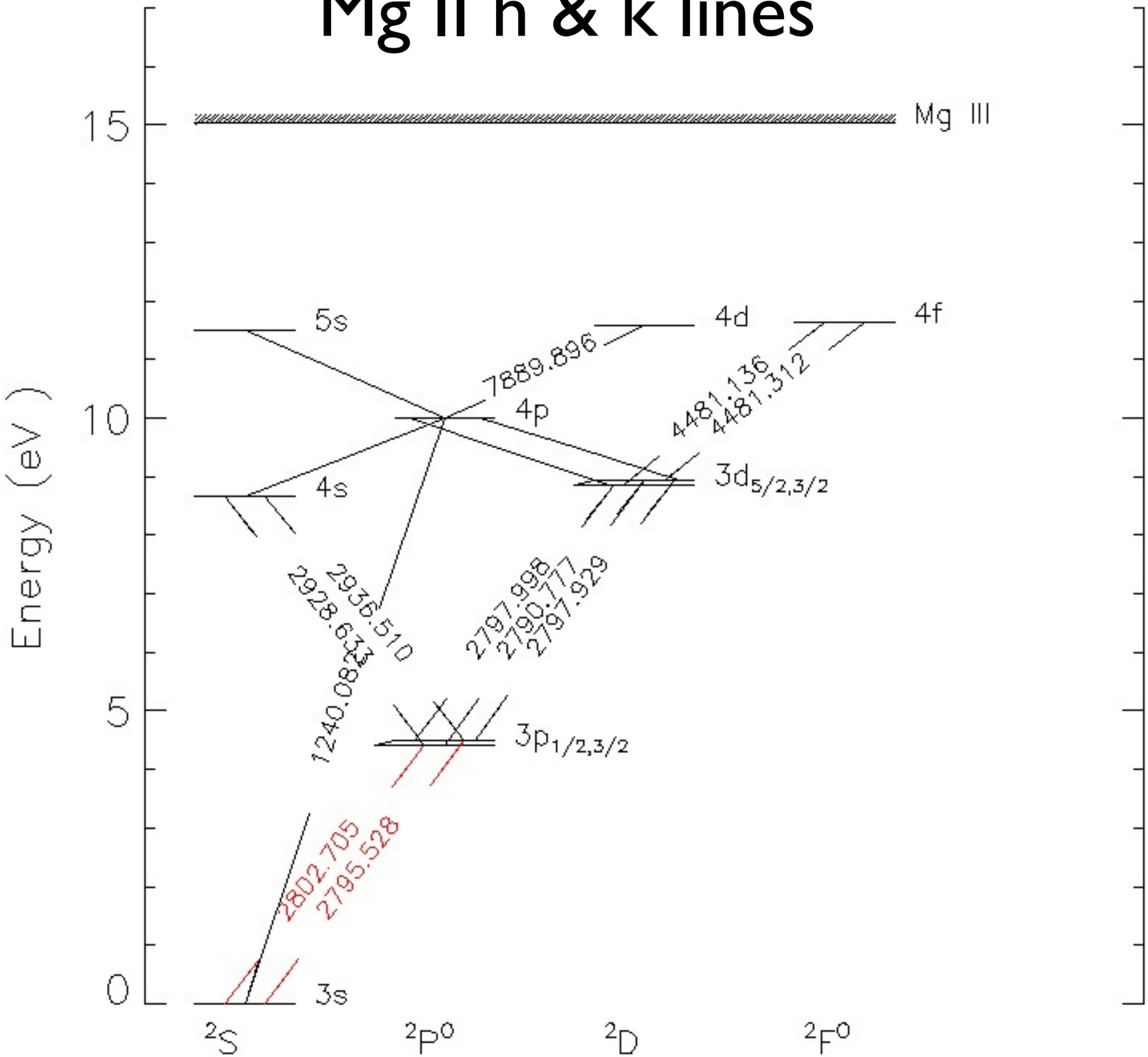



Stěpán et al, 2012, ApJ 758, L43

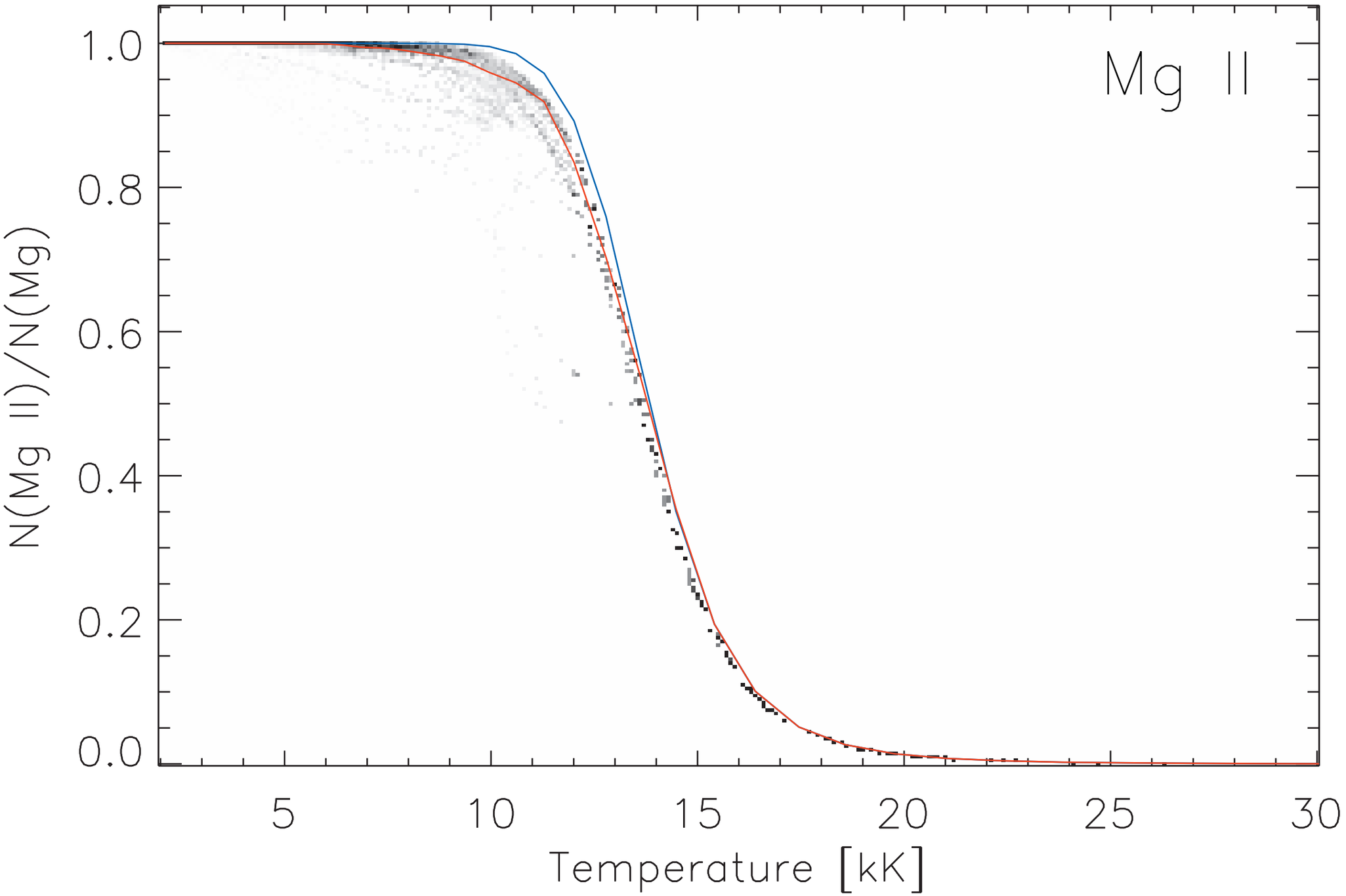



Stěpán et al, 2012, ApJ 758, L43

# Mg II h & k lines

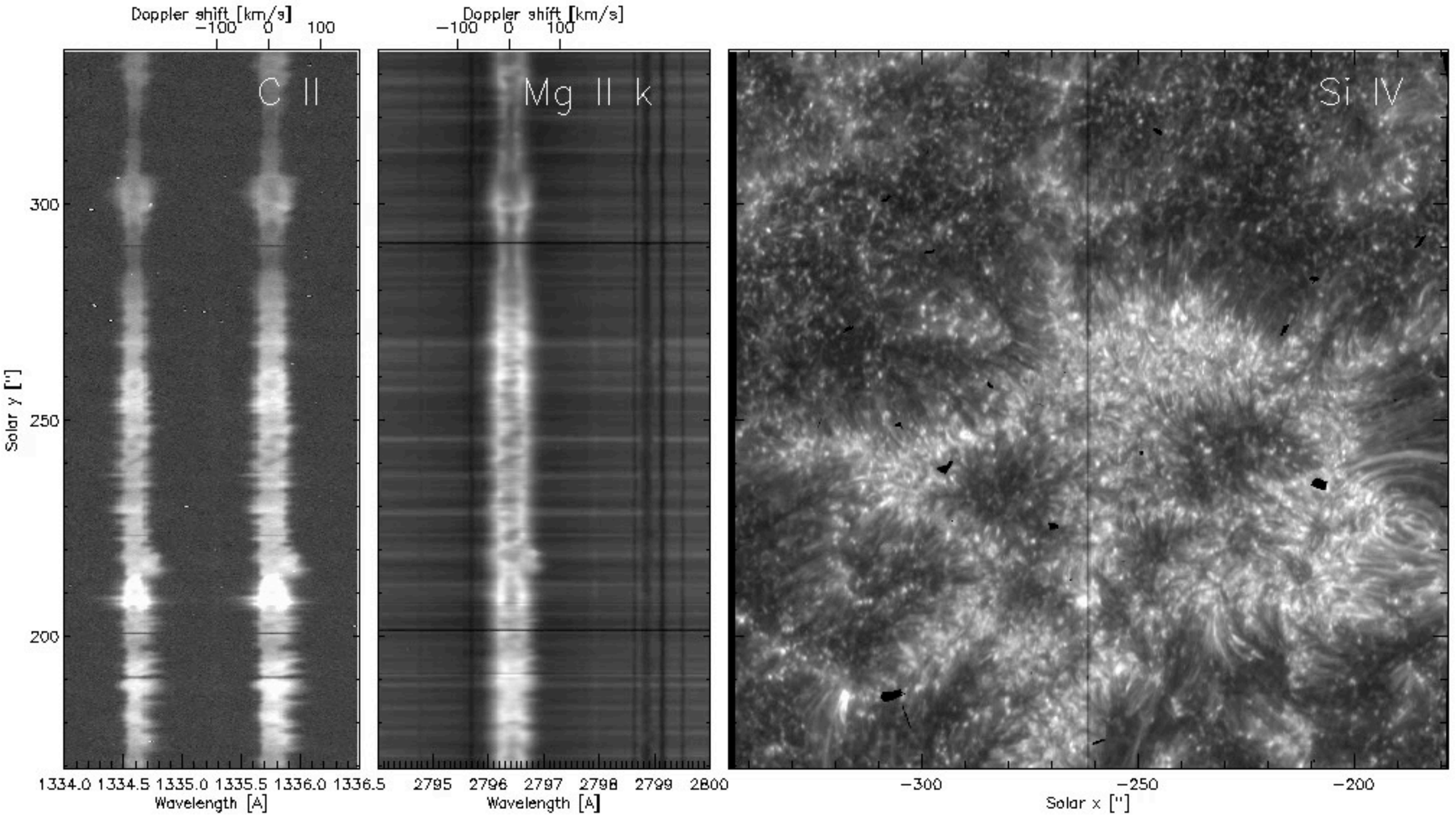


# Mg has 18 times the abundance of Ca formed 3 scale-heights higher up

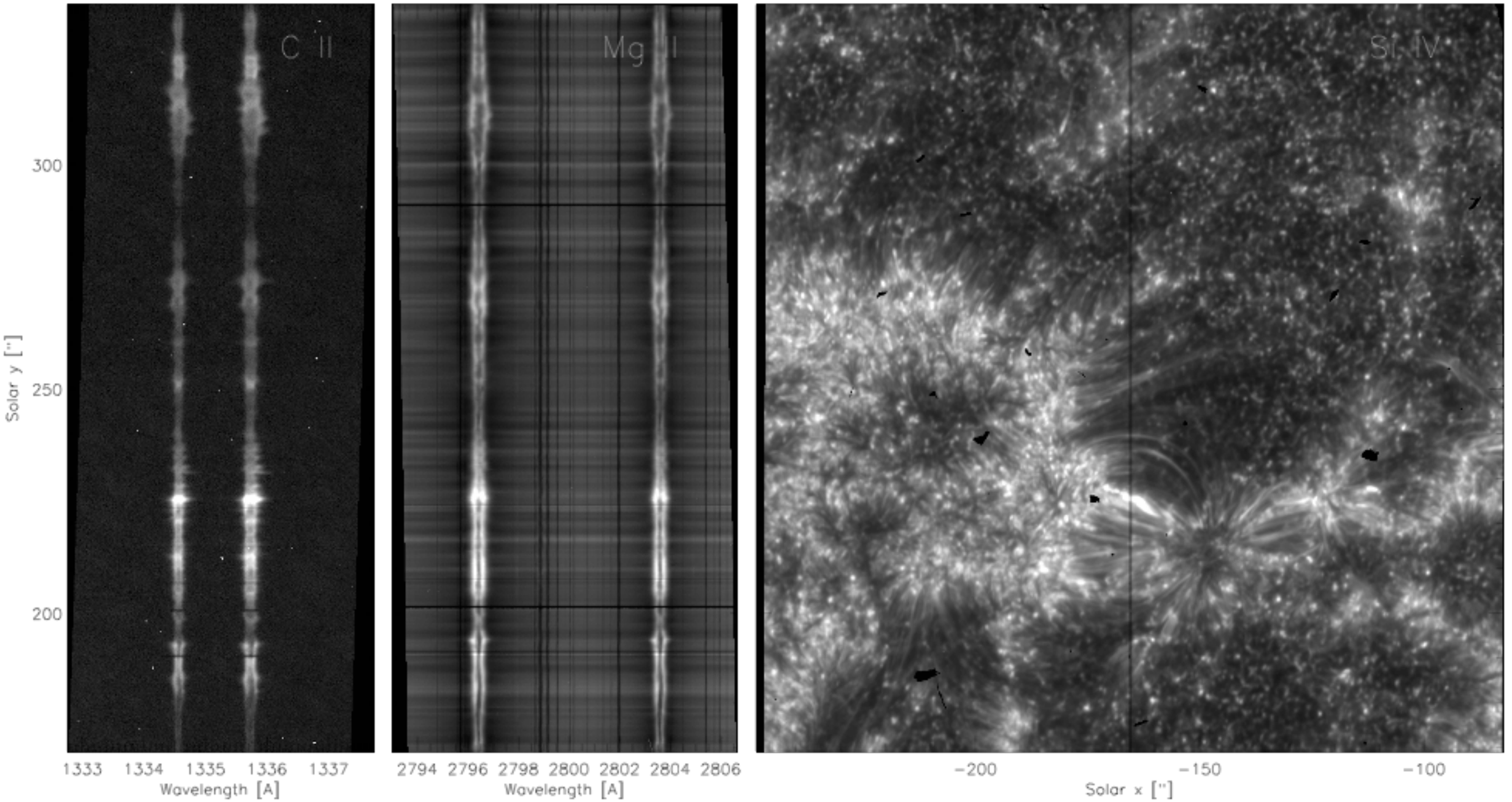


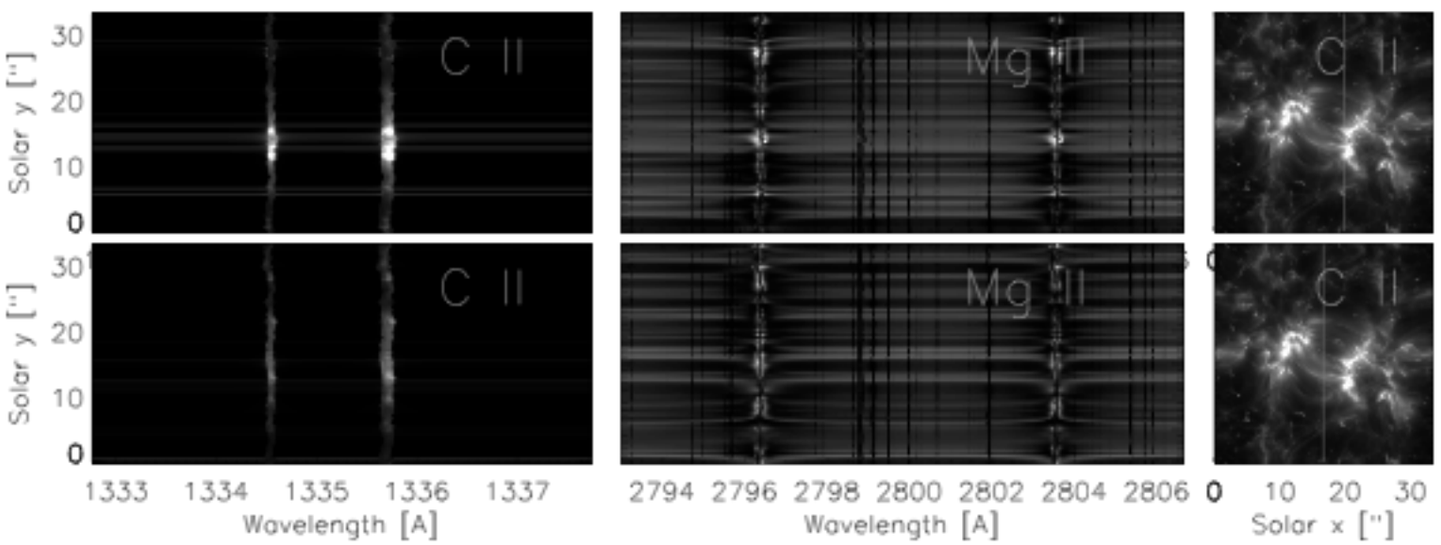
# IRIS observations

30s exposures, 400 step raster

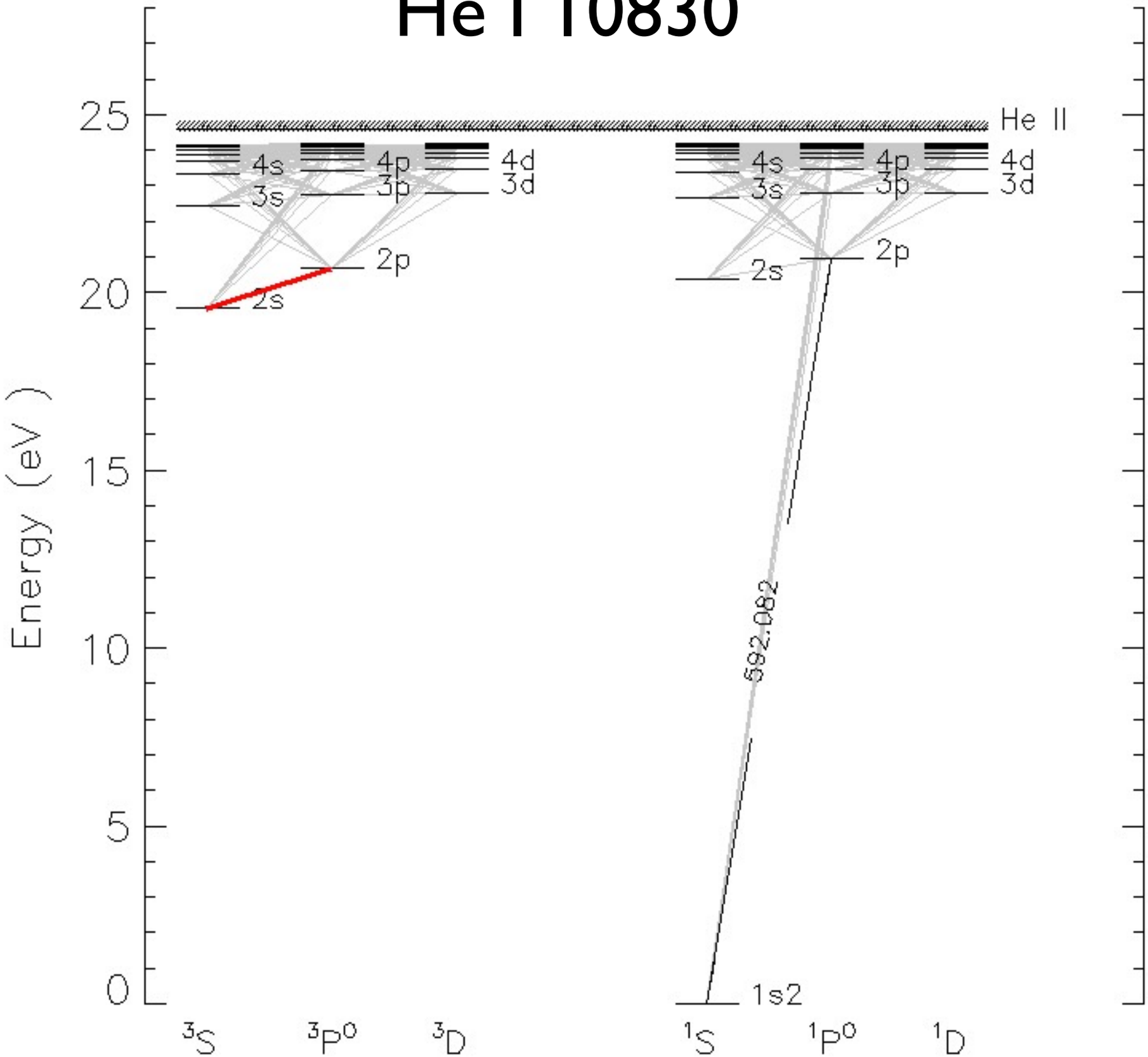



20131018_195030_3820013446


C II
Mg II
Si IV
Solar y ["]
300
250
200
1333 1334 1335 1336 1337
Wavelength [A]
2794 2796 2798 2800 2802 2804 2806
Wavelength [A]
−200
−150
−100
Solar x ["]

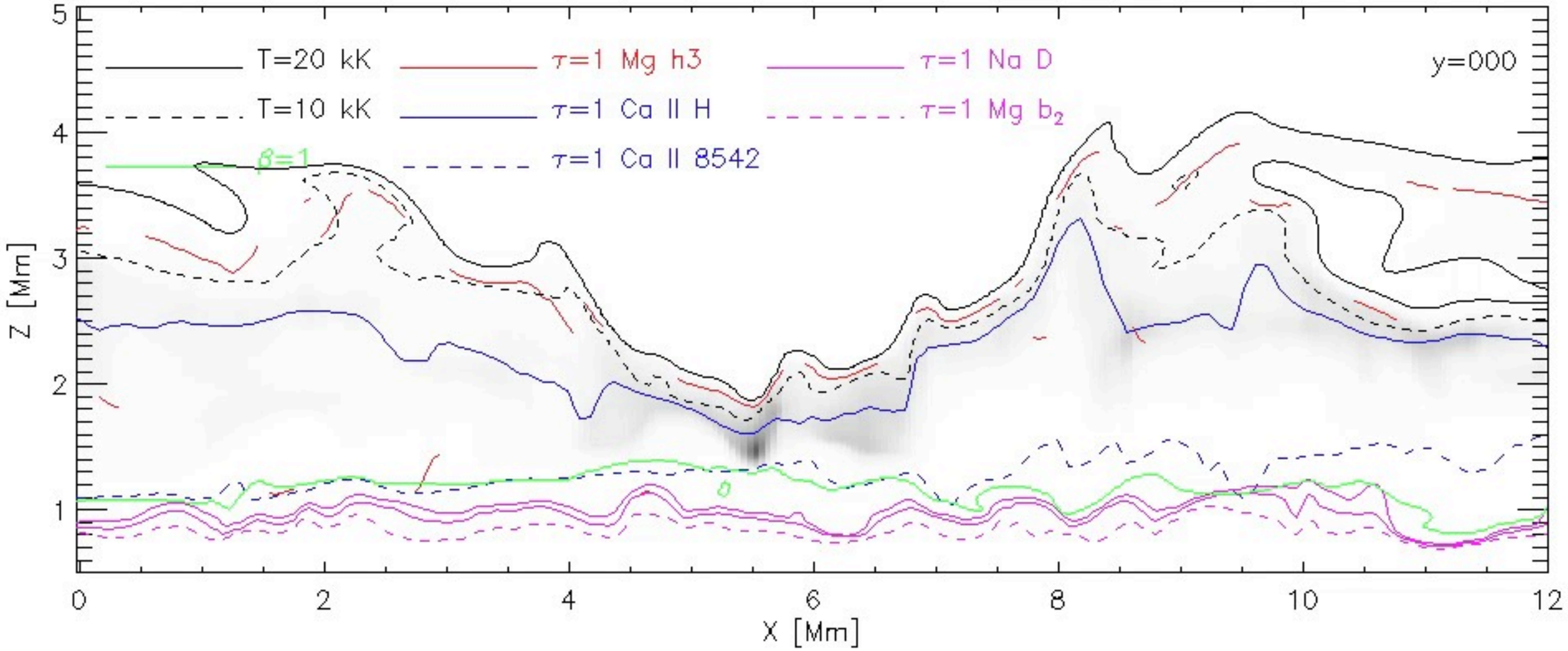

C II
Mg II
C II
C II
Mg II
C II
Solar y ["]
30
20
10
0
1333 1334 1335 1336 1337
Wavelength [A]
2794 2796 2798 2800 2802 2804 2806
Wavelength [A]
0 10 20 30
Solar x ["]

# He I 10830


25
20
15
10
5
0
Energy (eV)
He II
4s
4p
4d
3s
3p
3d
2p
2s
592.082
1s2
3S
3P°
3D
1S
1P°
1D

# Different diagnostics

## Grey-scale: $C_I$ for He 10830



# Conclusions

- diagnostic lines cover the whole chromosphere
- Formation height very corrugated surface
- Inversion possible but difficult
- Modeling is a necessary tool