Heating requirements of the solar chromosphere

Mats Carlsson

Institute of Theoretical Astrophysics, Univ Oslo

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SEVENTH FRAMEWORK PROGRAMME

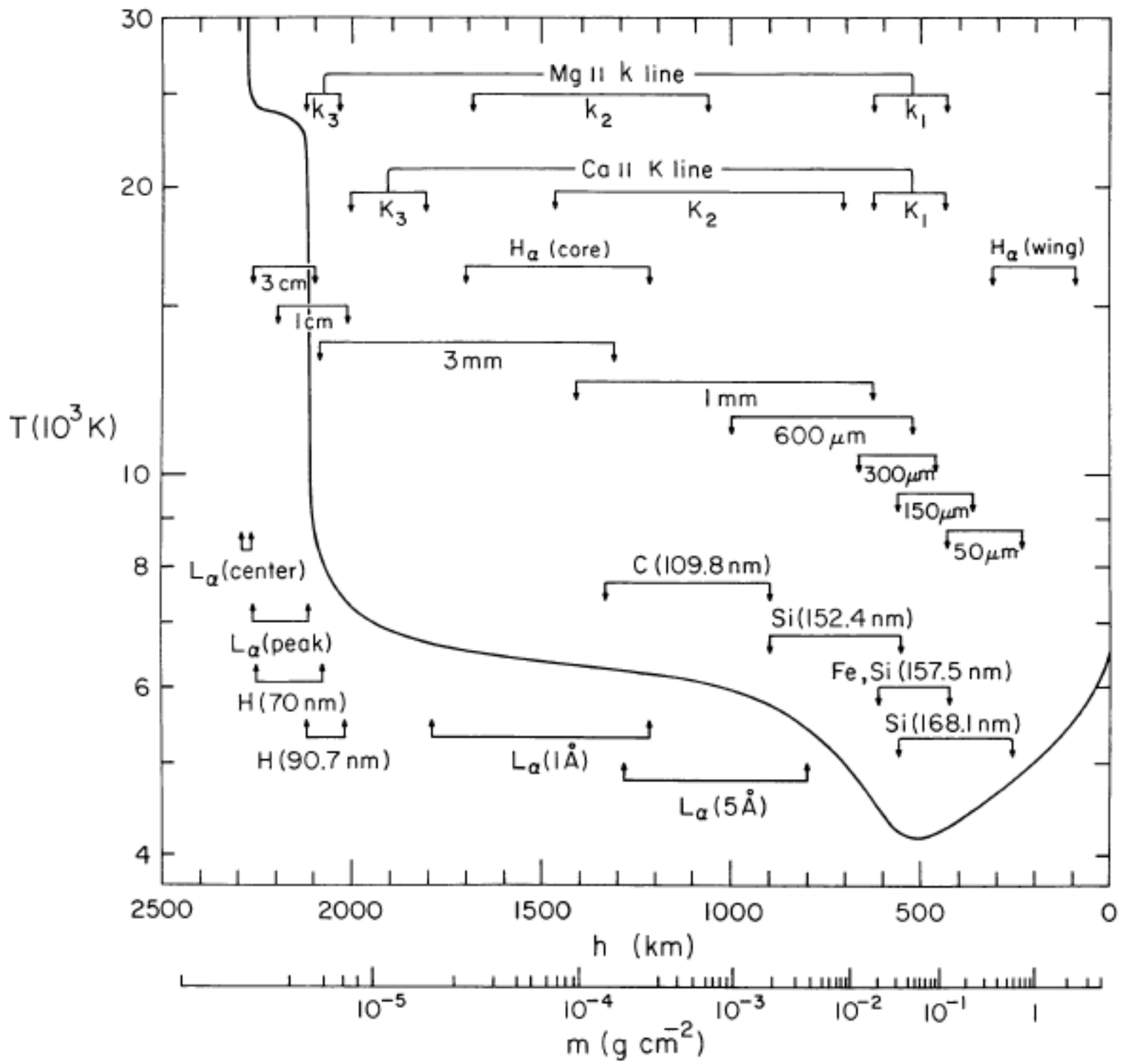
ERC: Physics of the Solar Chromosphere

Why is the chromosphere important?

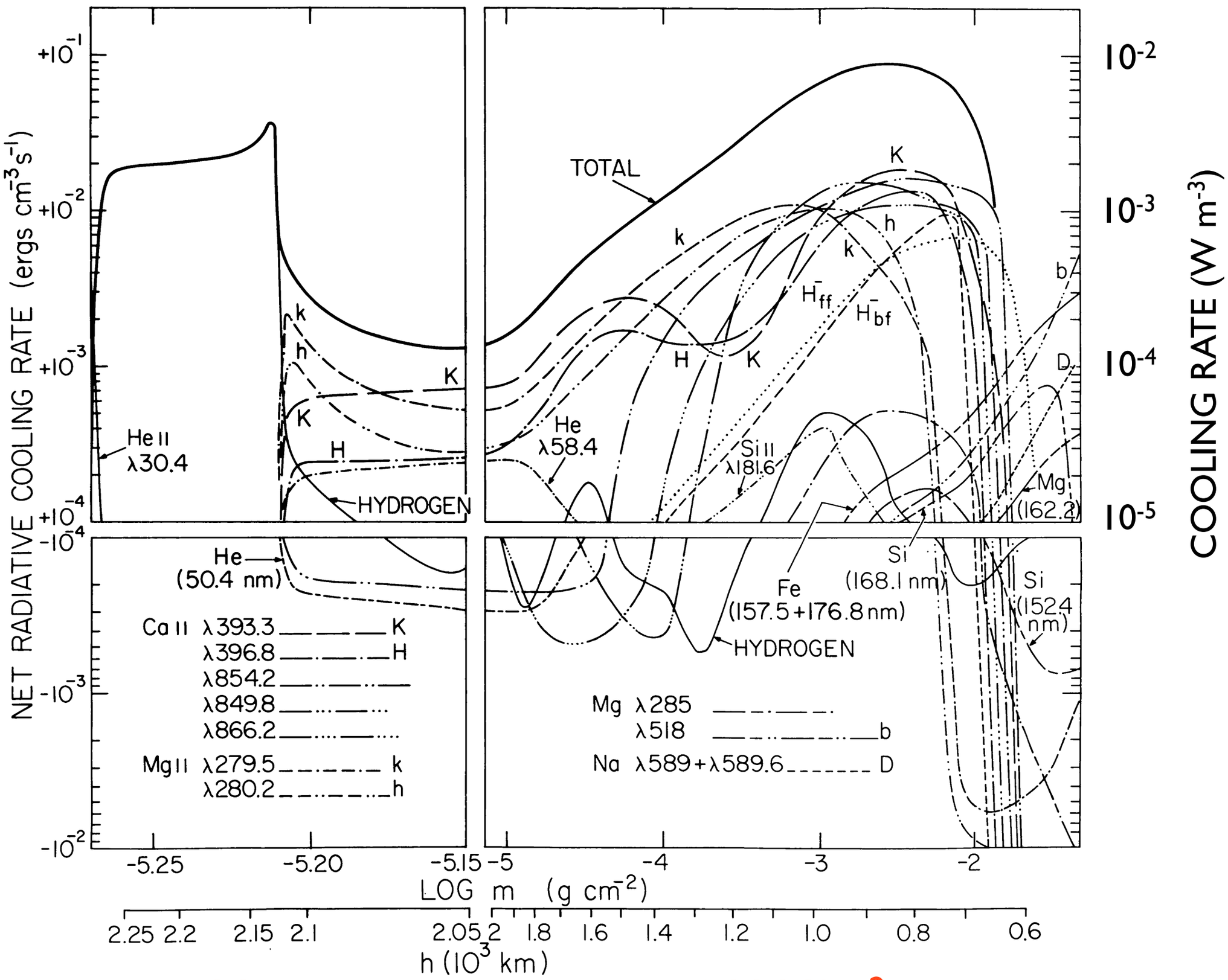
- Coronal heating and mass balance
  - energy/mass go through chromosphere
  - chromosphere needs 10-100 times more energy
- $P_g/P_B = 1$
  - from forced B to force-free
  - wave mode conversion layer
- Ion-neutral effects
  - ionization degree 10^{-4} - 1
  - non-magnetized - magnetized

Semi-empirical model

VAL3C

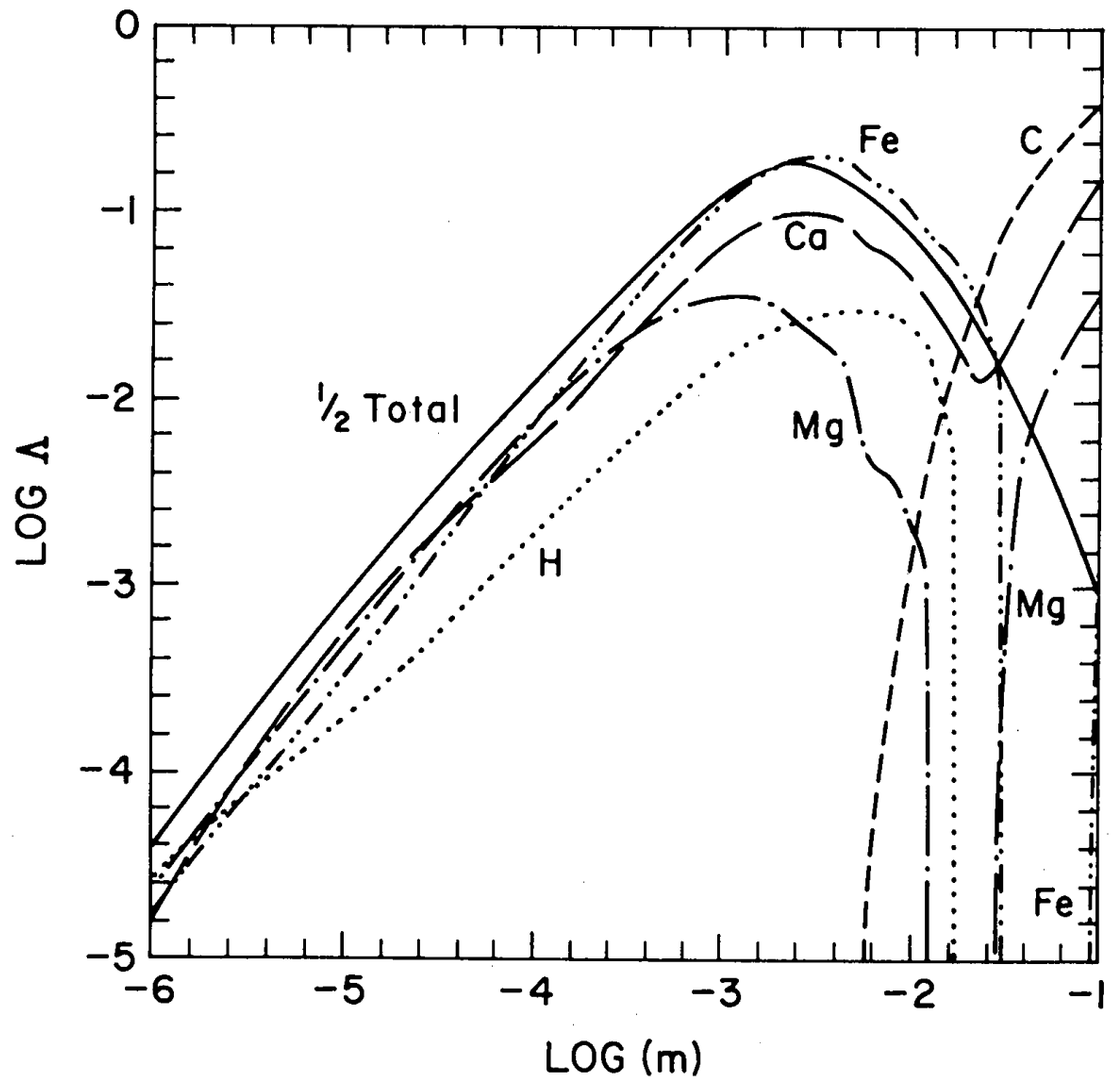


Heating requirement, VAL3C



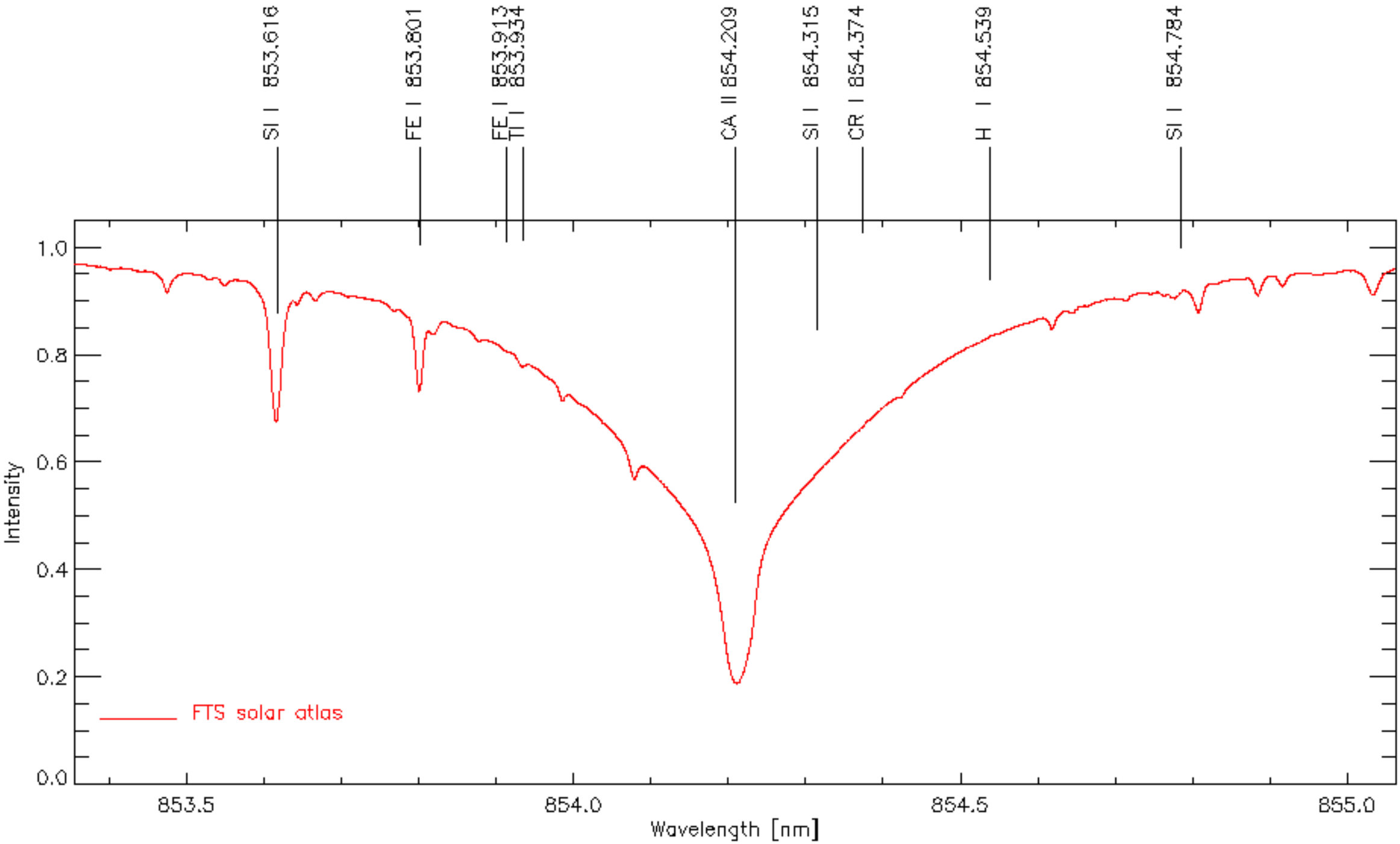
Heating requirement 4 kW/m^2

Heating requirement



Anderson, Athay 1989, ApJ 346, 1010

- Fe lines important (1/2 the cooling)
- Energy requirement 12 kW/m2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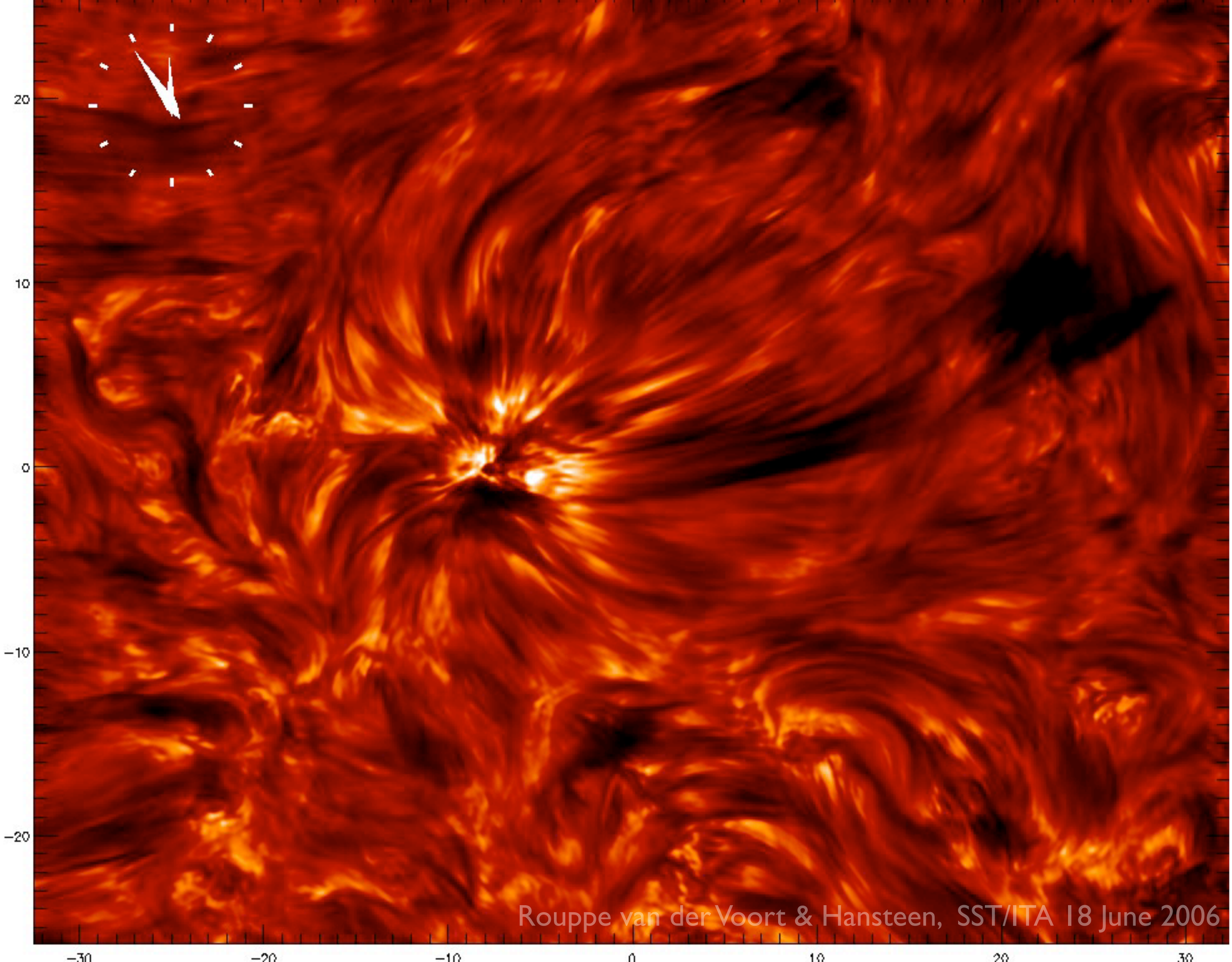
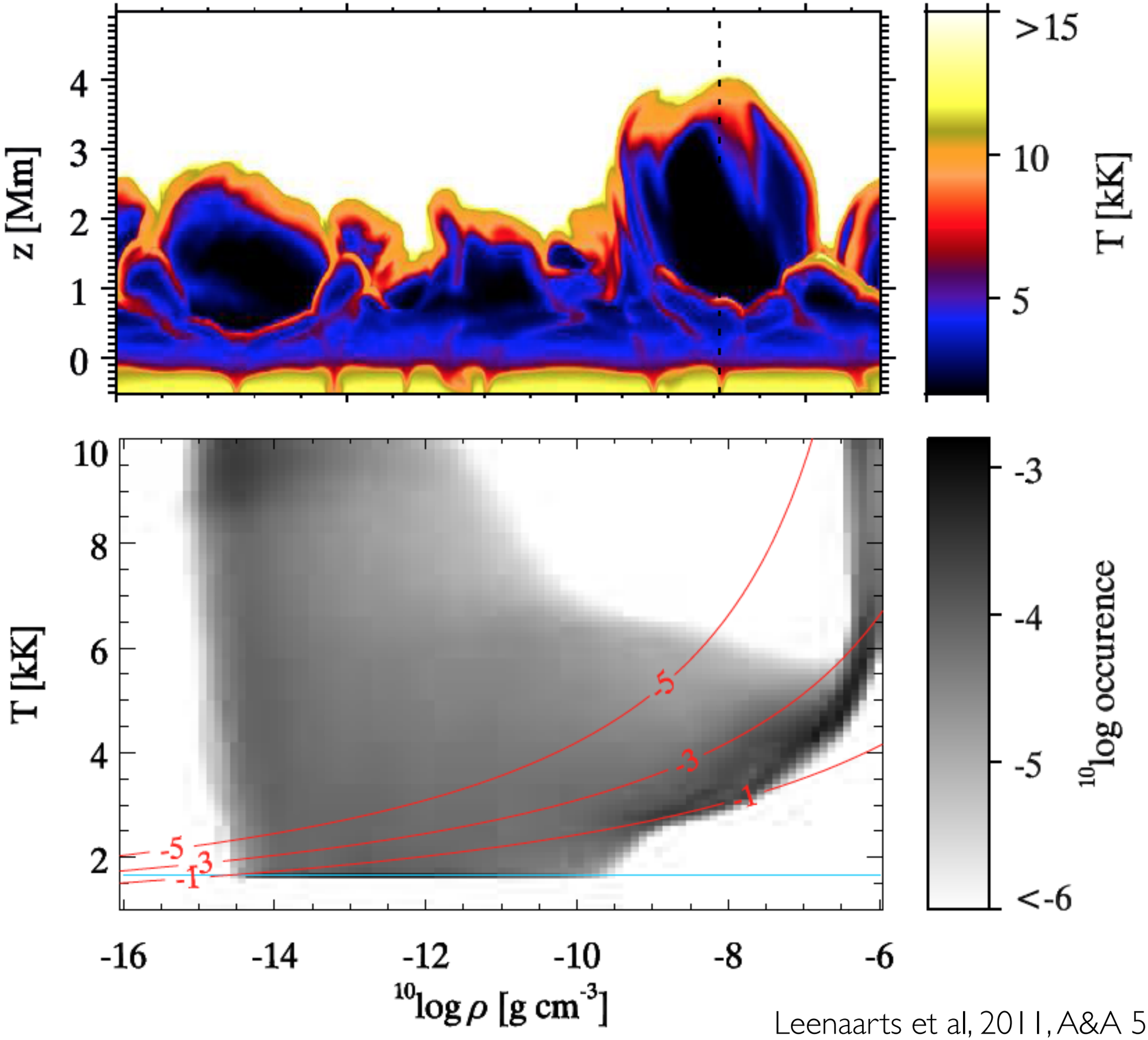
FE I 853.801
FE I 853.913
TI I 853.934
CA II 854.209
SI I 854.315
CR I 854.374
H I 854.539
SI I 854.784
1.0
0.8
0.6
0.4
0.2
0.0
Intensity
FTS solar atlas
853.5
854.0
854.5
855.0
Wavelength [nm]



Rouppe van der Voort & Hansteen, SST/ITA 18 June 2006

Heating requirement

- Cannot be determined observationally
- Model dependent
- Theoretical models have to produce synthetic observables
- Need detailed observations with maximum diagnostic power

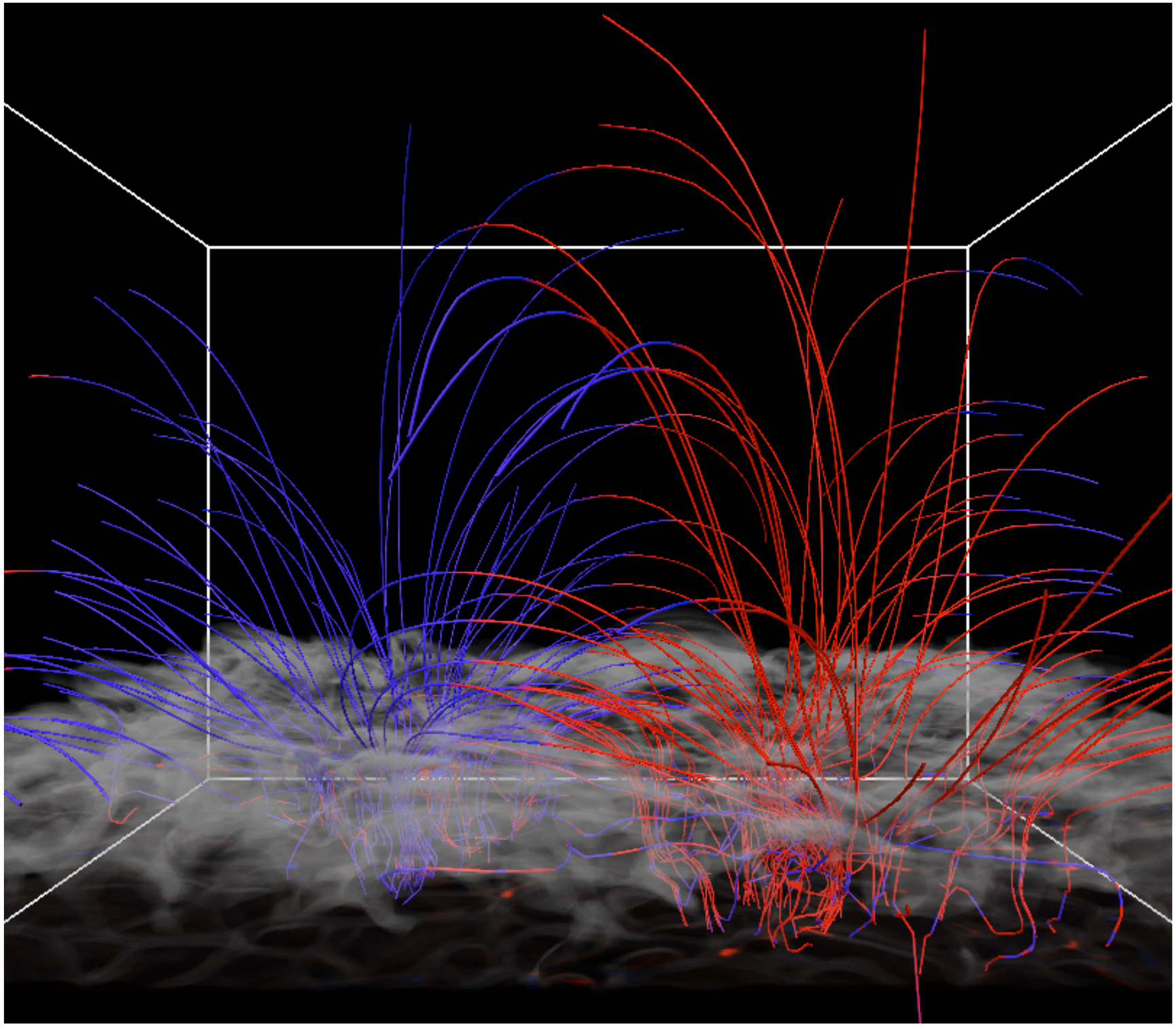


Leenaarts et al, 2011, A&A 530, A124

“enhanced network” simulation

http://sdc.uio.no/search/simulations

IRIS Technical Note 33; Carlsson et al 2014



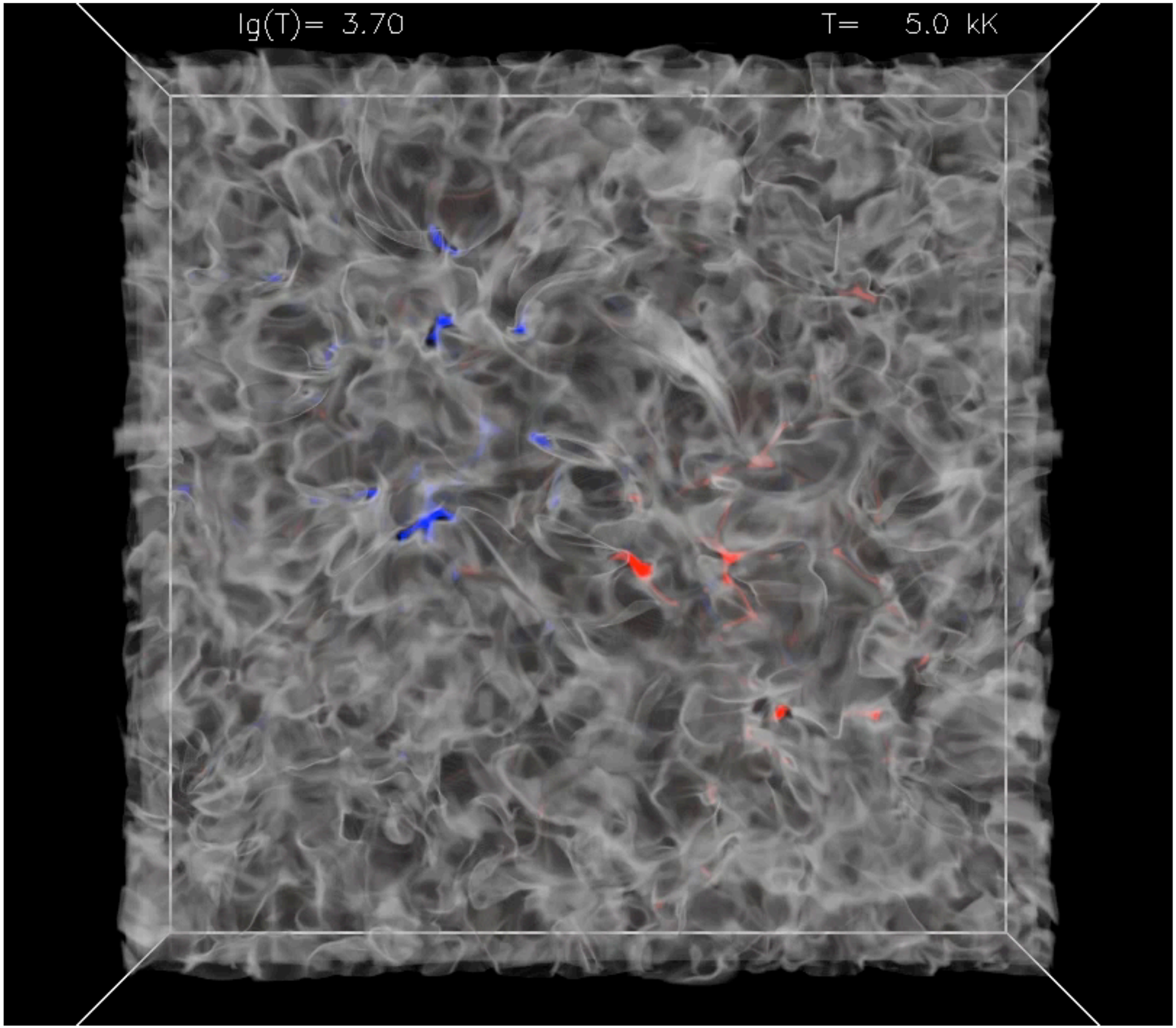
Corona

Transition region

Chromosphere

Photosphere

Convection zone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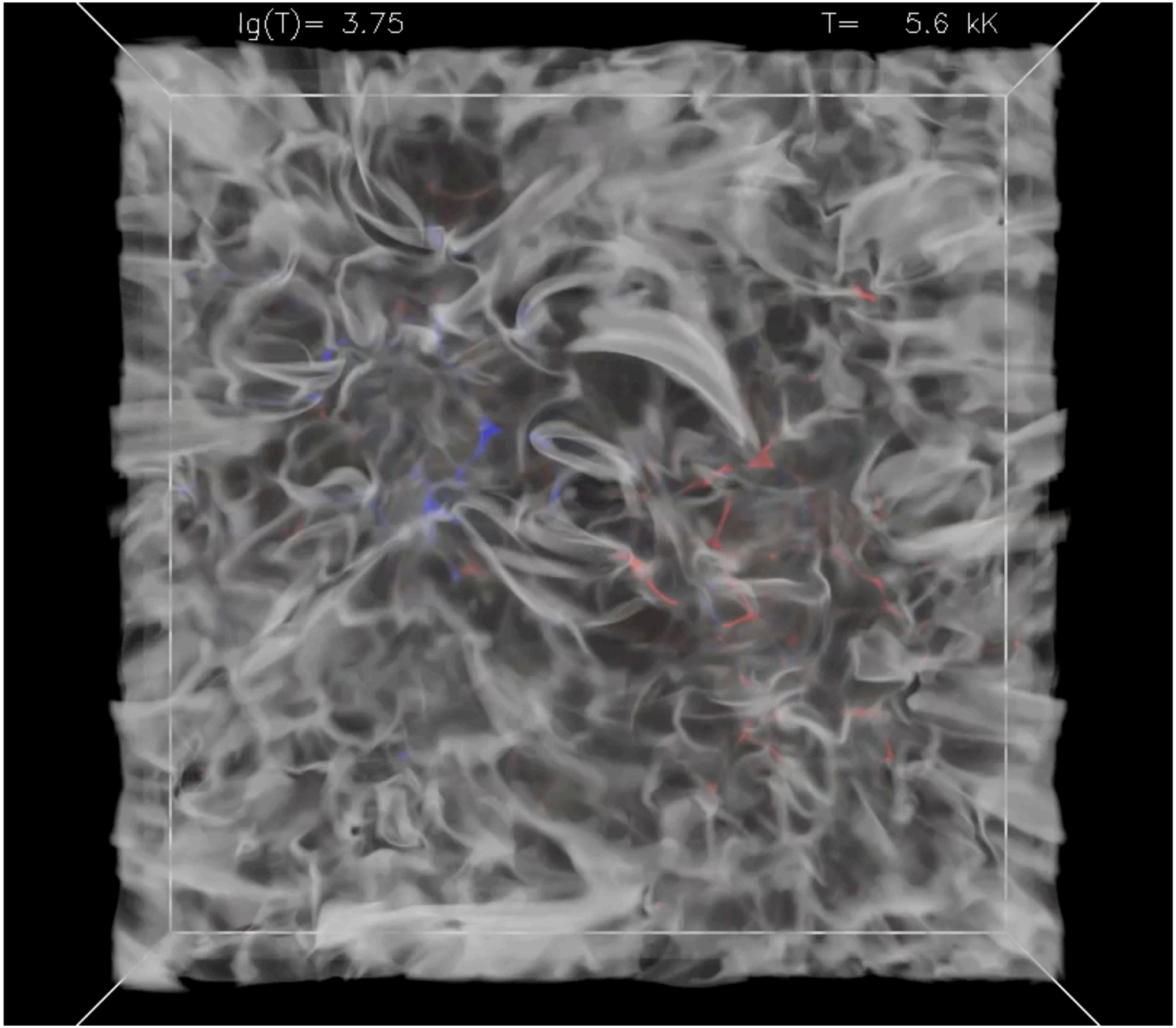
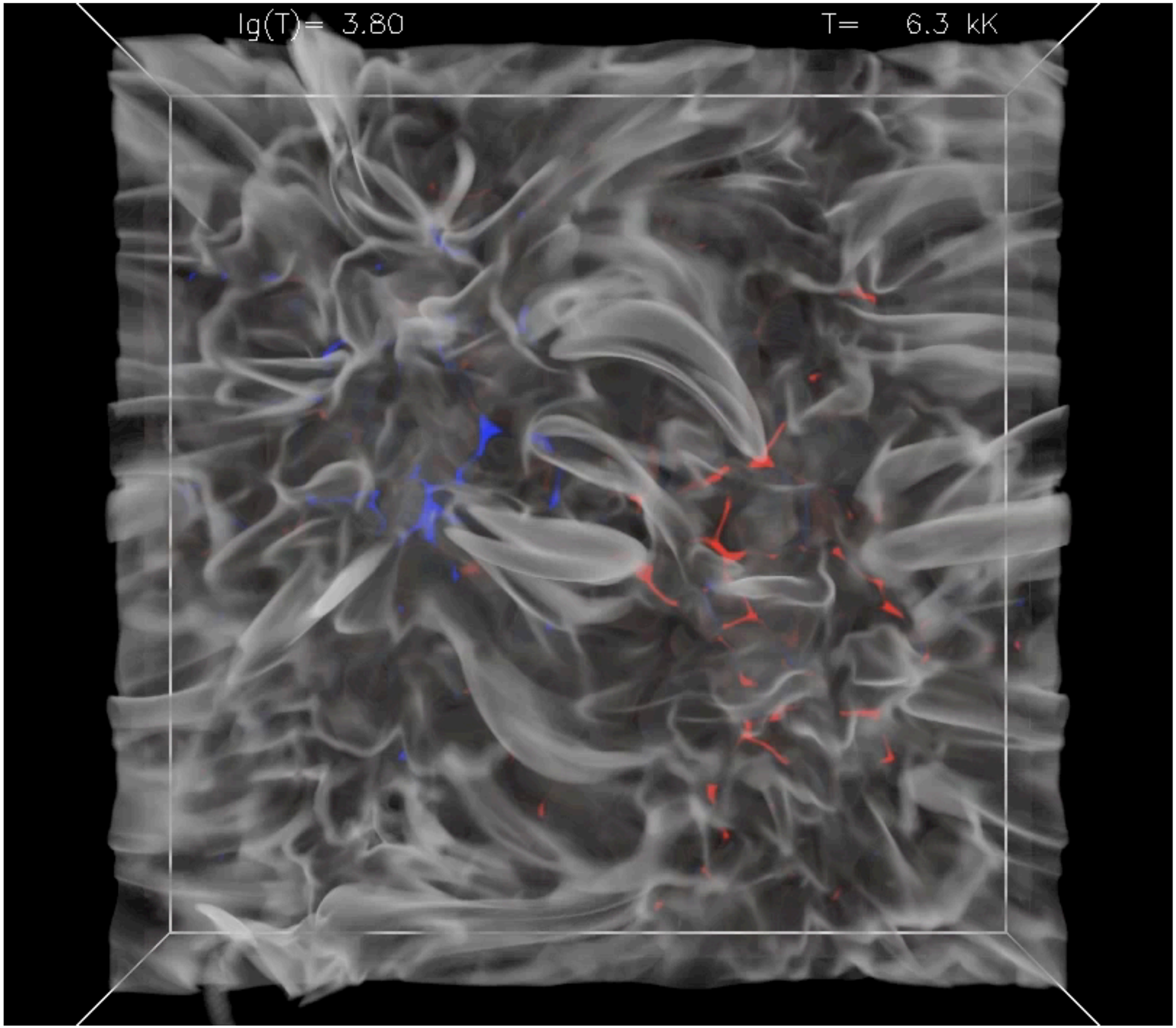
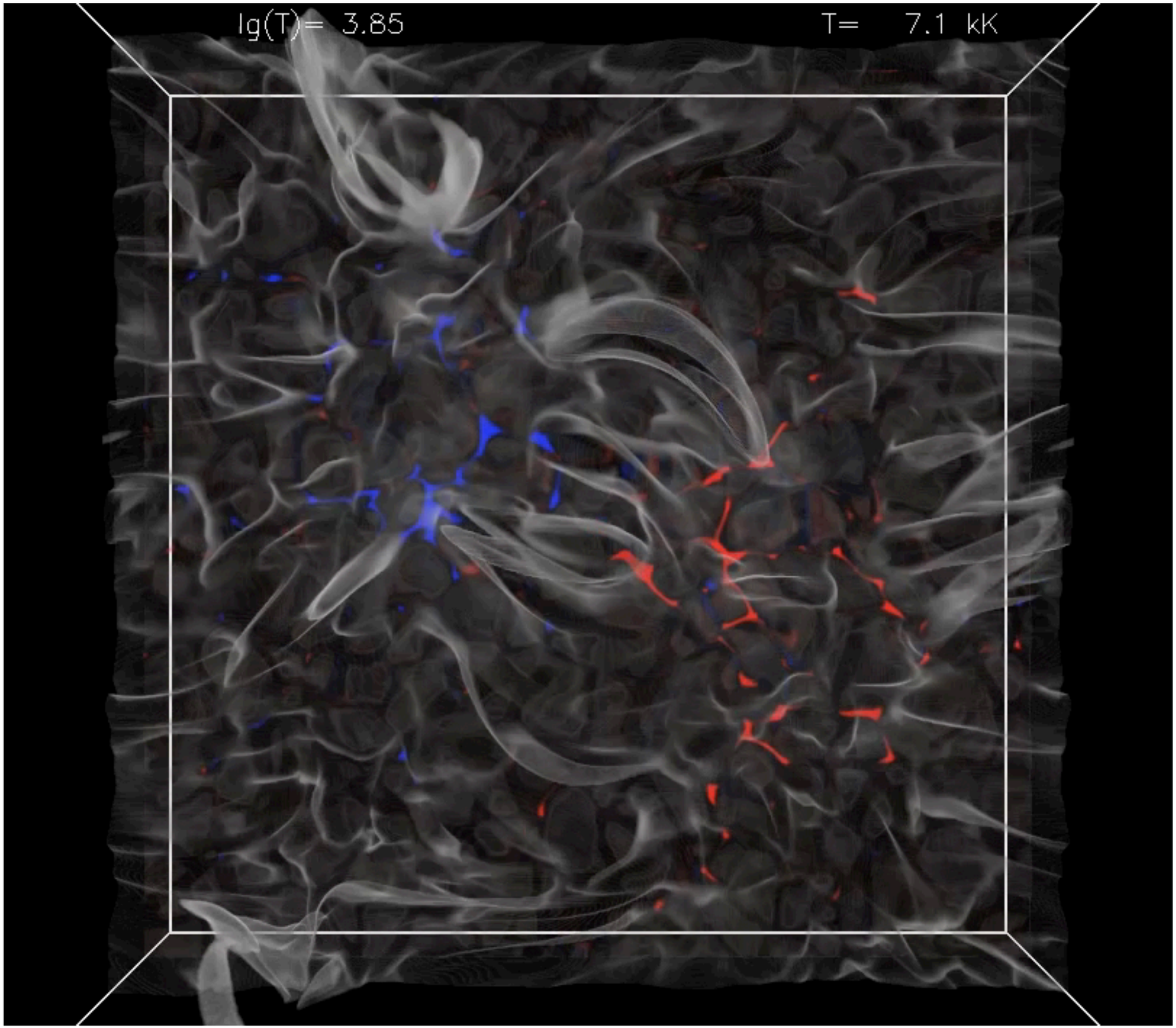
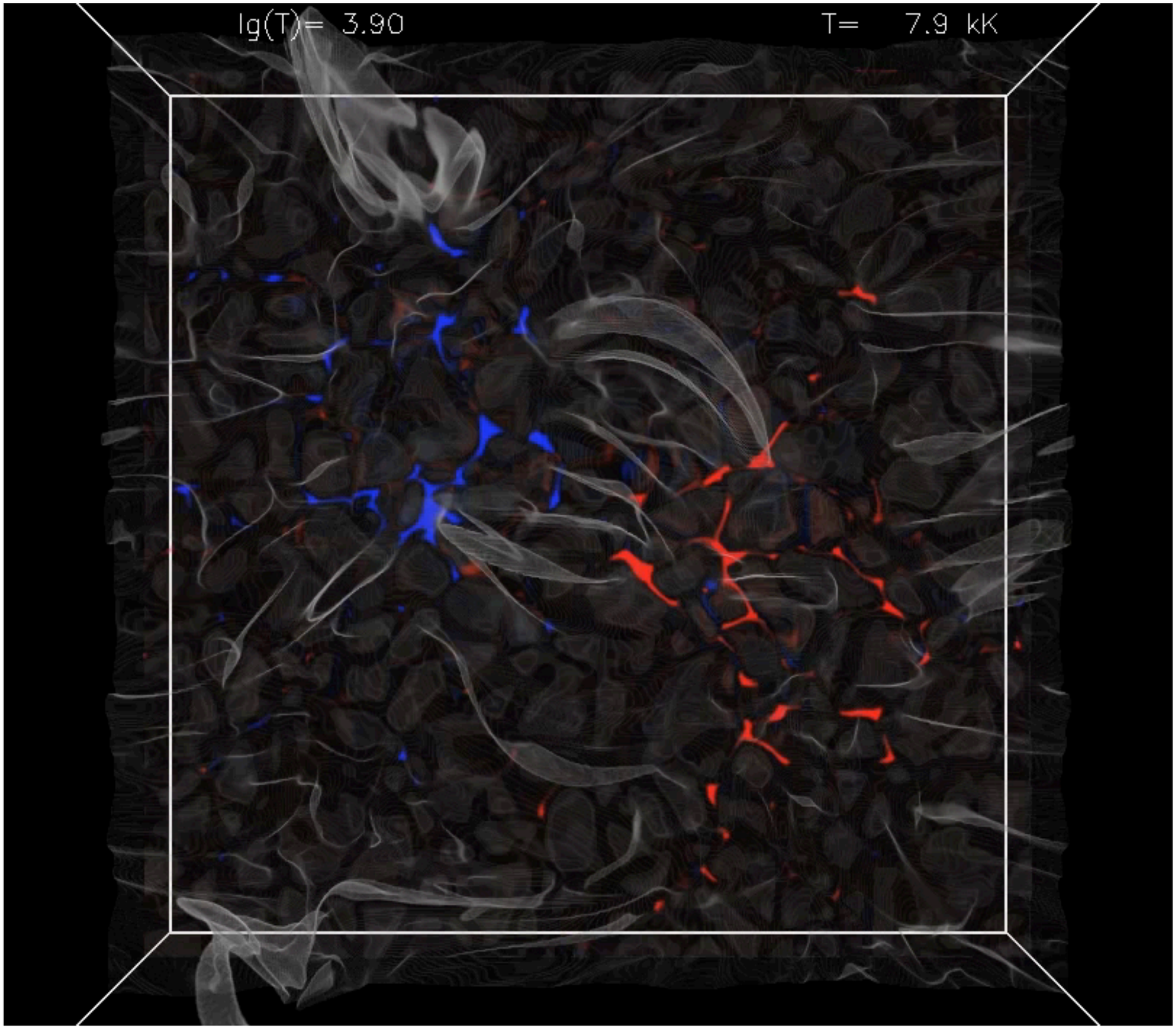
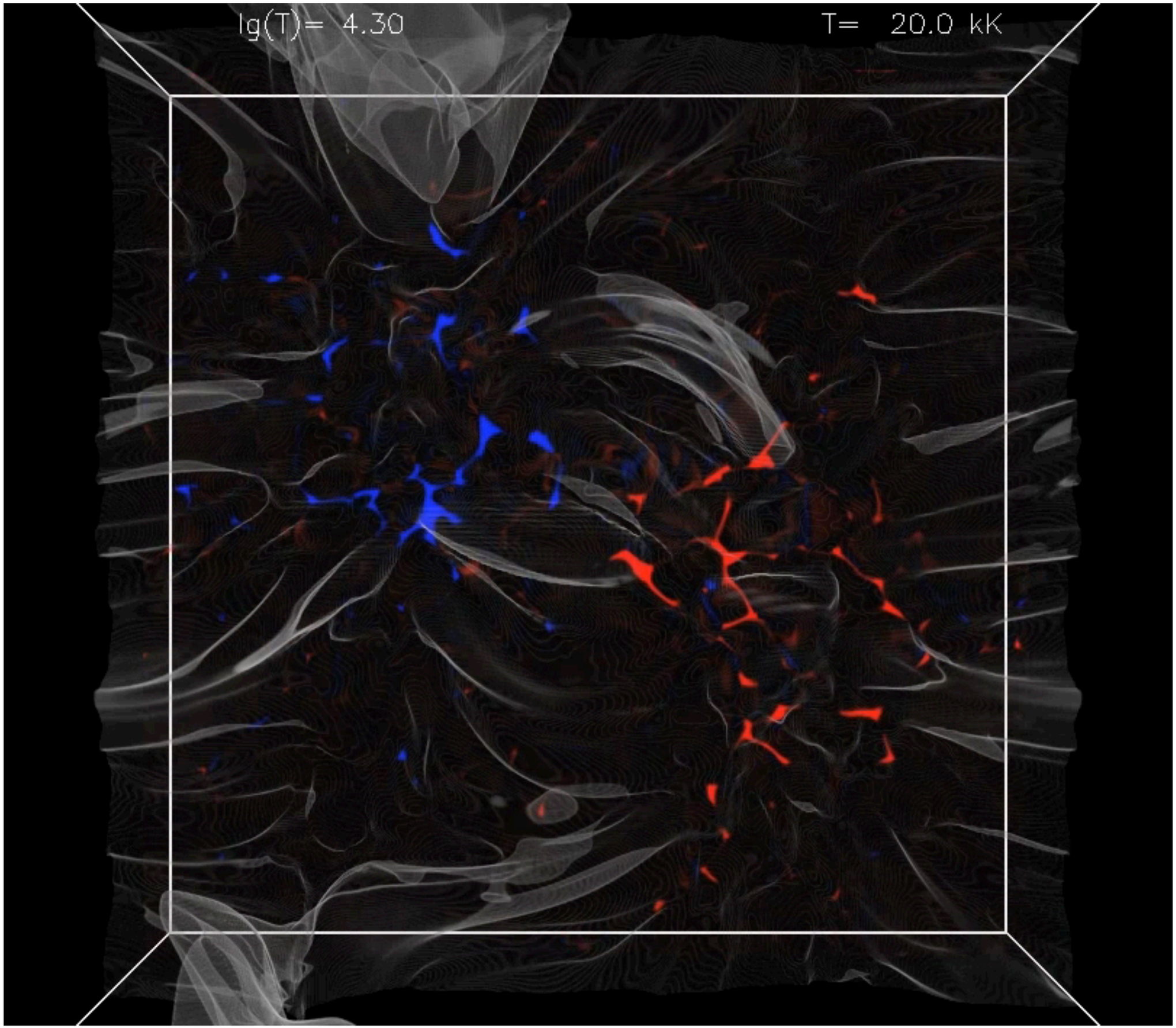
T= 5.0 kK


lg(T)= 3.75
T= 5.6 kK


lg(T)= 3.80
T= 6.3 kK


lg(T)= 3.85
T= 7.1 kK


lg(T)= 3.90
T= 7.9 kK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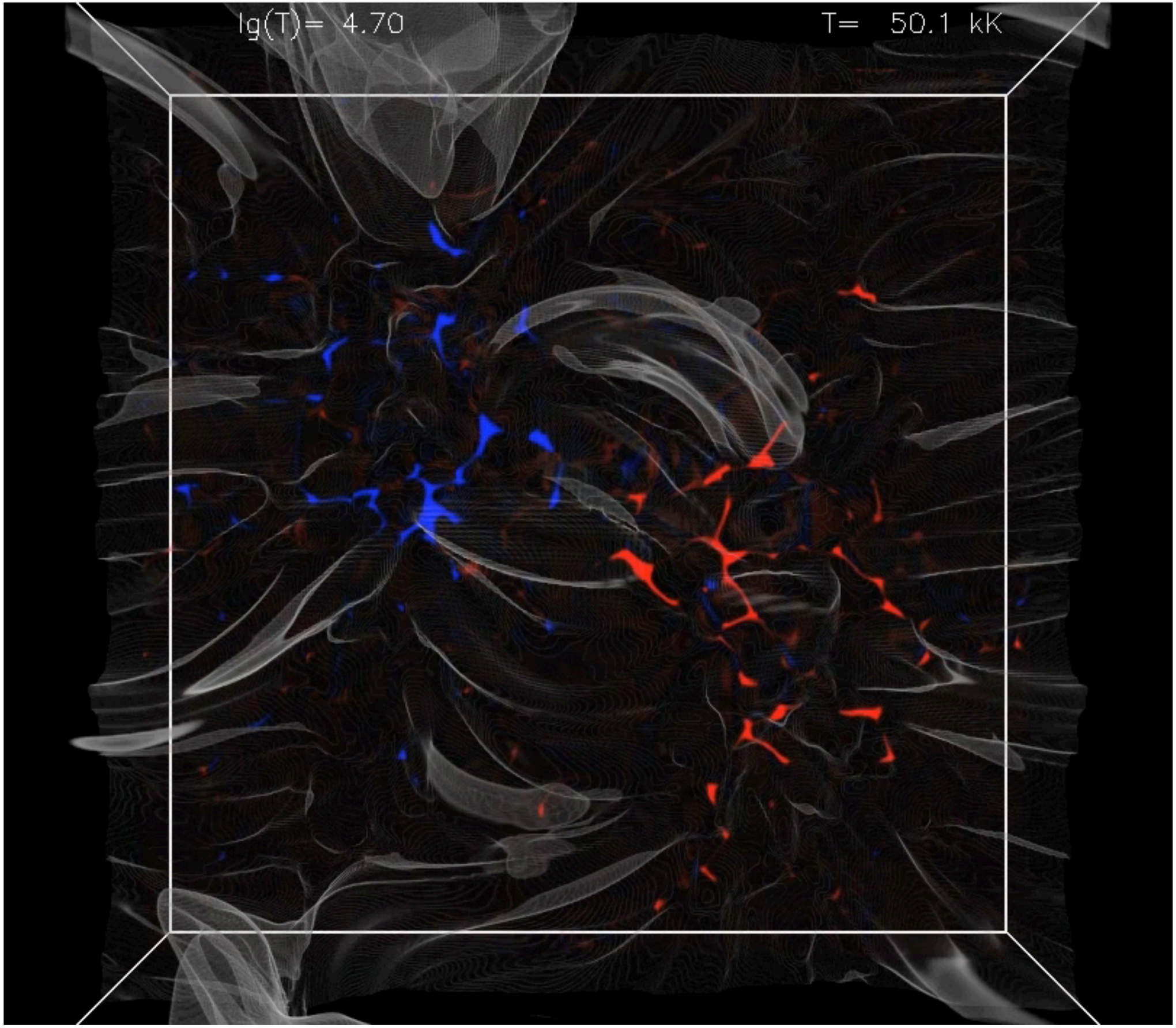
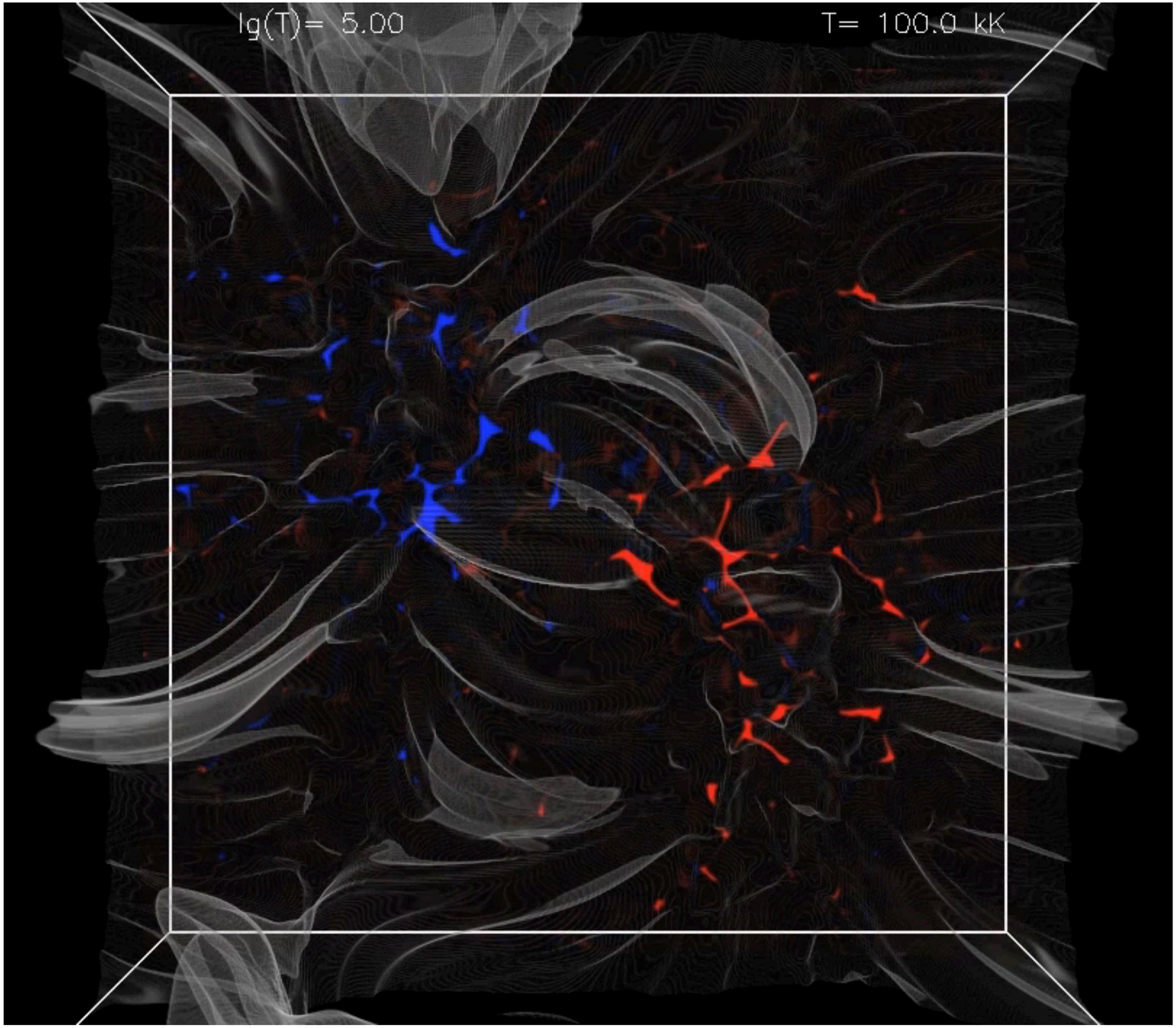

lg(T)= 4.70
T= 50.1 kK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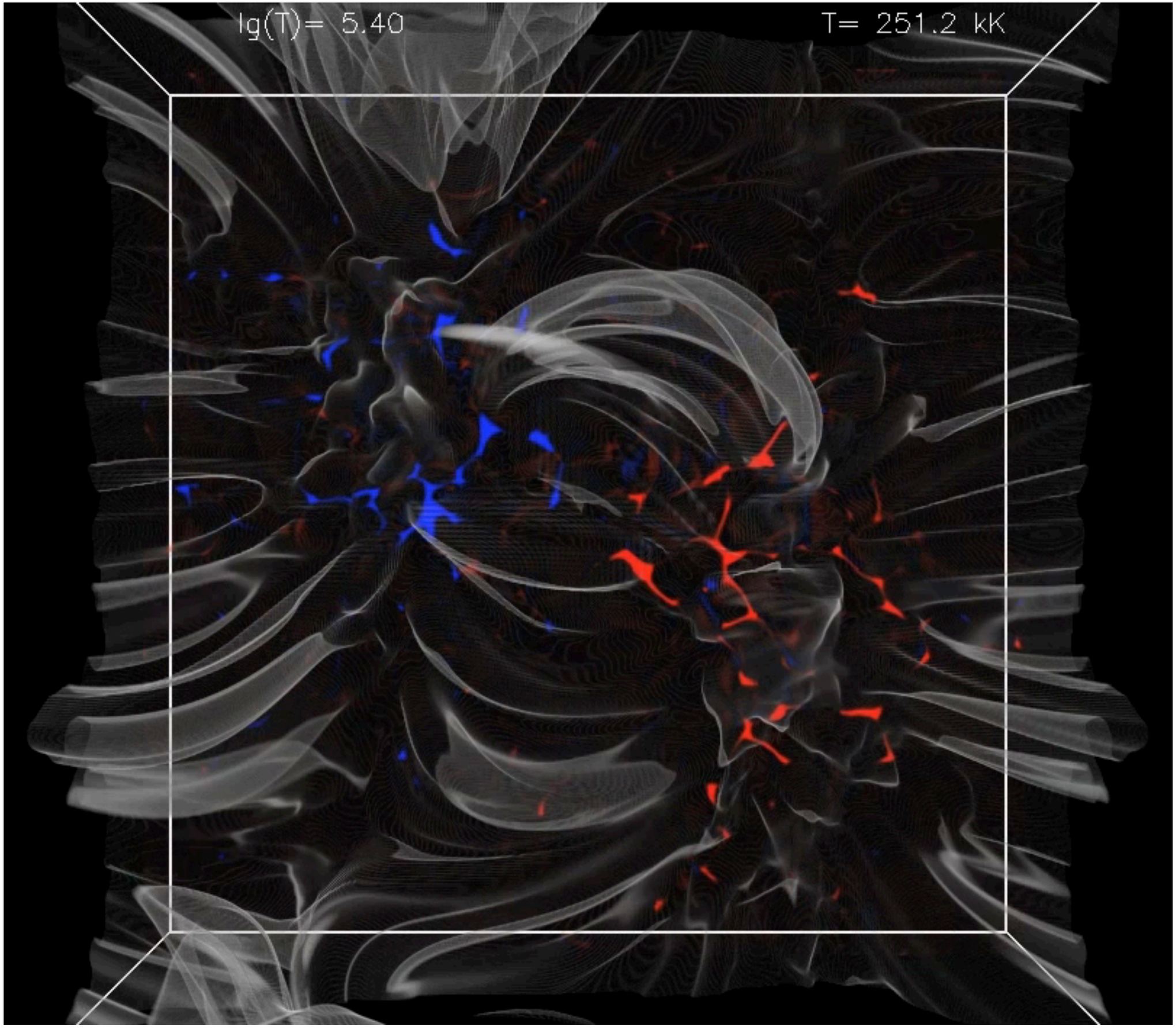
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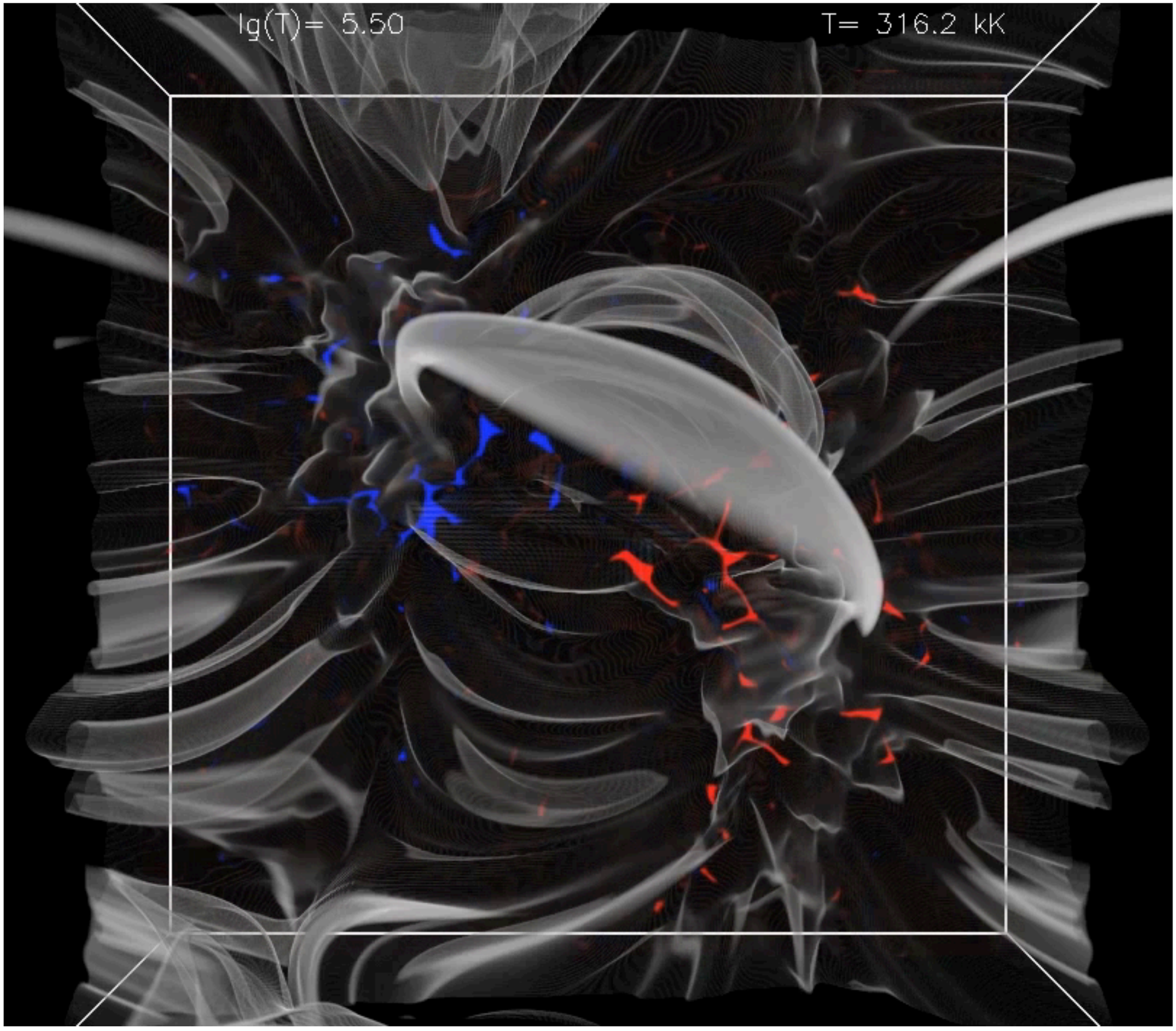
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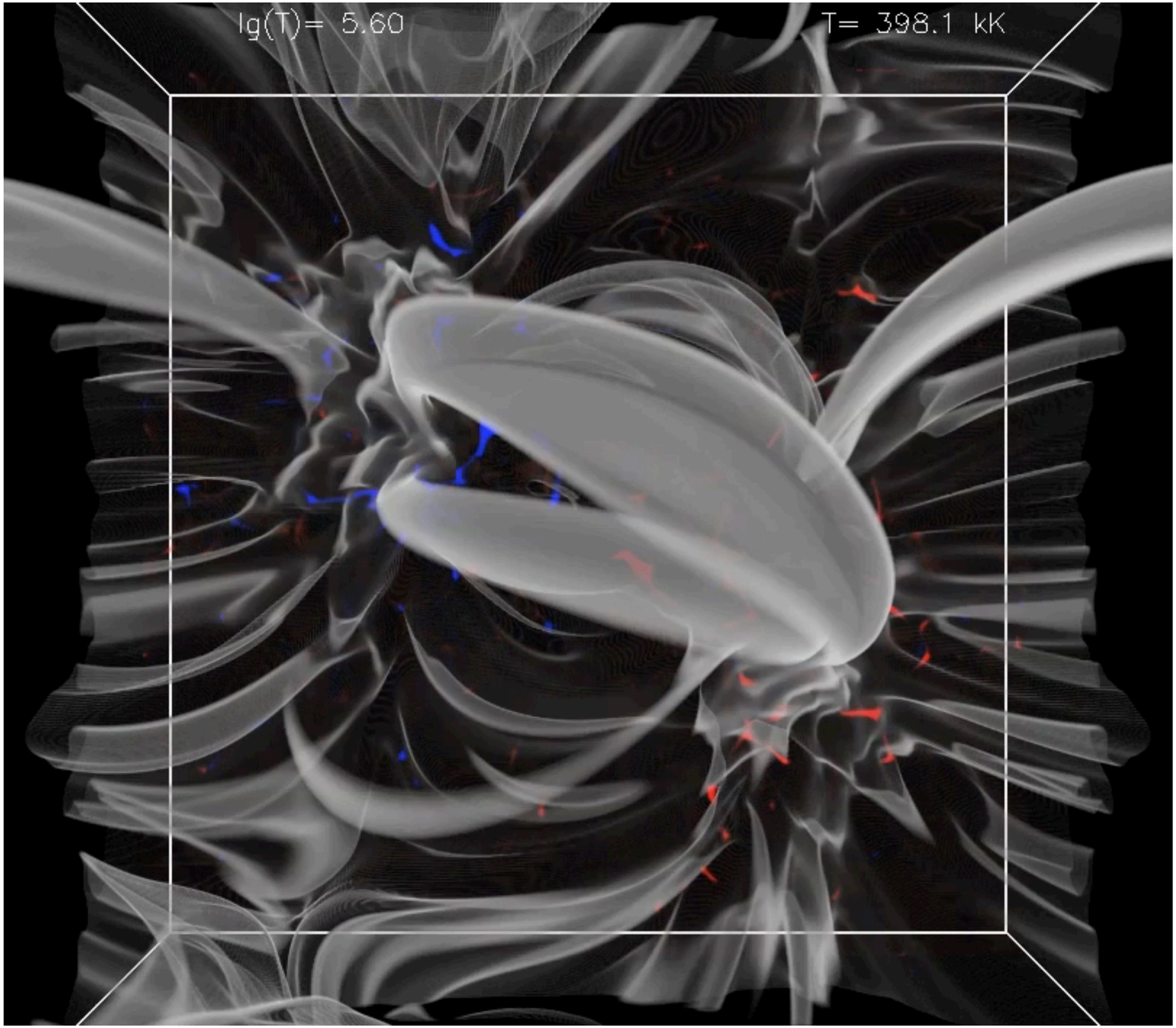
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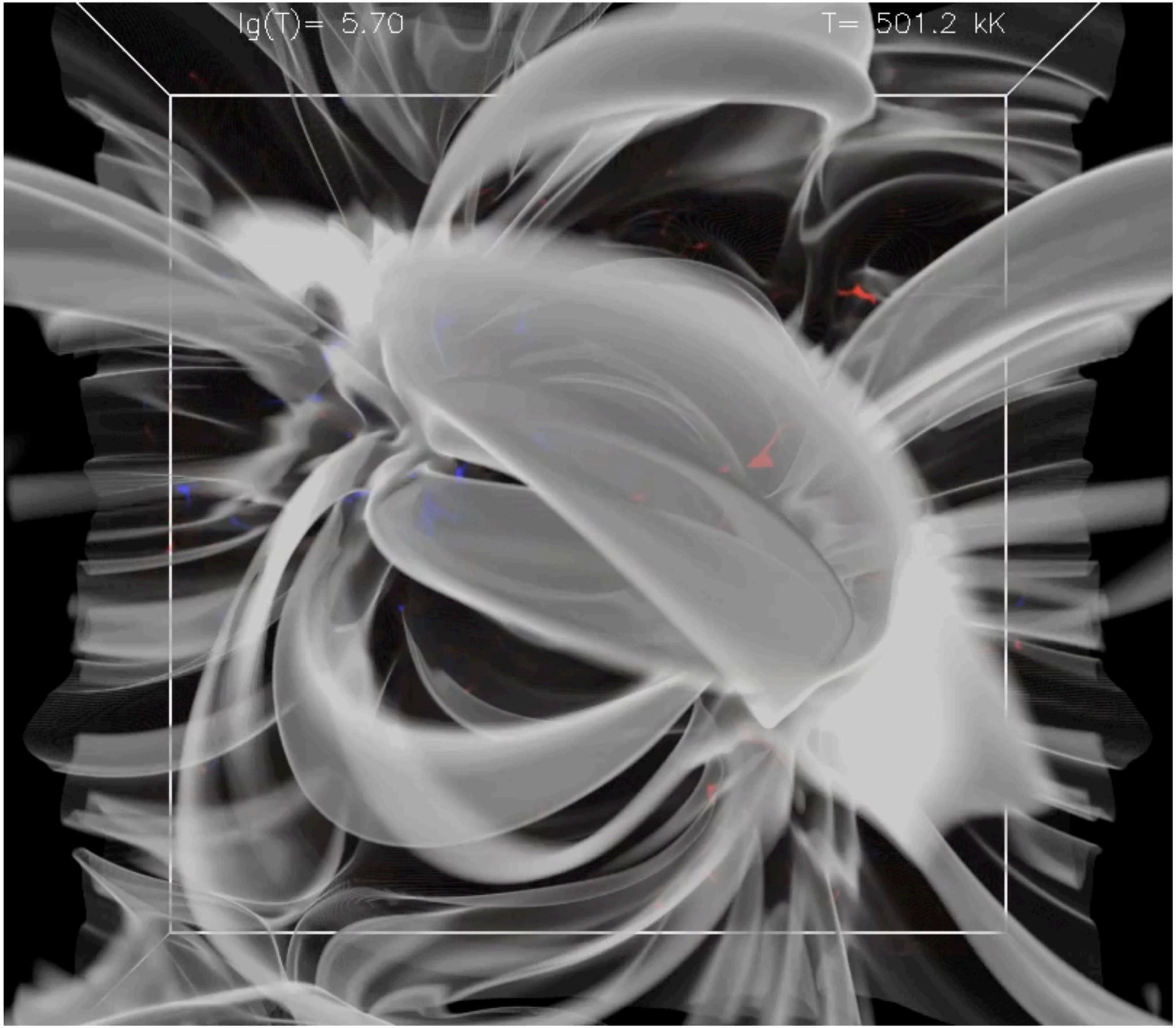
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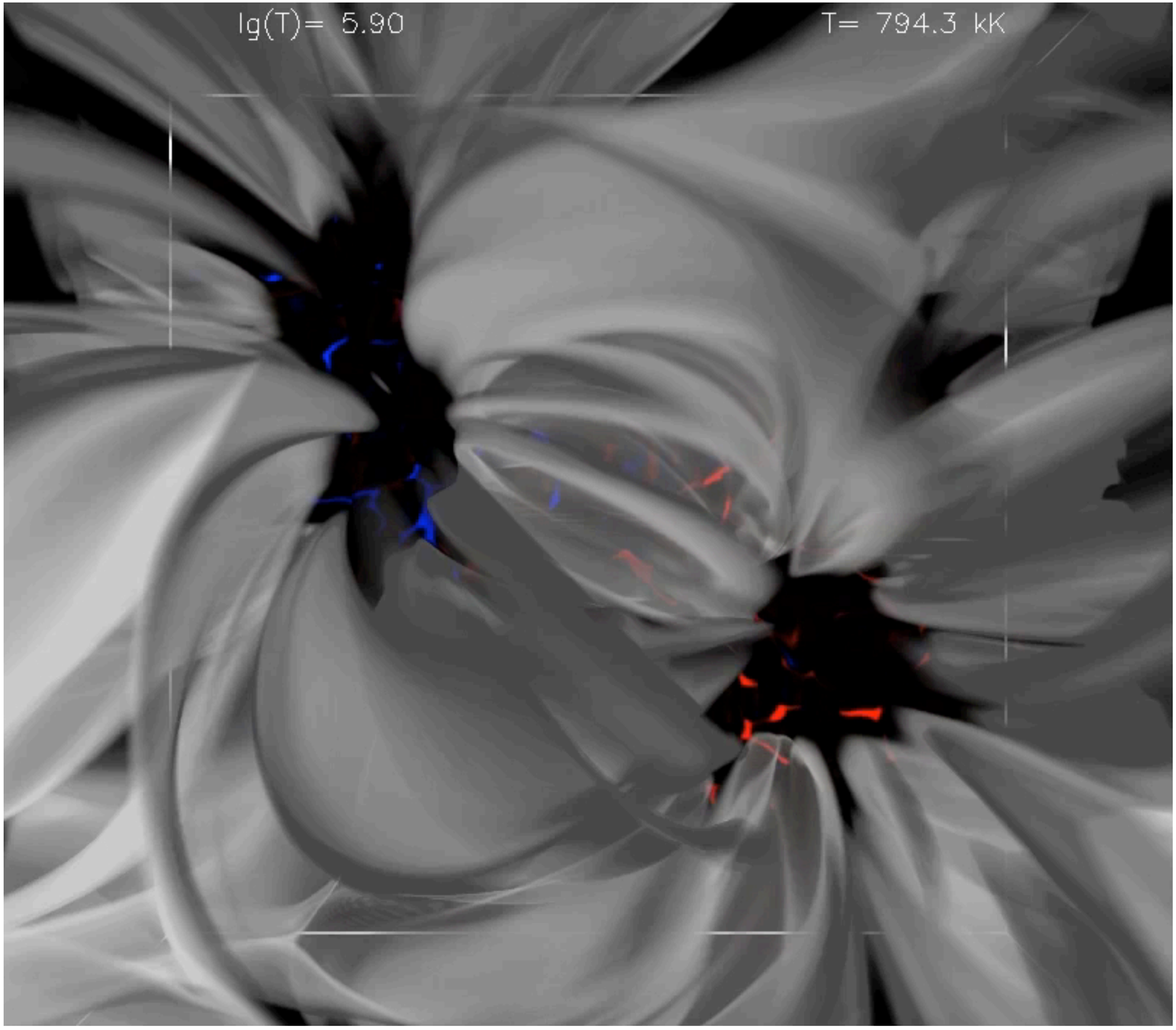
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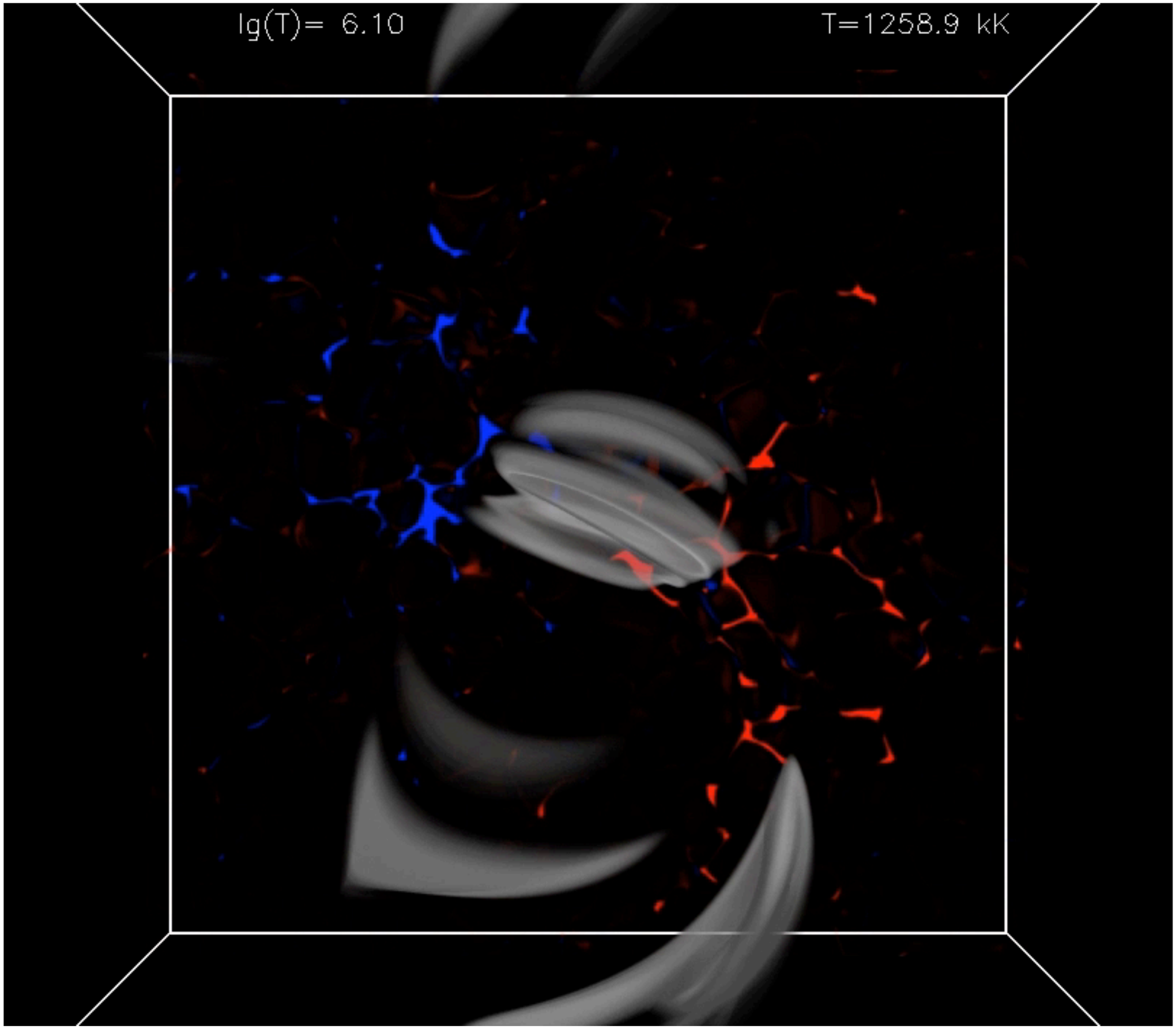
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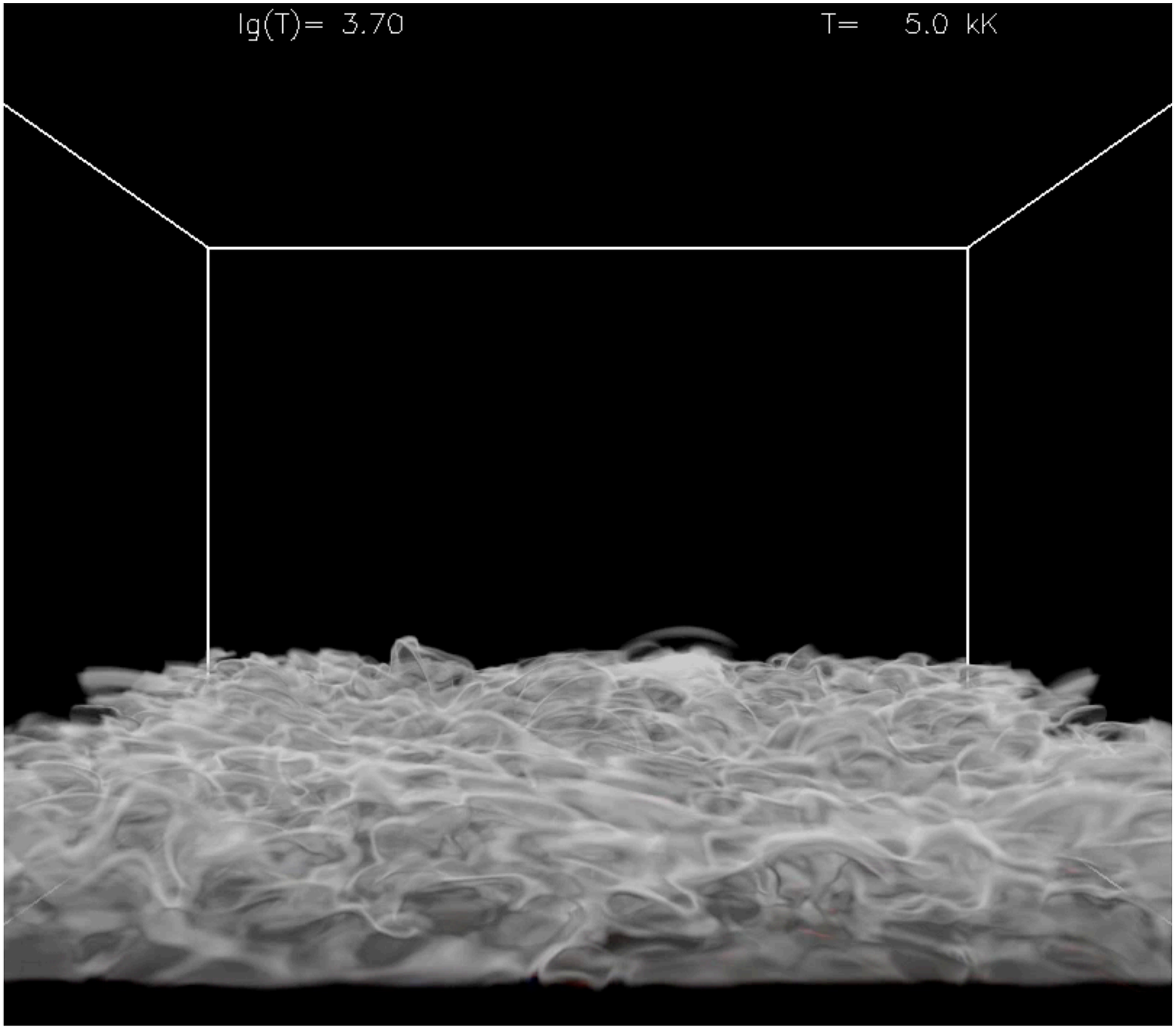
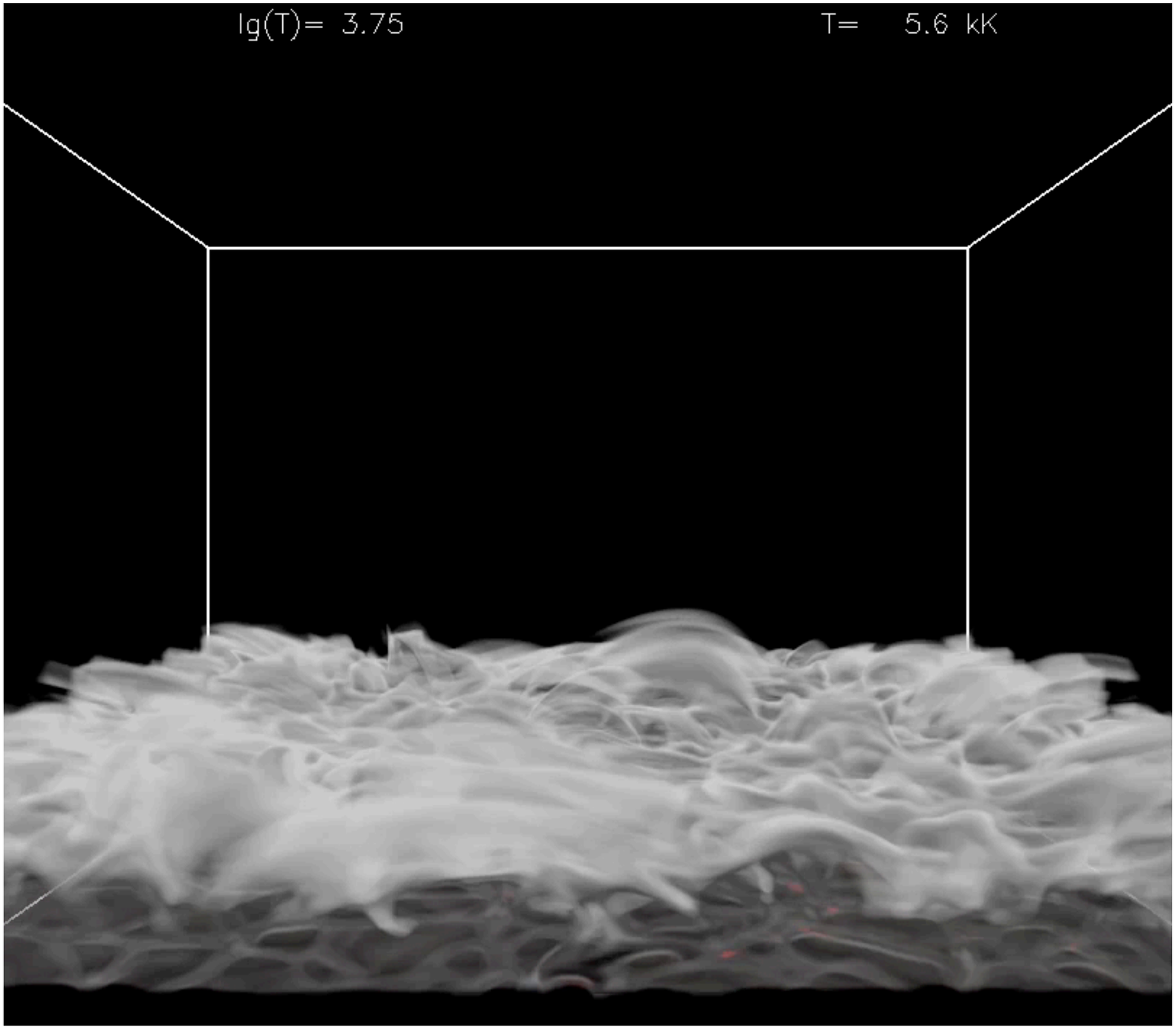

lg(T)= 3.70
T= 5.0 kK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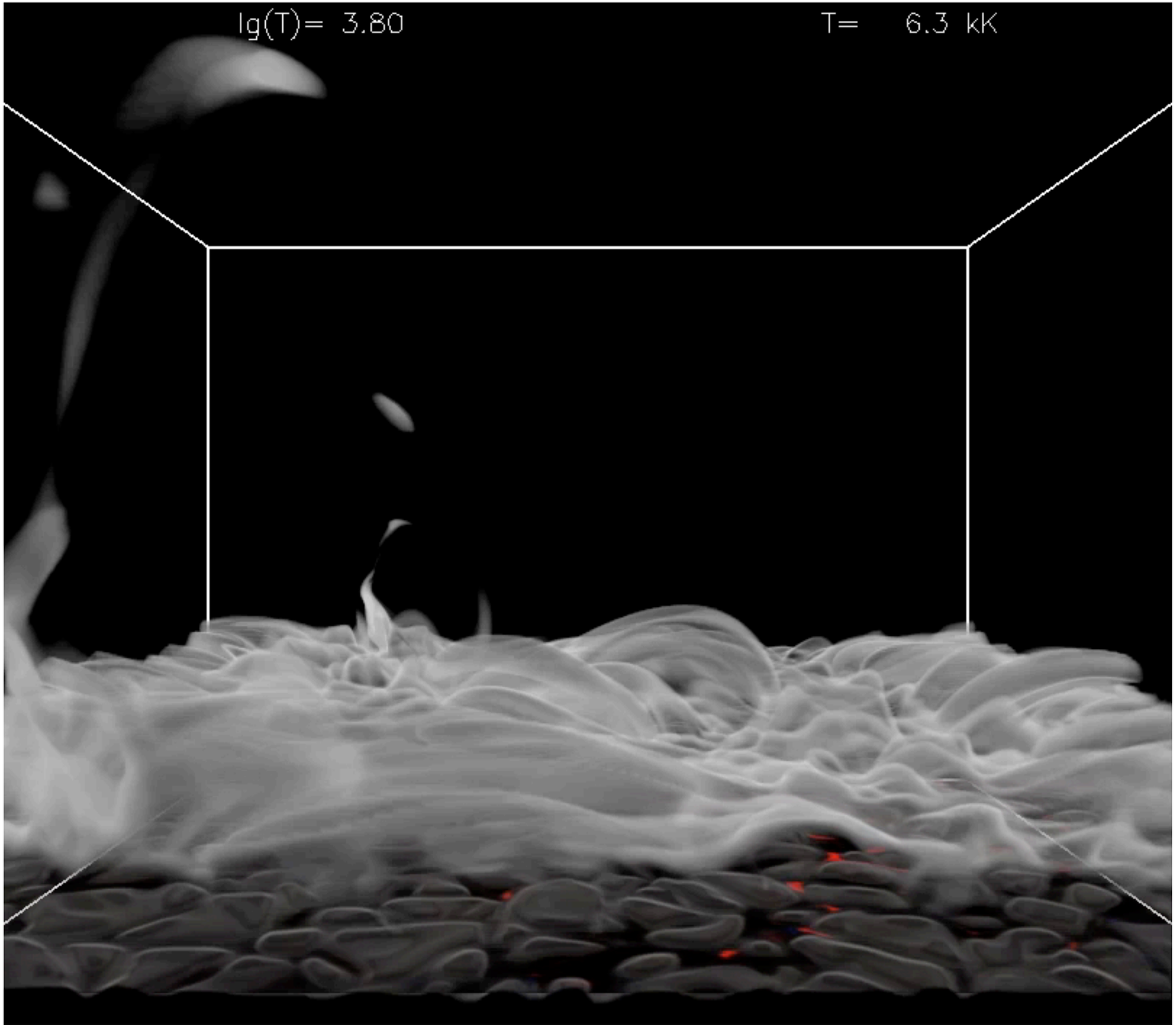
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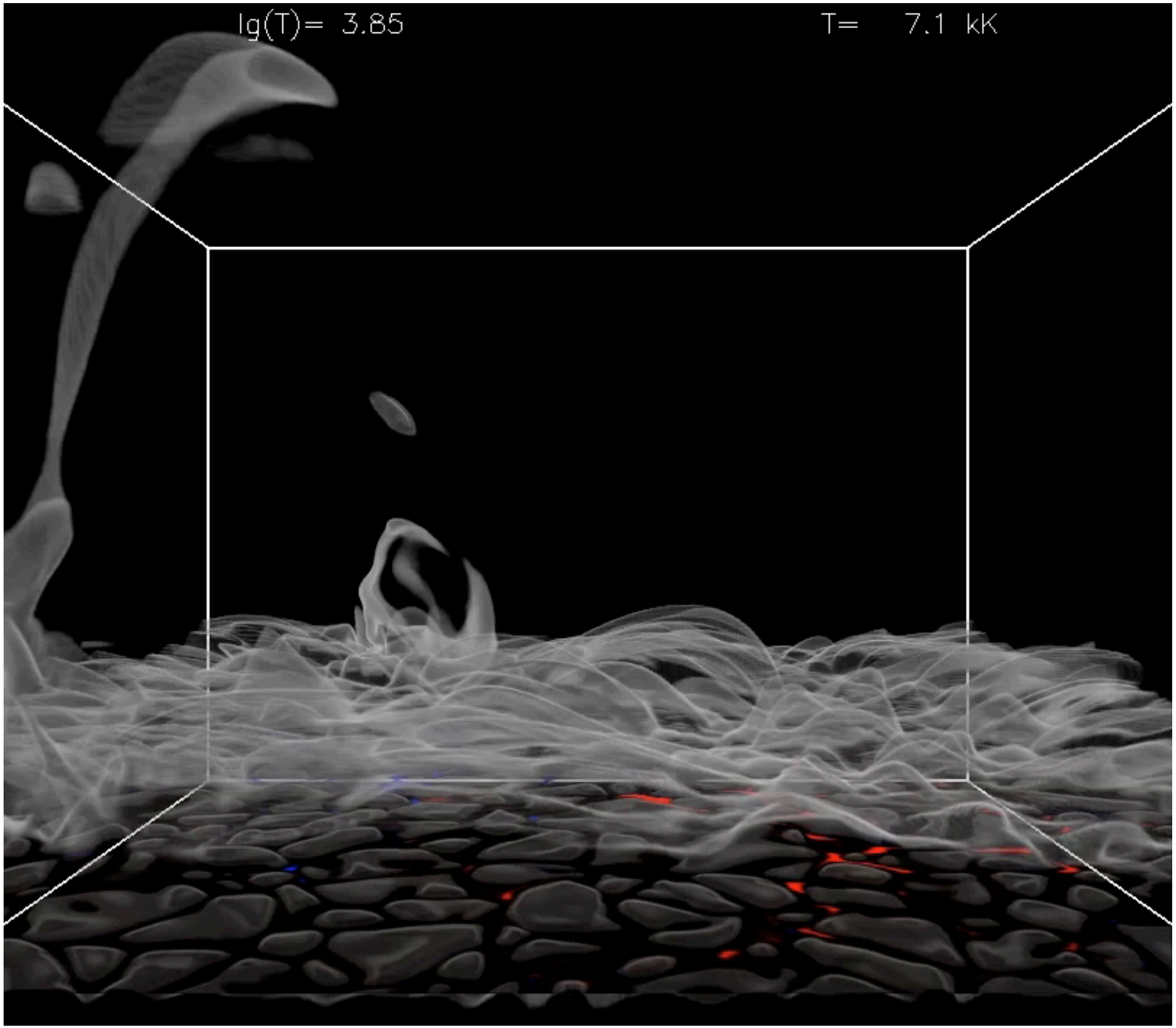
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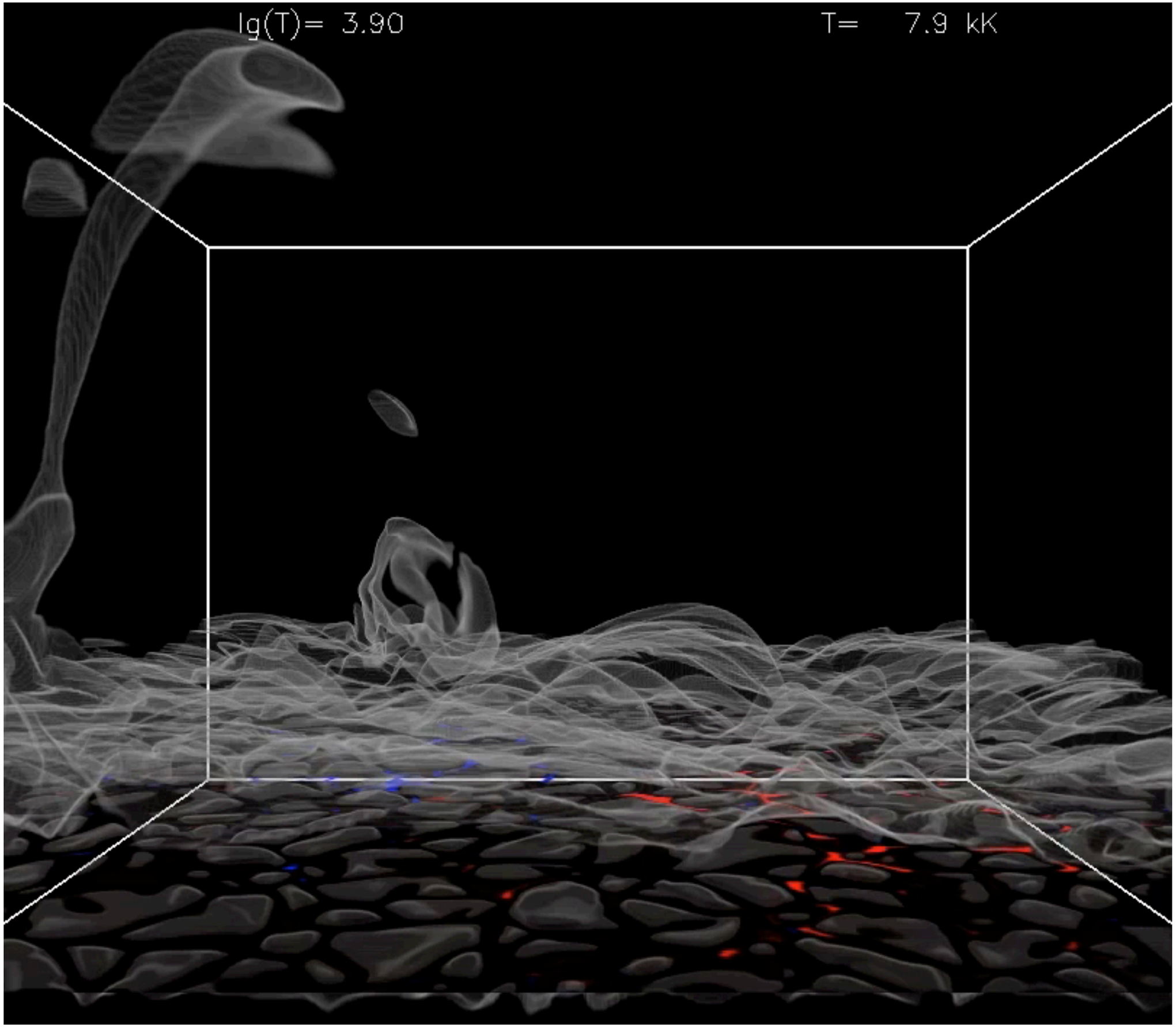
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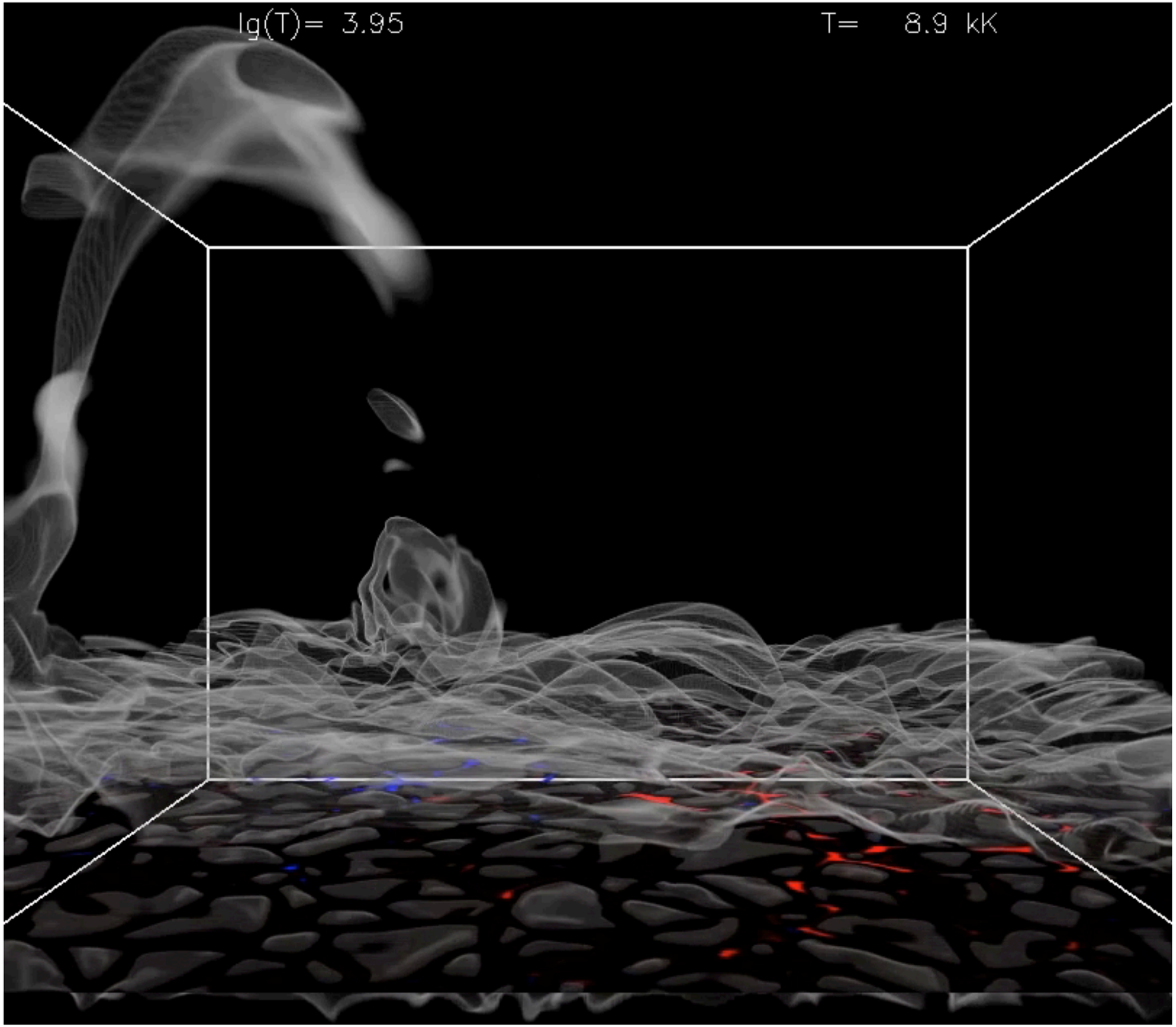
T= 7.9 kK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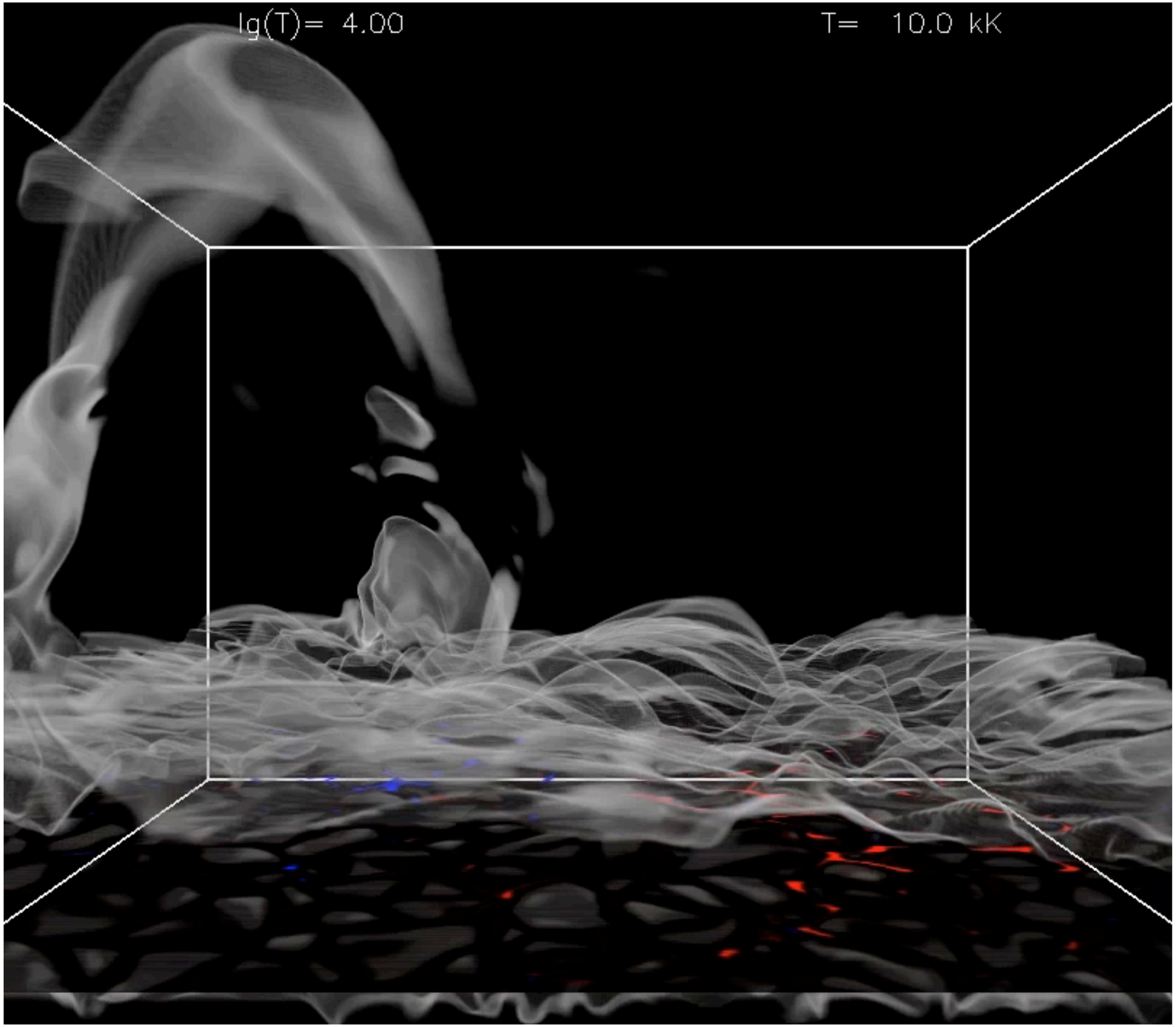
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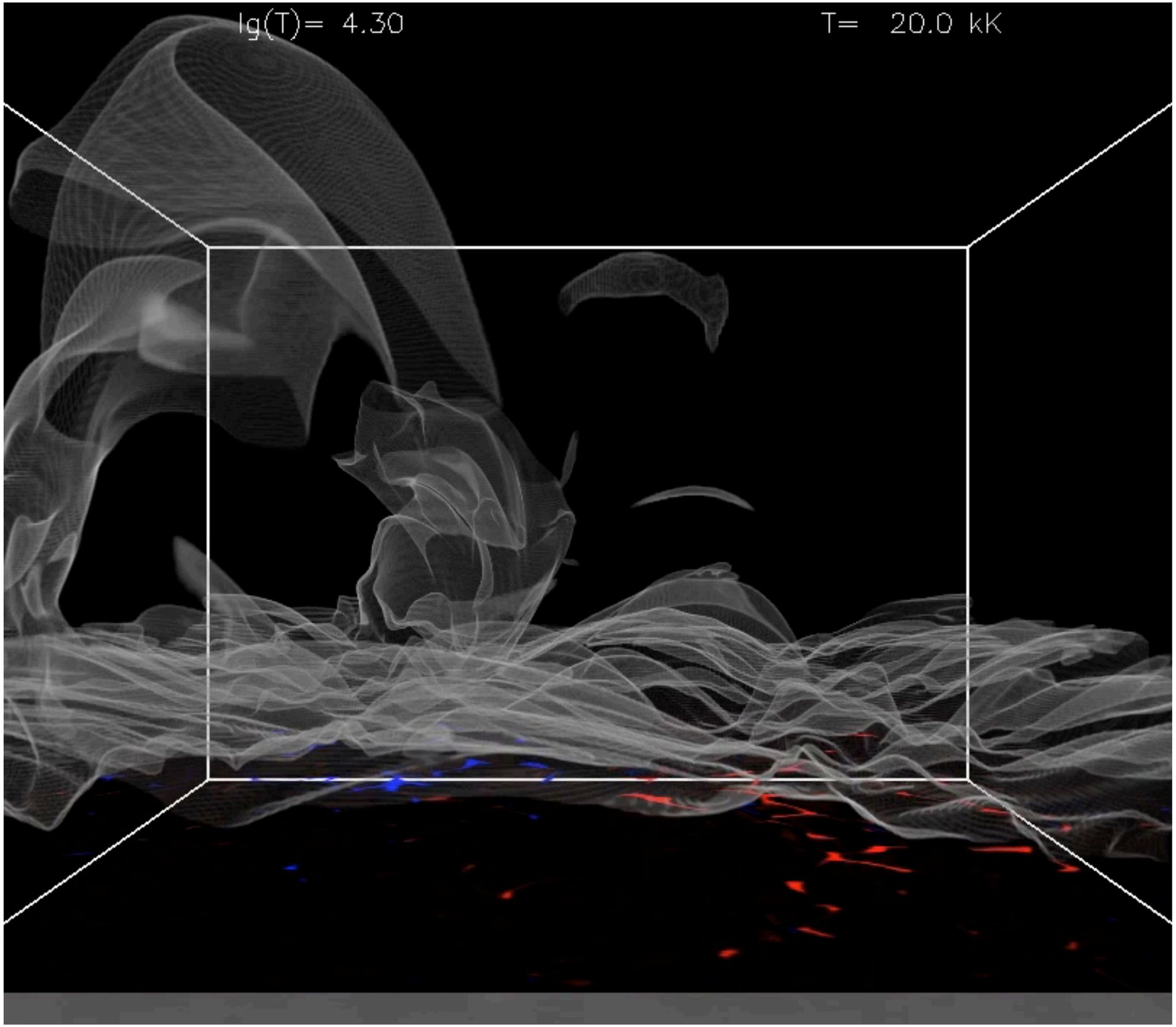
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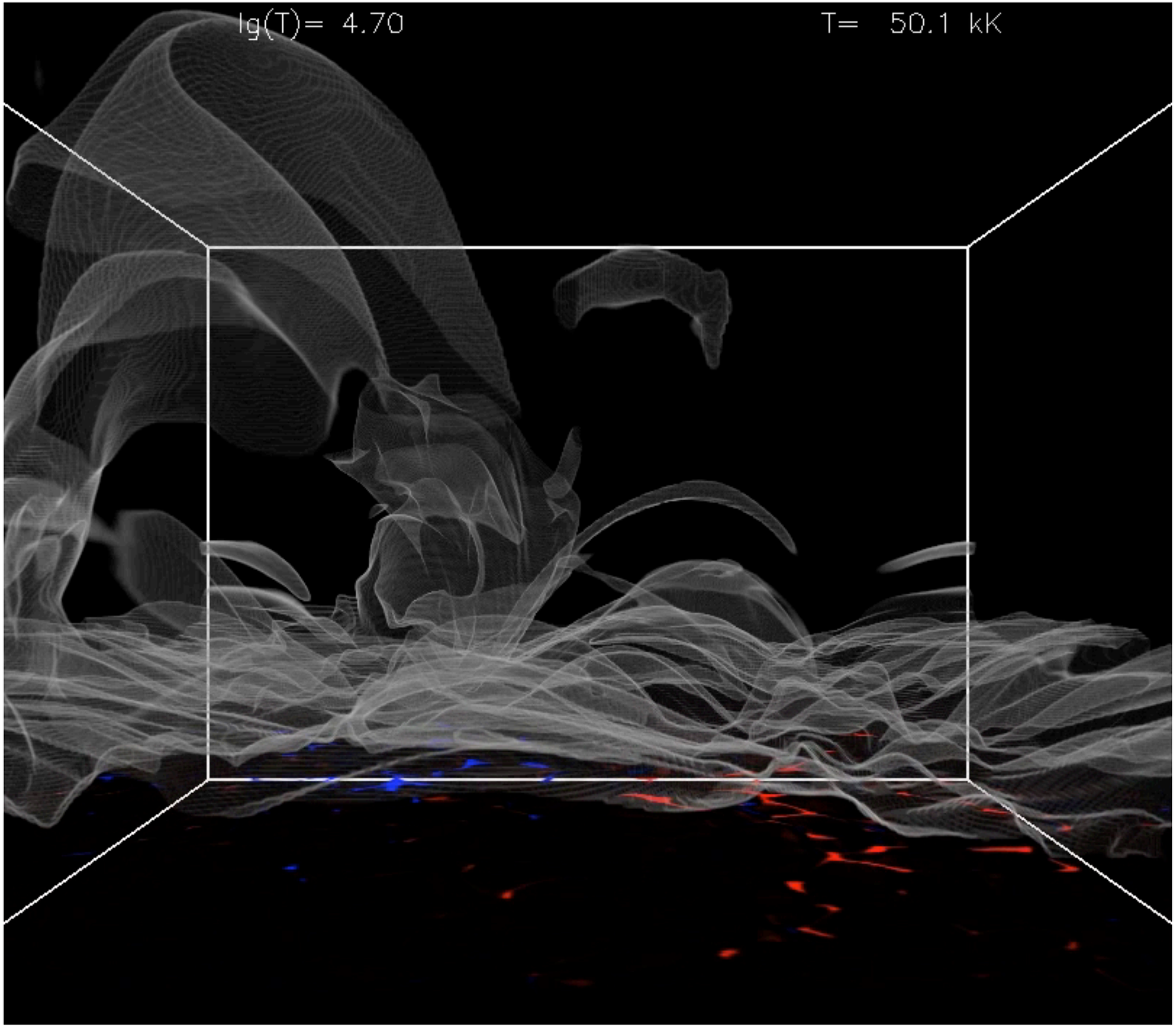
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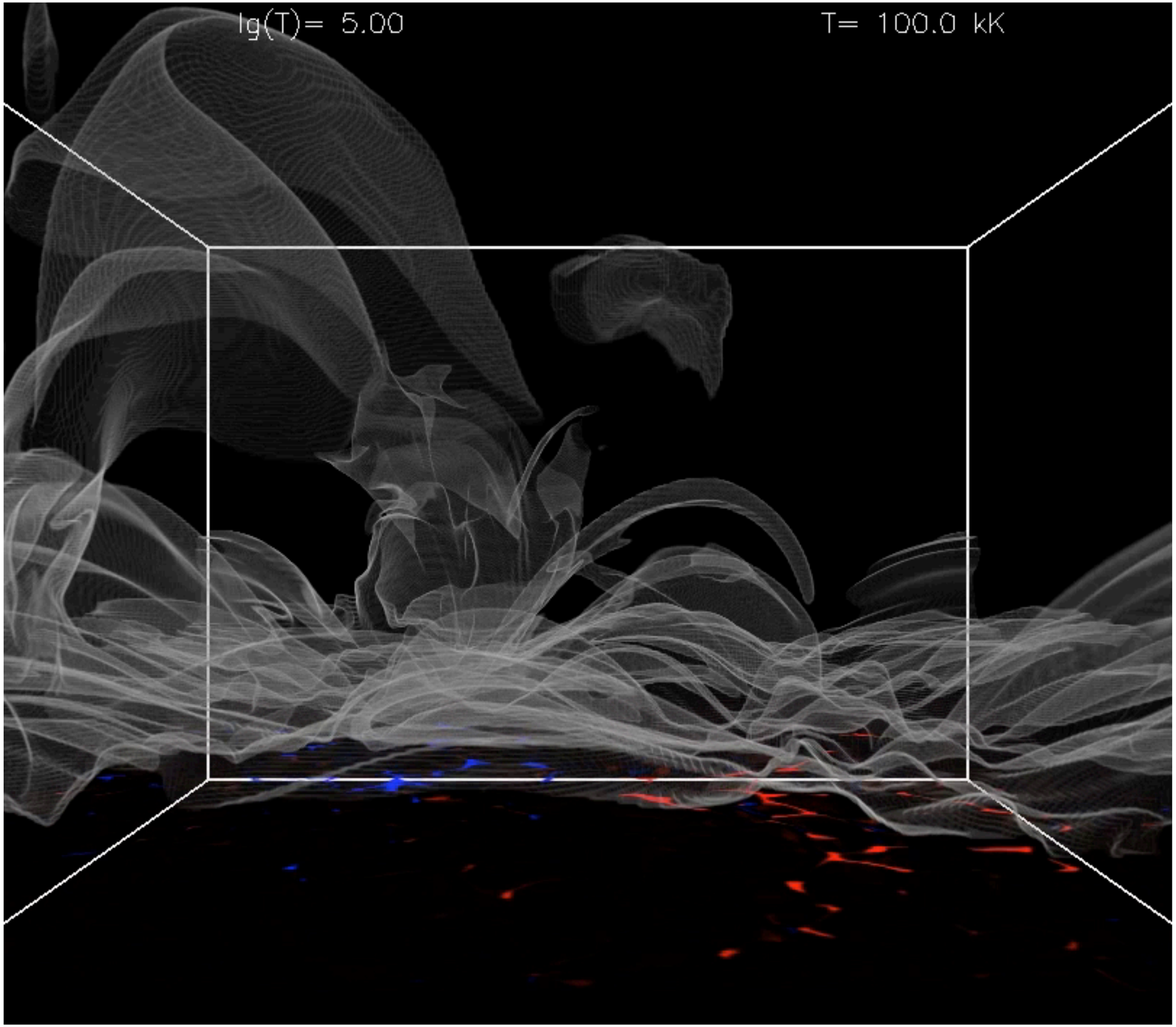
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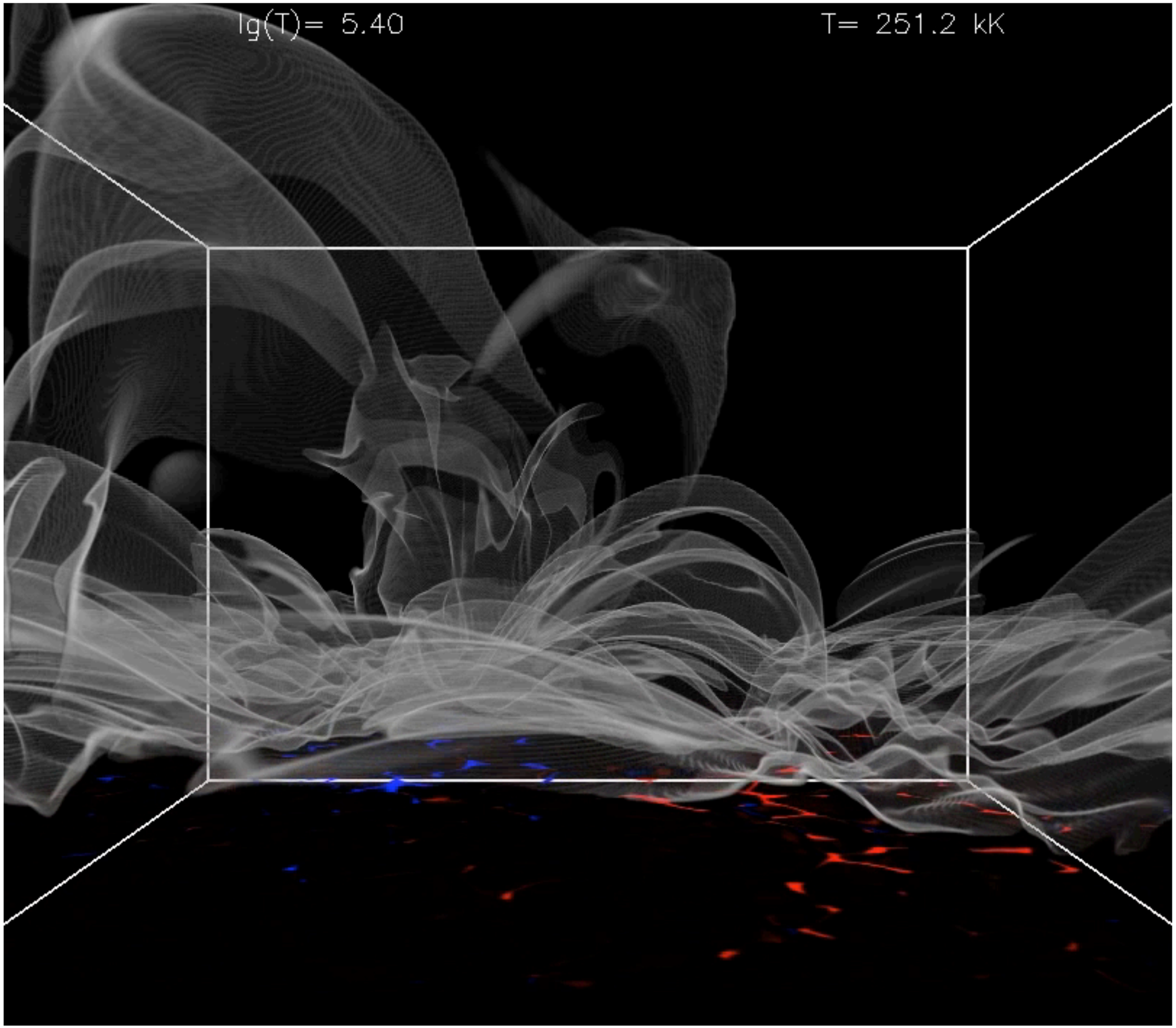
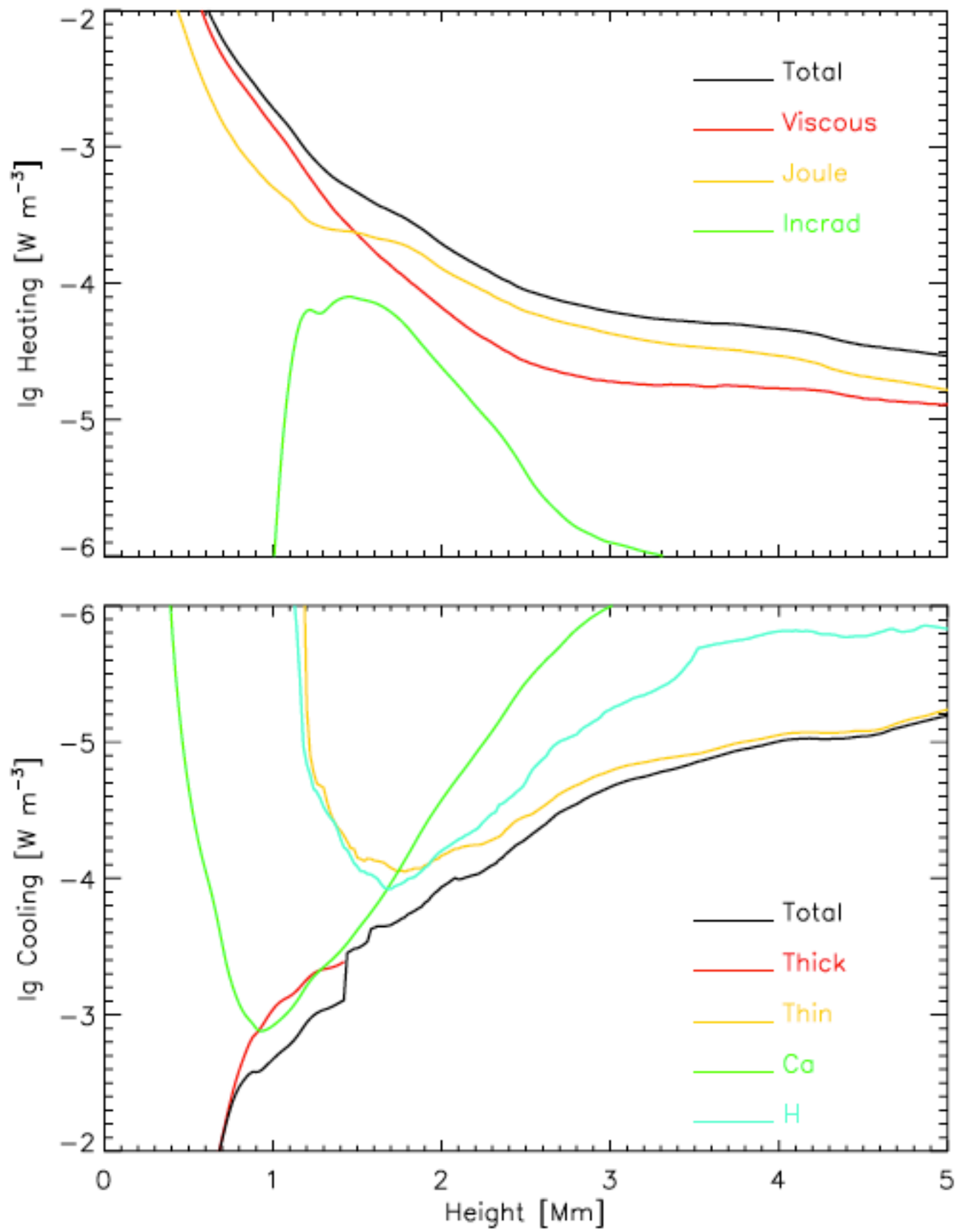
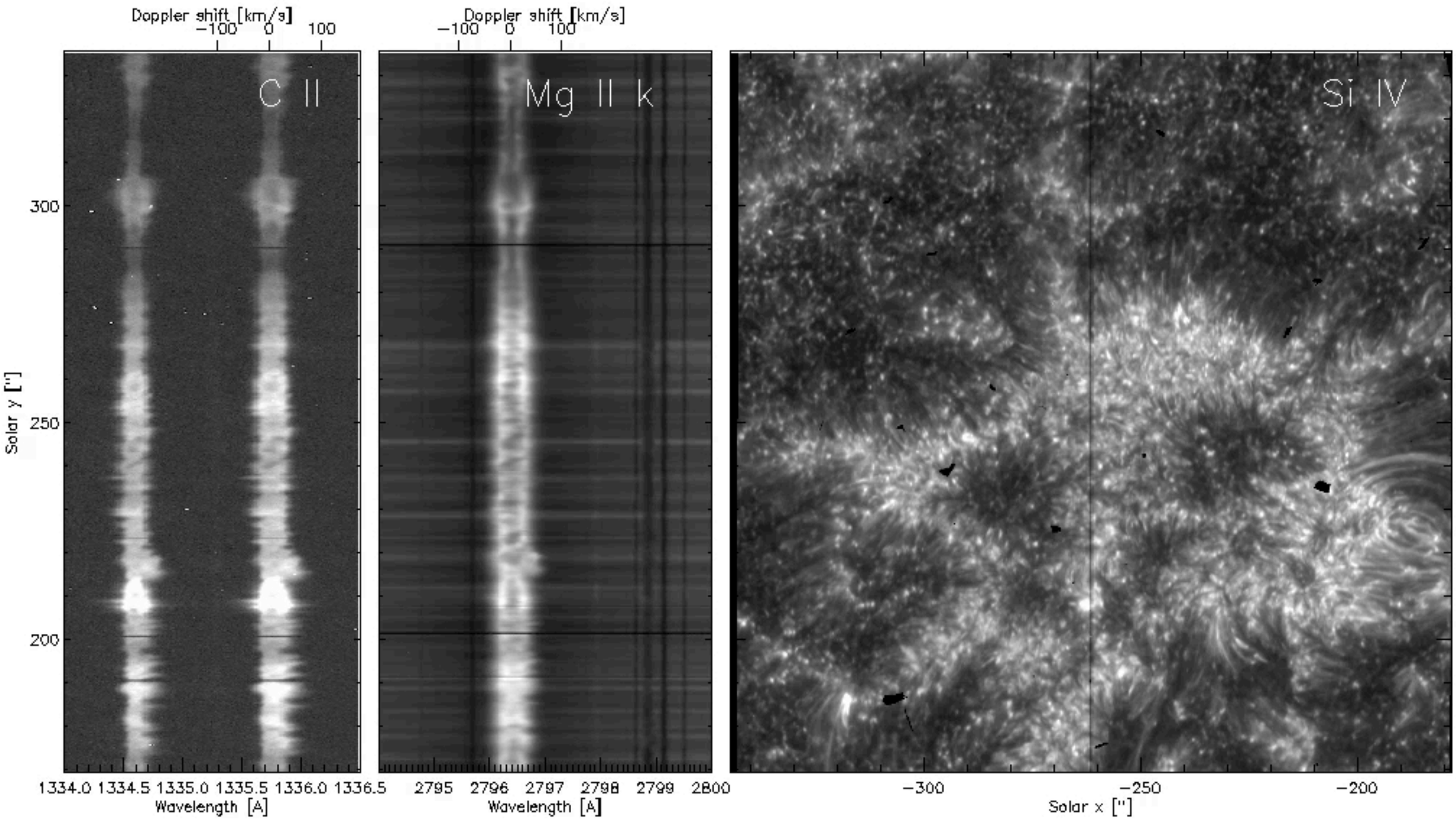

lg(T)= 5.40
T= 251.2 kK

Energy balance



IRIS observations

30s exposures, 400 step raster



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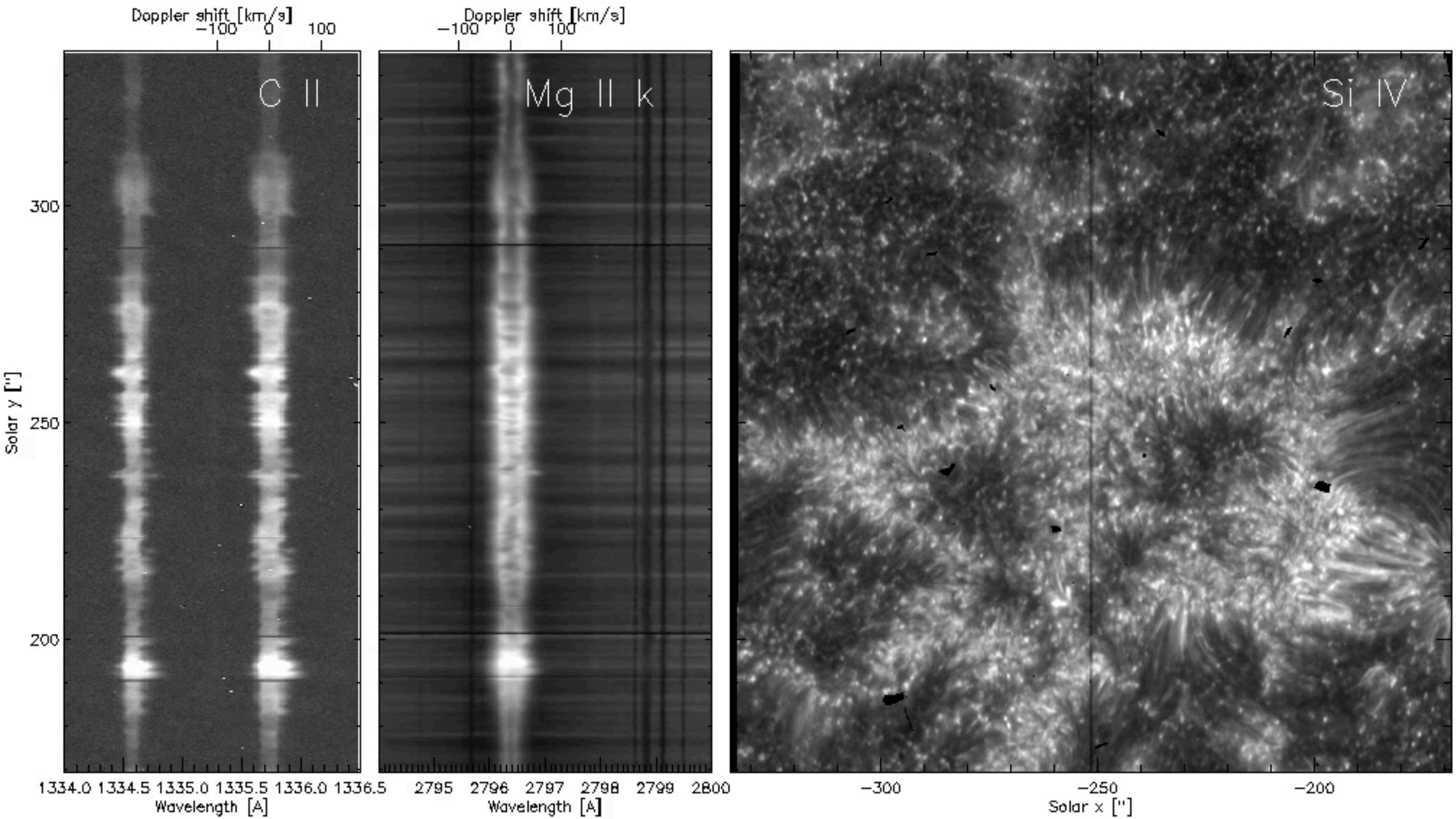
Doppler shift [km/s]
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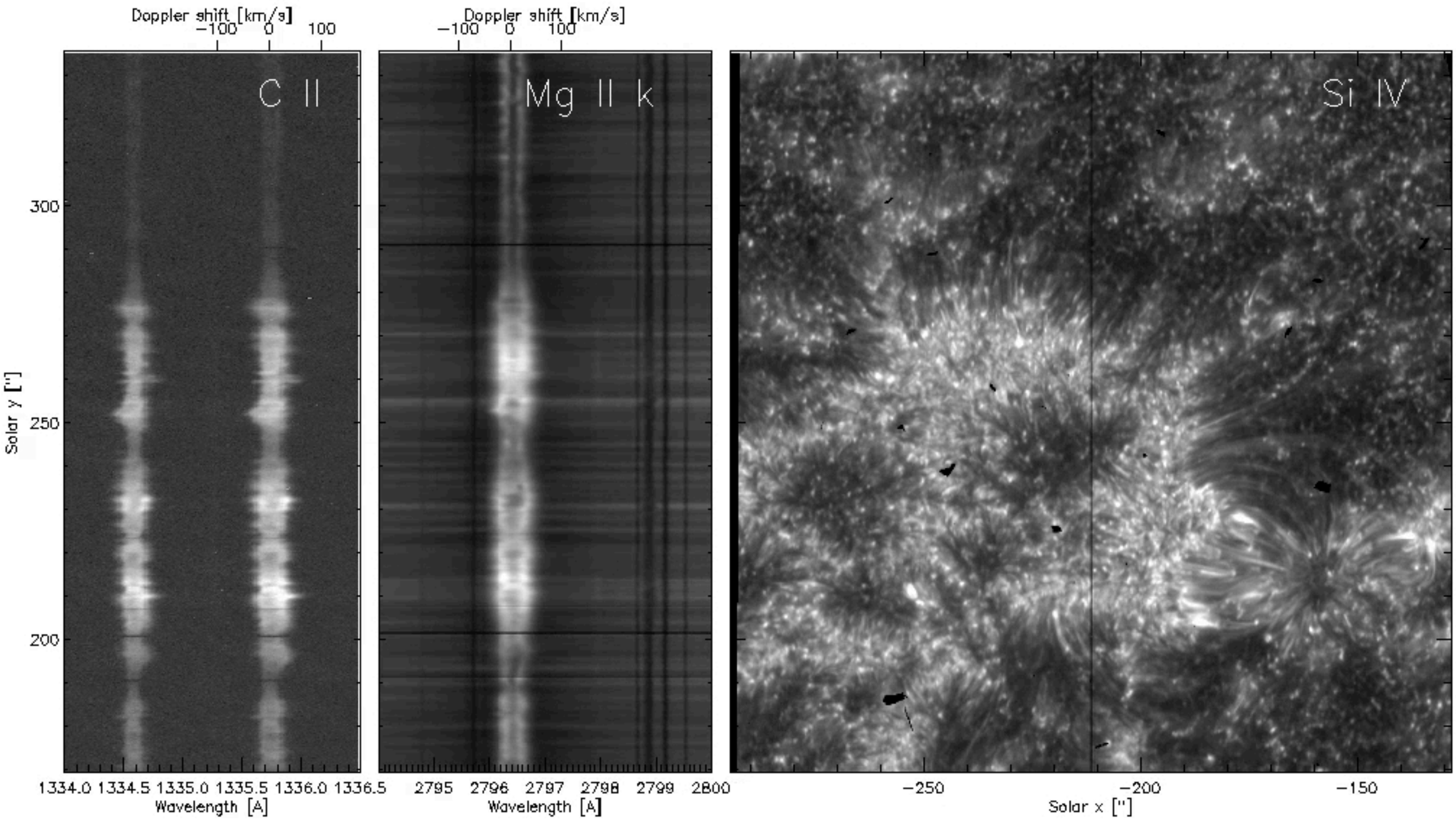
0
100
C II
Mg II k
Si IV
300
250
200
Solar y ["]
1334.0 1334.5 1335.0 1335.5 1336.0 1336.5
Wavelength [A]
2795 2796 2797 2798 2799 2800
Wavelength [A]
−300
−250
−200
Solar x ["]


Doppler shift [km/s]
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C II
Mg II k
Si IV
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Solar y ["]
1334.0 1334.5 1335.0 1335.5 1336.0 1336.5
Wavelength [A]
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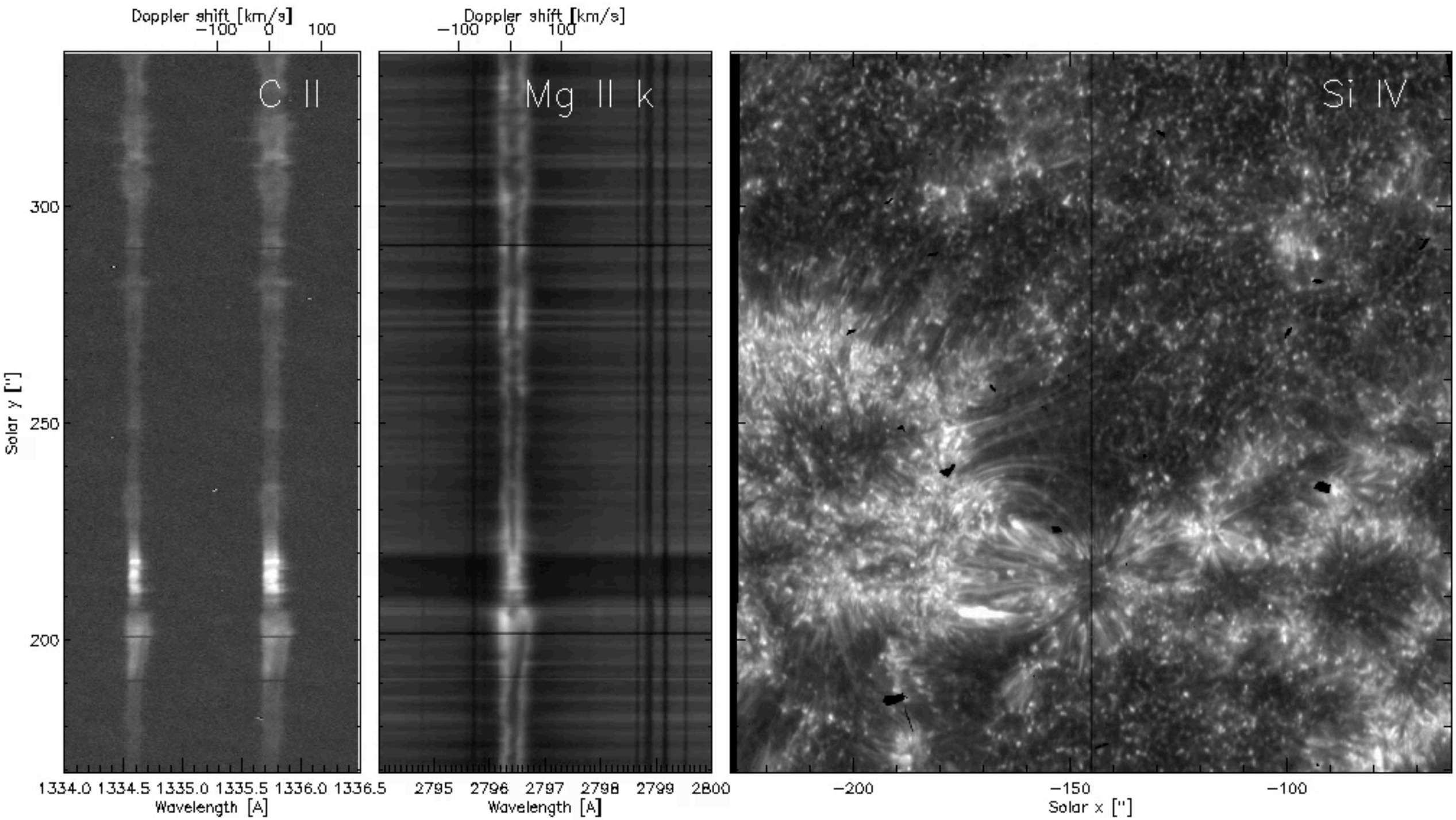
Wavelength [A]
−250
−200
−150
Solar x ["]


Doppler shift [km/s]
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C II
Mg II k
Si IV
300
250
200
Solar y ['']
1334.0 1334.5 1335.0 1335.5 1336.0 1336.5
Wavelength [A]
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Wavelength [A]
−200
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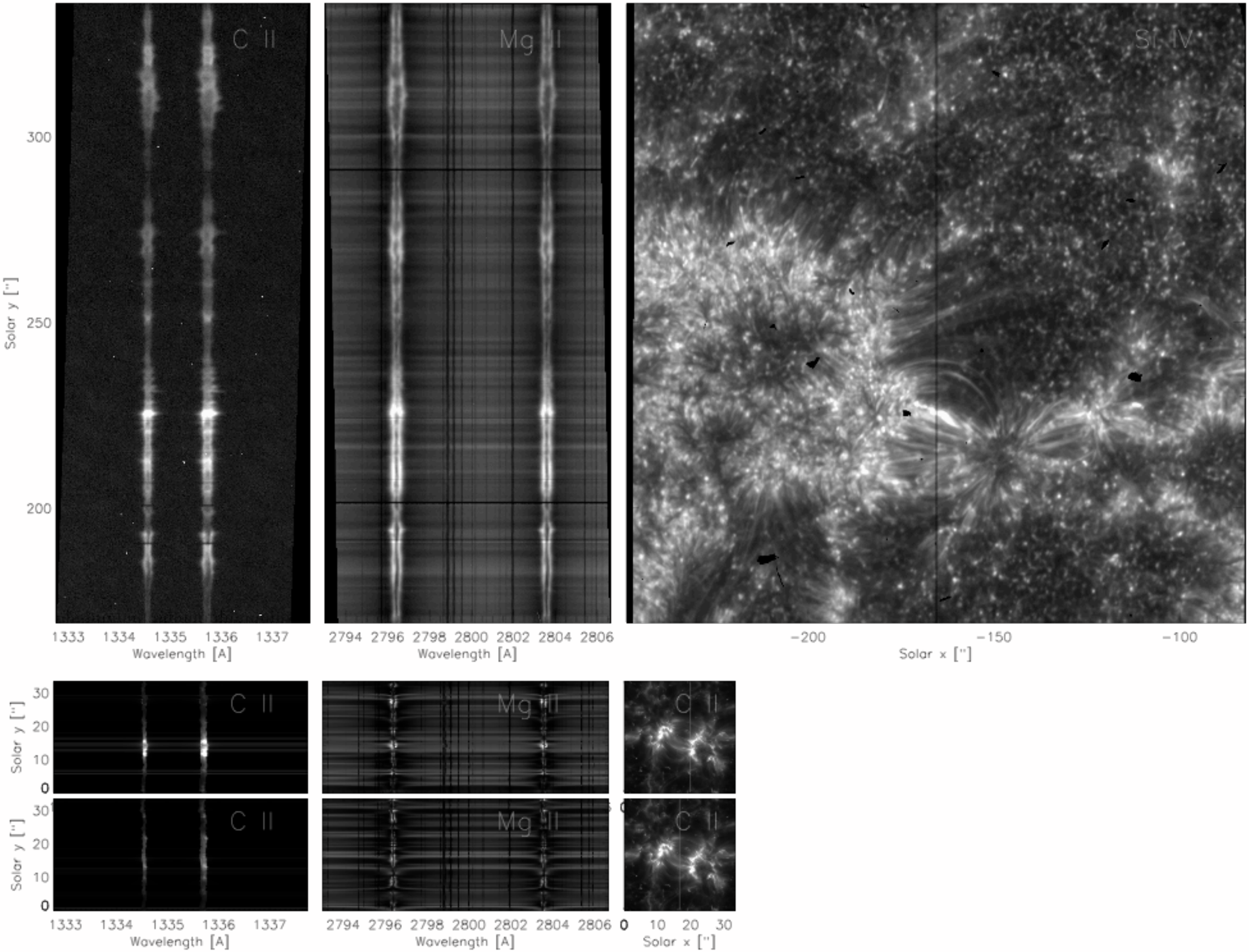
Solar x ['']


C II
Mg II
Si IV
Solar y ["]
300
250
200
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Wavelength [A]
2794 2796 2798 2800 2802 2804 2806
Wavelength [A]
−200
−150
−100
Solar x ["]
C II
Mg II
C II
Solar y ["]
30
20
10
0
C II
Mg II
C II
Solar y ["]
30
20
10
0
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Wavelength [A]
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Wavelength [A]
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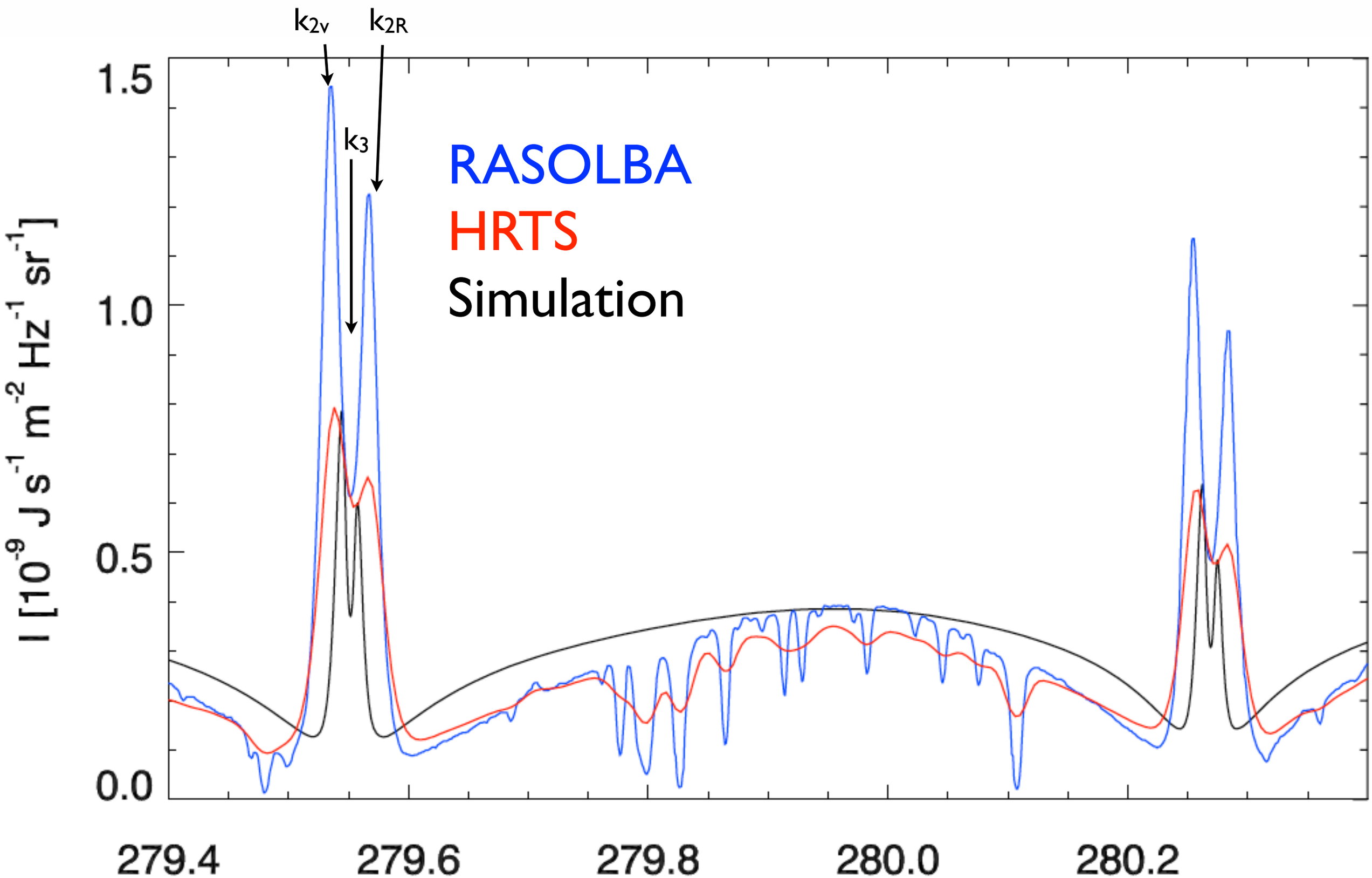
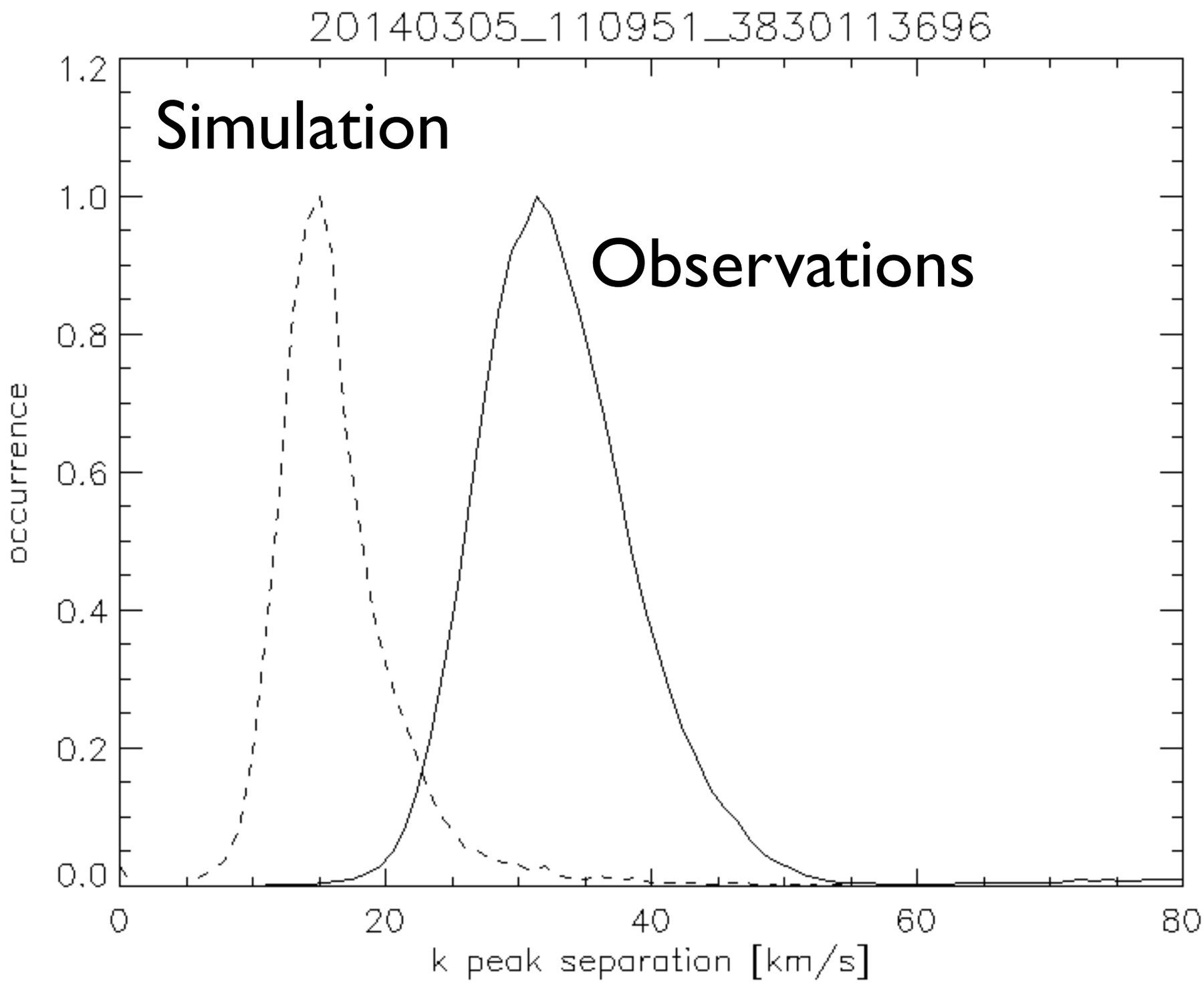
Solar x ["]

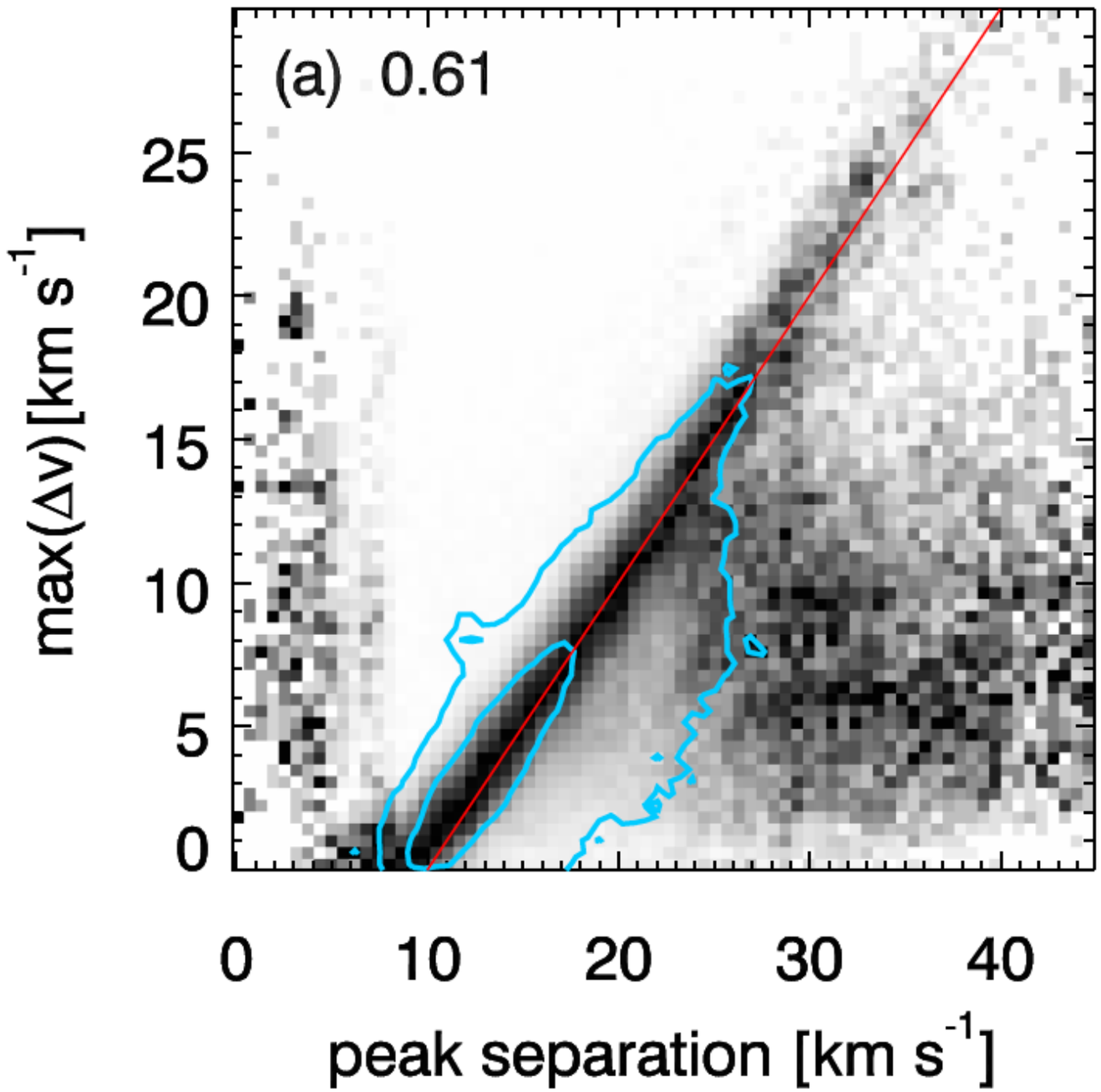
Syntetic profiles too narrow



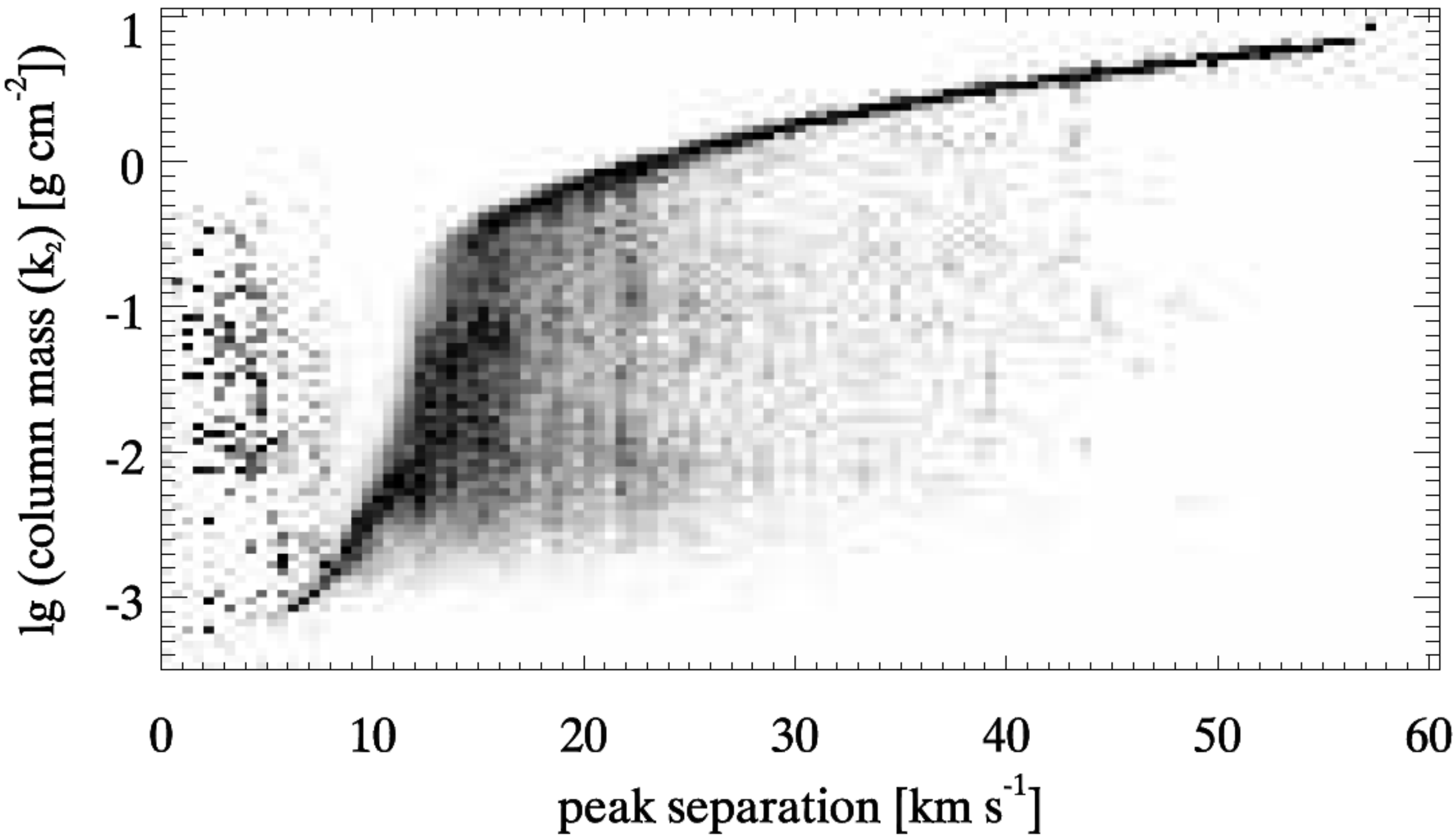
k2 peak separation



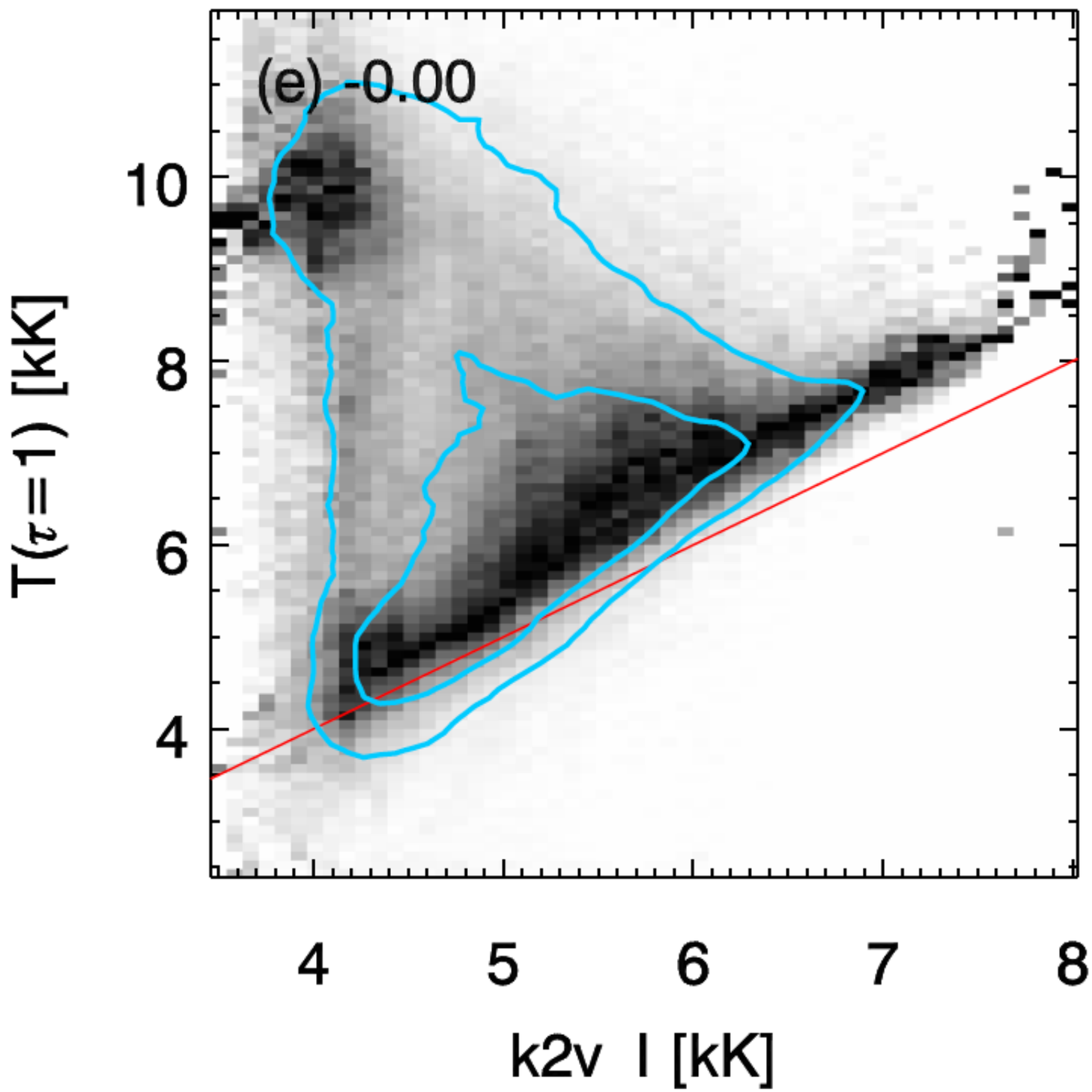
Mg II h&k: peak separation measures velocity extremes



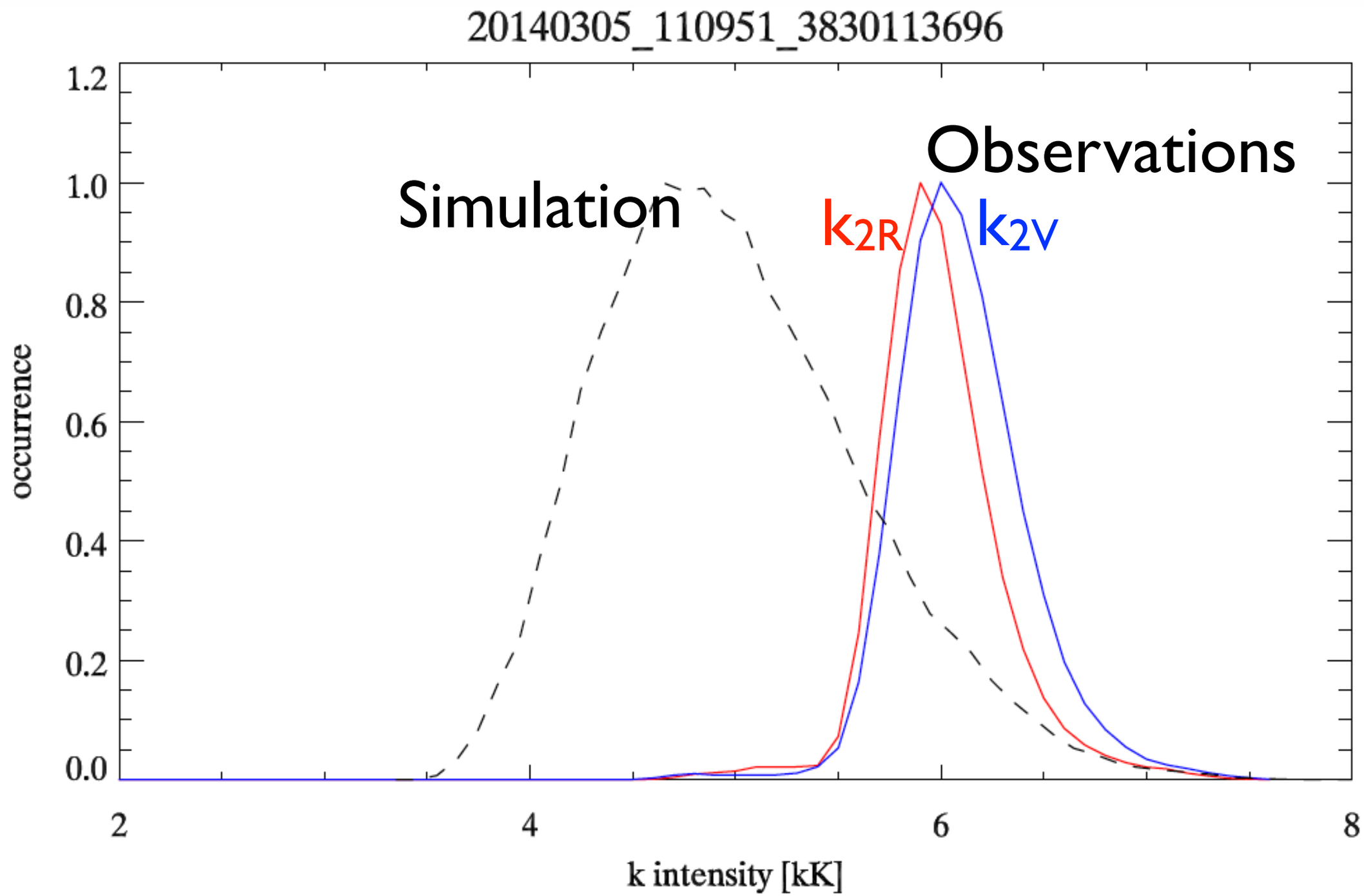
k2 separation also measure of column mass



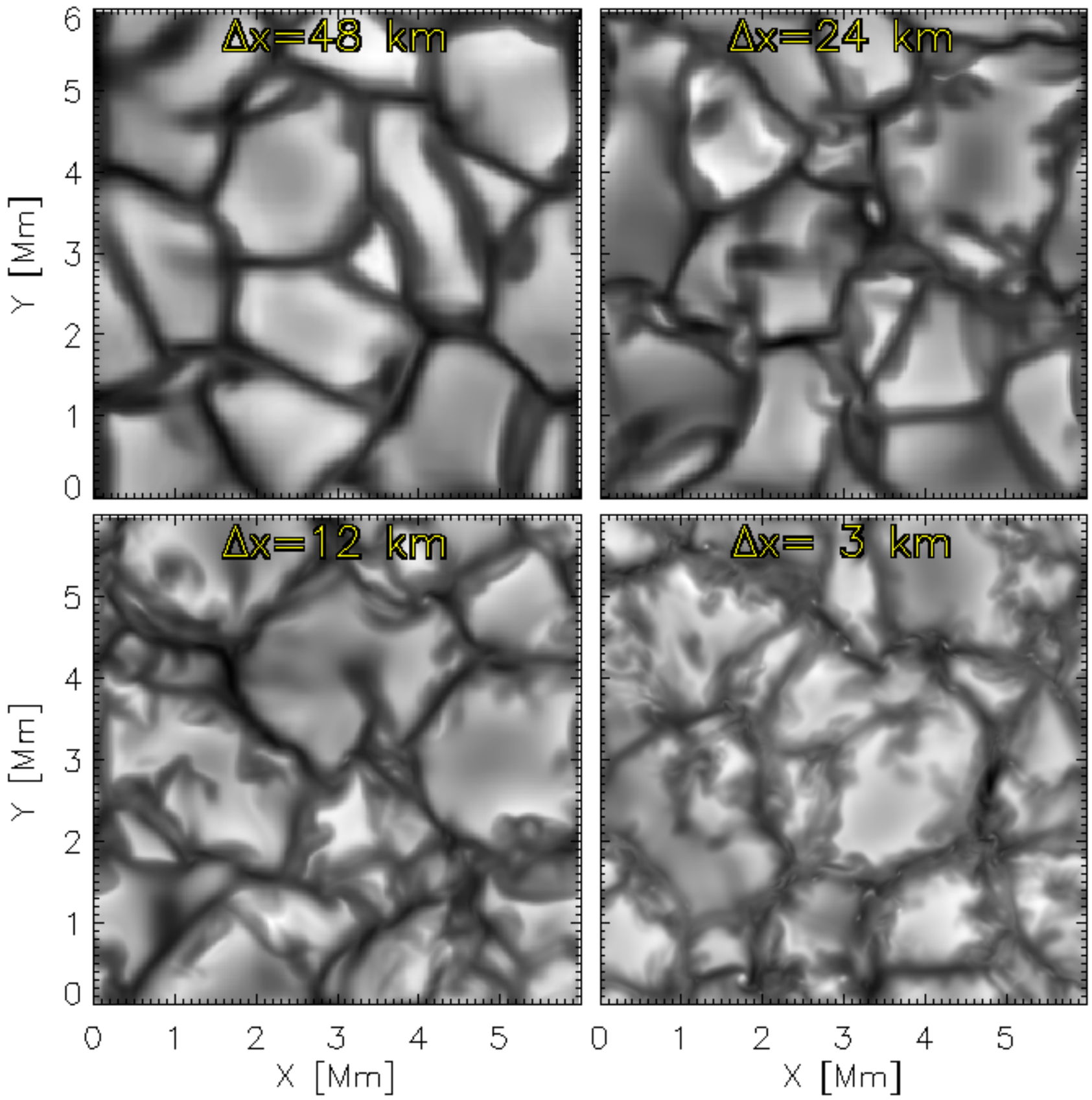
Mg II h&k: peak intensity measures temperature



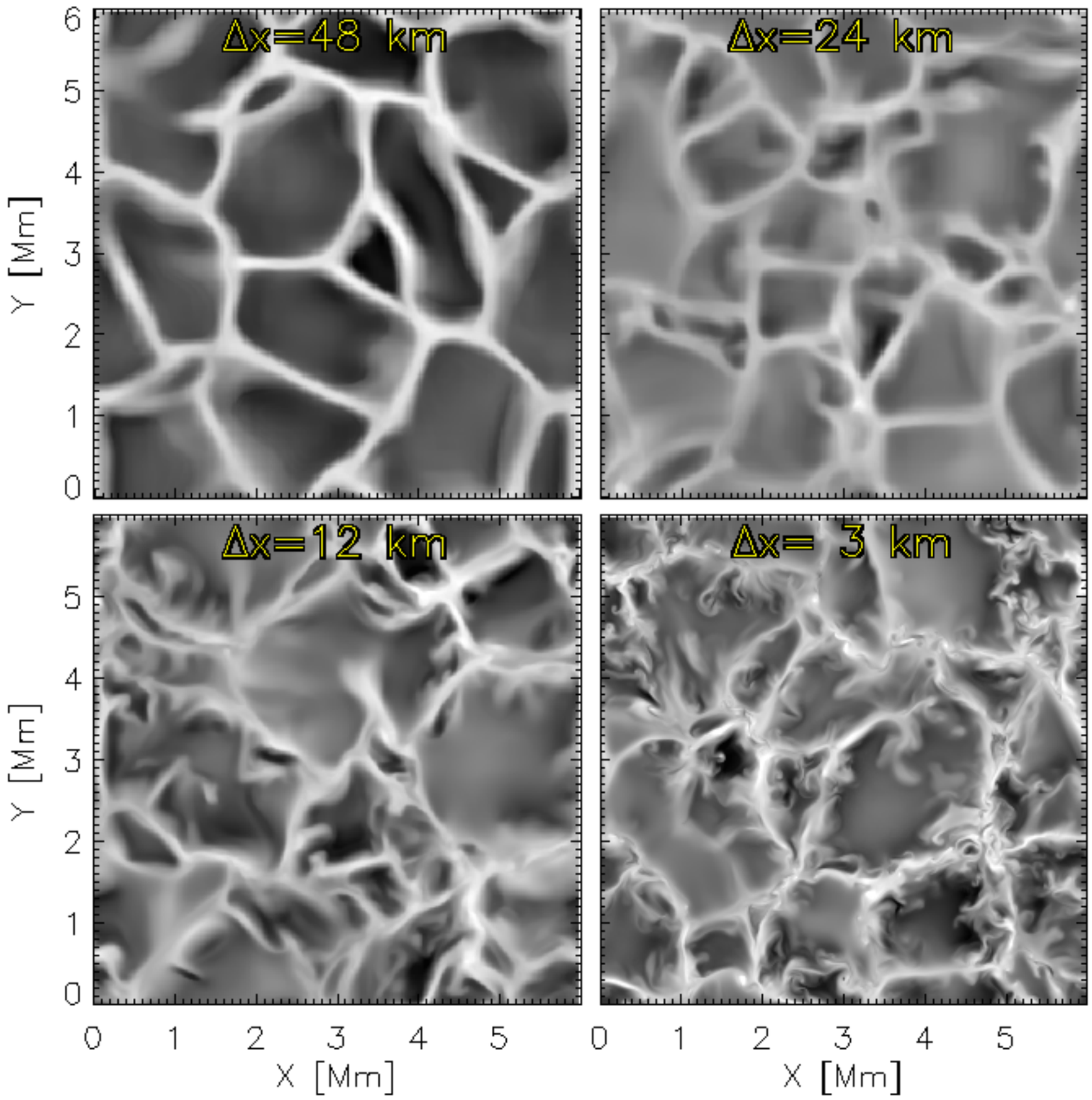
Mg k peak intensity



Effects of numerical resolution



Uz at z=0



Differences simulations/reality

- too low temperature in expanding bubbles
  - ion-neutral effects
- simulations show narrower profiles and too little emission on average
  - not enough chromospheric heating - lacking small scale magnetic field + ion-neutral effects + ?
  - not enough small scale dynamics in simulations - need higher resolution + ion-neutral effects + ?