

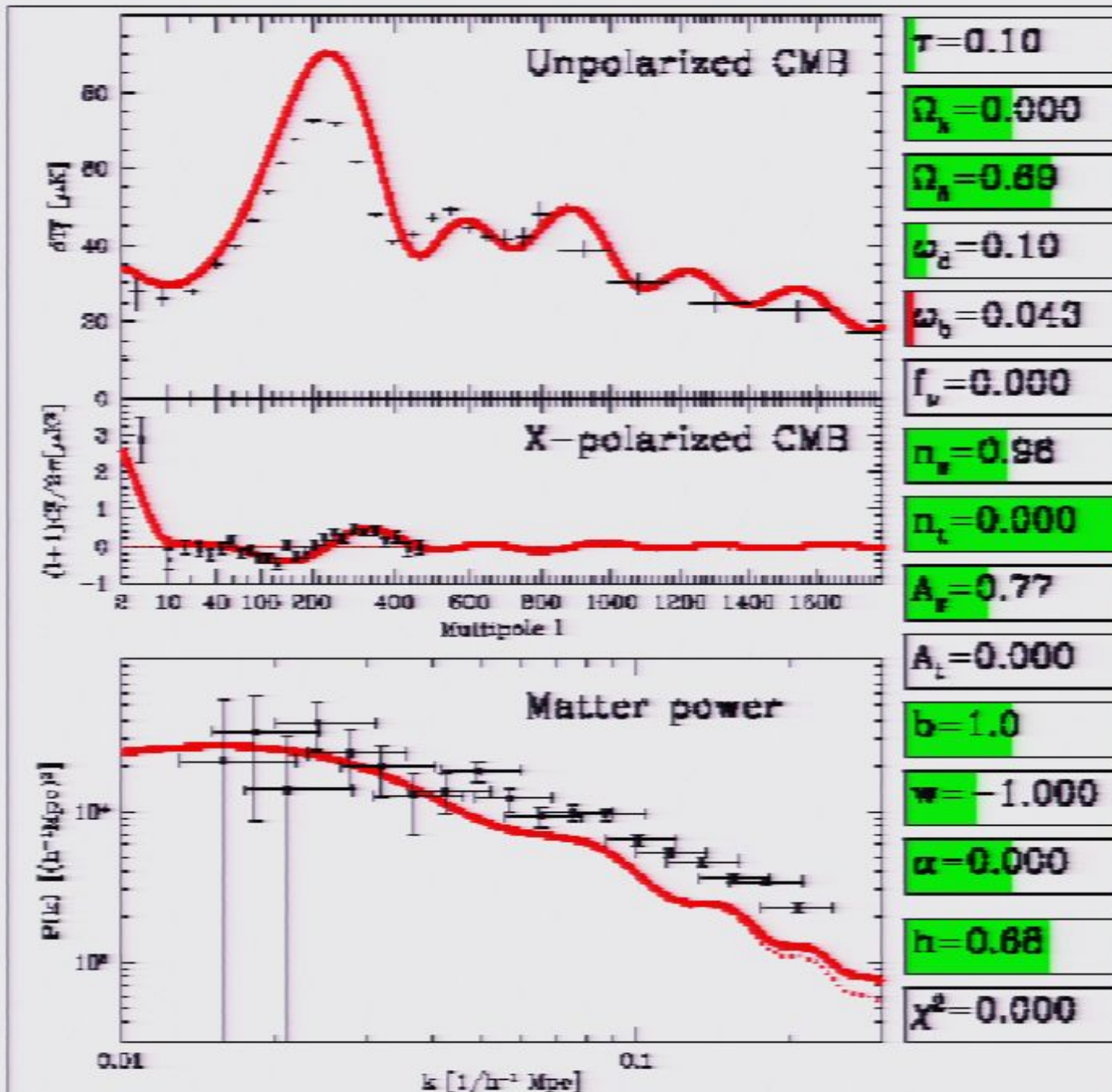
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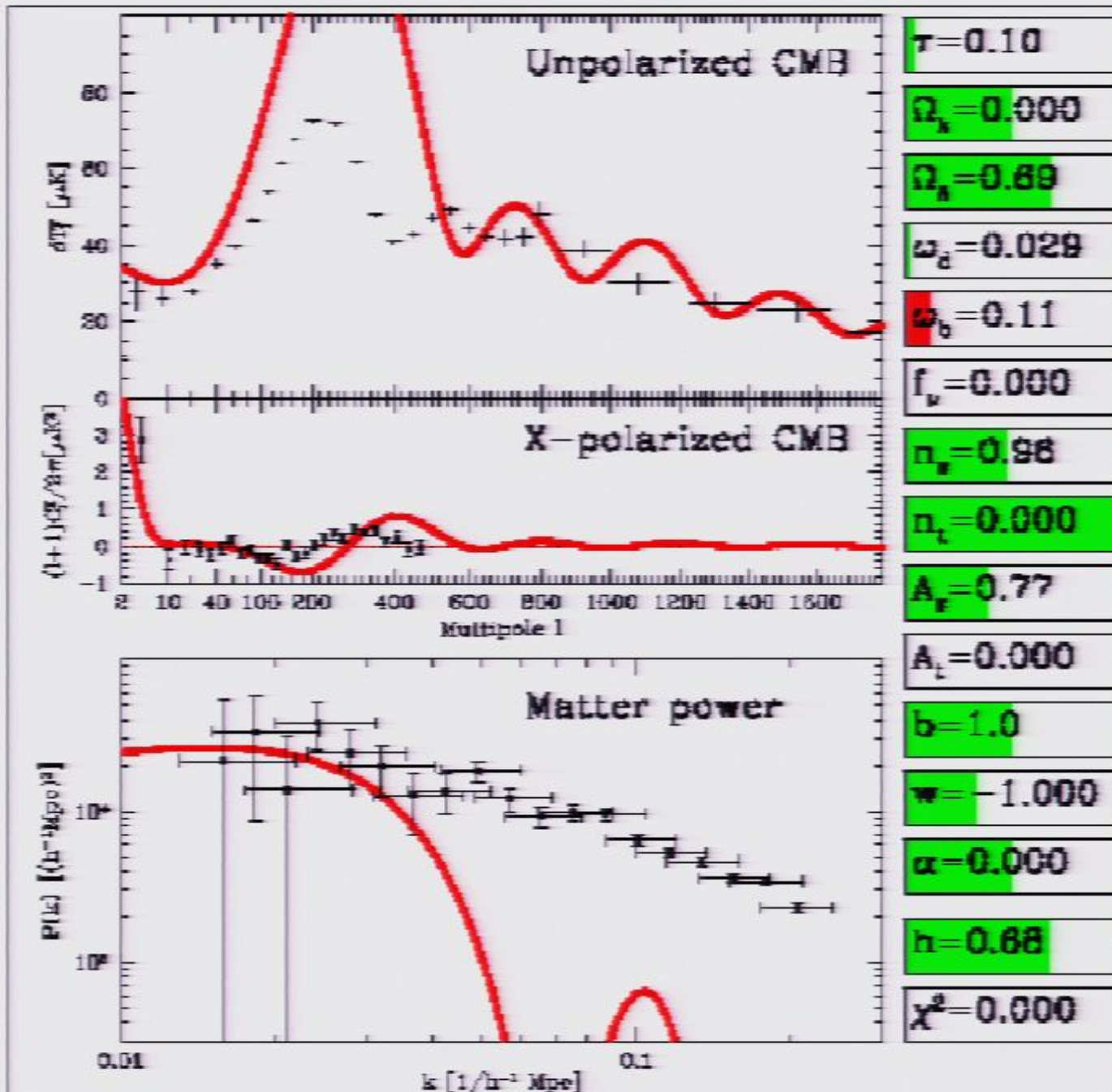
Date: Aug 15, 2007 12:45 PM

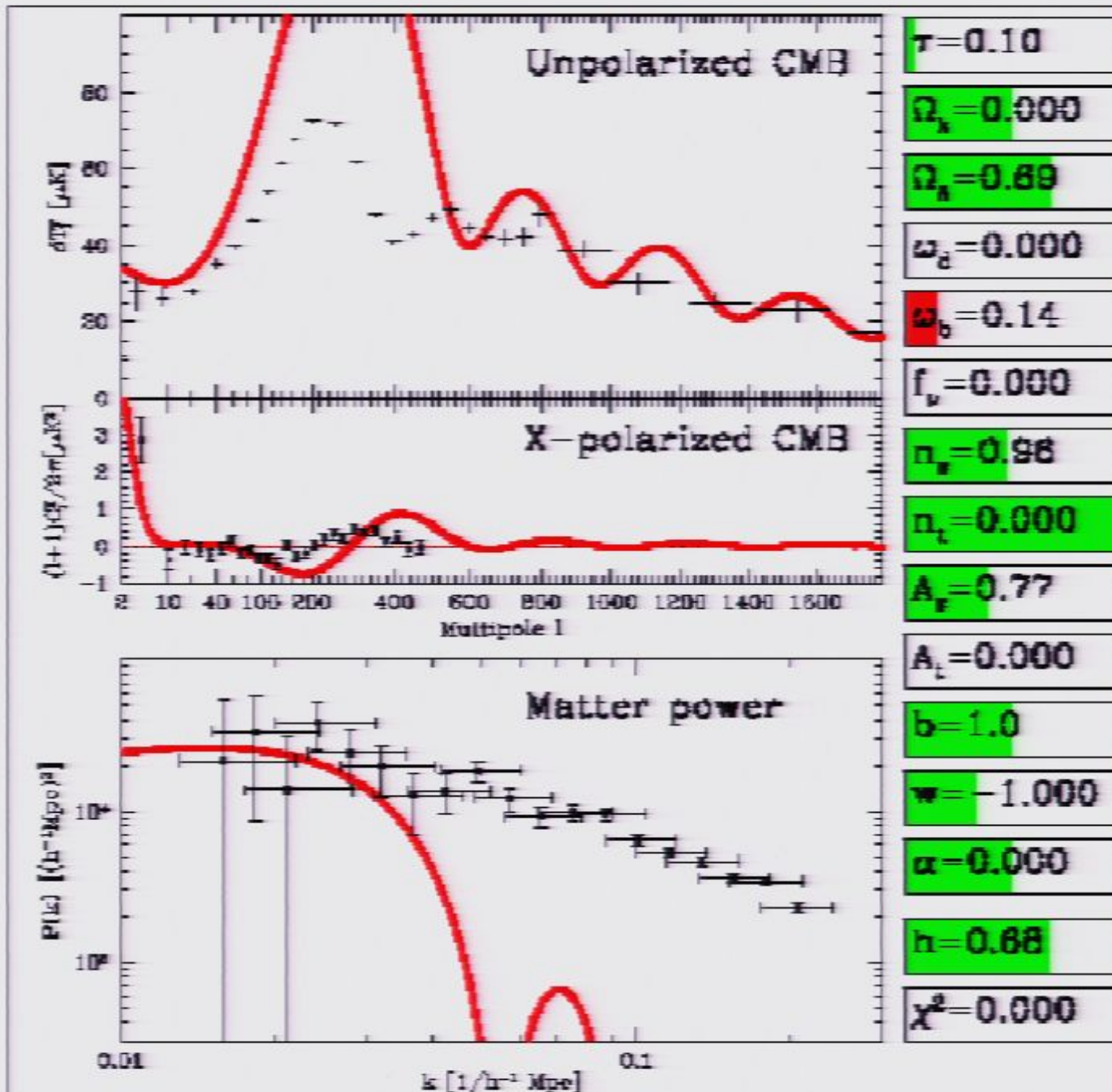
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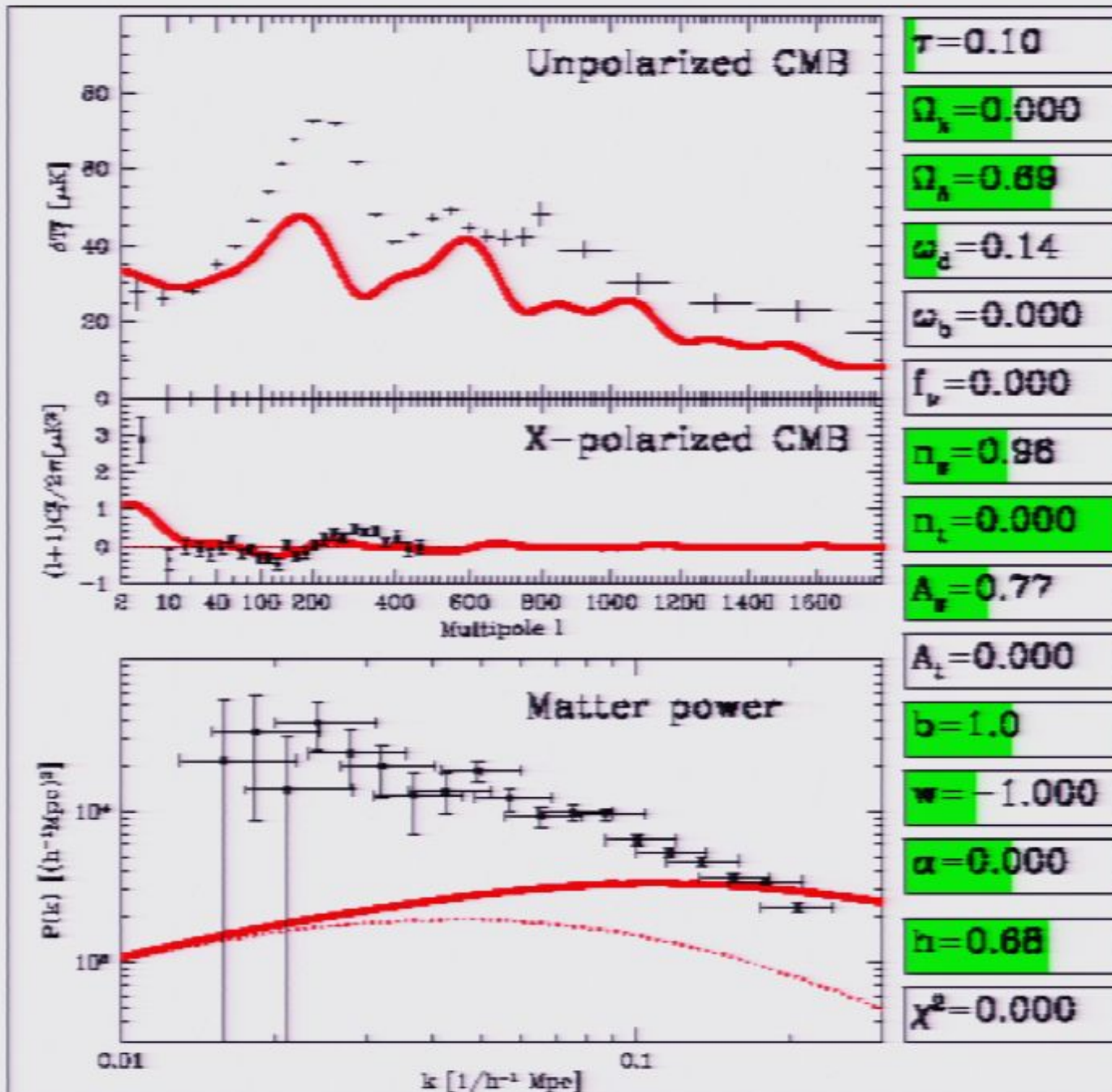
Abstract:

What about Baryons?





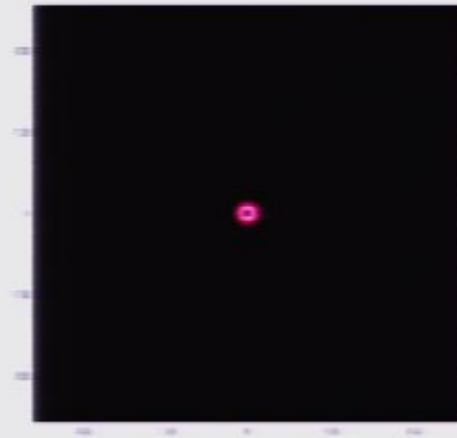




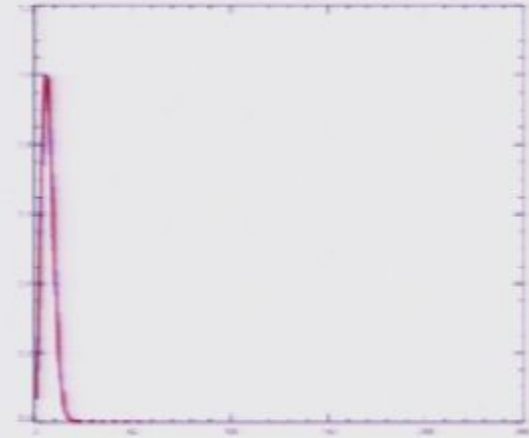
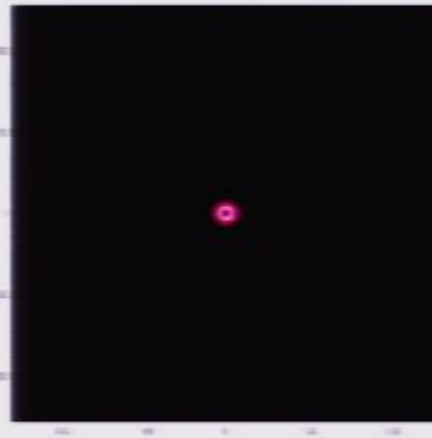
Baryon Acoustic Oscillations



baryons



photons



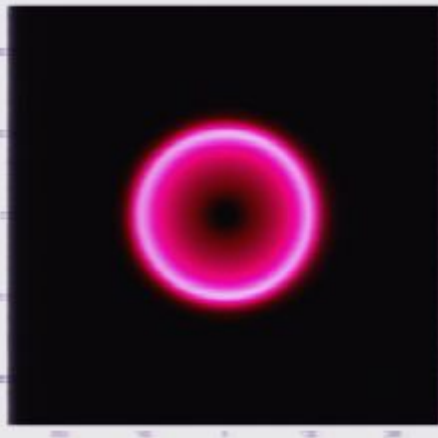
Initial fluctuation in DM. Sound wave driven out by intense pressure at $0.57c$.

Courtesy of Martin White

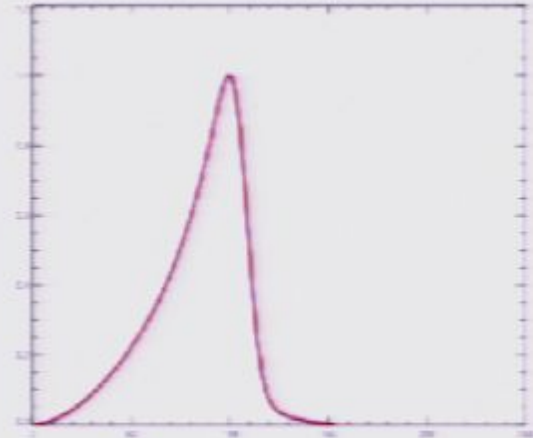
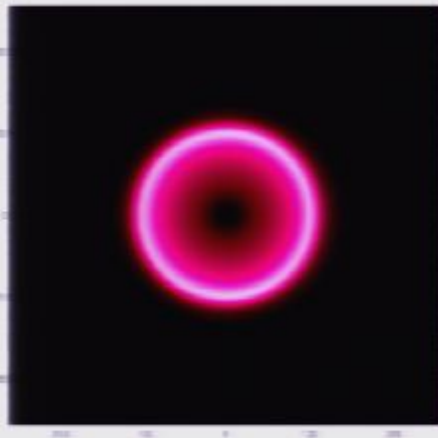
Baryon Acoustic Oscillations



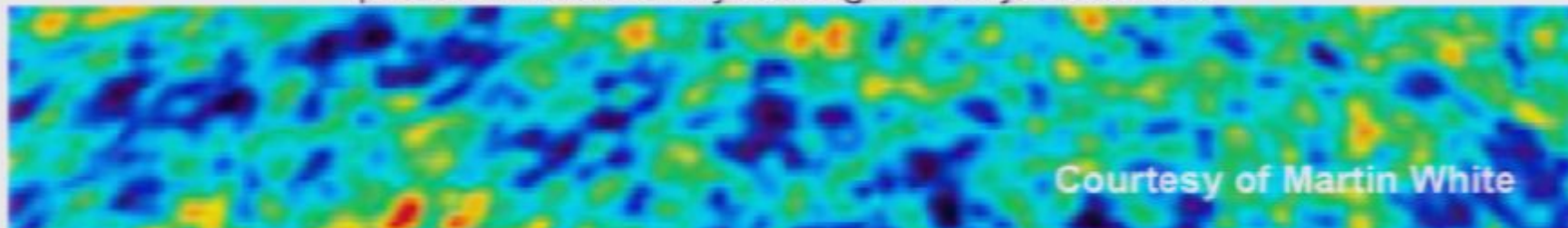
baryons



photons



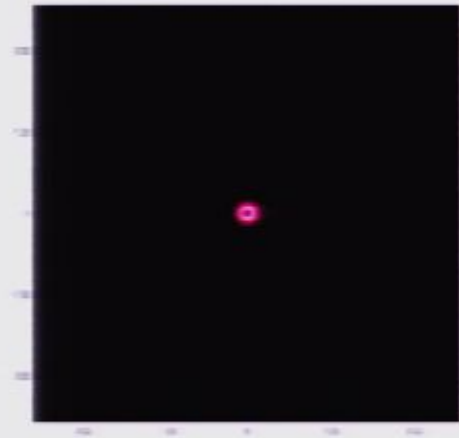
After 10^5 years, we reach recombination and photons stream away leaving the baryons behind



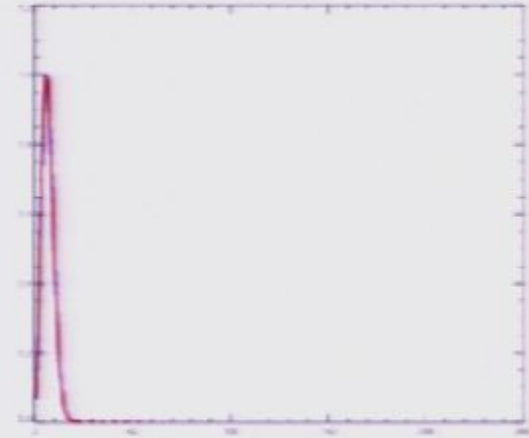
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baryons



photons



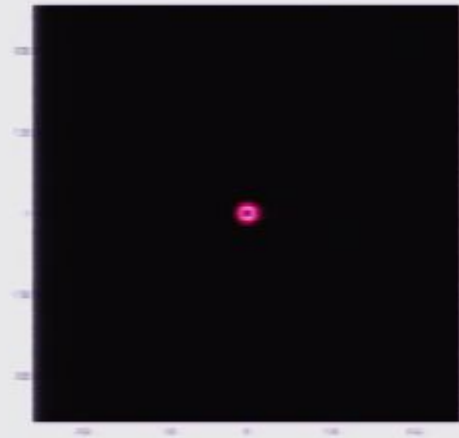
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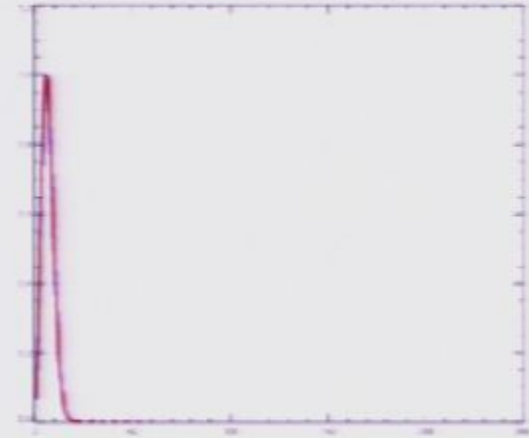
Baryon Acoustic Oscillations



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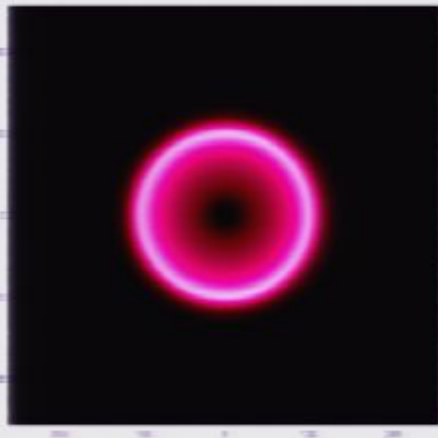
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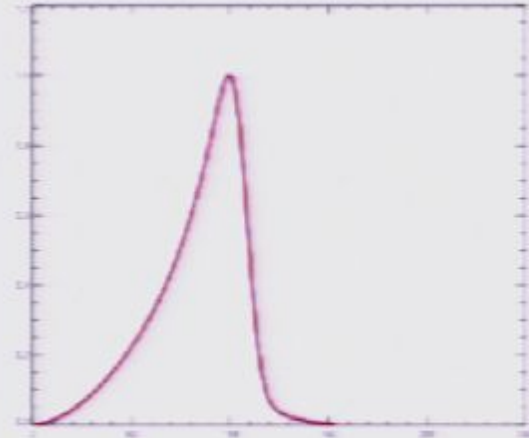
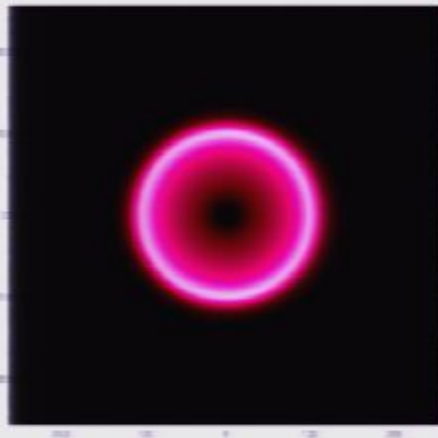
Baryon Acoustic Oscillations



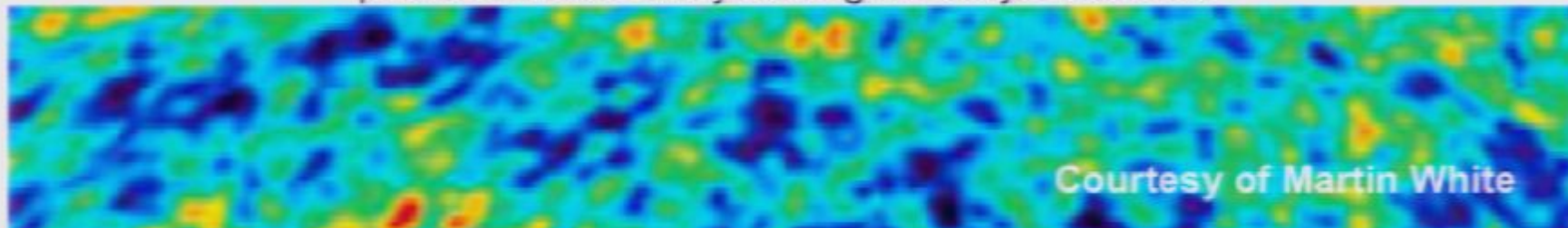
baryons



photons



After 10^5 years, we reach recombination and photons stream away leaving the baryons behind

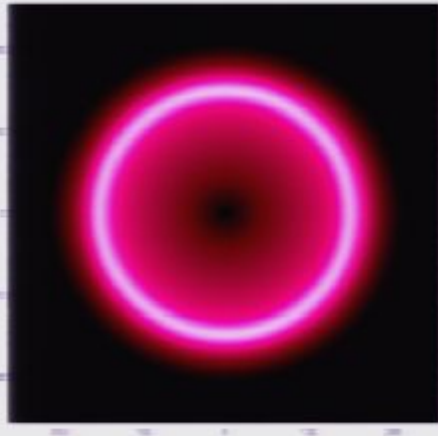


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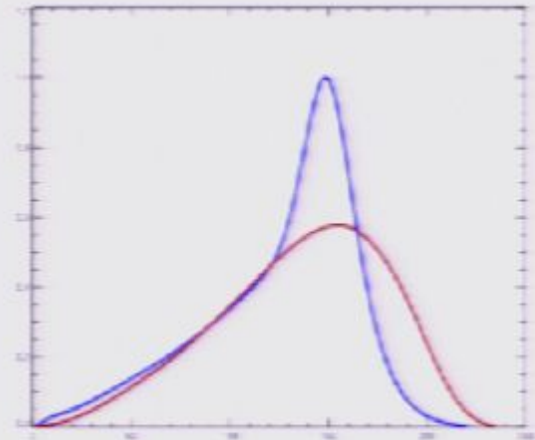
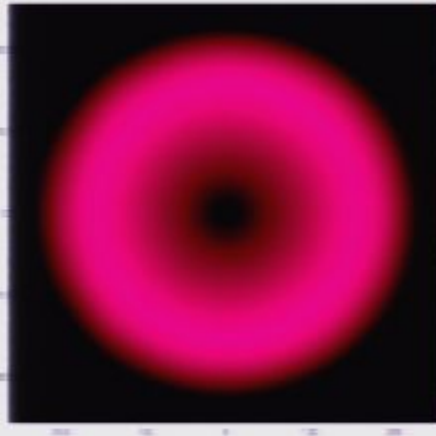
Baryon Acoustic Oscillations



baryons



photons



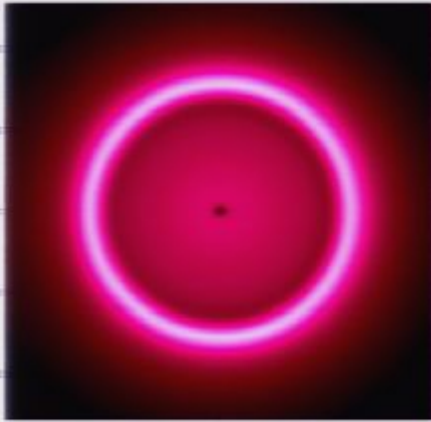
Photons free stream, while baryons remain still as pressure is gone

Courtesy of Martin White

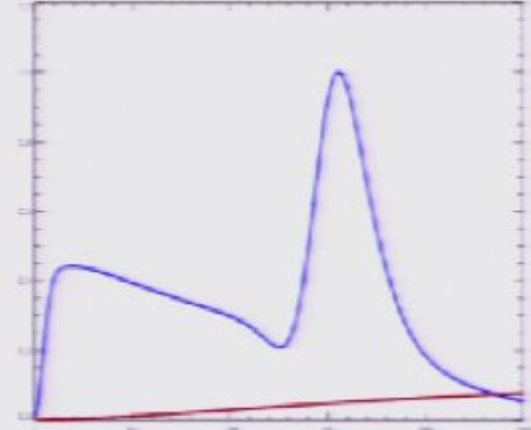
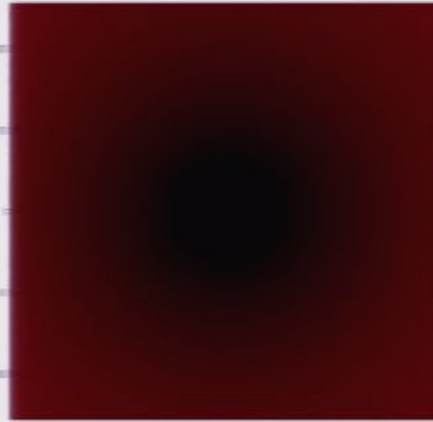
Baryon Acoustic Oscillations



baryons



photons



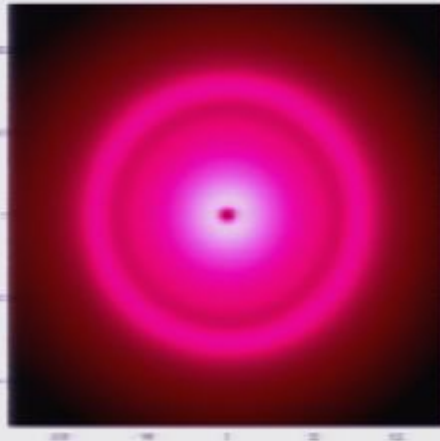
Photons almost fully uniform, baryons are attracted back by the central DM fluctuation

Courtesy of Martin White

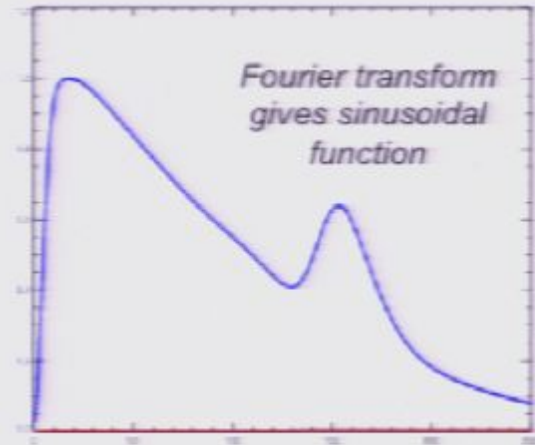
Baryon Acoustic Oscillations



baryons



photons



Today. Baryons and DM in equilibrium. The final configuration is the original peak at the center and an echo roughly 100Mpc in radius

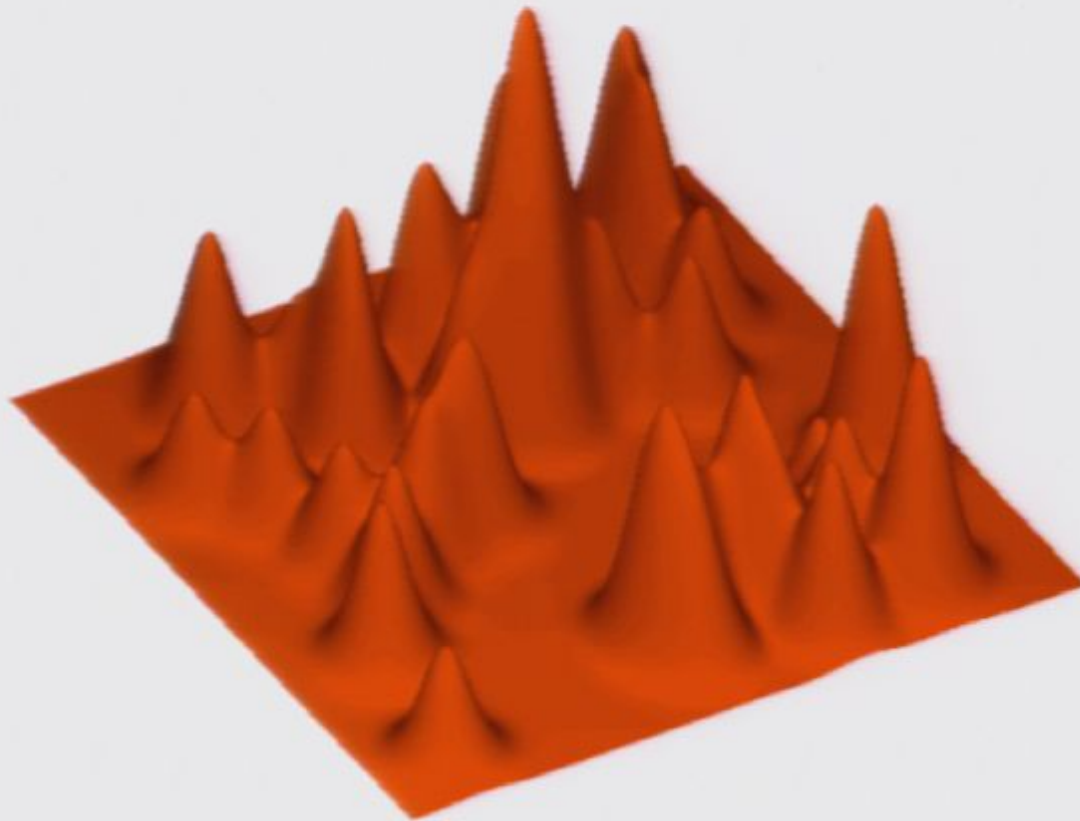
Courtesy of Martin White

Baryon Acoustic Oscillations

Many superimposed waves. See them statistically

icg

Portsmouth



- Positions predicted once (physical) matter and baryon density known - calibrated by the CMB.

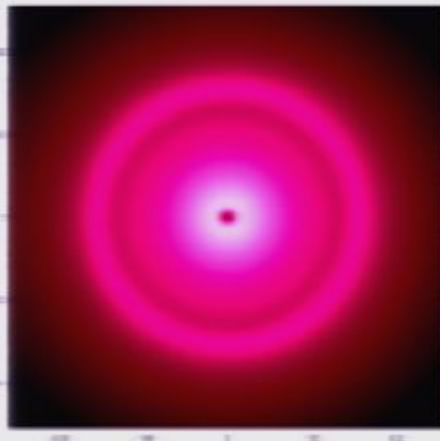
- Oscillations are sharp, unlike other features of the power spectrum

Daniel Eisenstein

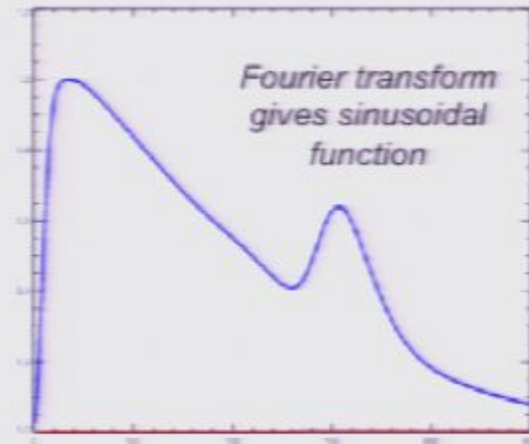
Baryon Acoustic Oscillations



baryons



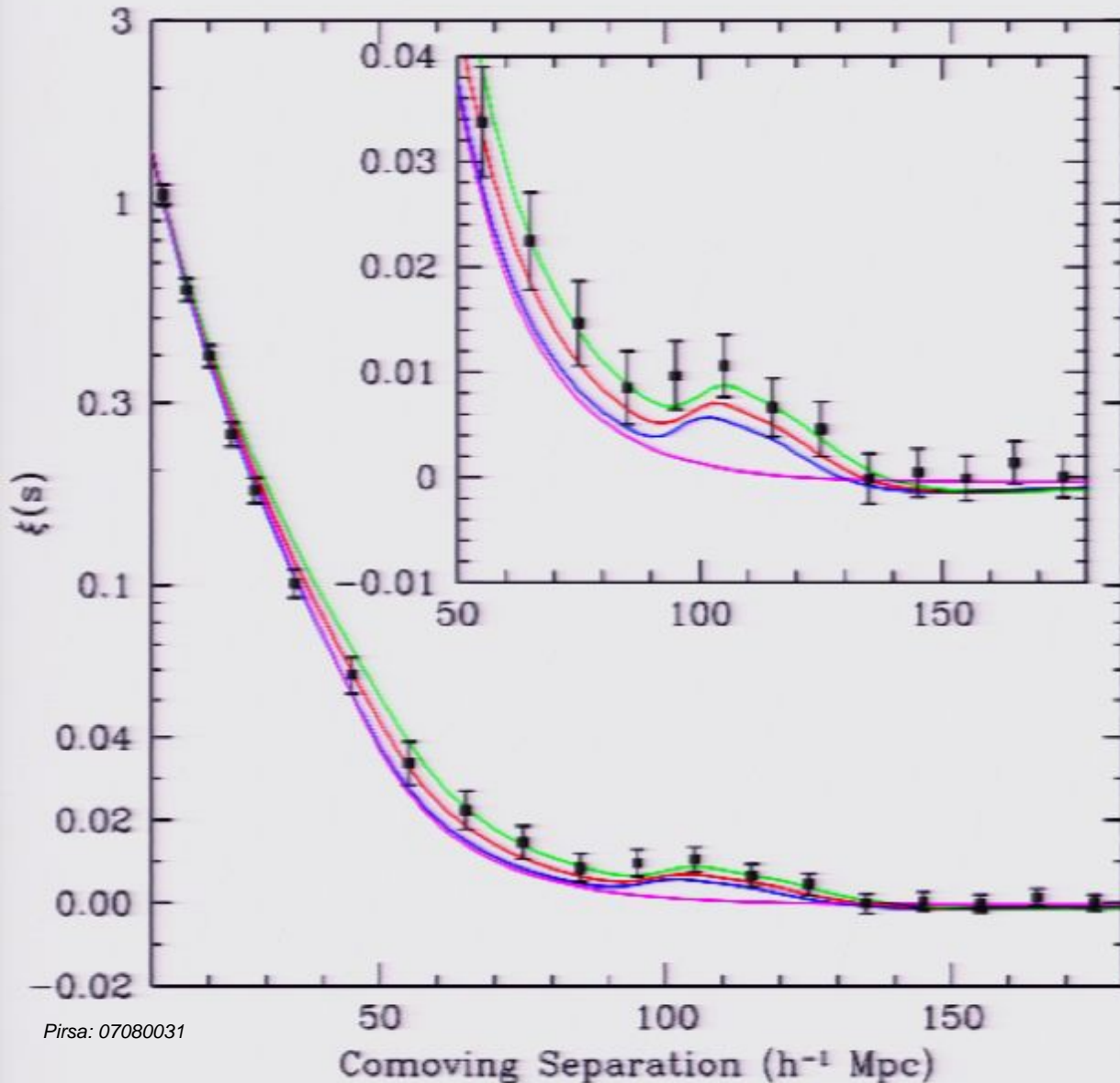
photons



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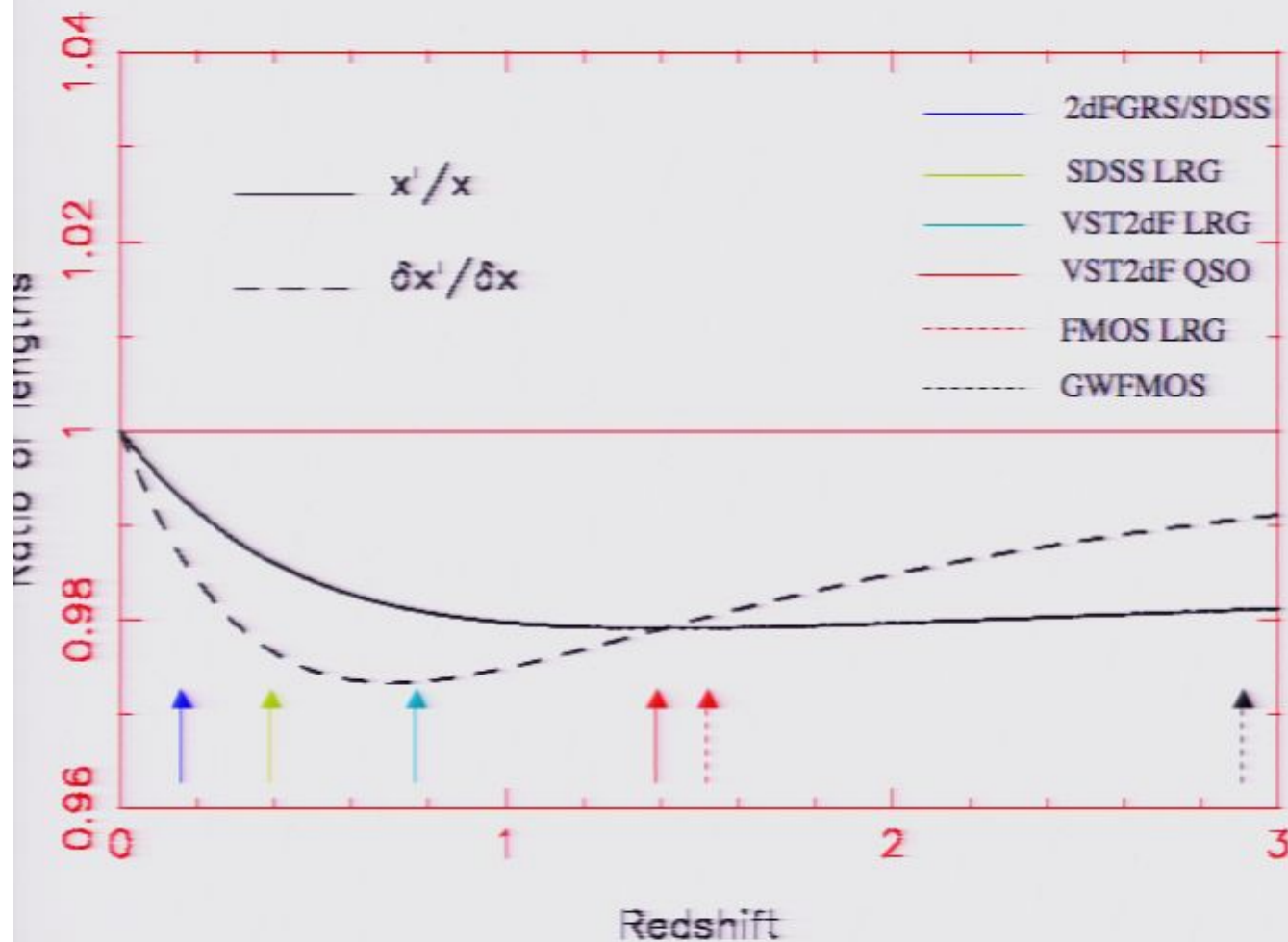
Courtesy of Martin White

SDSS LRG Correlation function



- Correlation function from 45000 SDSS LRGs (Eisenstein et al 2005)

Baryon wiggles z dependence



- If $\Omega_m = 0.3$, $w = -1$, but assumed cosmology is $\Omega_m = 0.3$, $w = -0.9$ \Rightarrow lengths distort by $\sim 2\%$ as shown ($k=0$)
- Solid line - θ
- Dashed line - z
- (Blake & Glazebrook 2003)

In Practice:

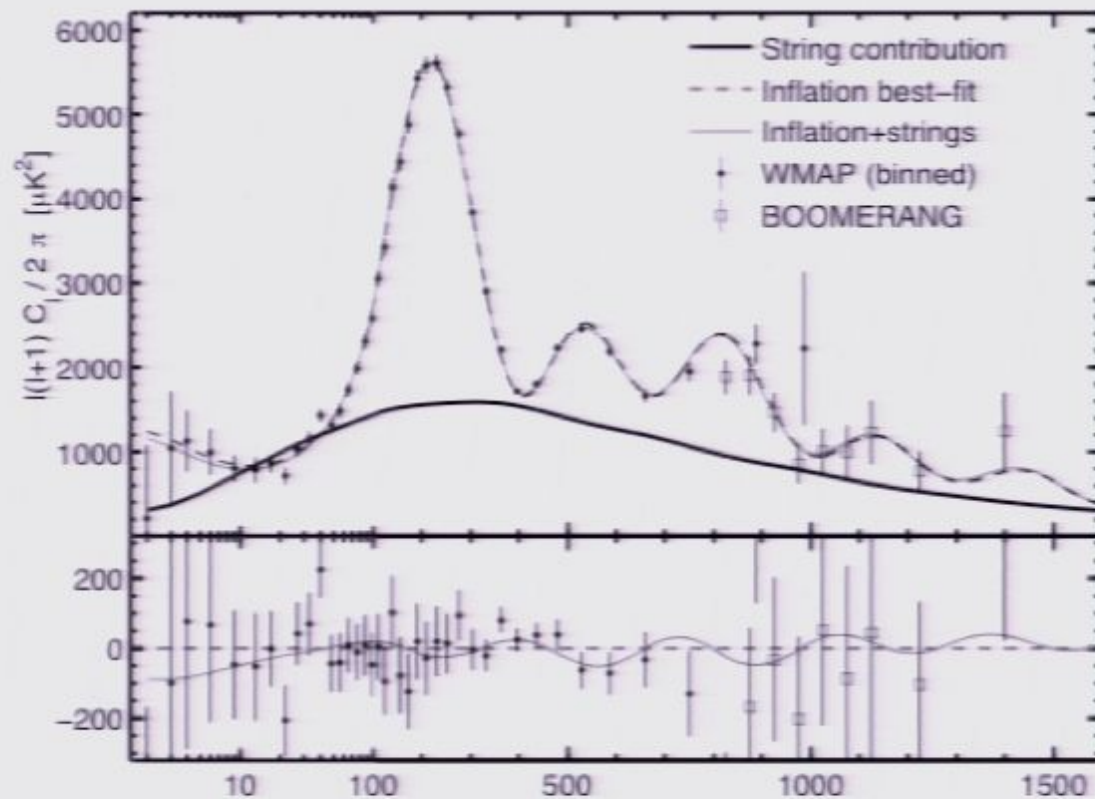
Two Ways to Use these Data

1. Predict and test primordial $P(k)$
 - Inflation? Ekpyrosis? String gas?
 - This usually means comparing n_s
2. Constrain intervening cosmology
 - Examples: neutrino masses, hubble parameter, dark energy eqn. of state

In Practice:

Example of 1: Cosmic Strings

Determination by Bevis et al, astro-ph/0702223v2



In Practice:

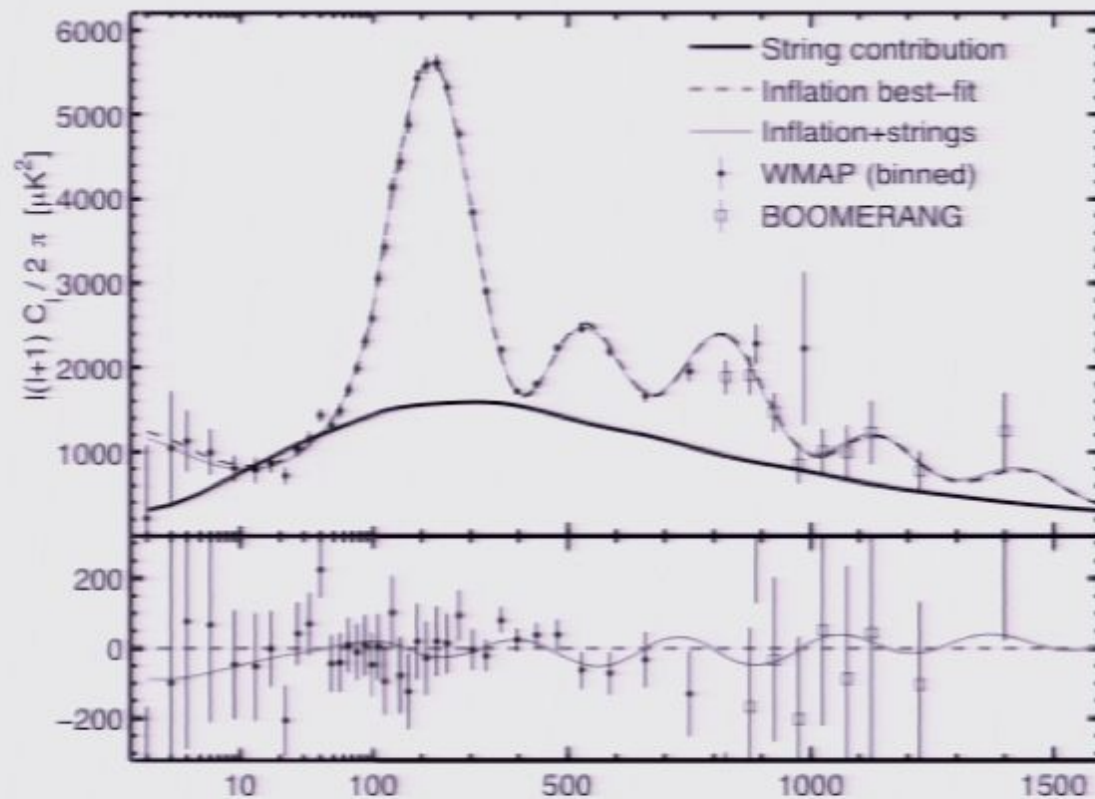
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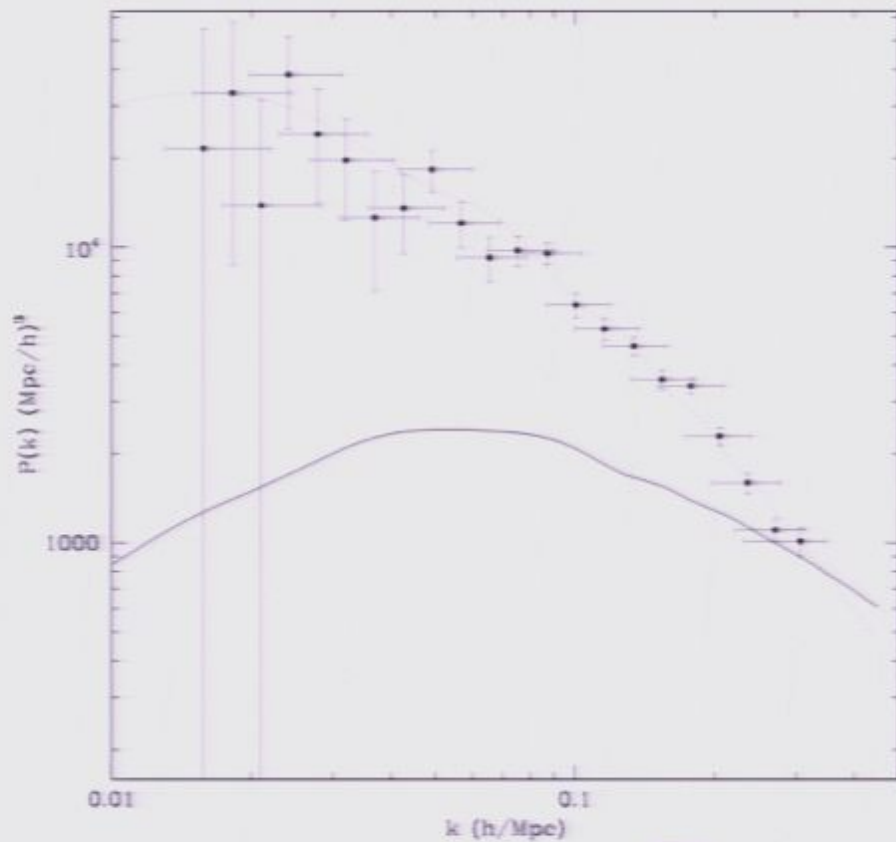
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In Practice: Example of 1: Cosmic Strings

Determination by Wyman et al, astro-ph/0503364

add SDSS...



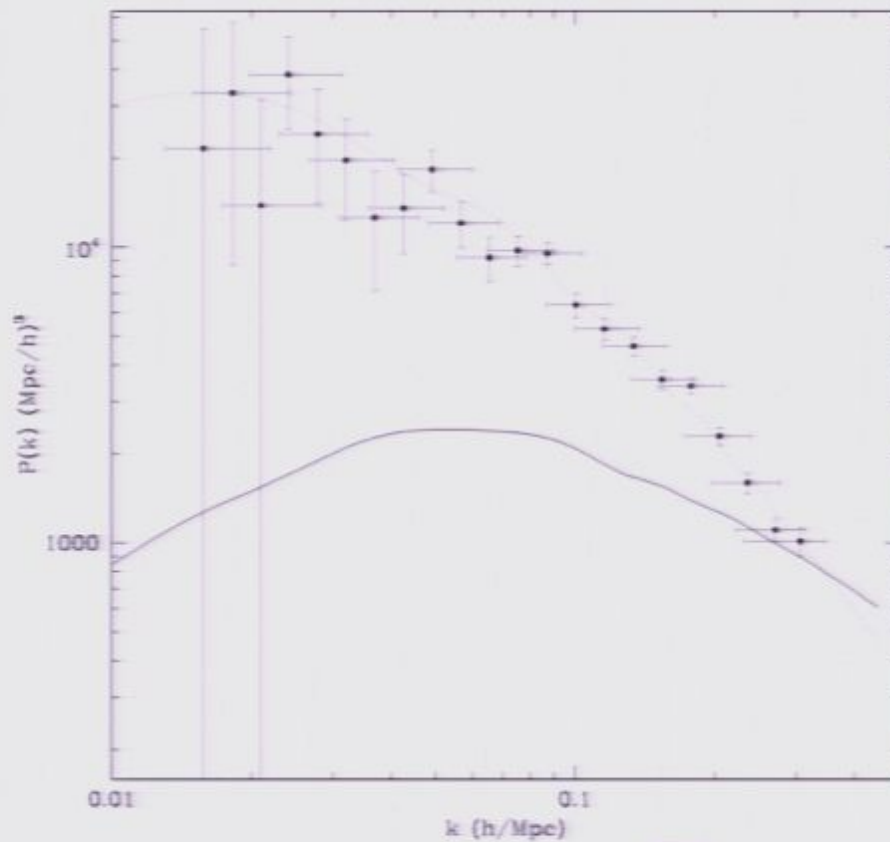
$$G\mu < 2 \times 10^{-7}$$

In Practice:

Example of 1: Cosmic Strings

Determination by Wyman et al, astro-ph/0503364

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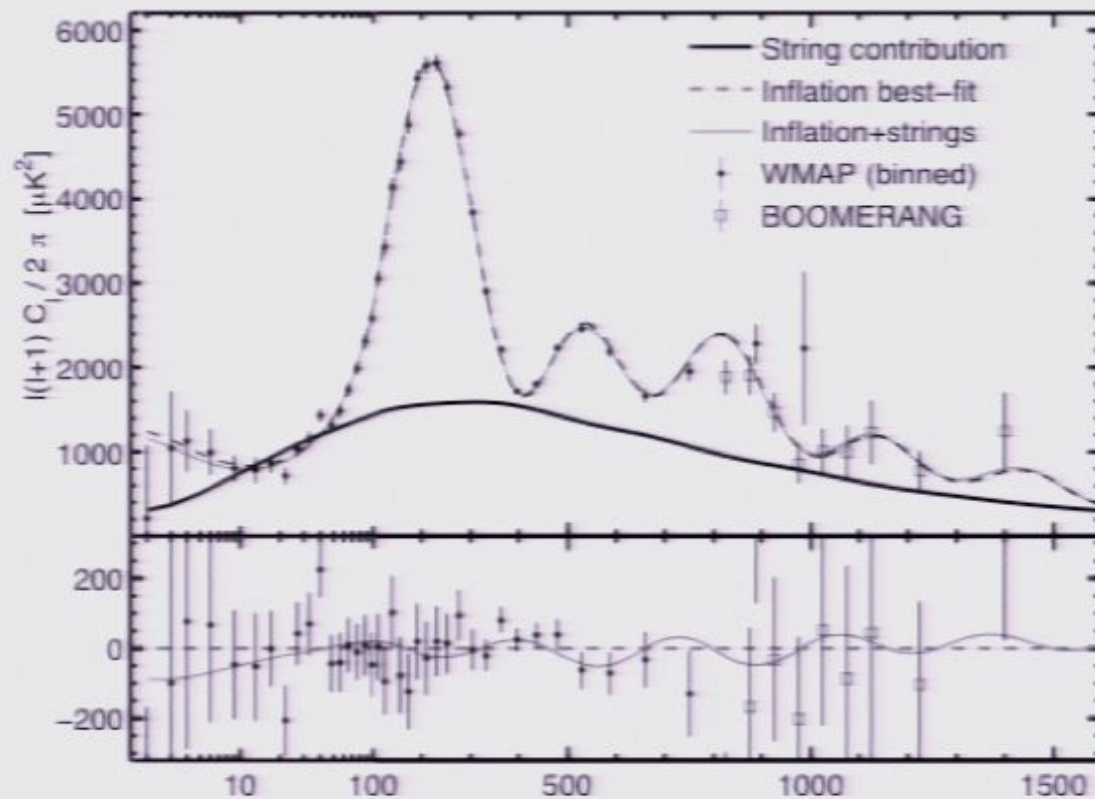


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Example of 1: Cosmic Strings

Determination by Bevis et al, astro-ph/0702223v2

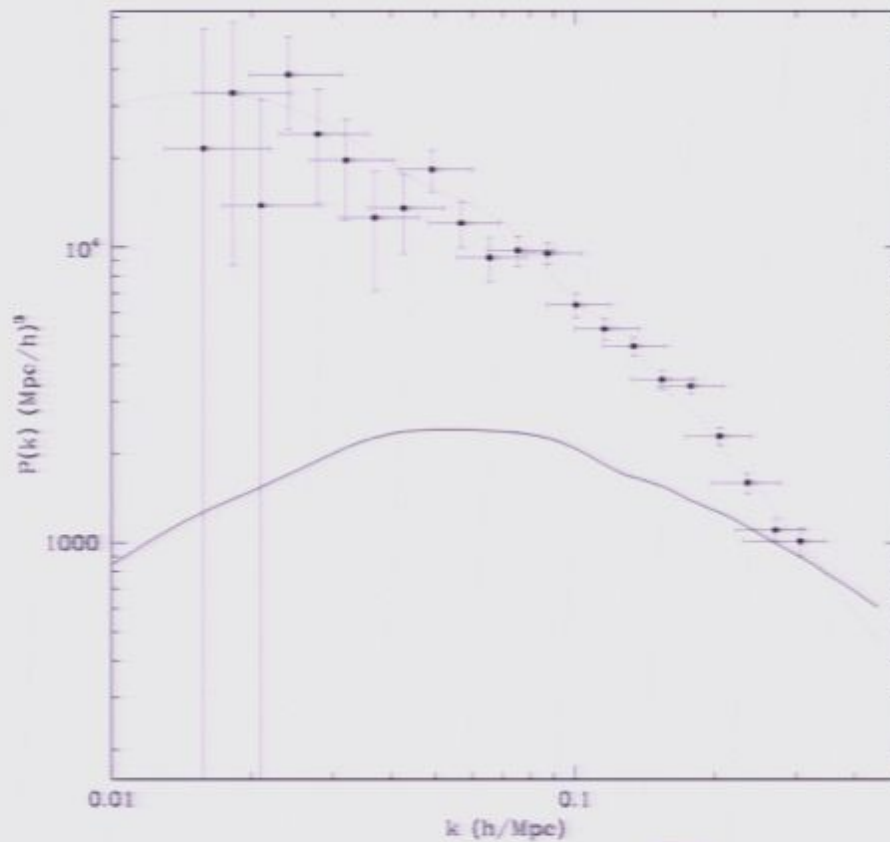


In Practice:

Example of 1: Cosmic Strings

Determination by Wyman et al, astro-ph/0503364

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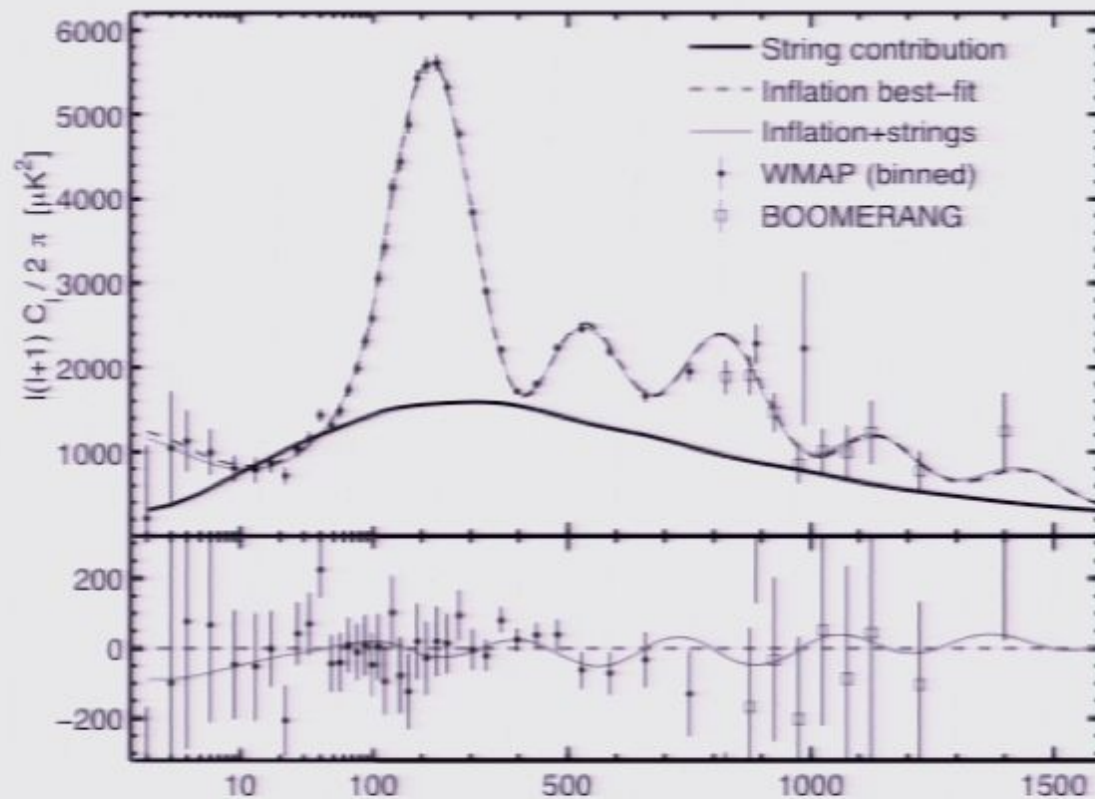


$$G\mu < 2 \times 10^{-7}$$

In Practice:

Example of 1: Cosmic Strings

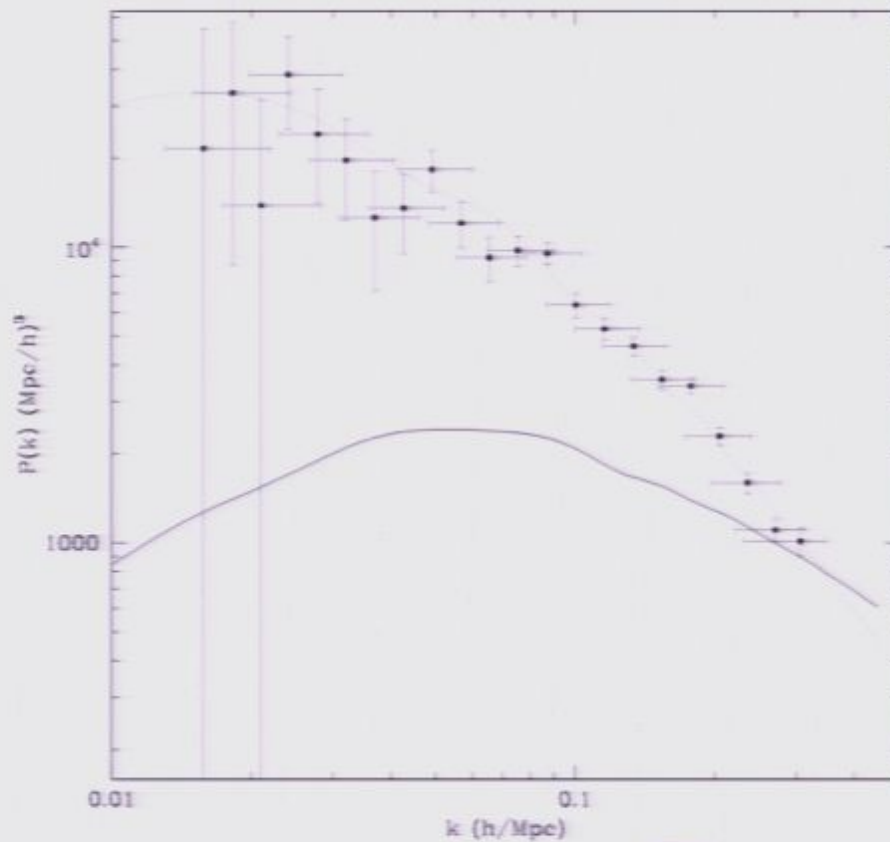
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In Practice: Example of 1: Cosmic Strings

Determination by Wyman et al, astro-ph/0503364

add SDSS...



$$G\mu < 2 \times 10^{-7}$$

What Can You Trust?

- Less certain constraints:
 - neutrino masses
 - running of n_s (*value* of n_s ?)
- Why mention?
 - if you're a theorist, you'll want these constraints to *go away* at some point!

What Can You Trust?

- What can go wrong?
 - So-called “gastrophysics” -- does the parameter depend on understanding gas clouds?
 - Nonlinear effects -- which are generally poorly understood?
 - Remember: stars must *collapse* and *form* before they can *emit* light
 - Experimental ... error?

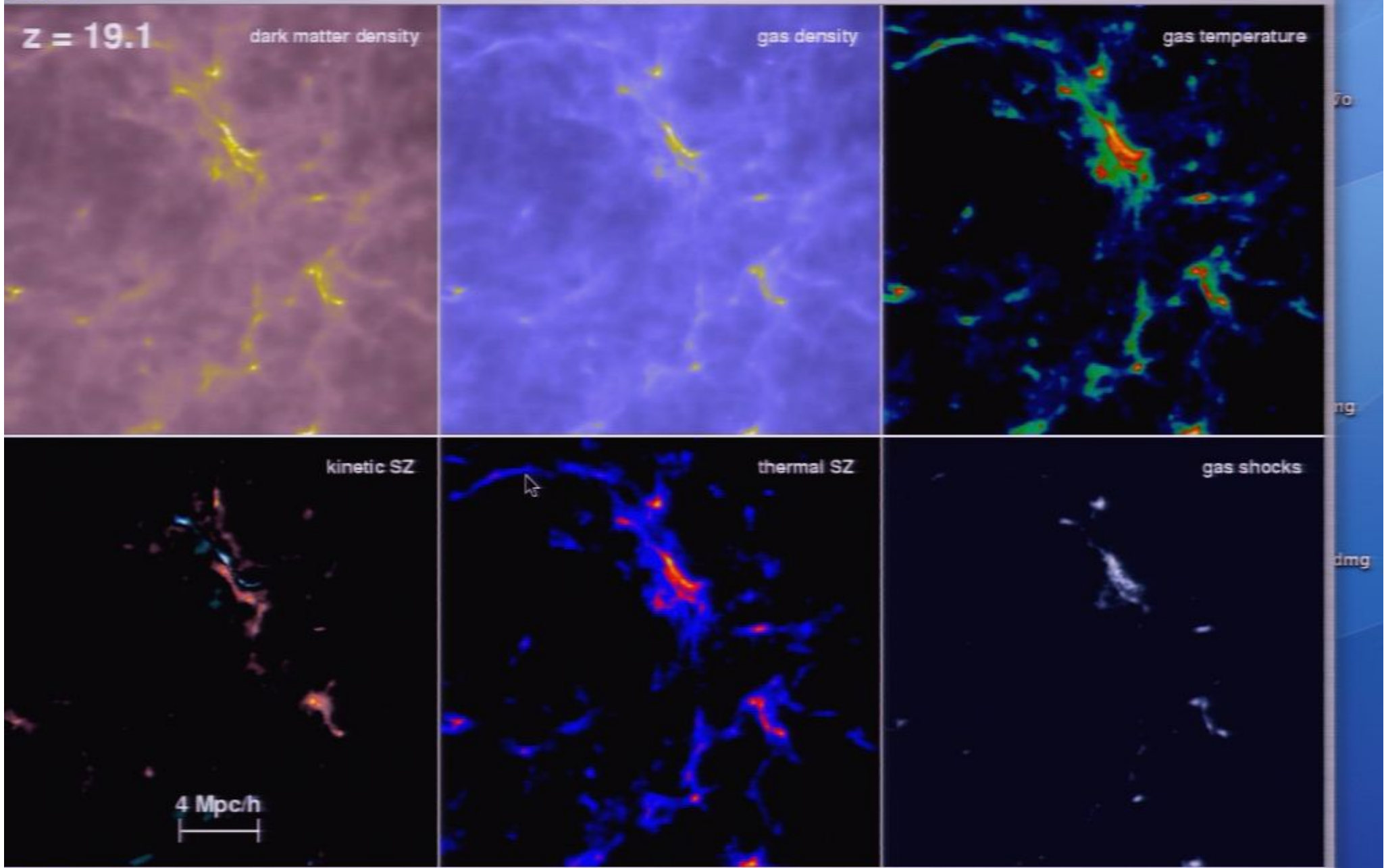
Movie ...

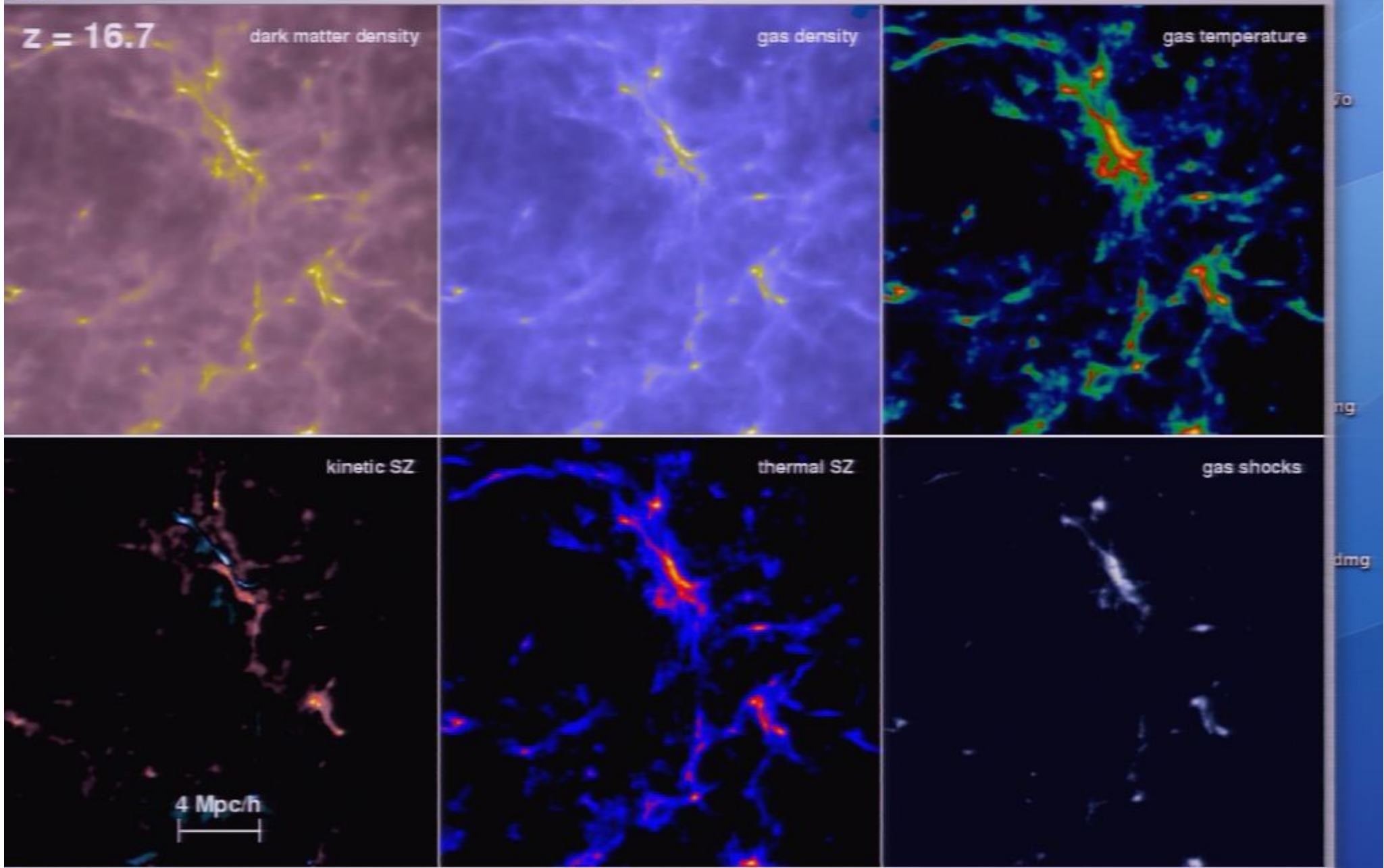
1 Gpc/h

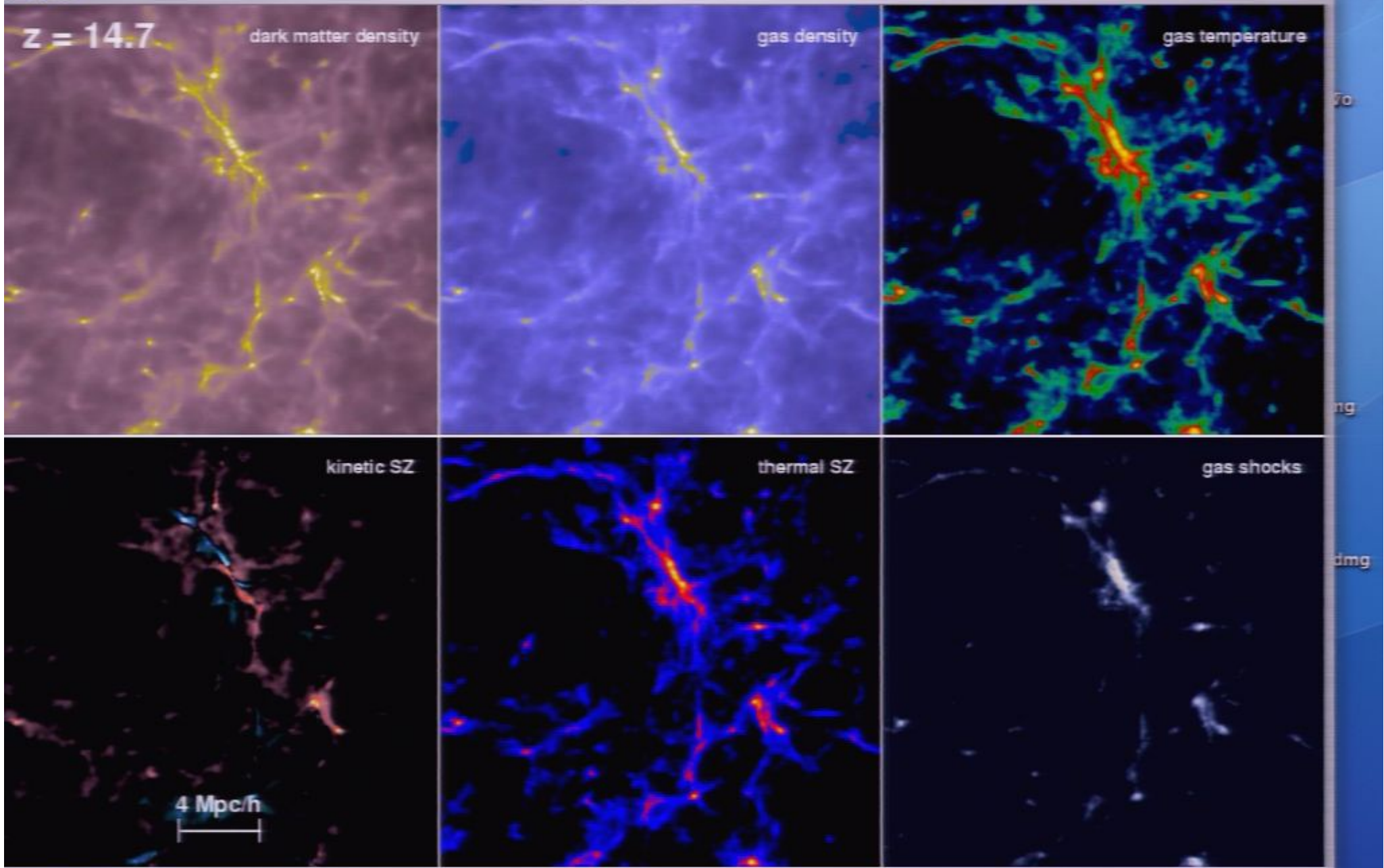
Millennium Simulation

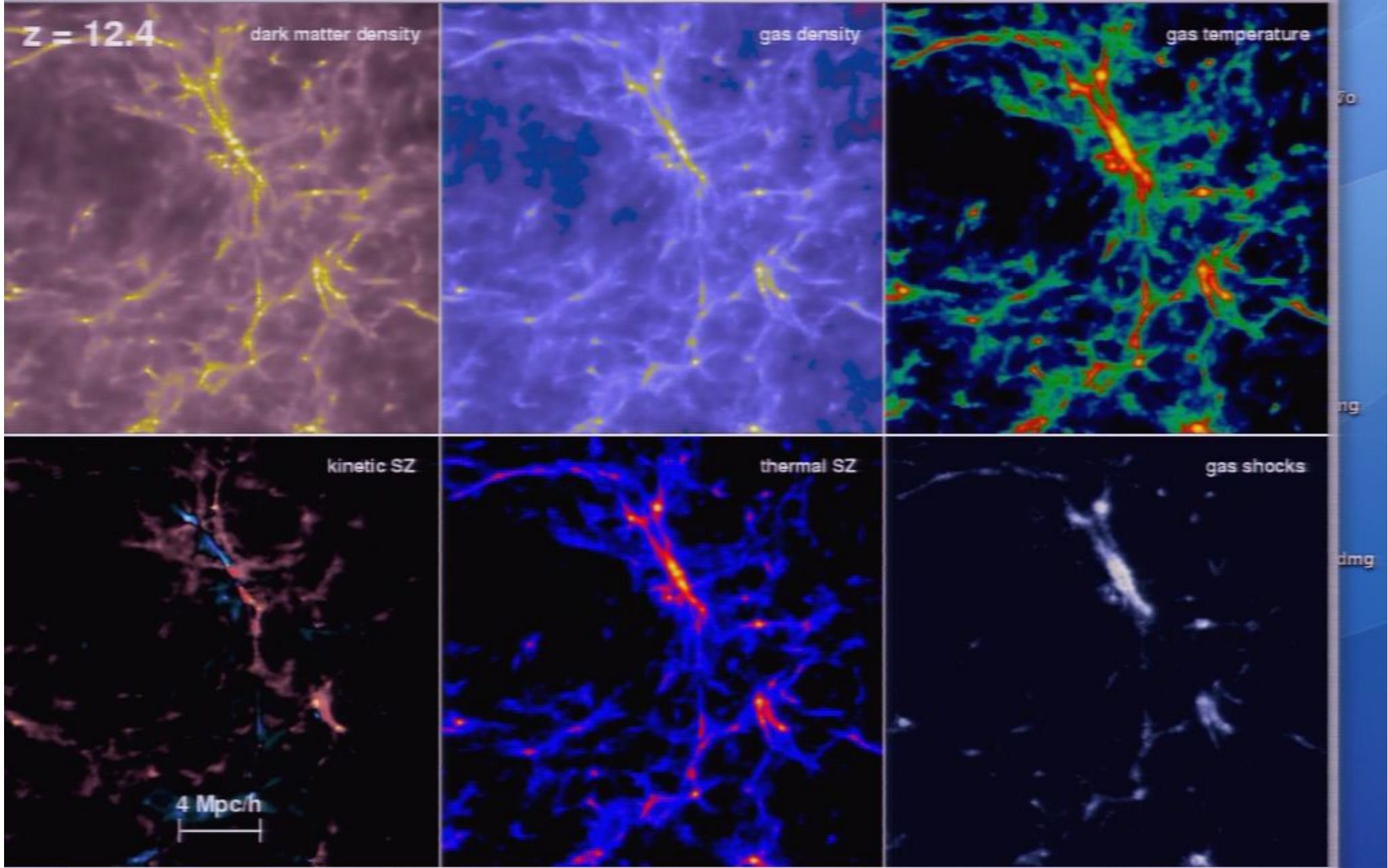
10,077,696,000 particles

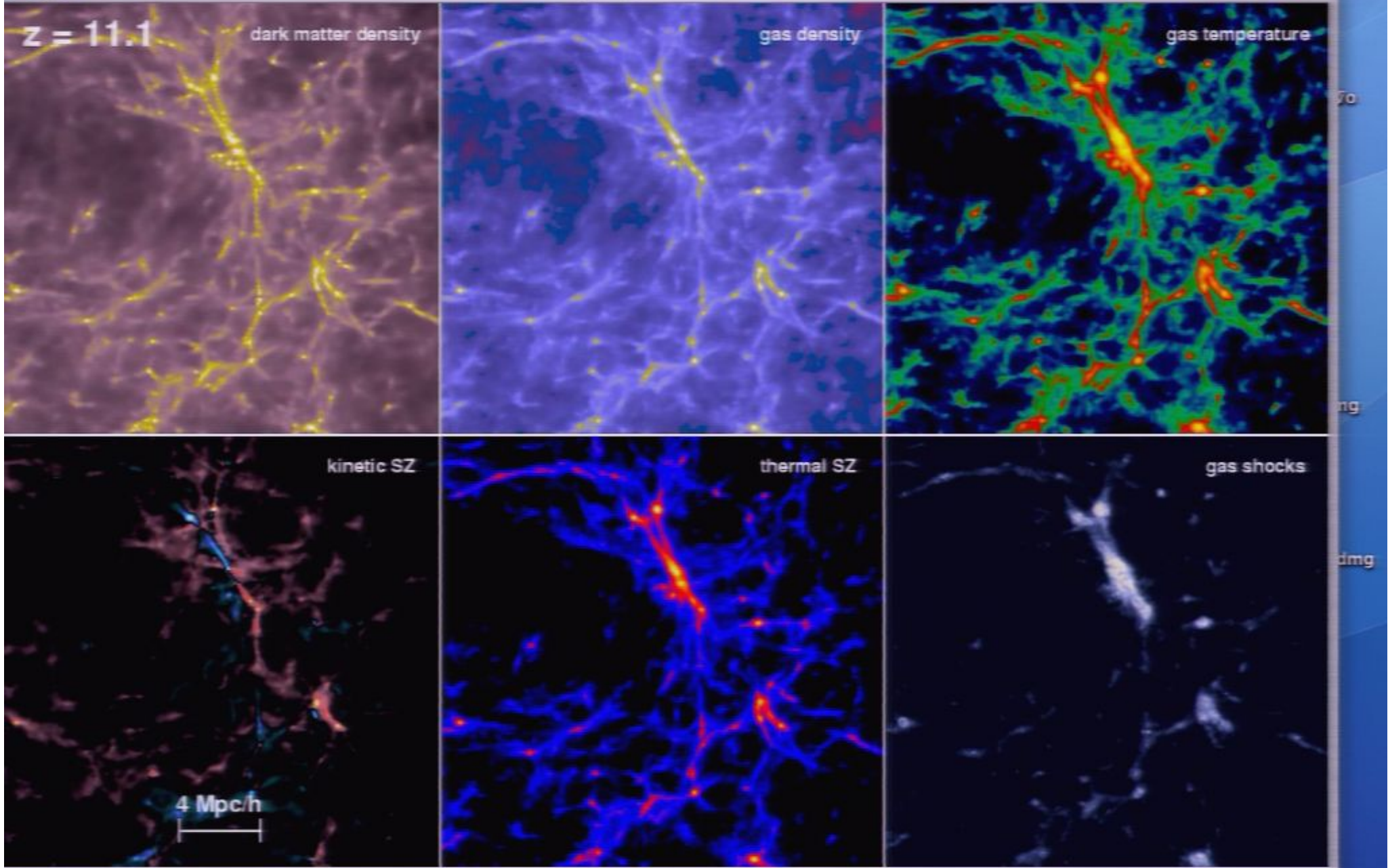
(z = 0)

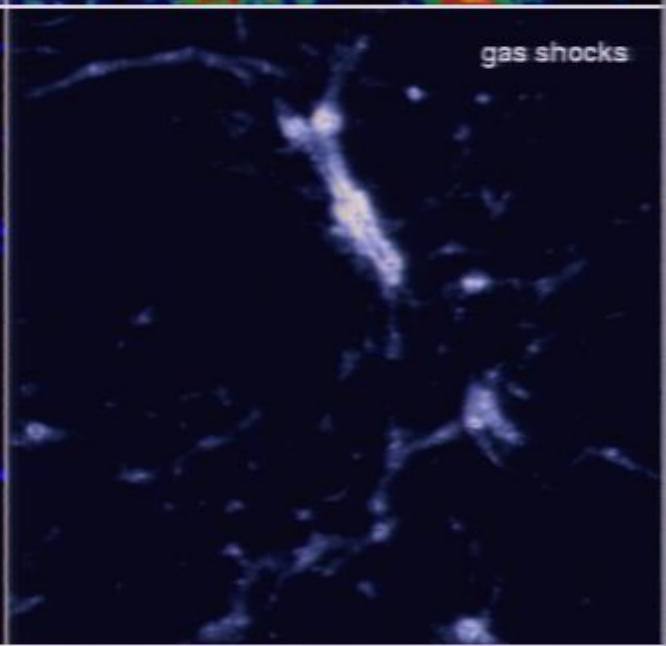
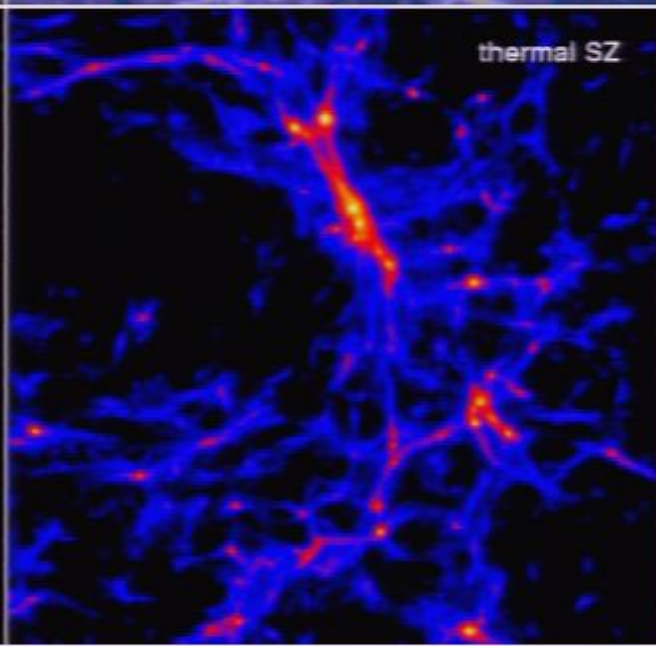
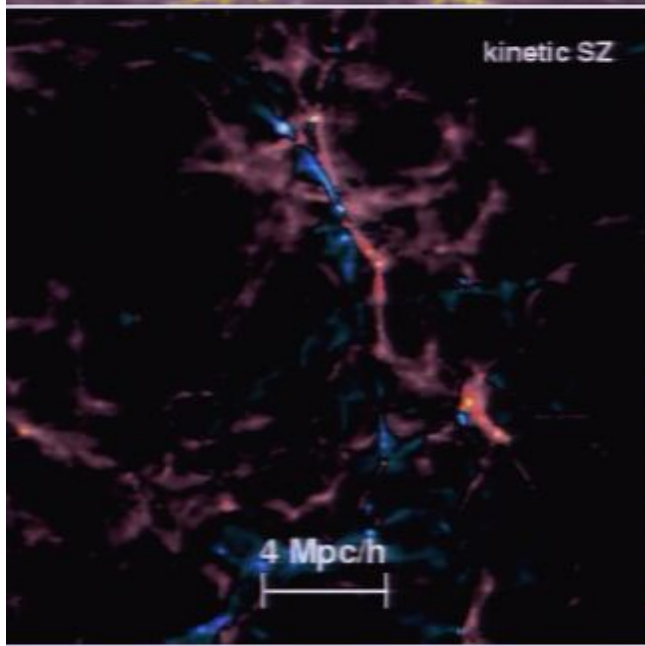
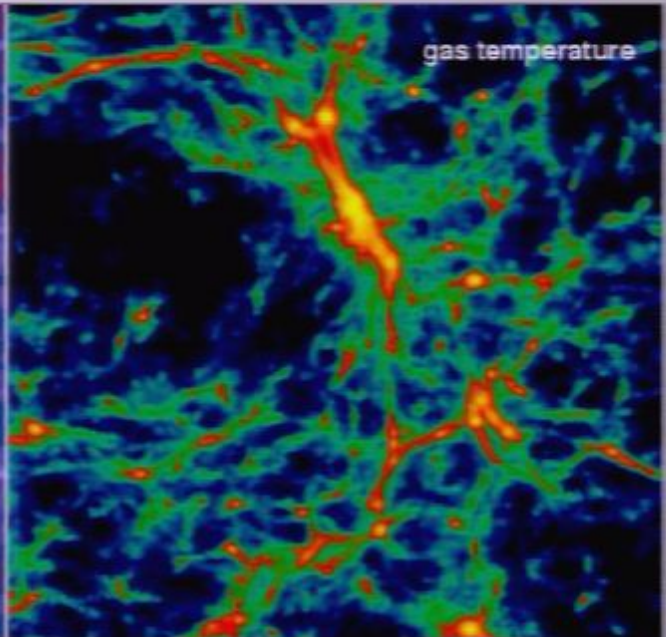
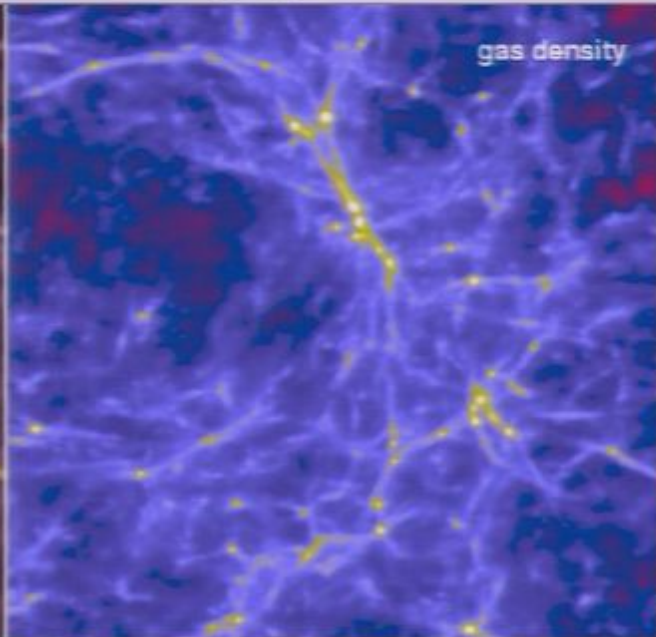
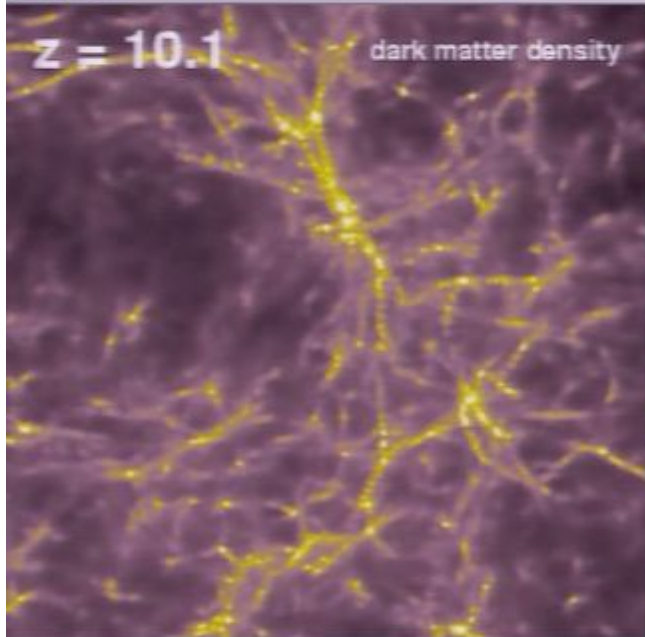


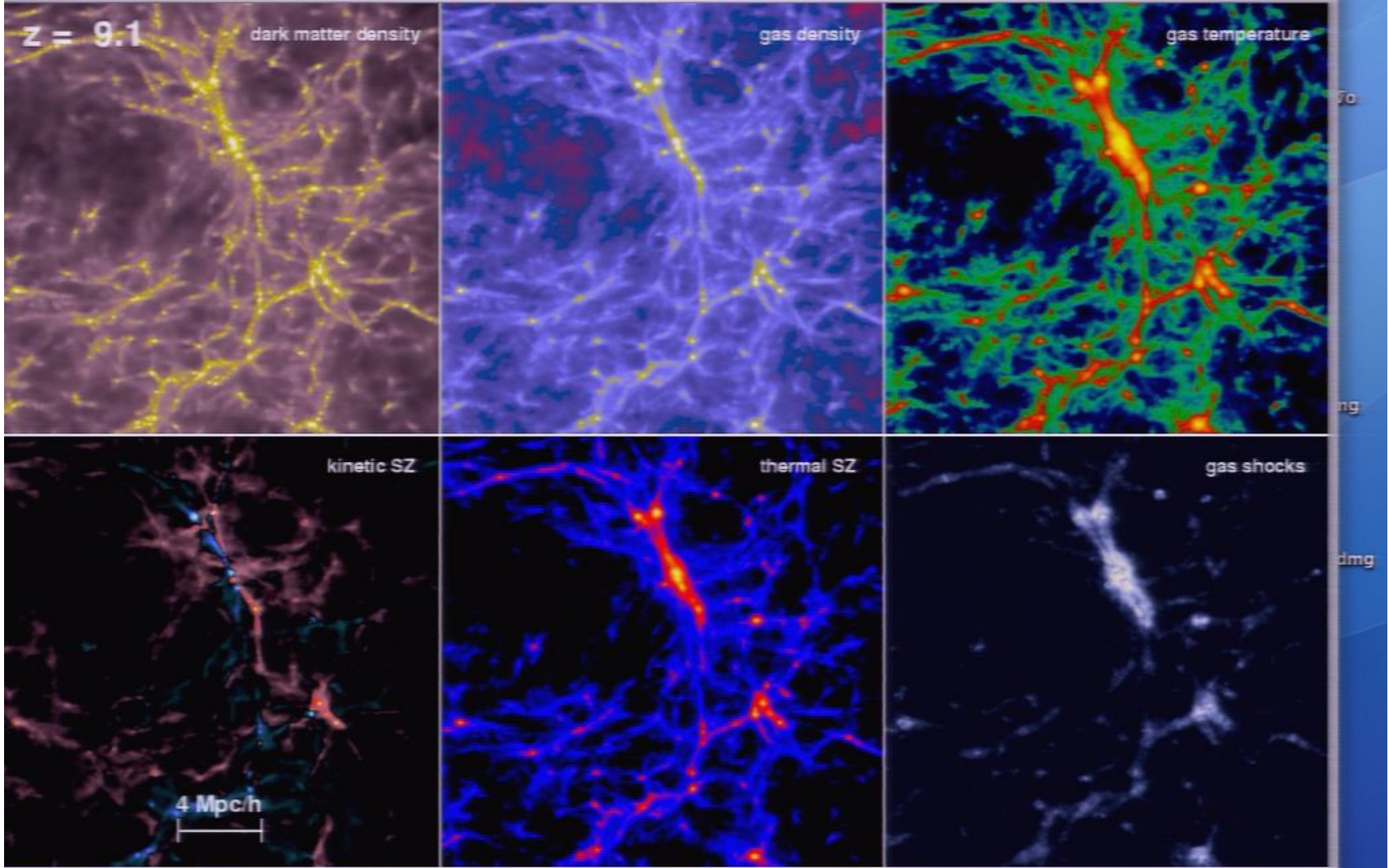


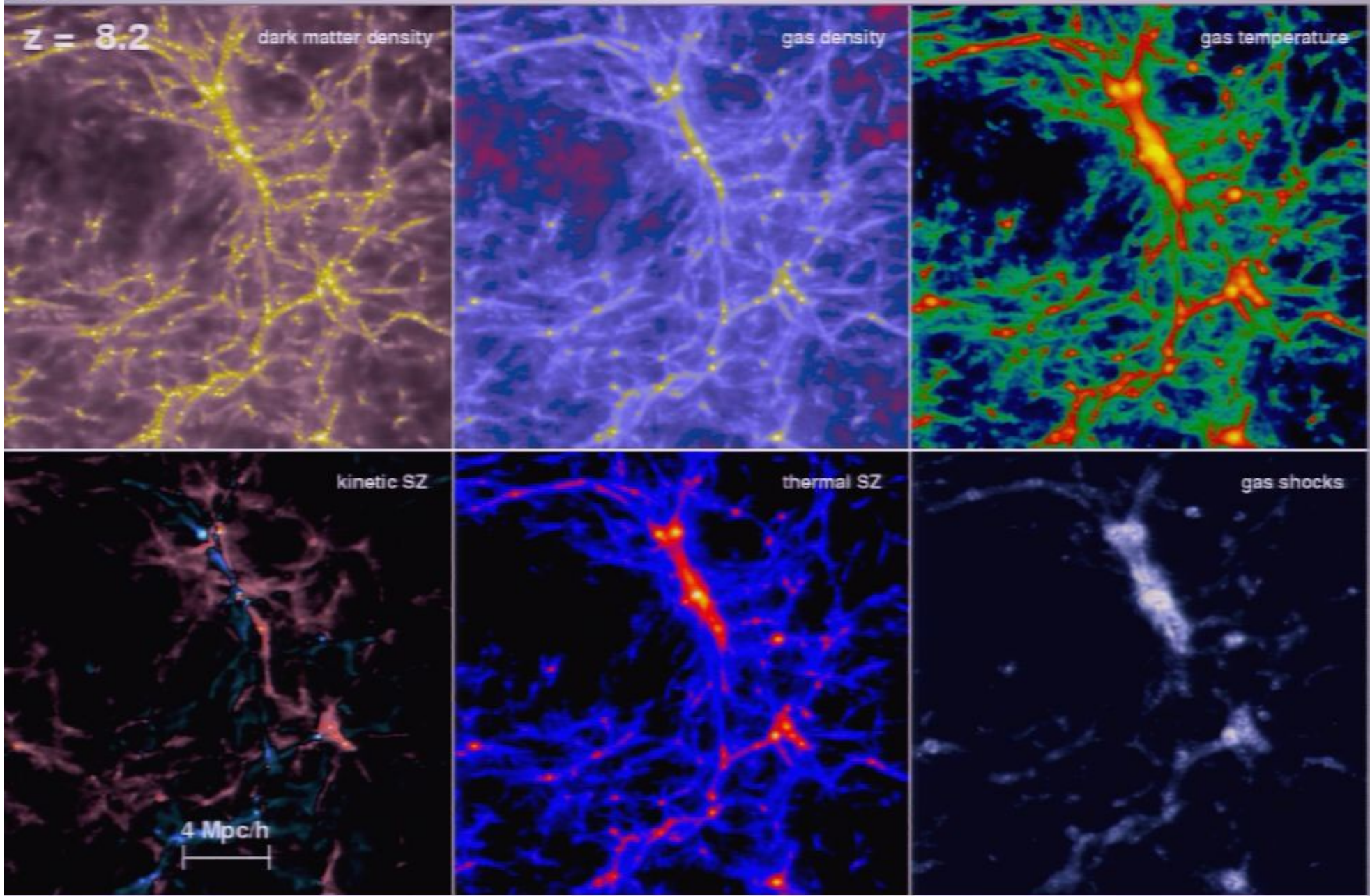


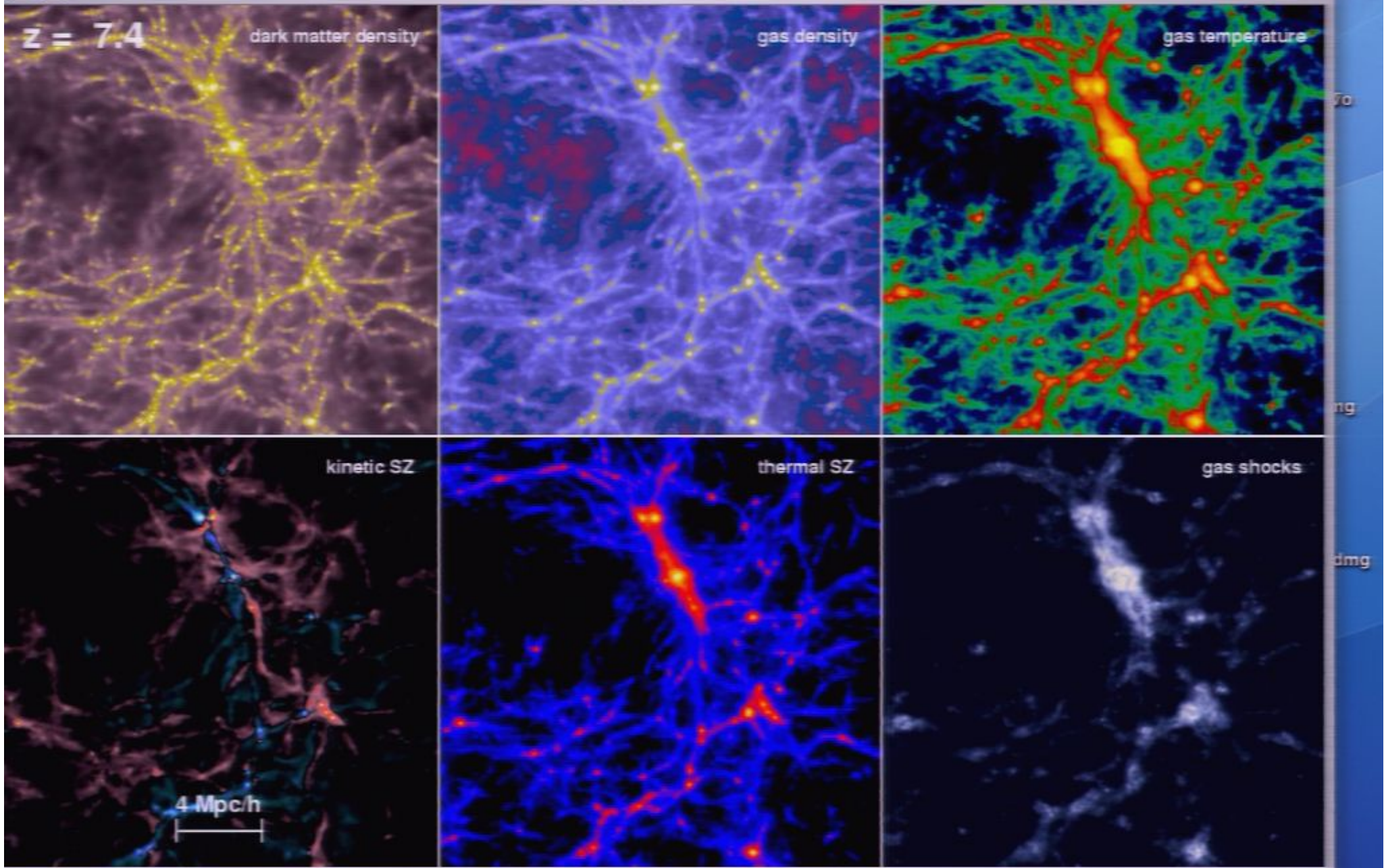


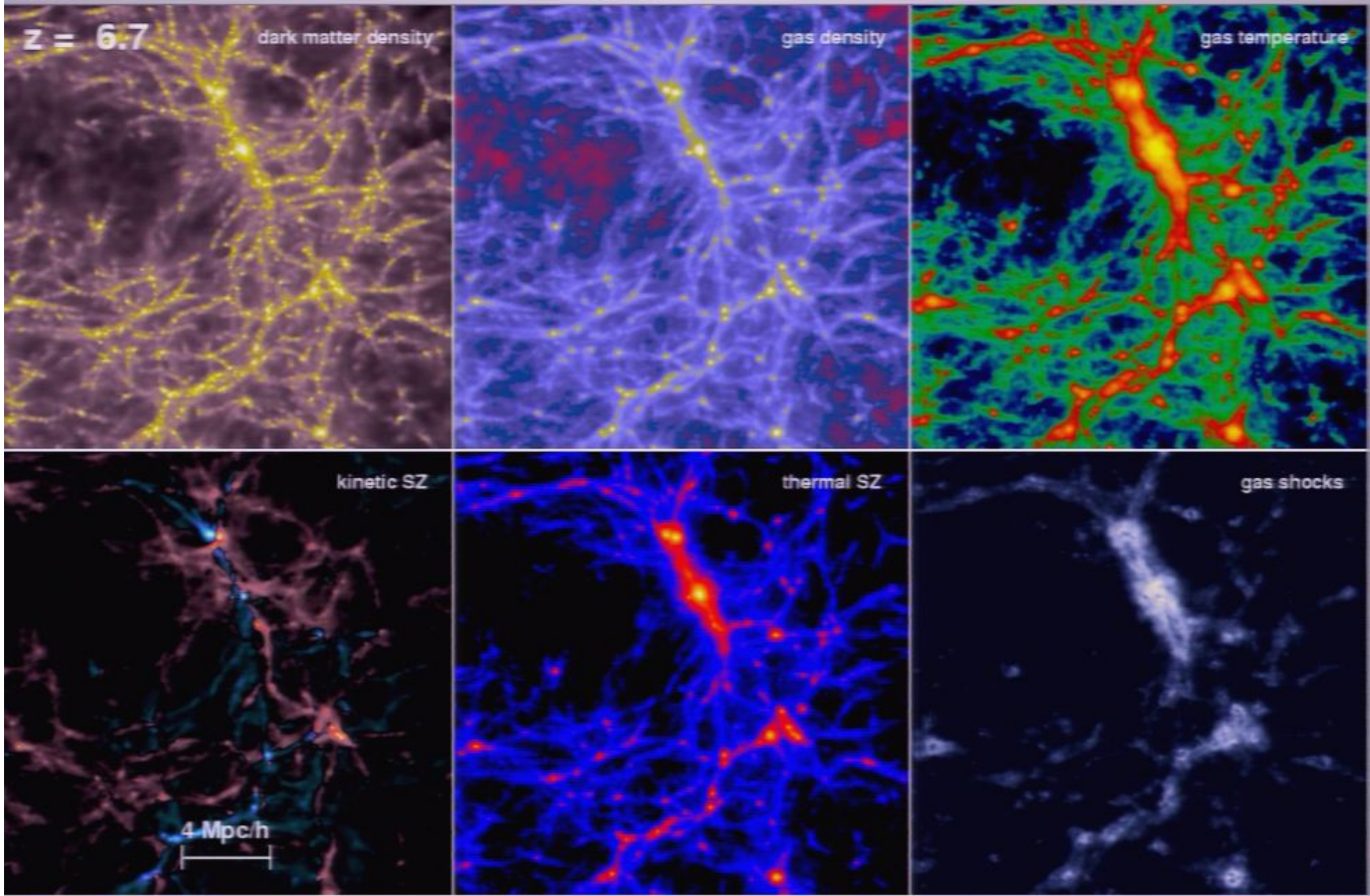


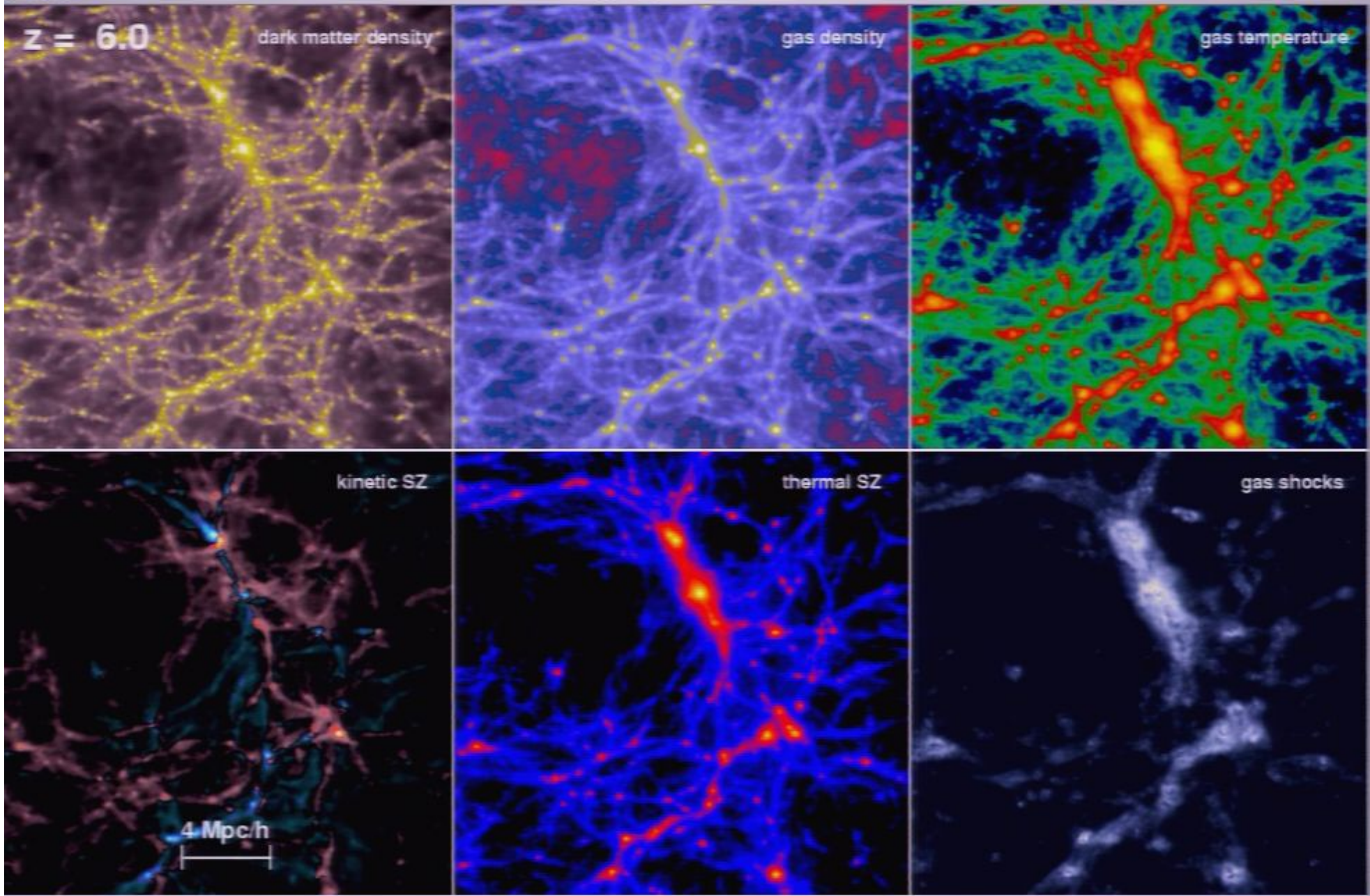


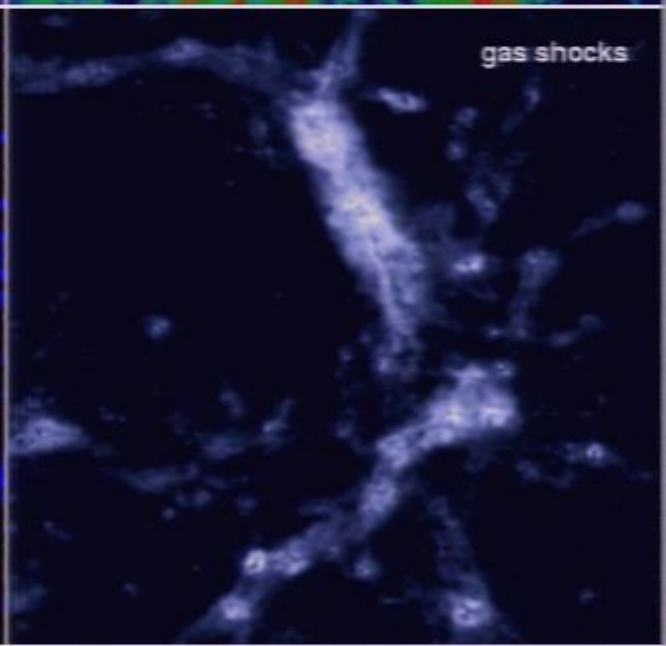
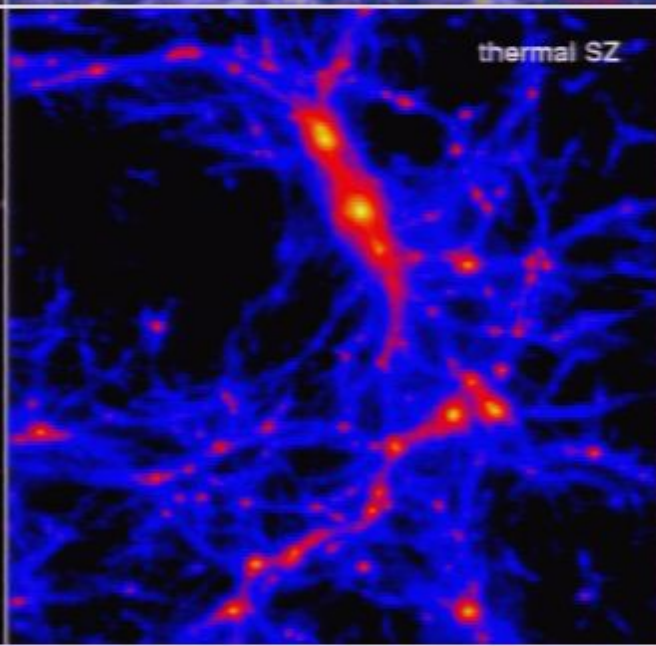
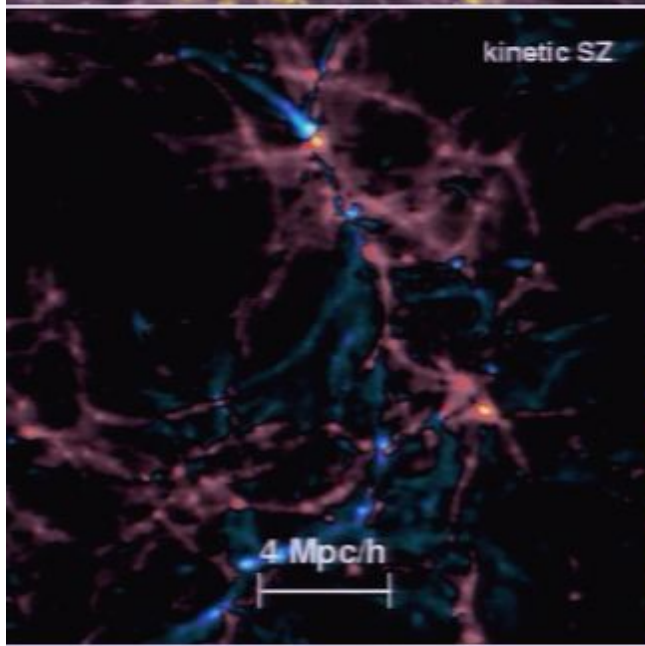
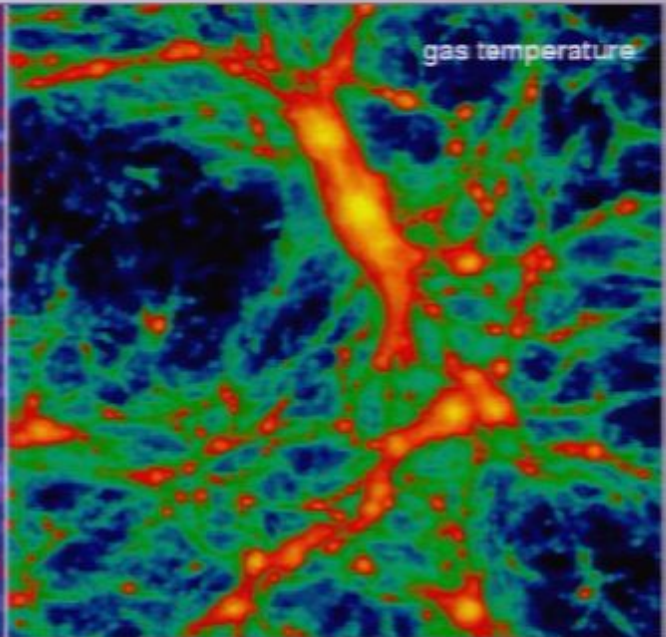
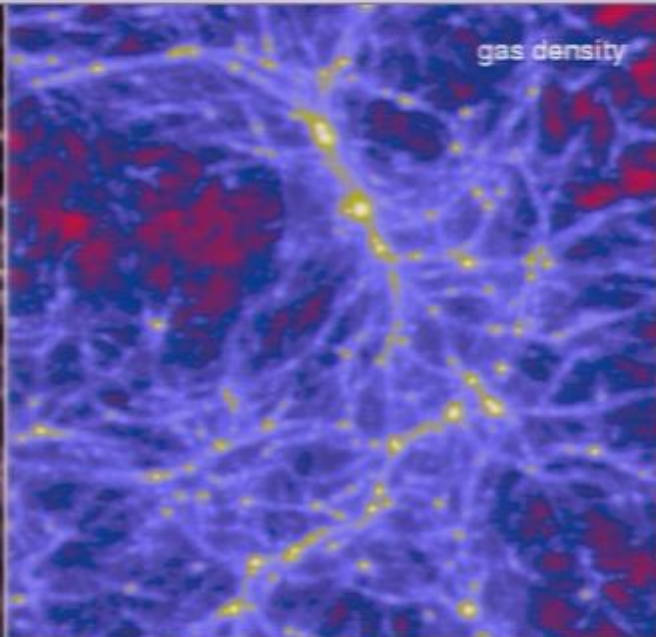
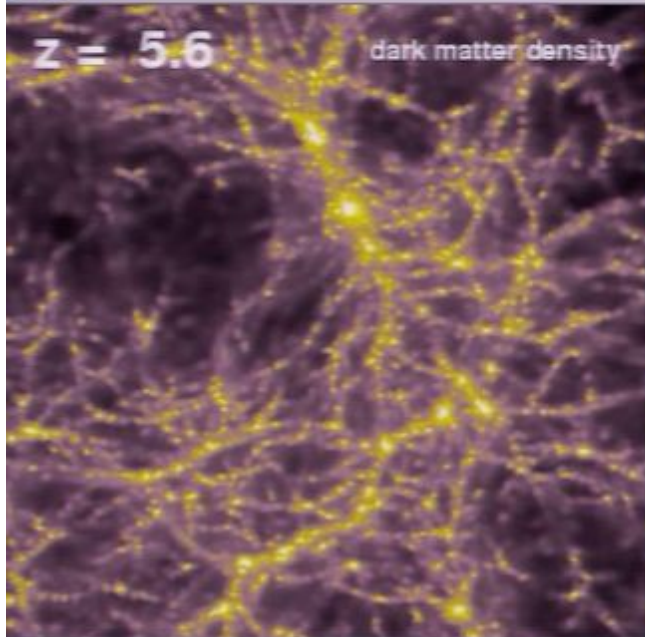


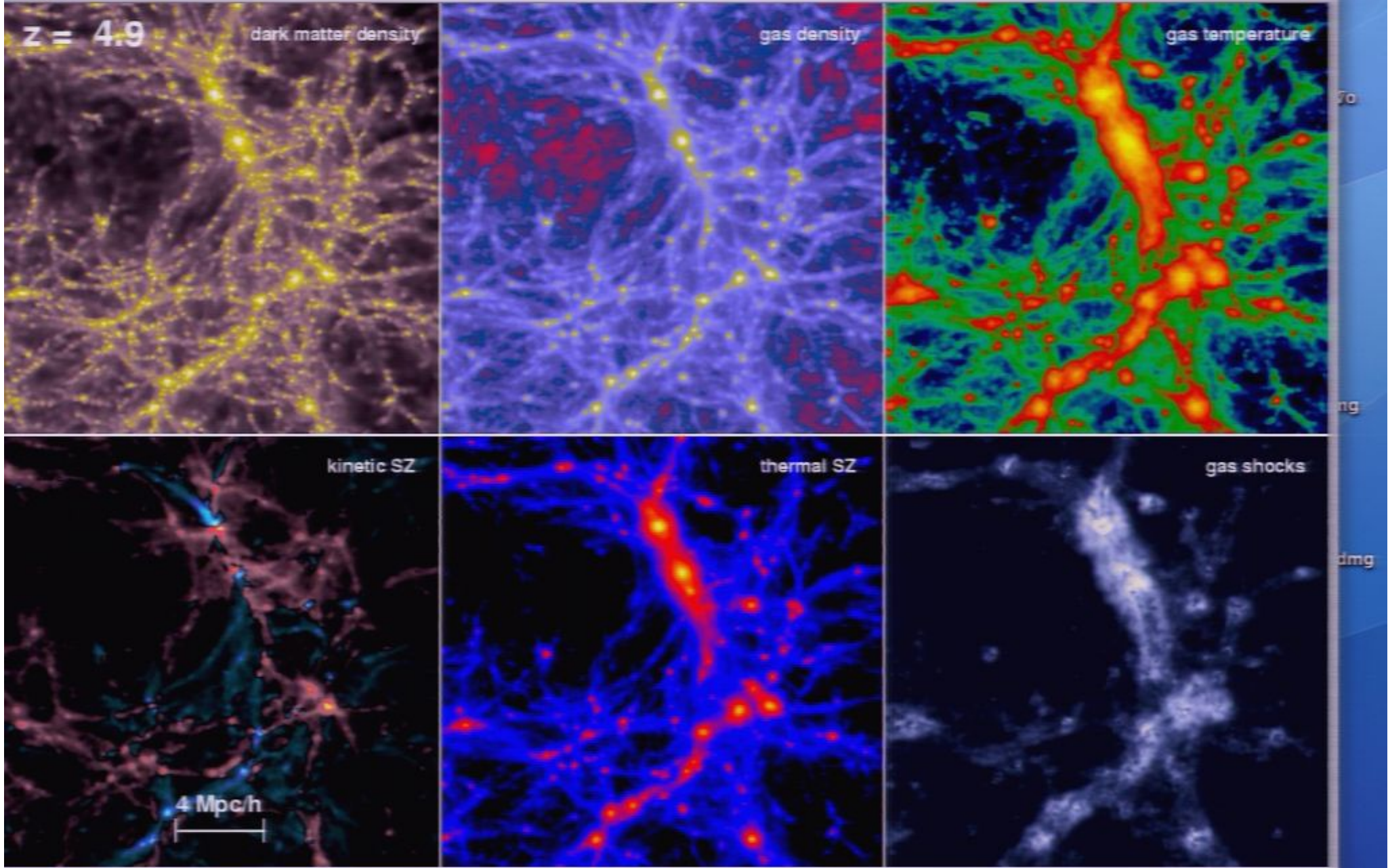


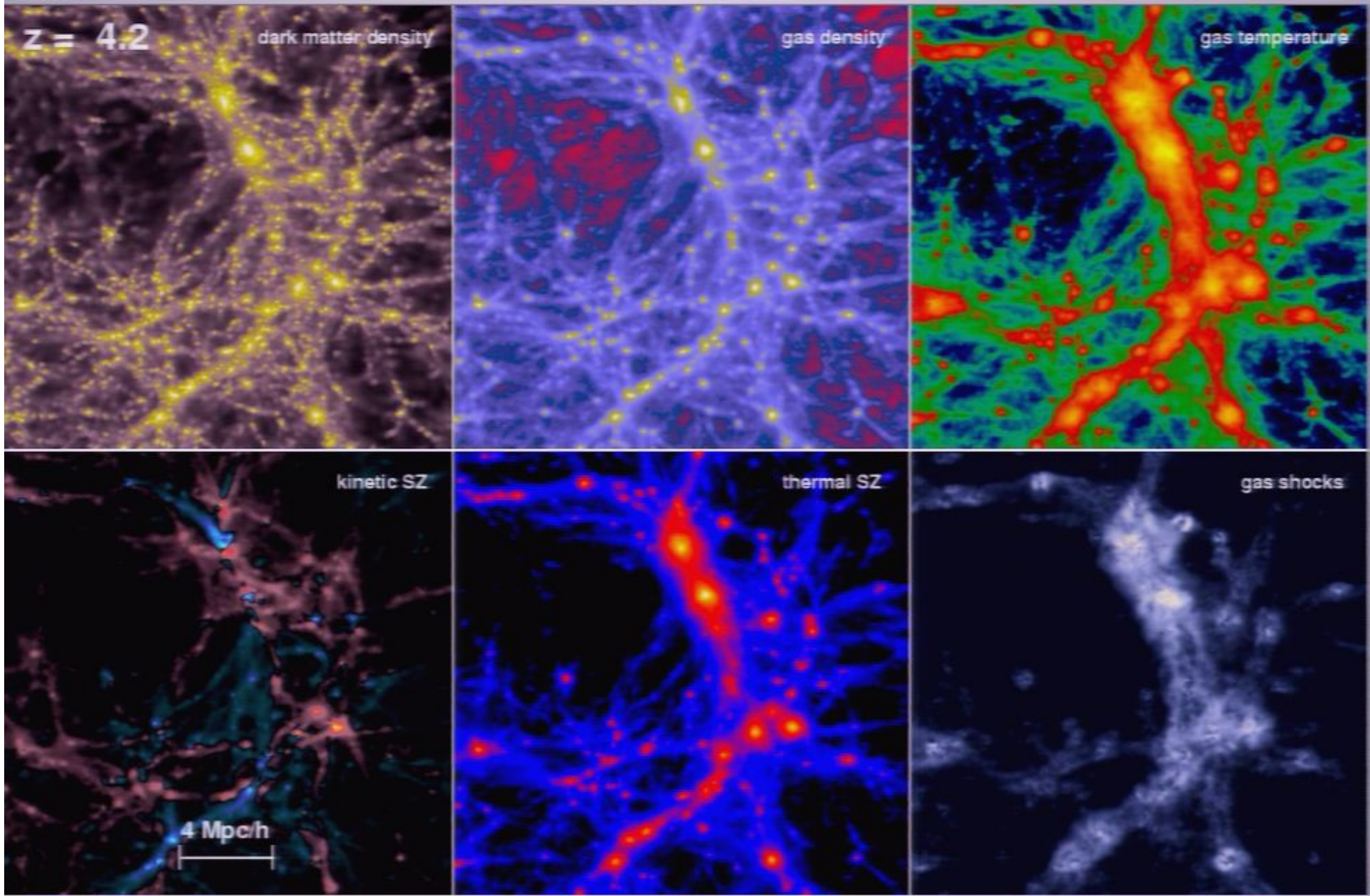


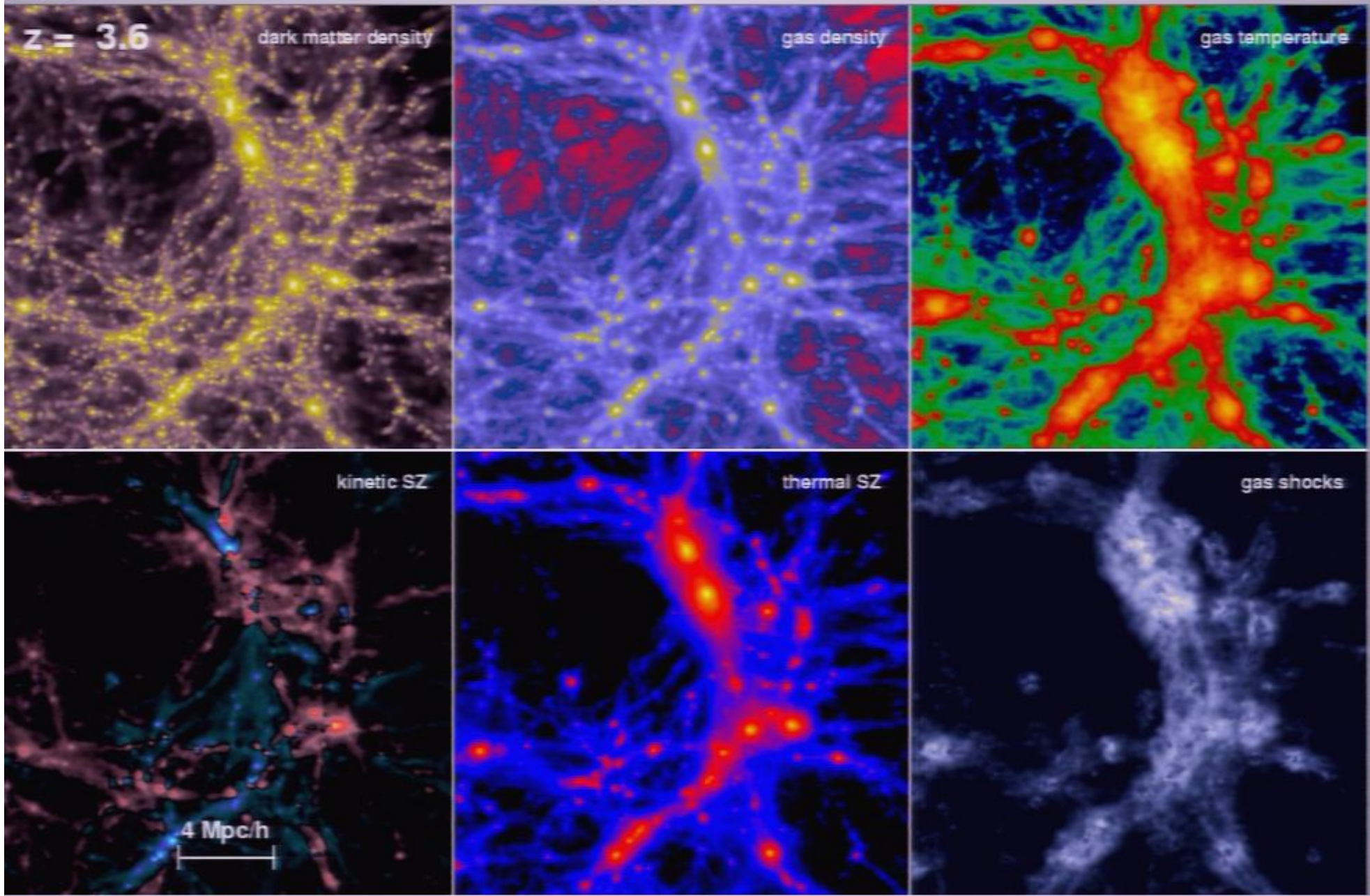


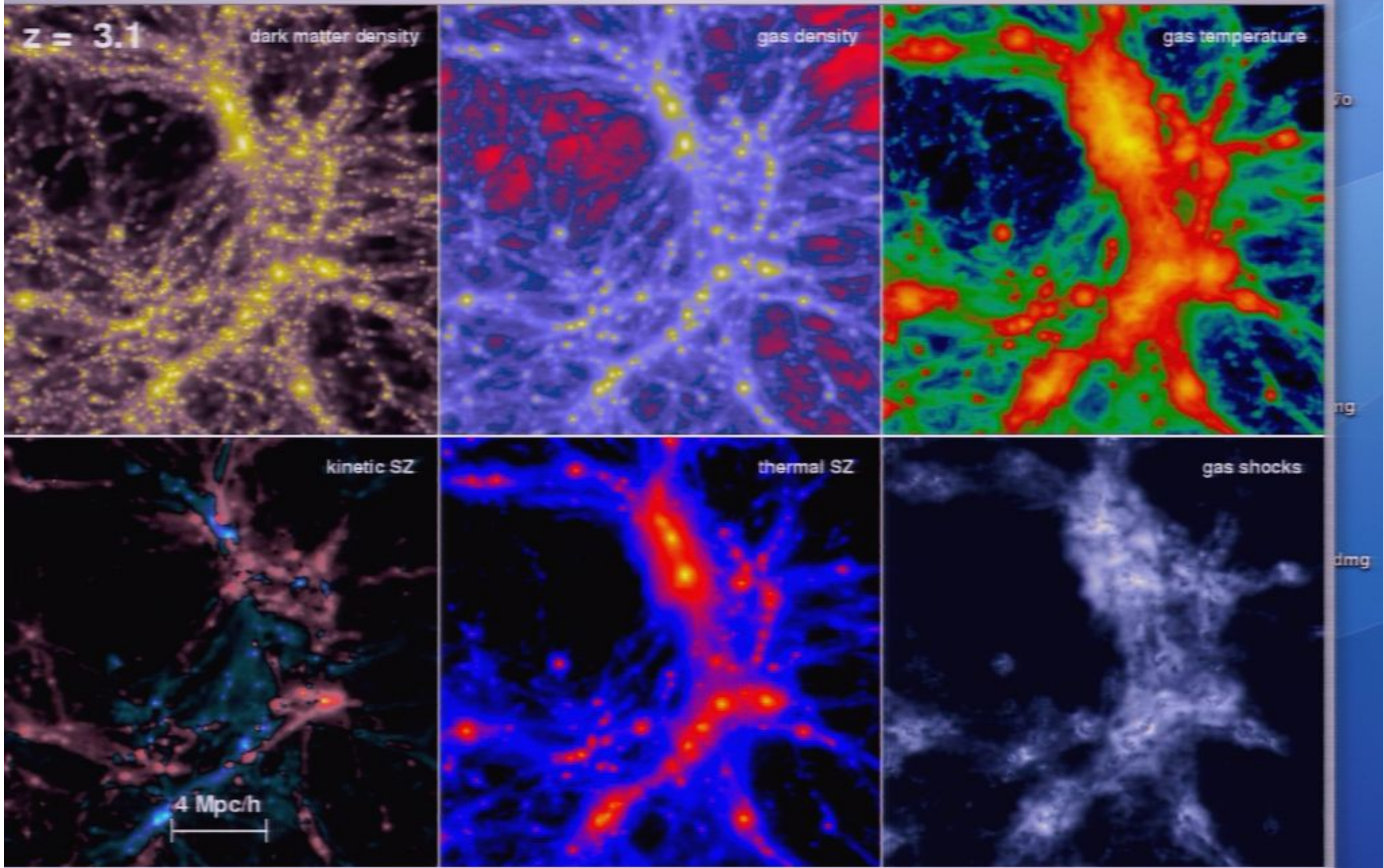


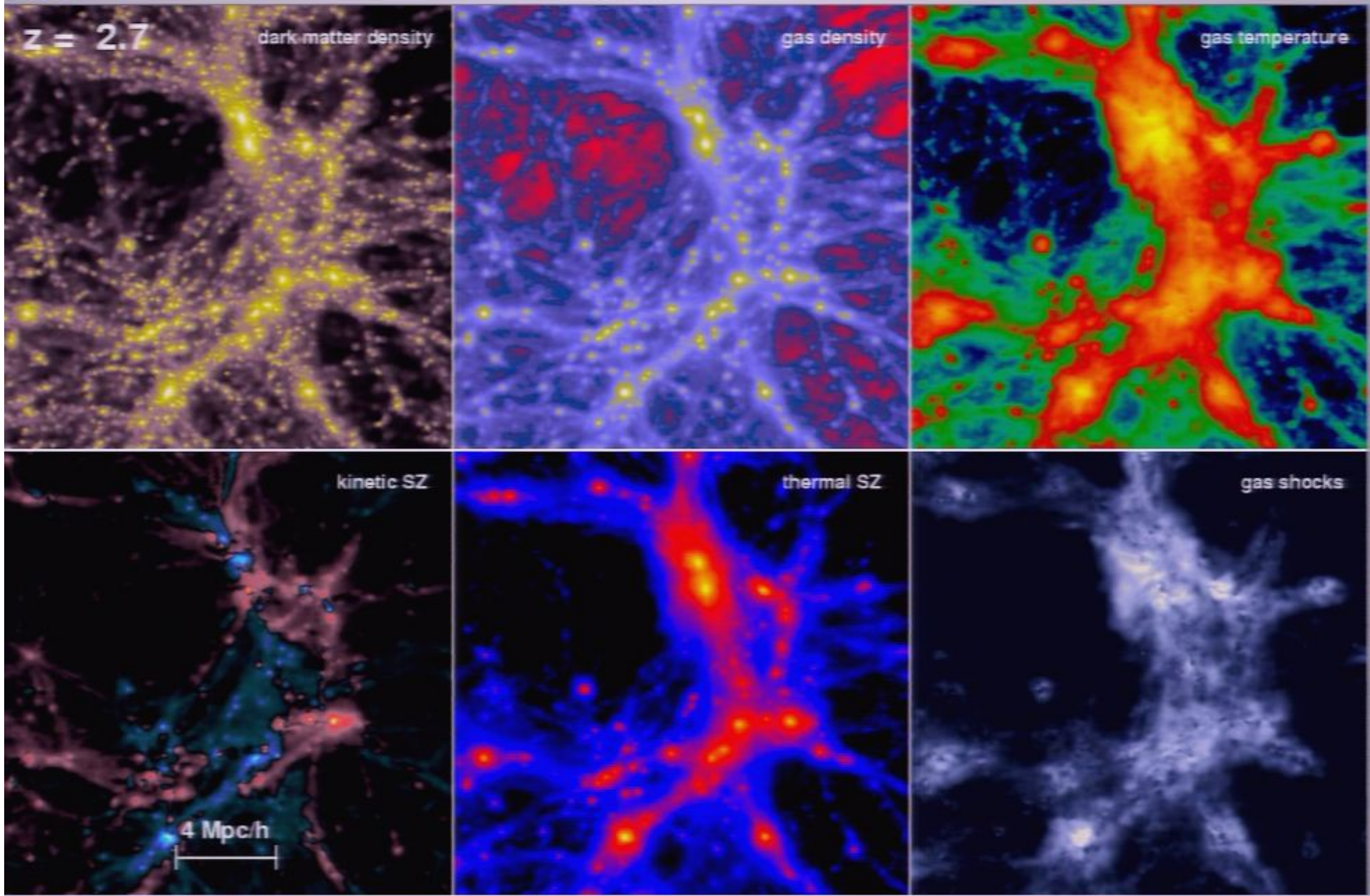


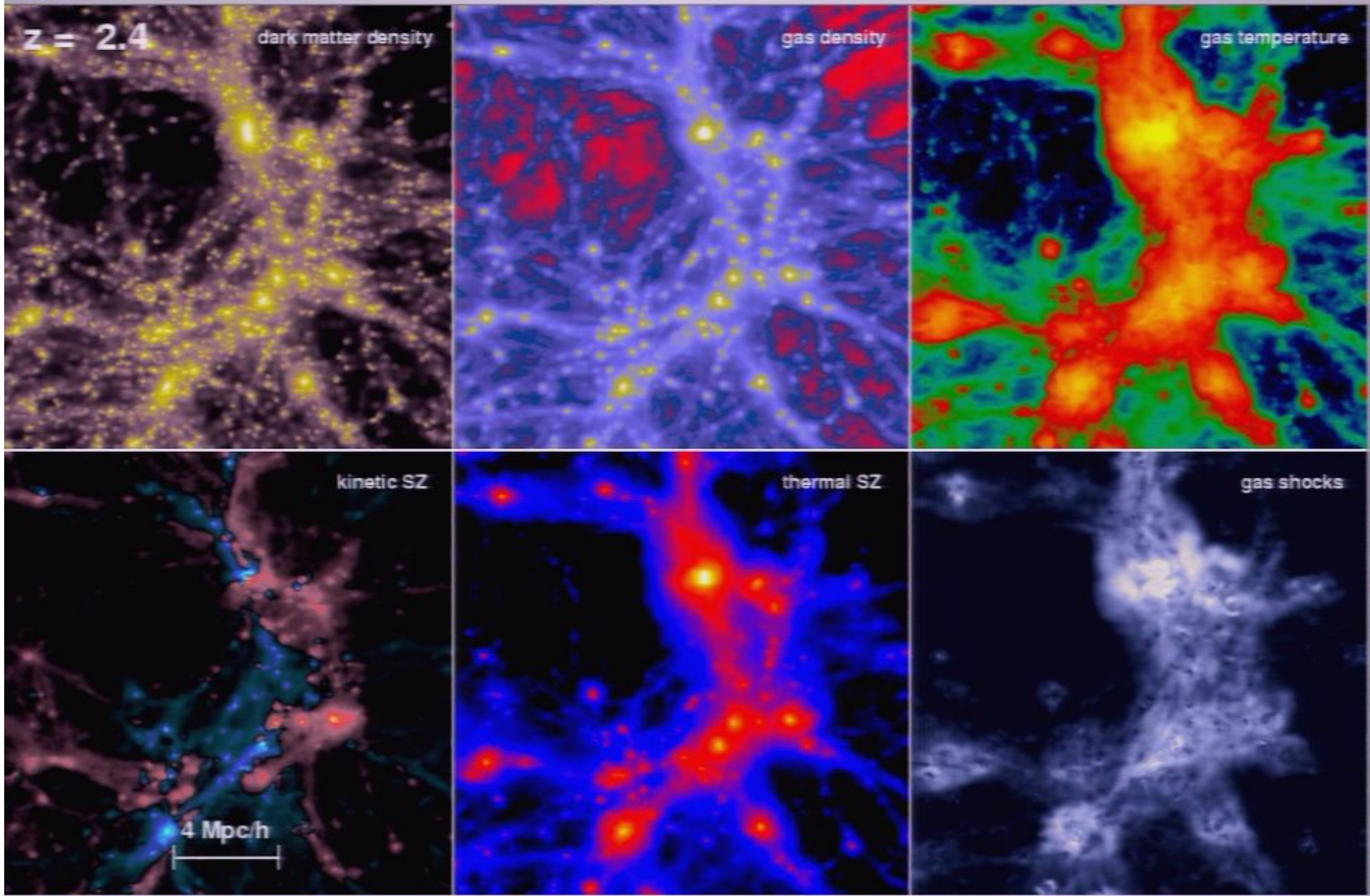


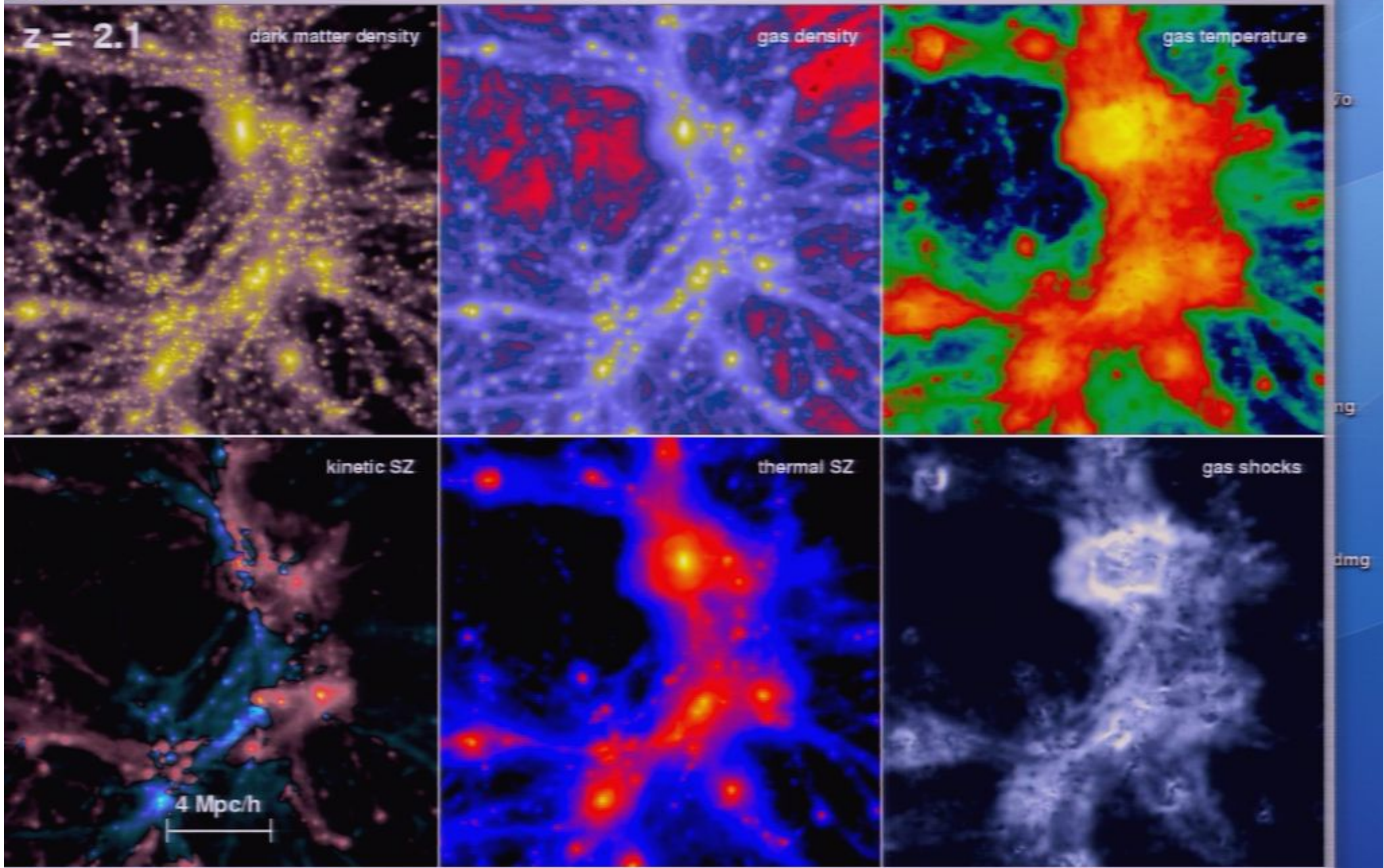


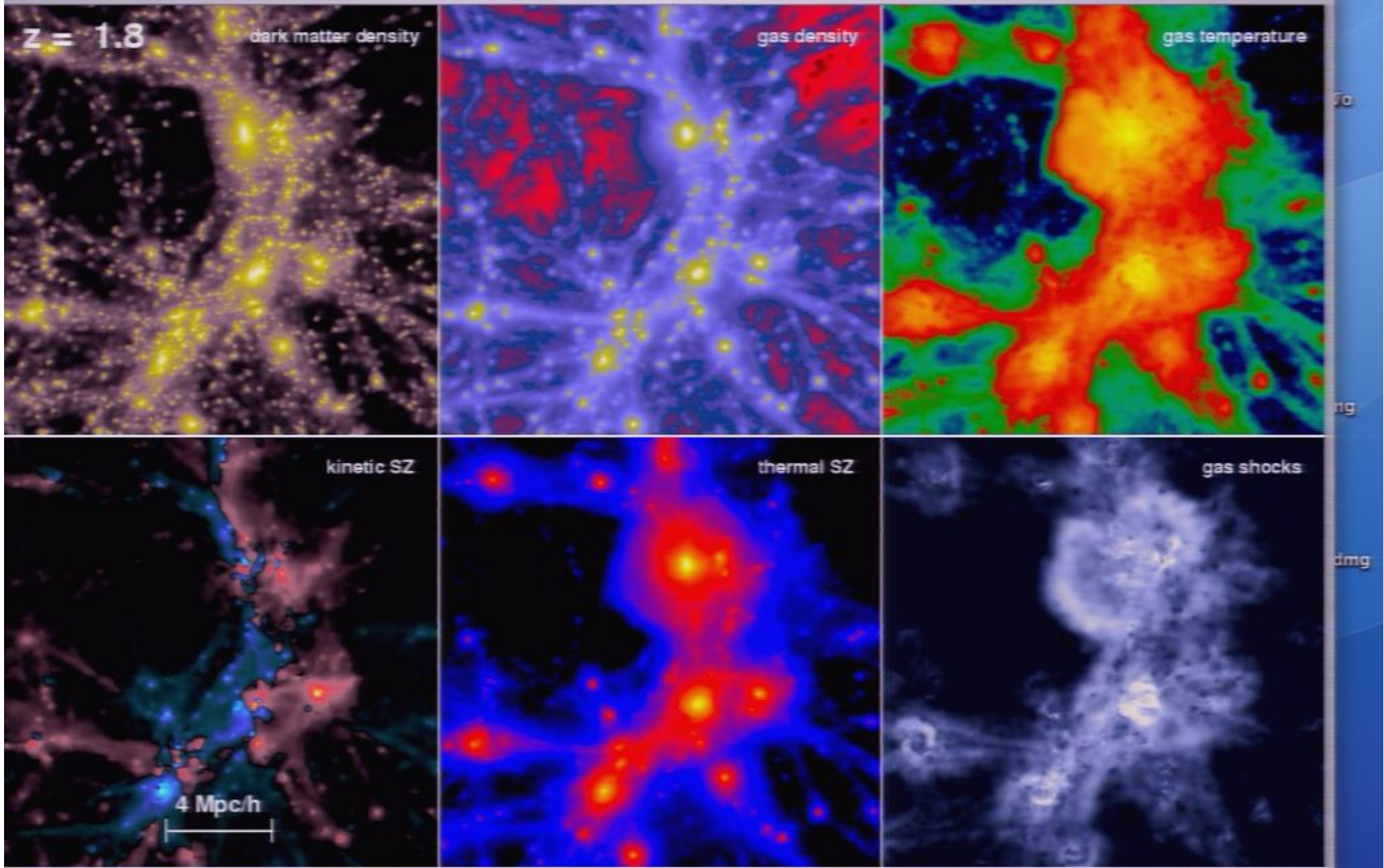


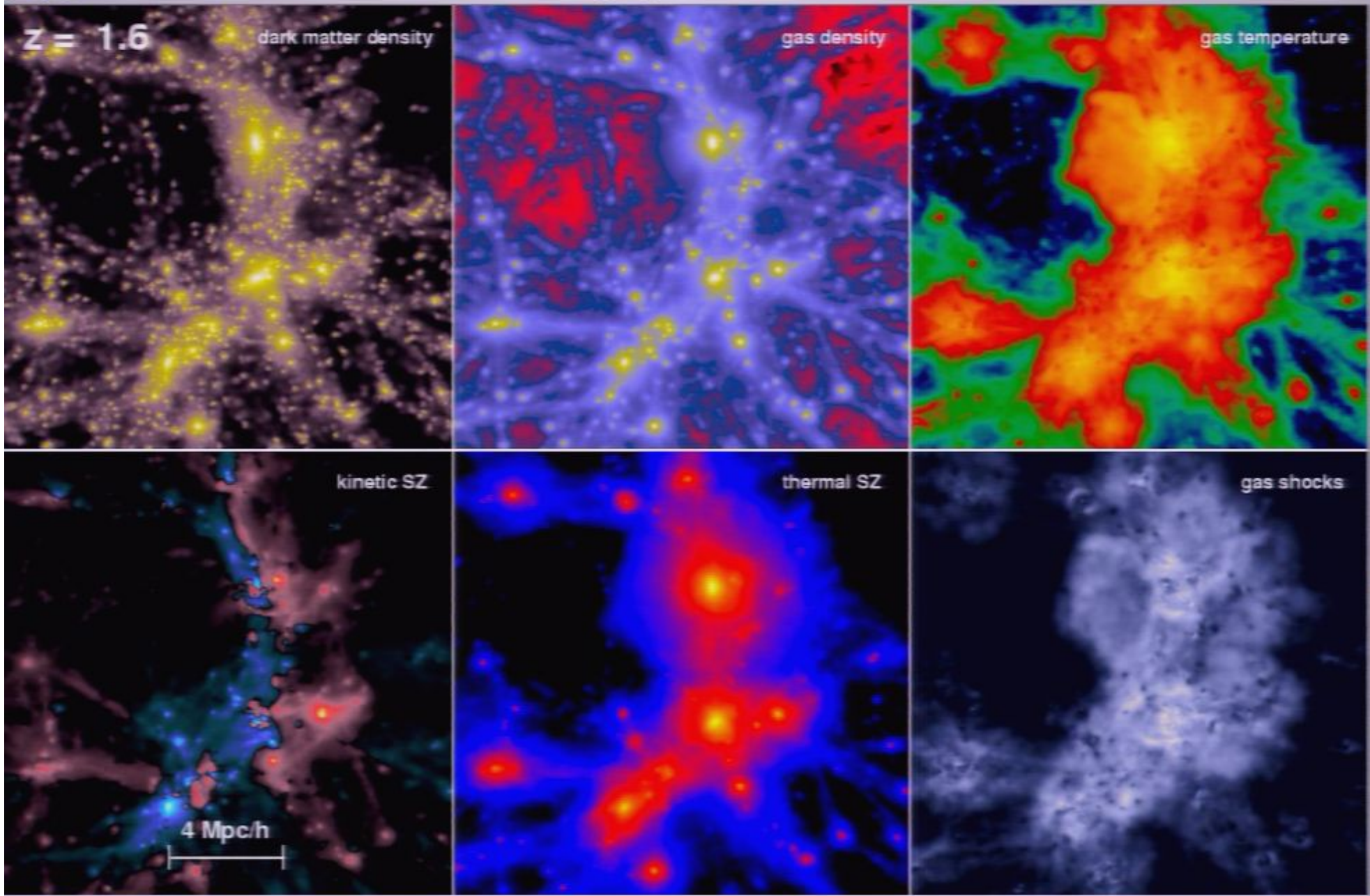


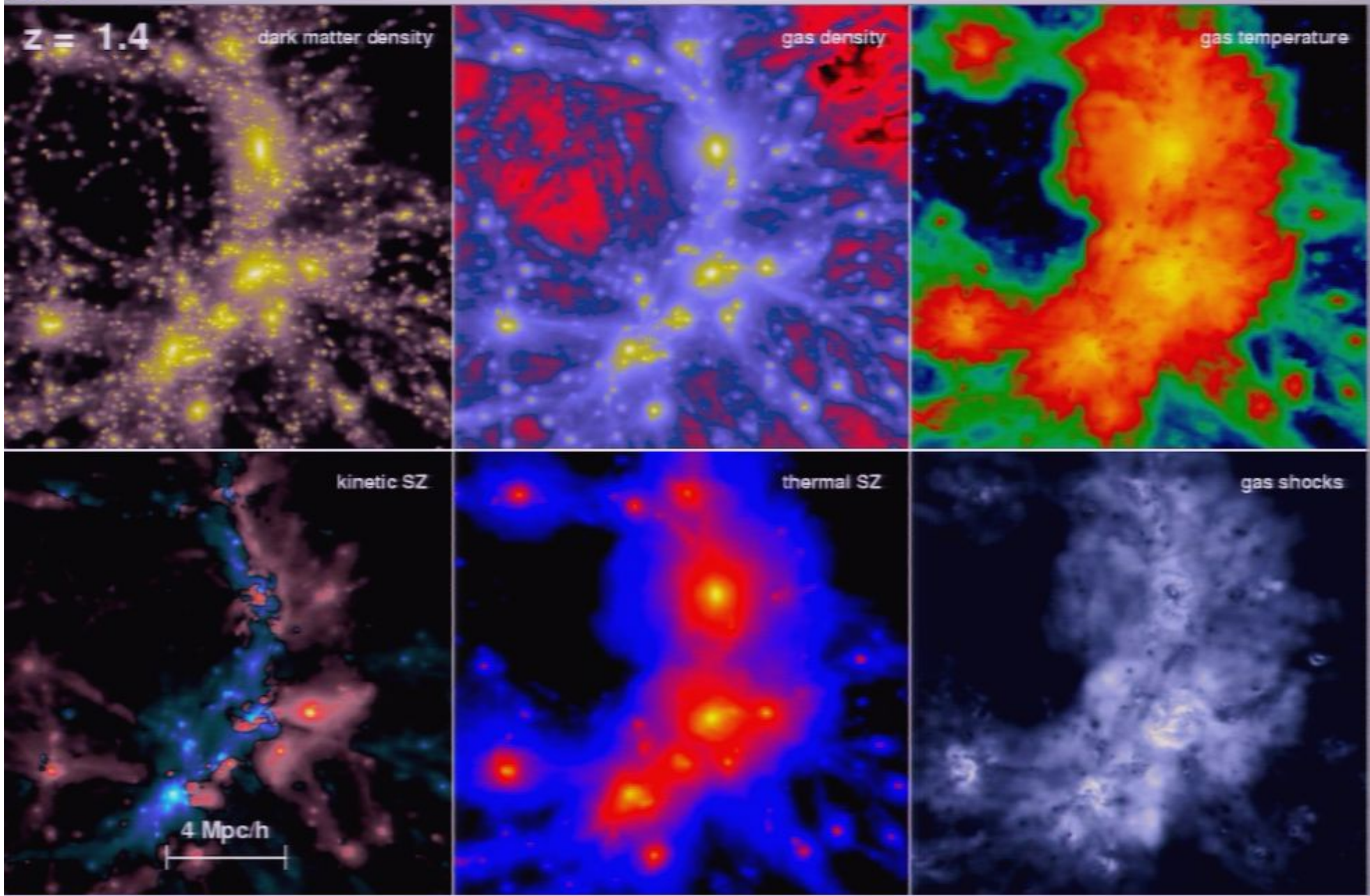


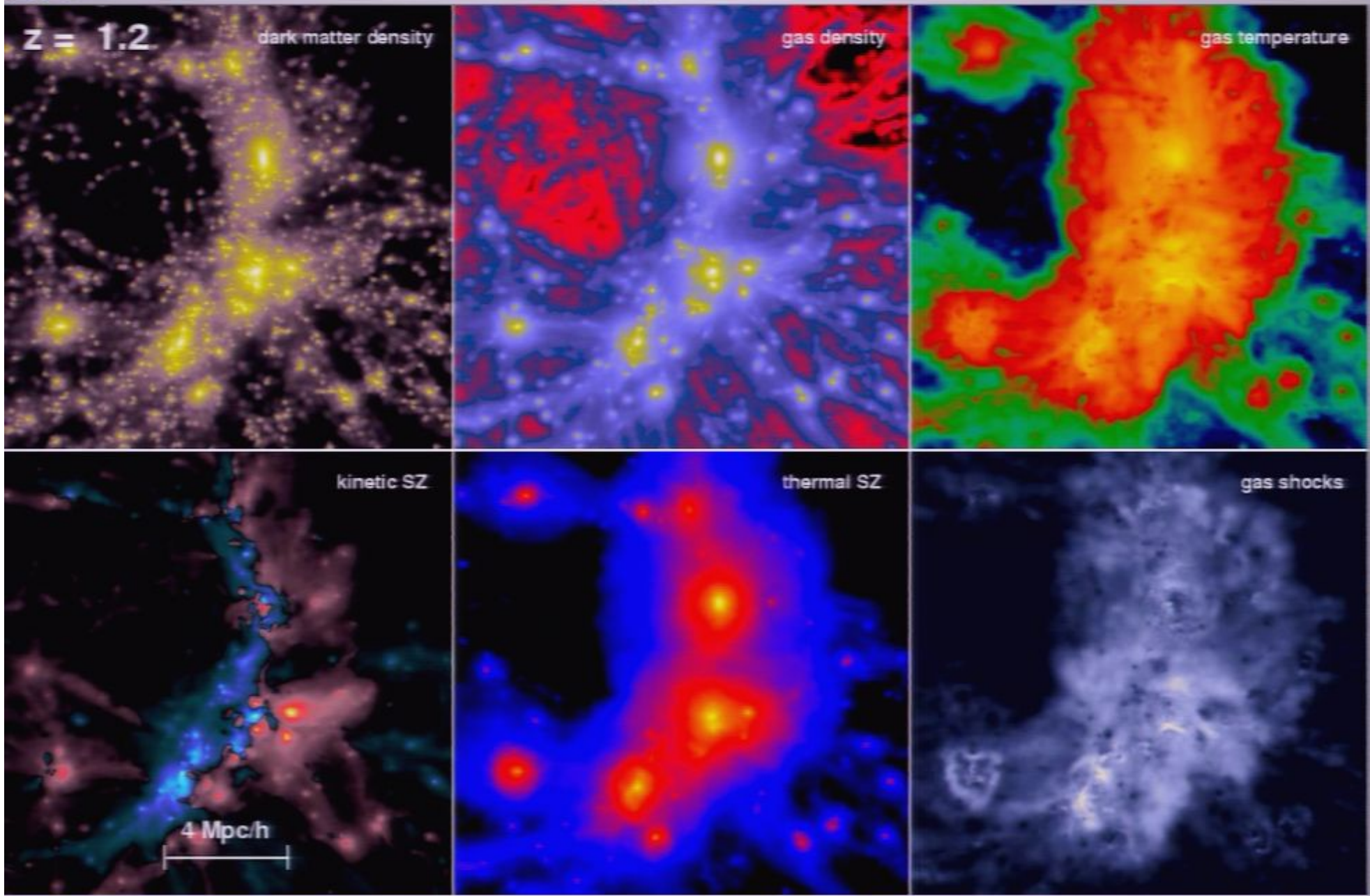


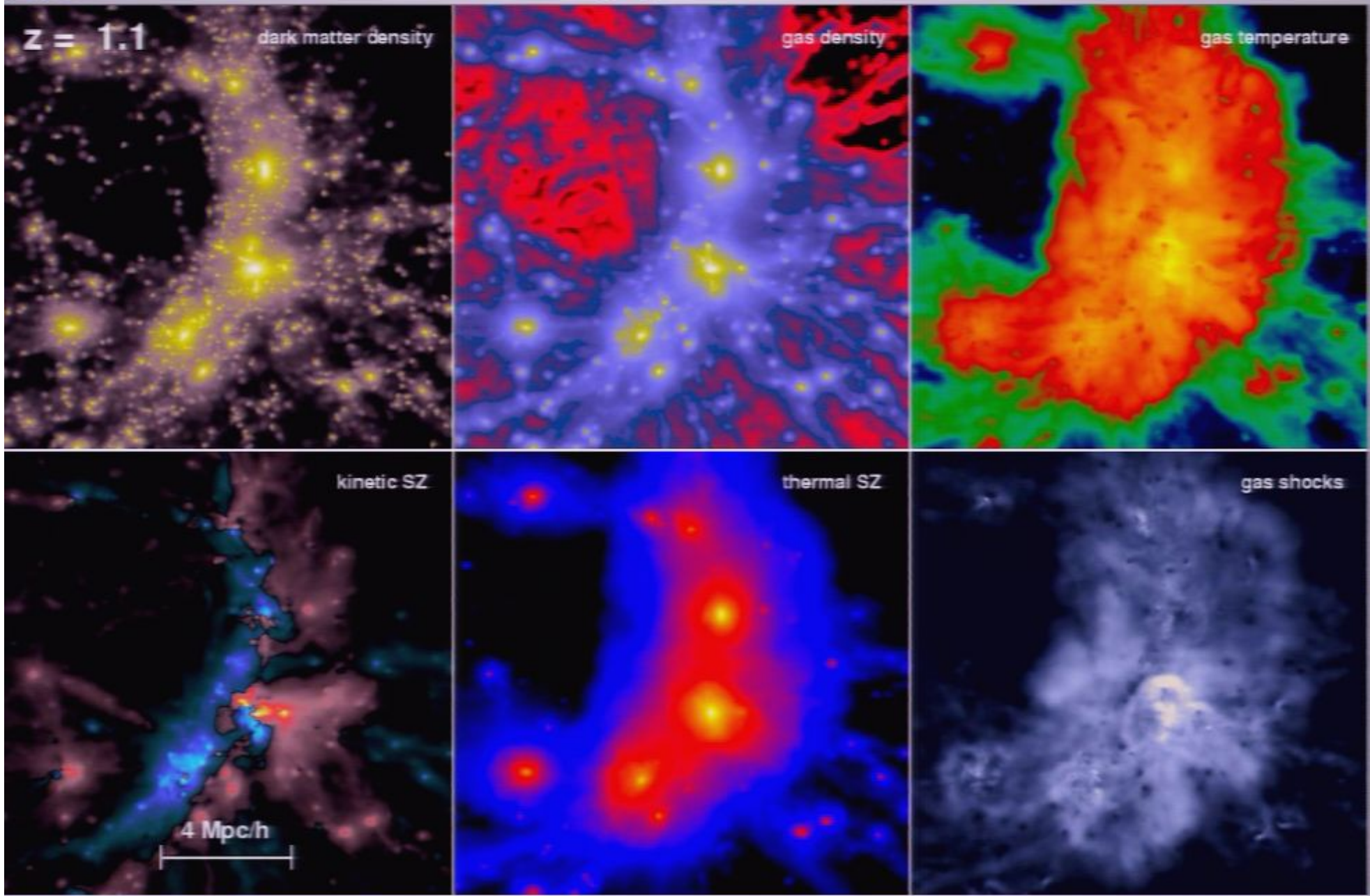


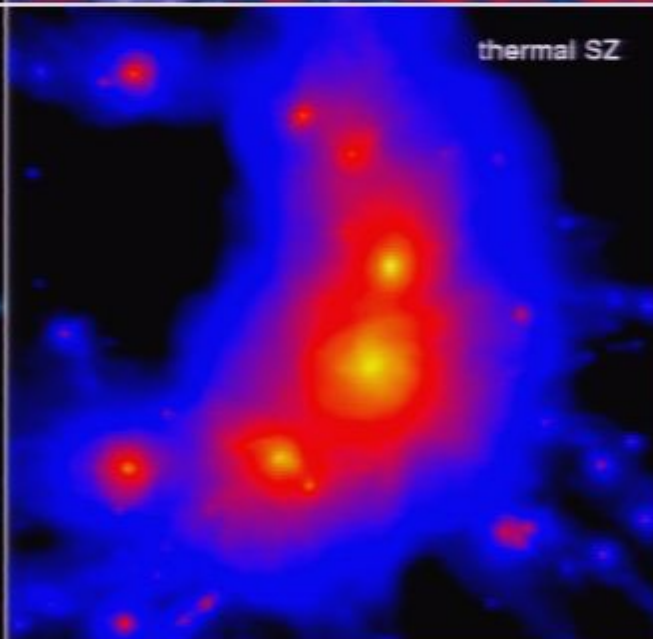
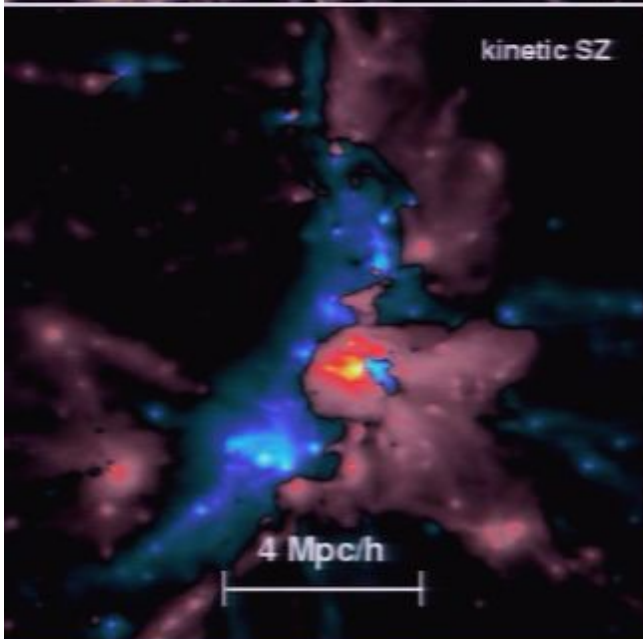
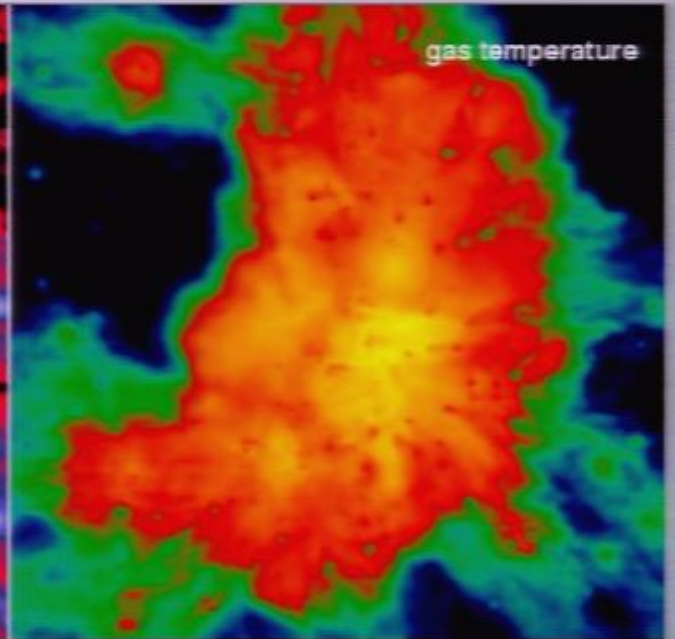
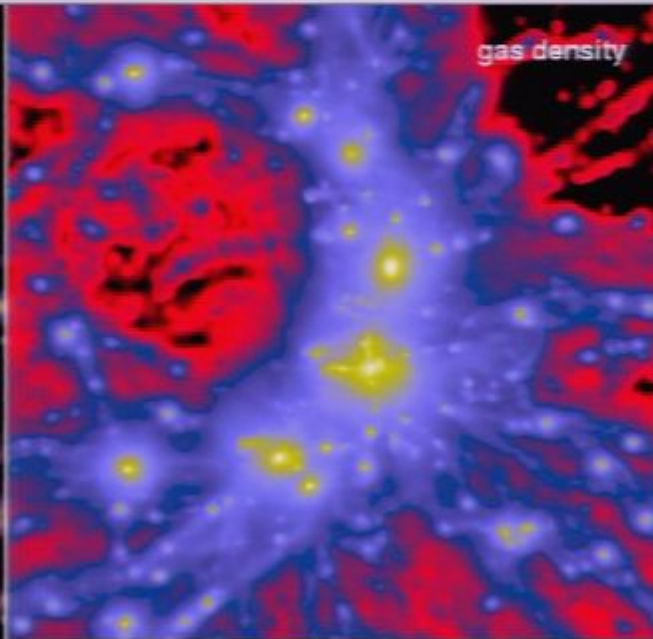
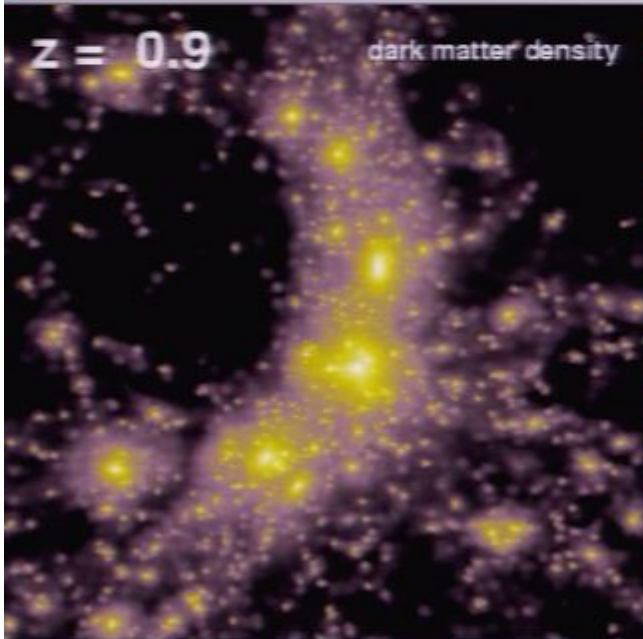


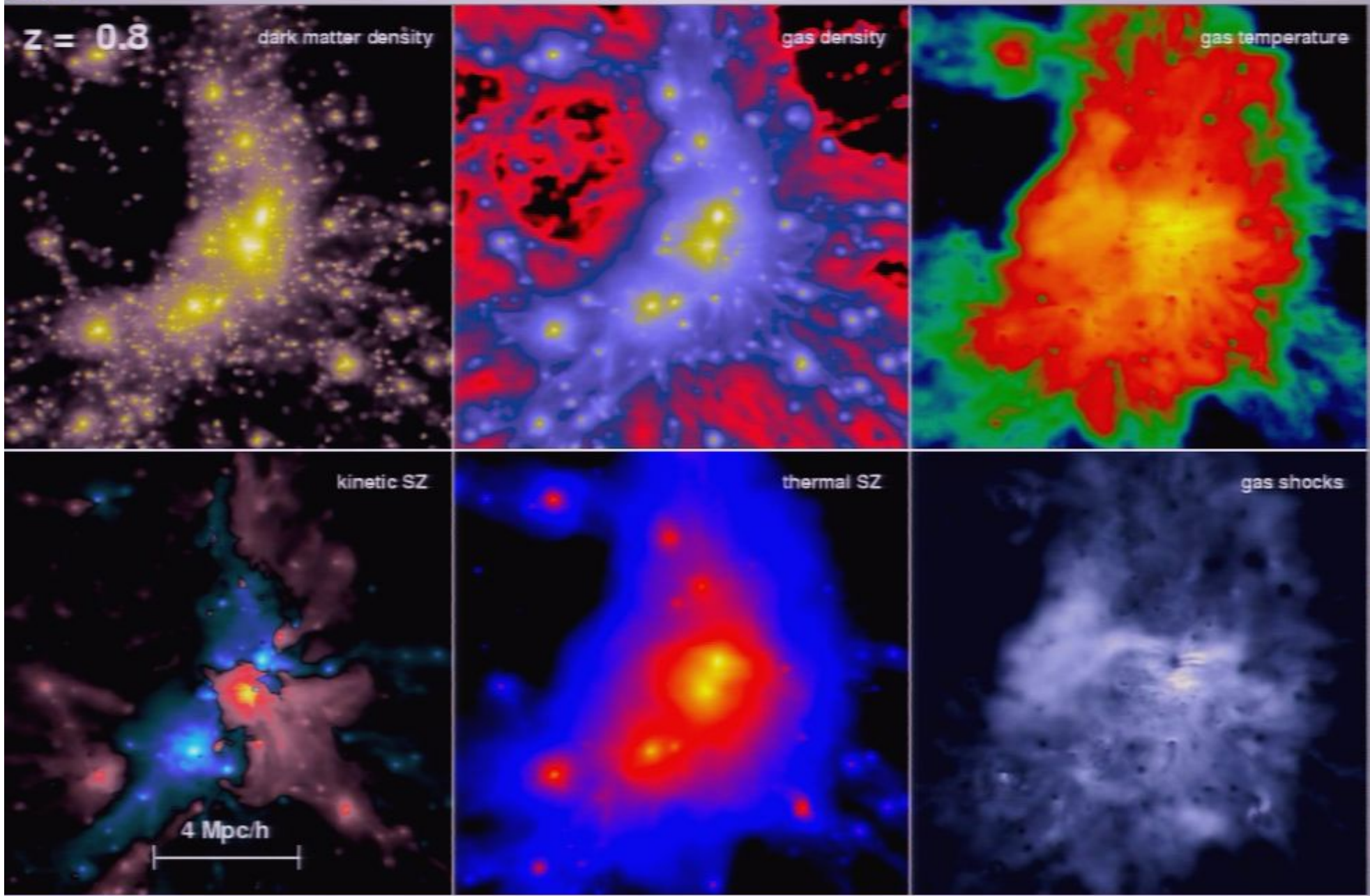


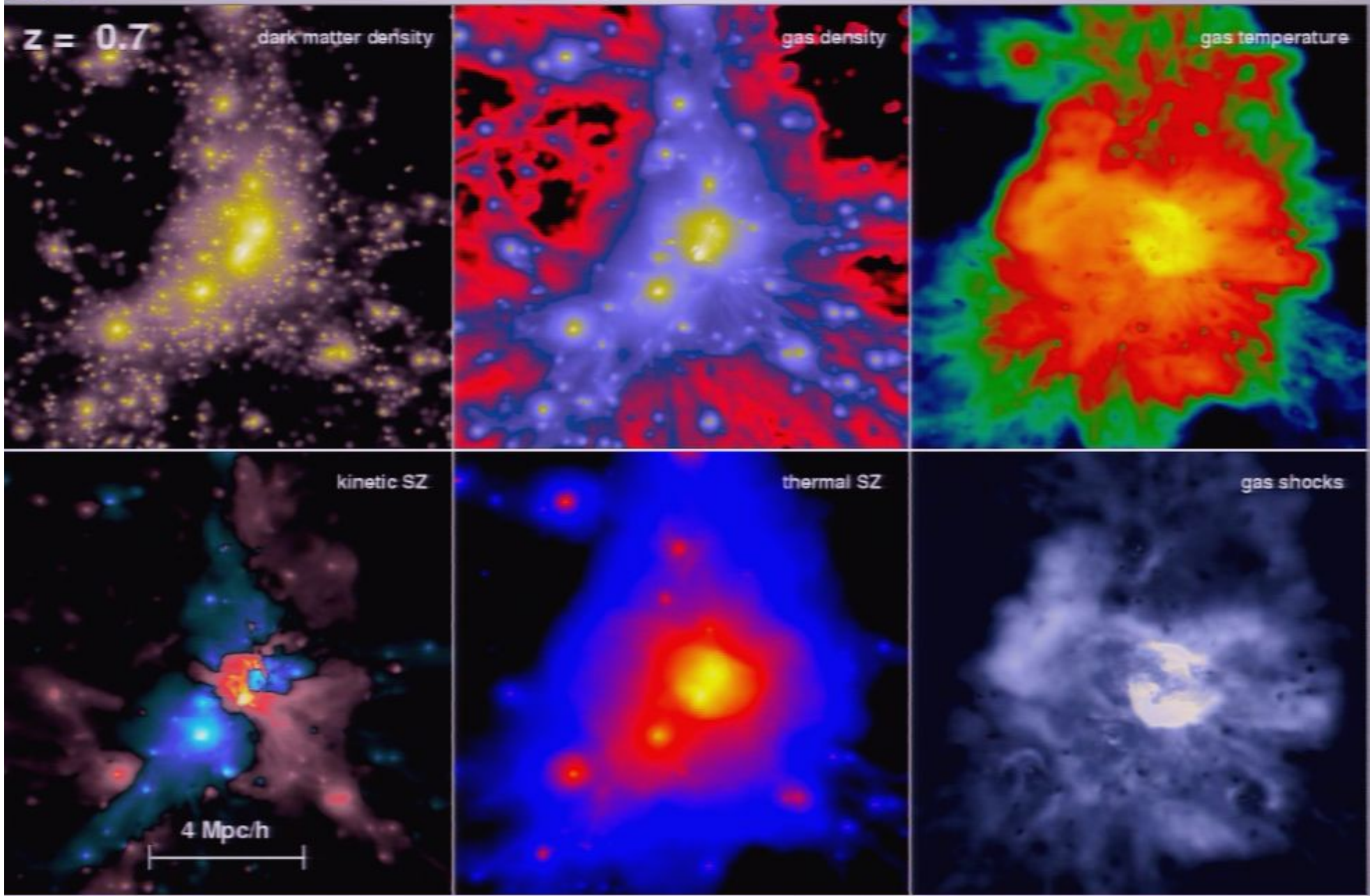


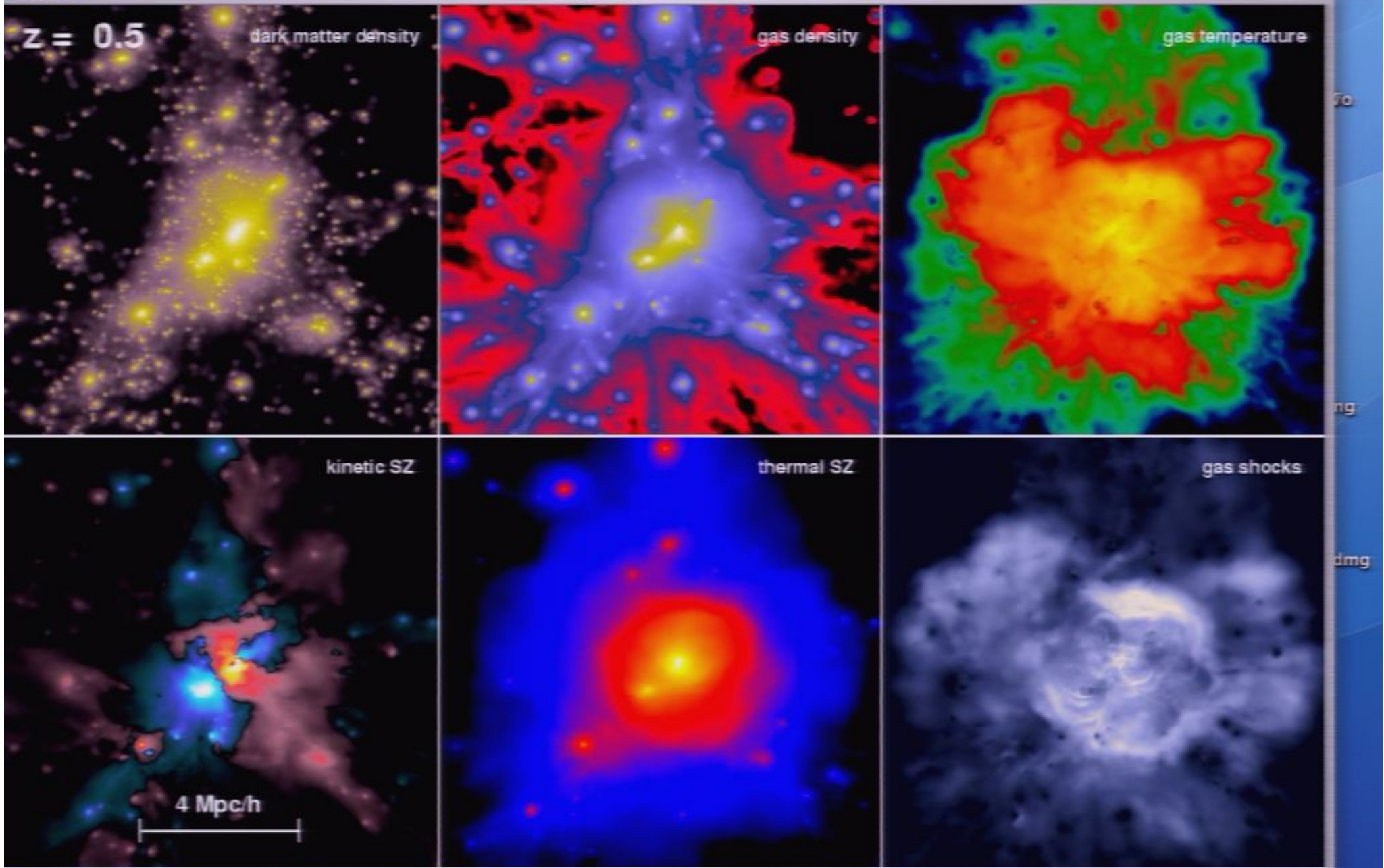


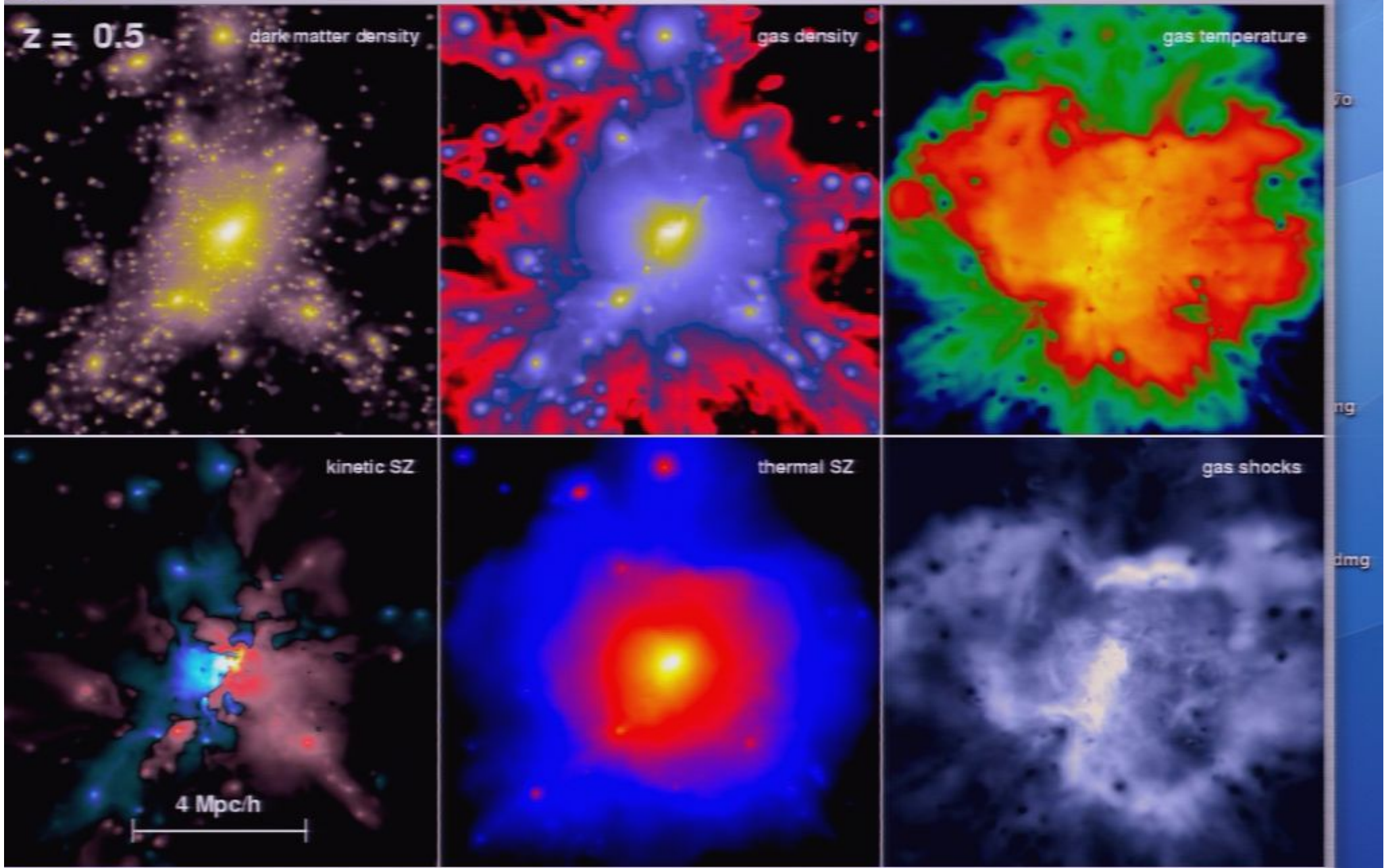


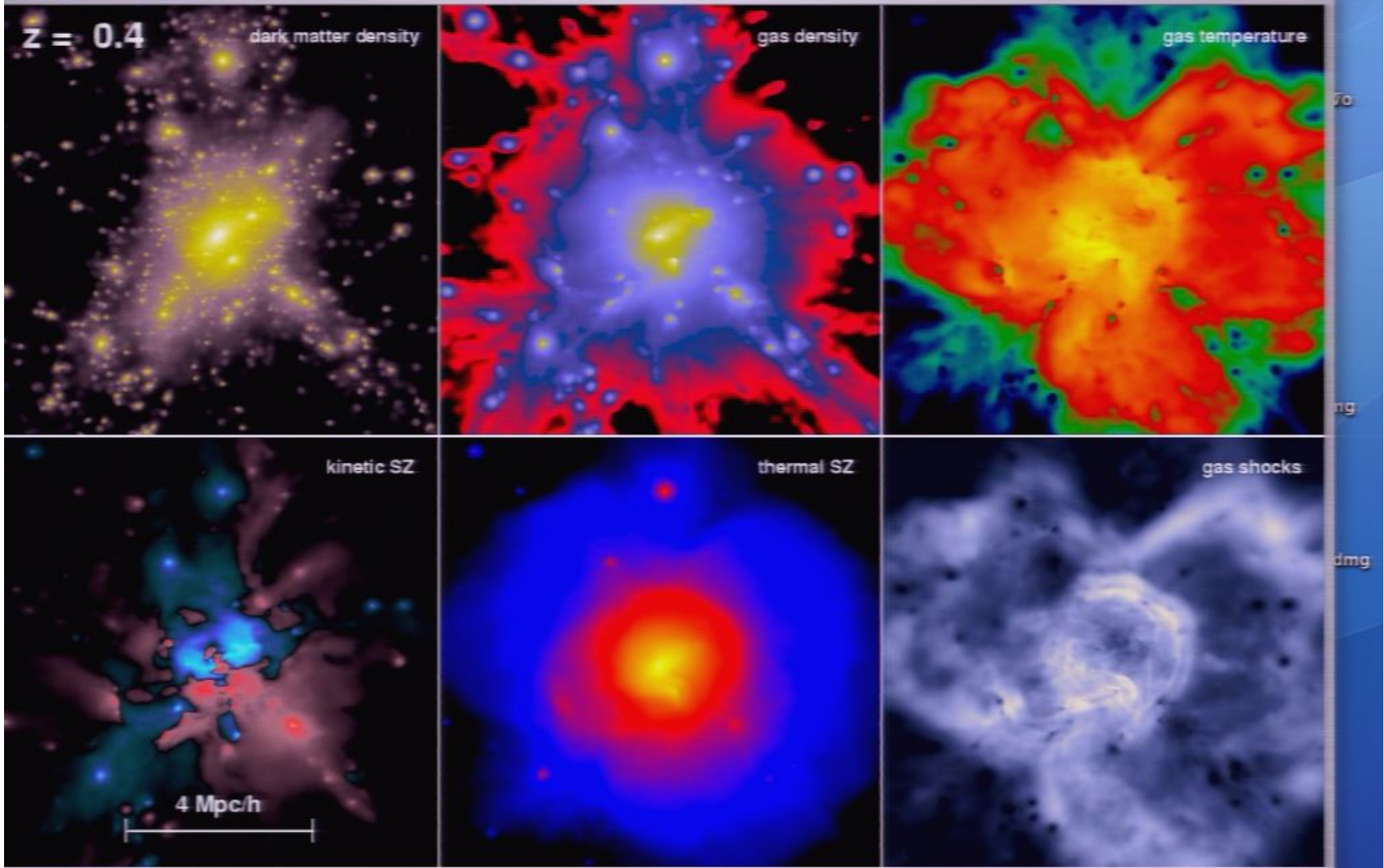


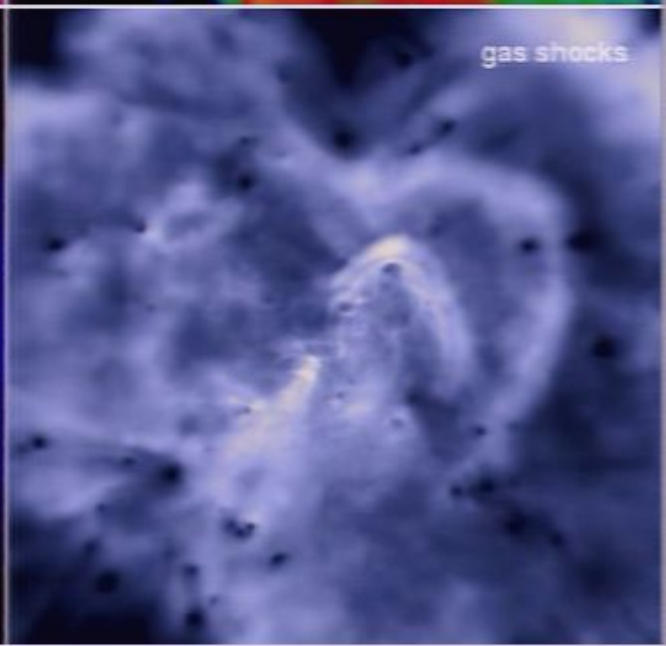
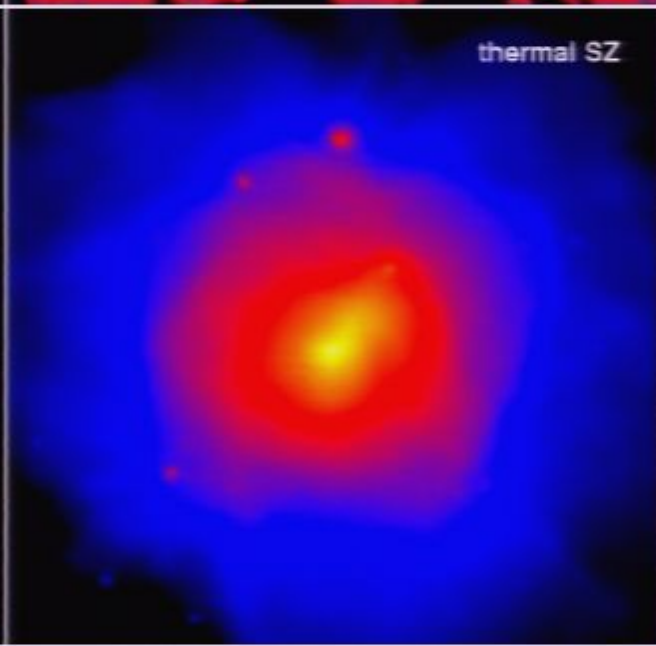
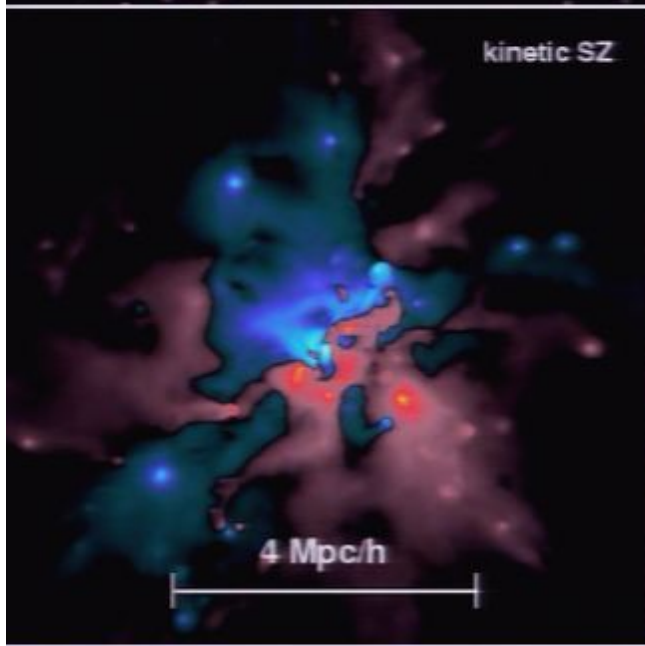
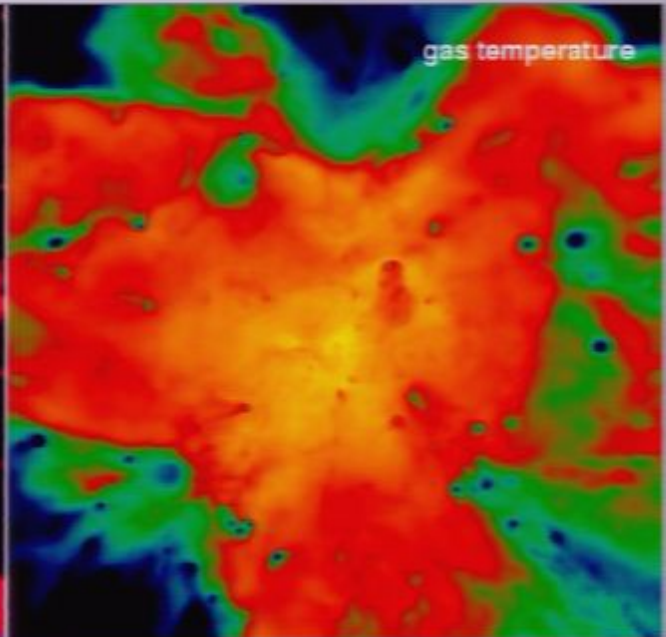
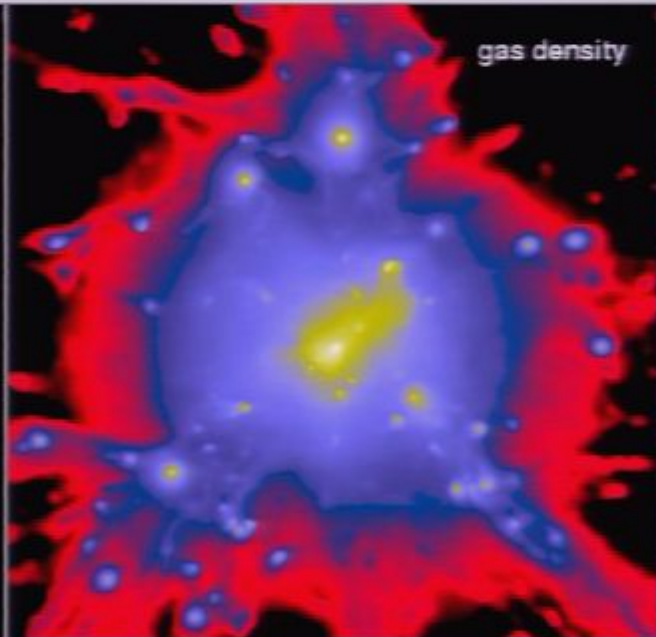
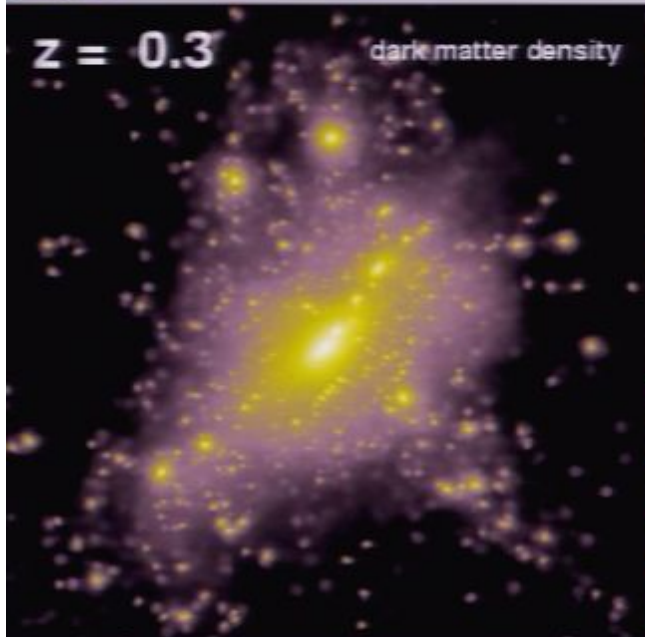


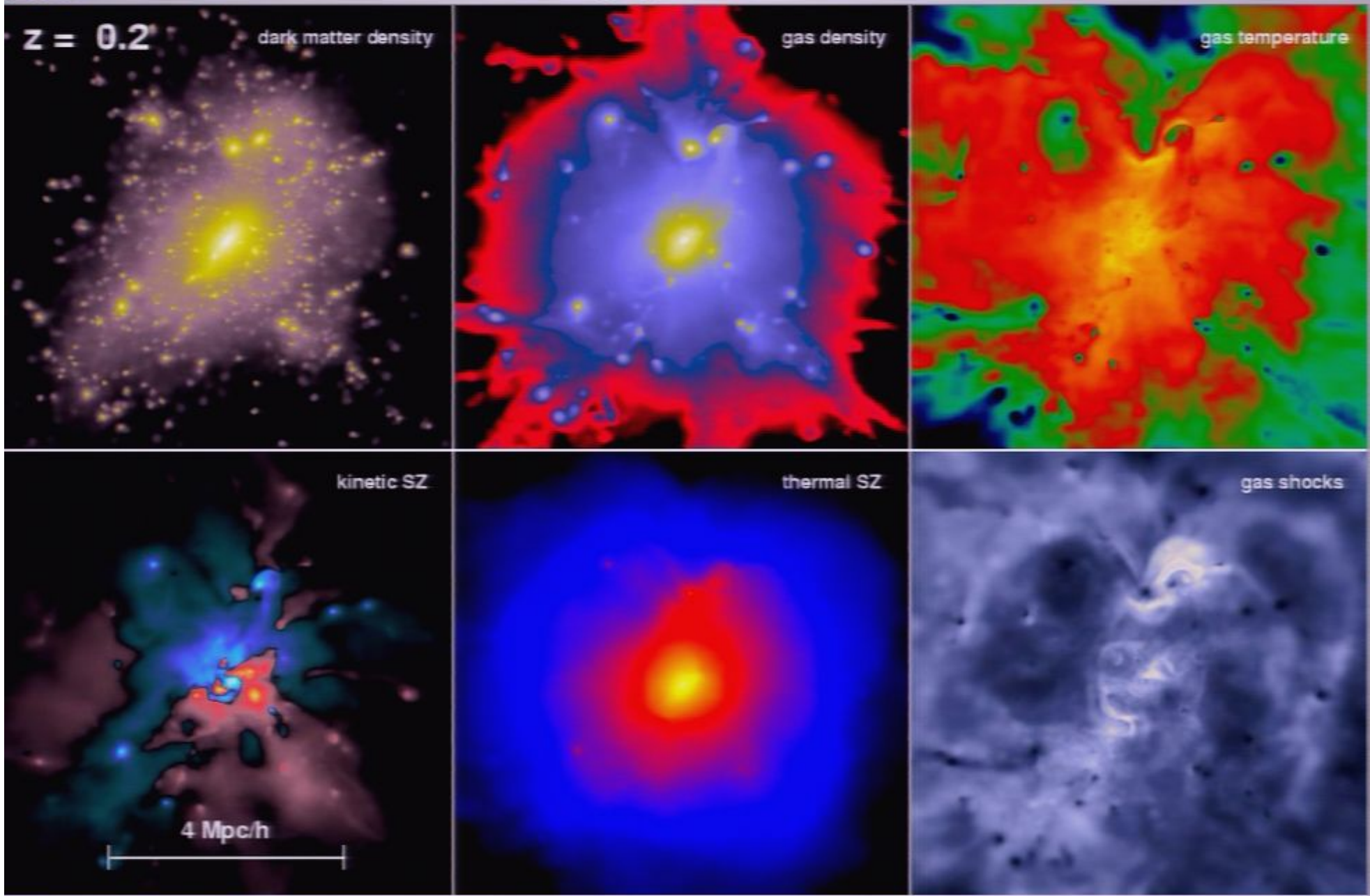


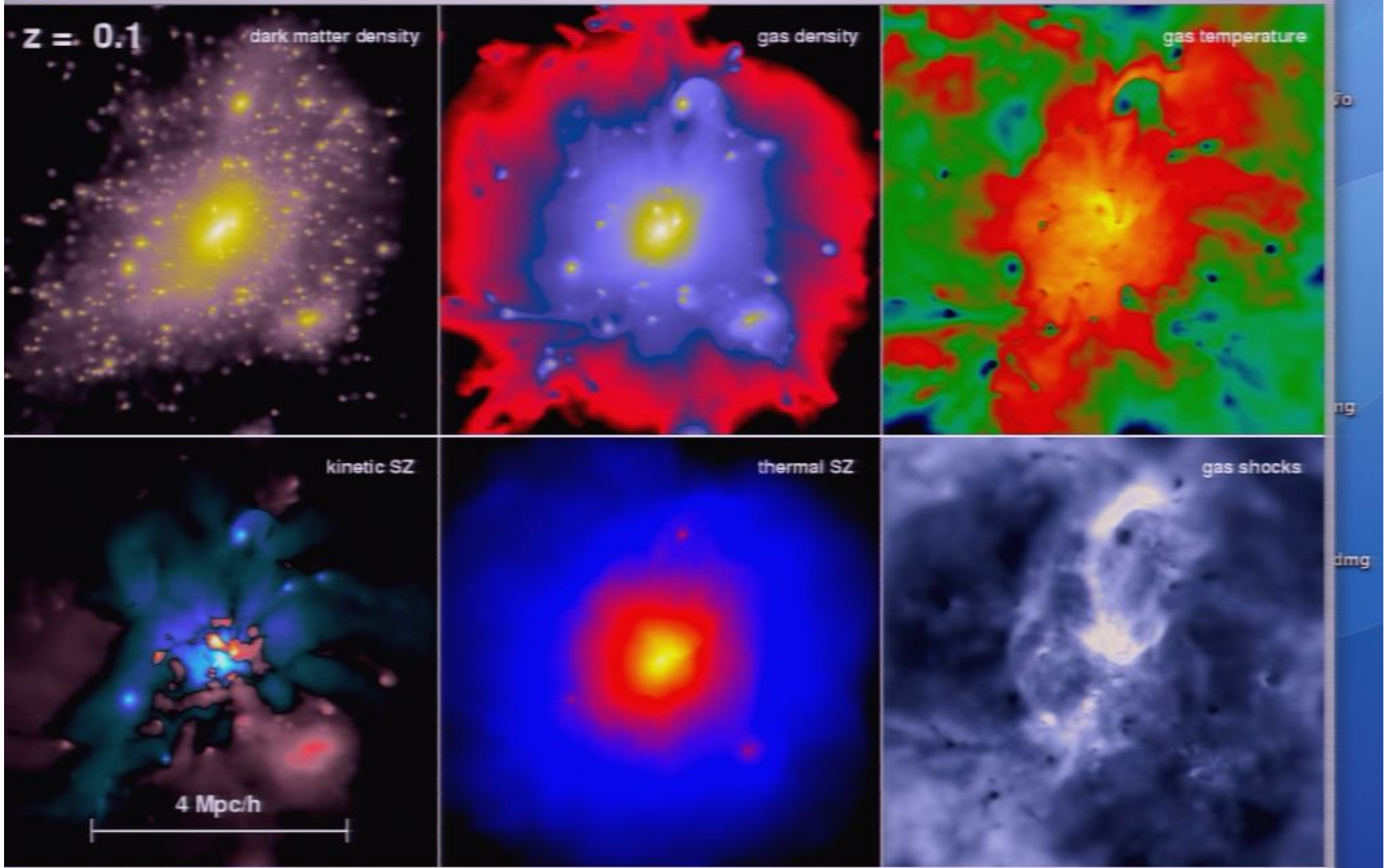


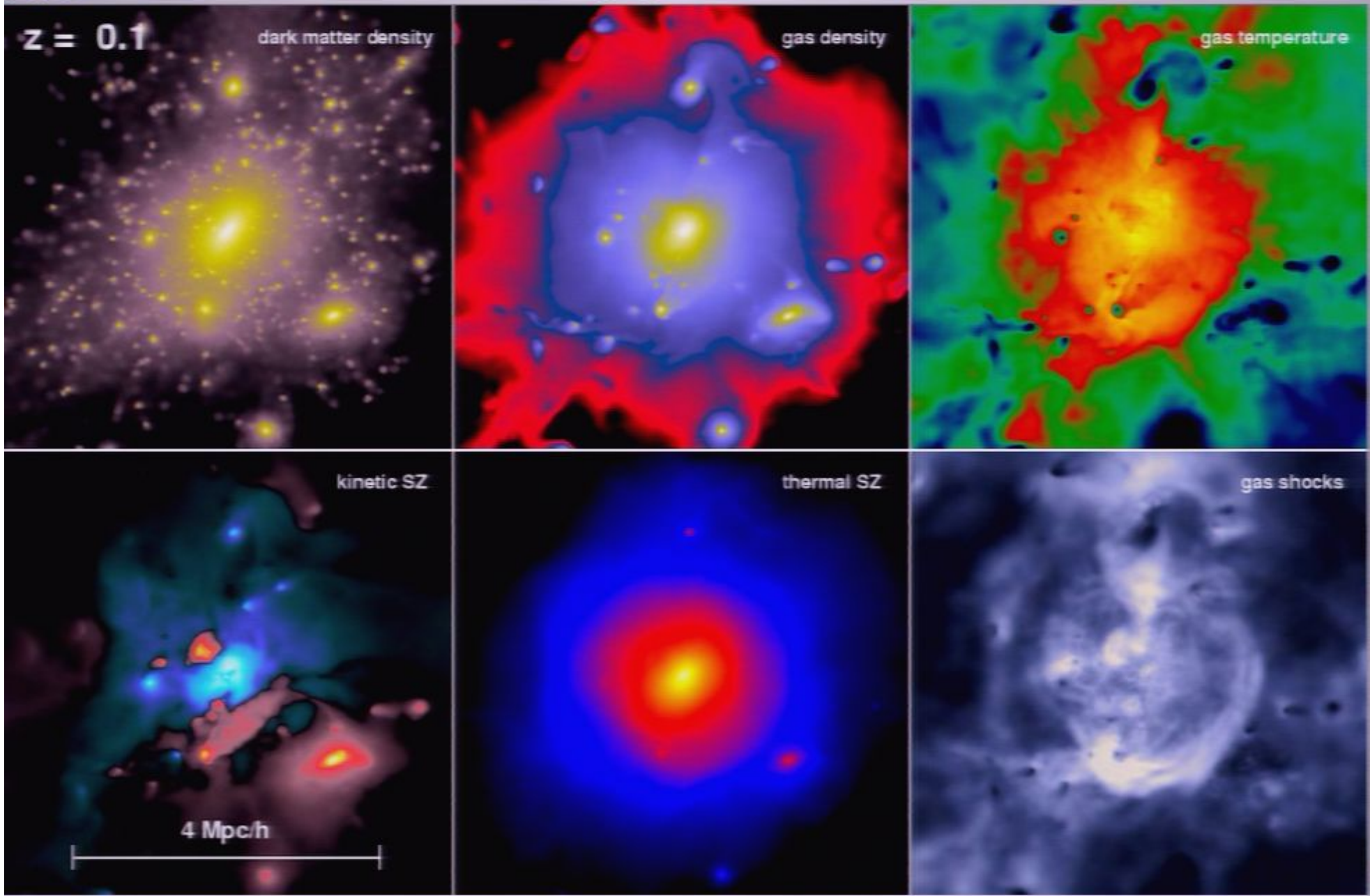


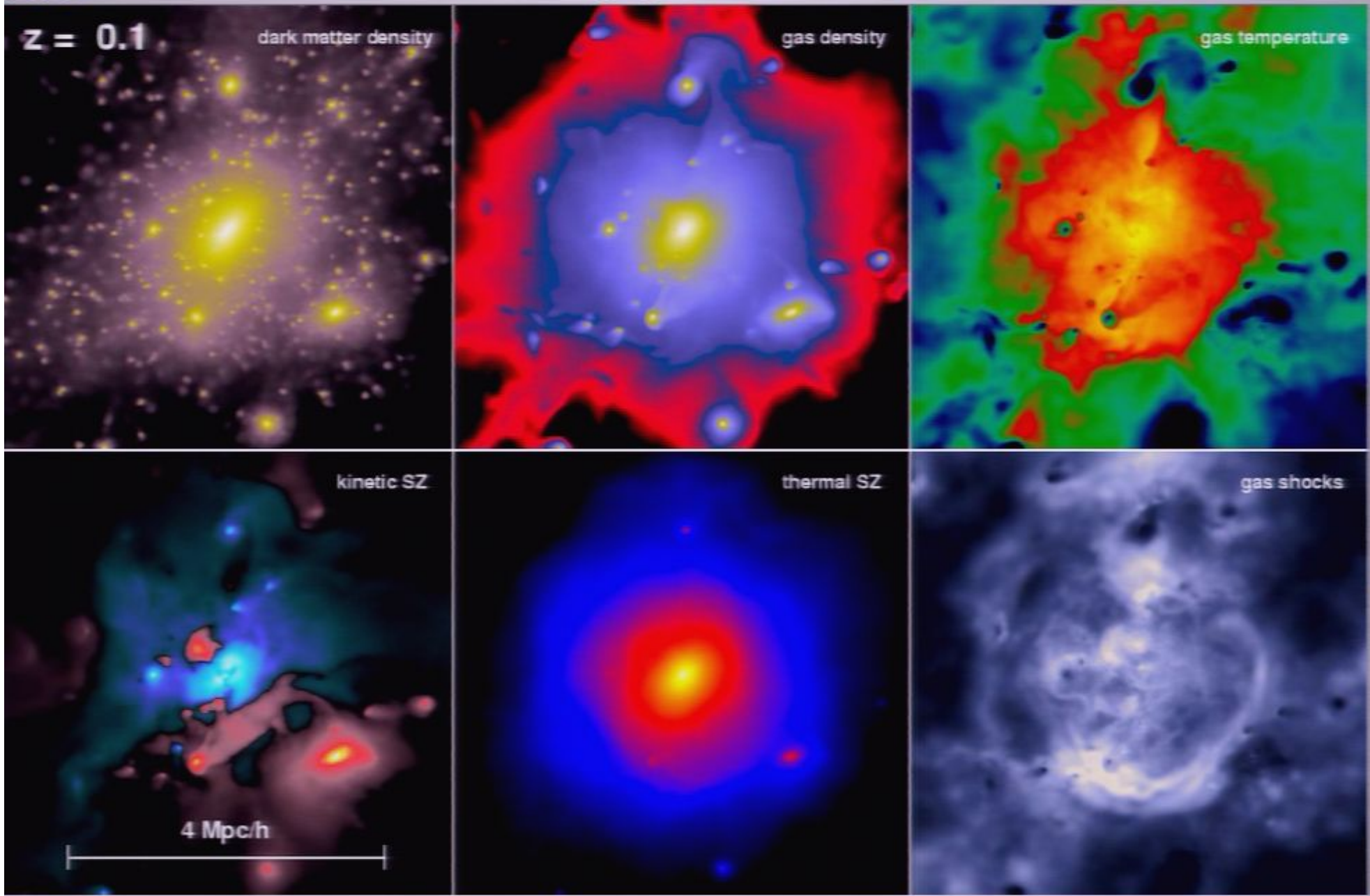








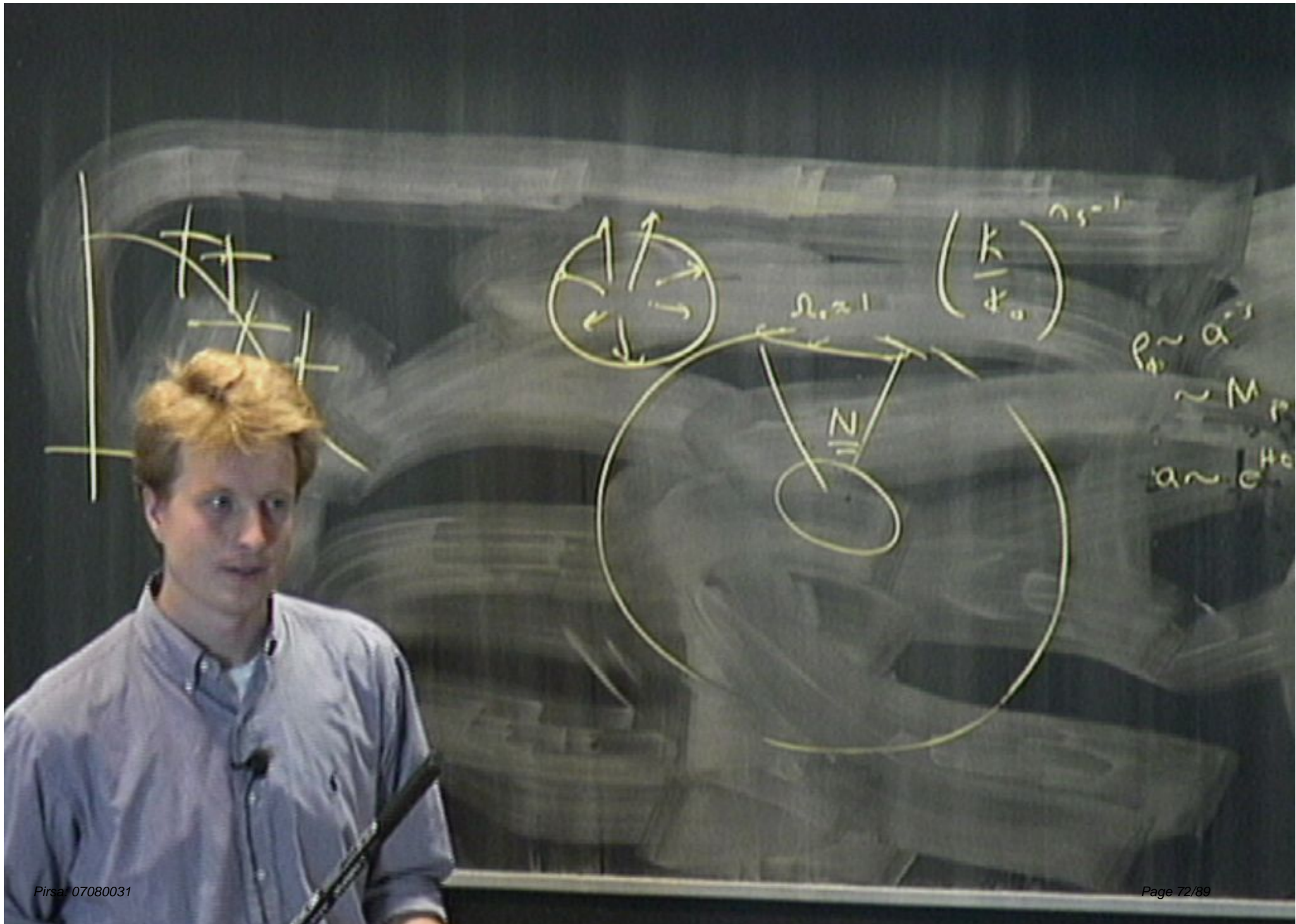


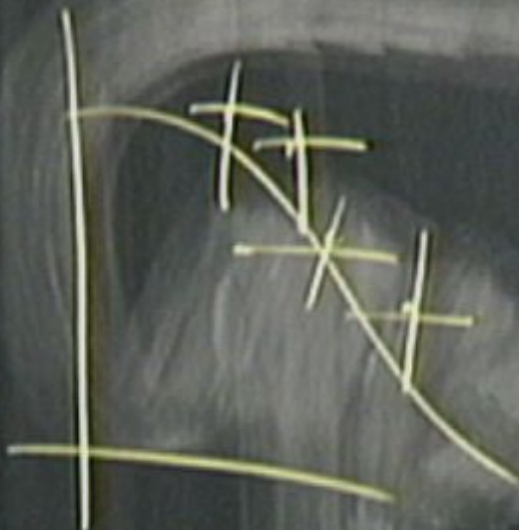


Movie ...

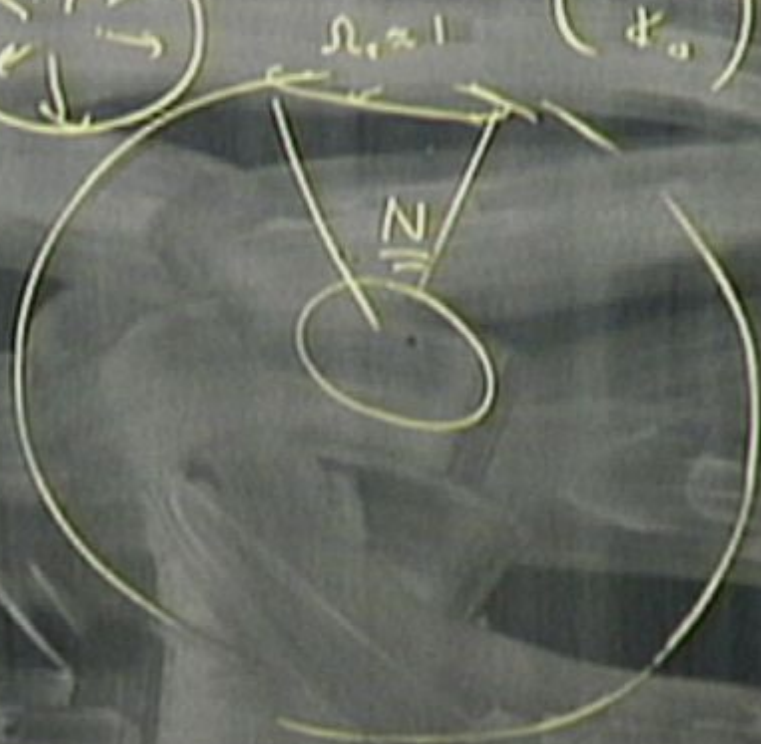
What Can You Trust?

- Combining experiments
 - **Good:** different experiments measure different things in different ways, which reduces systematic errors (ie, errors intrinsic to the particular method)
 - **Bad:** can “over” measure parameters, giving apparently tight constraints when none really exist

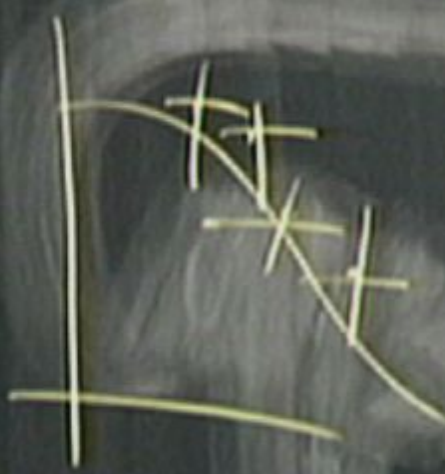




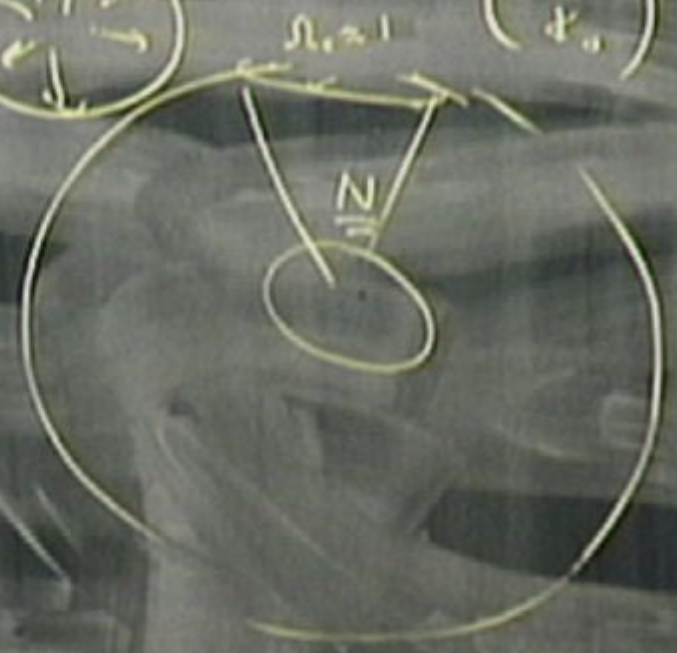
$$\begin{pmatrix} k \\ \phi_0 \end{pmatrix} \sim s^{-1}$$



$P \sim a^3$
 $\sim M^3$
 $a \sim \phi_0$



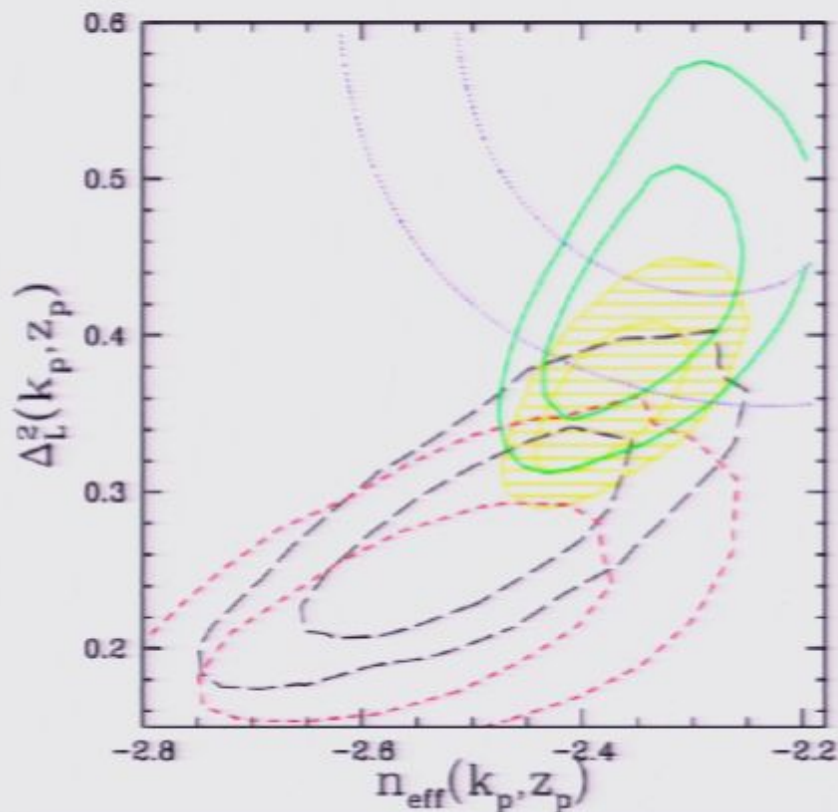
$$\left(\frac{k}{\omega_0} \right)$$



$\omega_0 \sim \omega_1$
 $\sim \omega_2$
 $\sim \omega_3$
 $\sim \omega_4$

WMAP vs. Ly α F (including running)

Linear amp. & slope constraints at $z=3$, $k=0.009$ s/km



- Green: Ly α F
- Red: WMAP
- Black: WMAP, SDSS-main, SN
- Yellow: All
- Blue: Viel et al. (2004) independent Ly α F

parameter	ALL DATA	ALL DATA - LYA
ω_b	$0.0230^{+0.0006+0.0011+0.0017}_{-0.0006-0.0011-0.0019}$	$0.0224^{+0.0007+0.0012+0.0018}_{-0.0006-0.0013-0.0019}$
ω_{dm}	$0.117^{+0.003+0.005+0.007}_{-0.002-0.005-0.008}$	$0.114^{+0.003+0.006+0.009}_{-0.003-0.005-0.008}$
h	$0.705^{+0.013+0.025+0.038}_{-0.013-0.023-0.038}$	$0.703^{+0.013+0.025+0.037}_{-0.013-0.028-0.037}$
τ	$0.108^{+0.010+0.039+0.063}_{-0.010-0.043-0.069}$	$0.077^{+0.014+0.045+0.083}_{-0.015-0.046-0.064}$
n_s	$0.964^{+0.012+0.025+0.037}_{-0.012-0.026-0.038}$	$0.951^{+0.013+0.027+0.041}_{-0.013-0.027-0.041}$
σ_8	$0.847^{+0.022+0.042+0.070}_{-0.022-0.045-0.062}$	$0.798^{+0.030+0.059+0.083}_{-0.030-0.053-0.075}$

Table 1: Parameter constraints for the simplest 6-parameter model. Limits are probabilities corresponding to 1, 2 and 3 sigma.

parameter	ALL DATA	ALL DATA - LYA
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Table 1: Parameter constraints for the simplest 6-parameter model. Limits are probabilities corresponding to 1, 2 and 3 sigma.

parameter	ALL DATA
r	< 0.22 (< 0.37)
α	$-0.015^{+0.012+0.023+0.036}_{-0.012-0.021-0.029}$
N_{ν}^{eff}	$5.3^{+0.4+2.1+3.8}_{-0.6-1.7-2.5}$
$\sum m_{\nu}$	$< 0.17\text{eV}$ ($< 0.32\text{eV}$)
m_s	$< 0.26\text{eV}$ ($< 0.43\text{eV}$)
Ω_k	$-0.003^{+0.0060+0.0109+0.0157}_{-0.0061-0.0122-0.0180}$
w	$-1.040^{+0.063+0.124+0.178}_{-0.063-0.130-0.208}$
$A_{\text{iso,bar}}$	$-0.06^{+0.18+0.35+0.50}_{-0.18-0.34-0.55}$
$A_{\text{iso,CDM}}$	$-0.007^{+0.034+0.068+0.110}_{-0.035-0.067-0.104}$
$G\mu$	$< 2.3 \times 10^{-7}$ ($< 2.9 \times 10^{-7}$)

Running of spectral index

Sum of neutrino masses

Table 1: Parameter constraints for the simplest model plus one parameter. Limits are probabilities corresponding to 1, 2 and 3 sigma; when only upper limits are given, these are at 95% and 99.9%..

parameter	ALL DATA	ALL DATA - LYA
ω_b	$0.0230^{+0.0006+0.0011+0.0017}_{-0.0006-0.0011-0.0019}$	$0.0224^{+0.0007+0.0012+0.0018}_{-0.0006-0.0013-0.0019}$
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Table 1: Parameter constraints for the simplest 6-parameter model. Limits are probabilities corresponding to 1, 2 and 3 sigma.

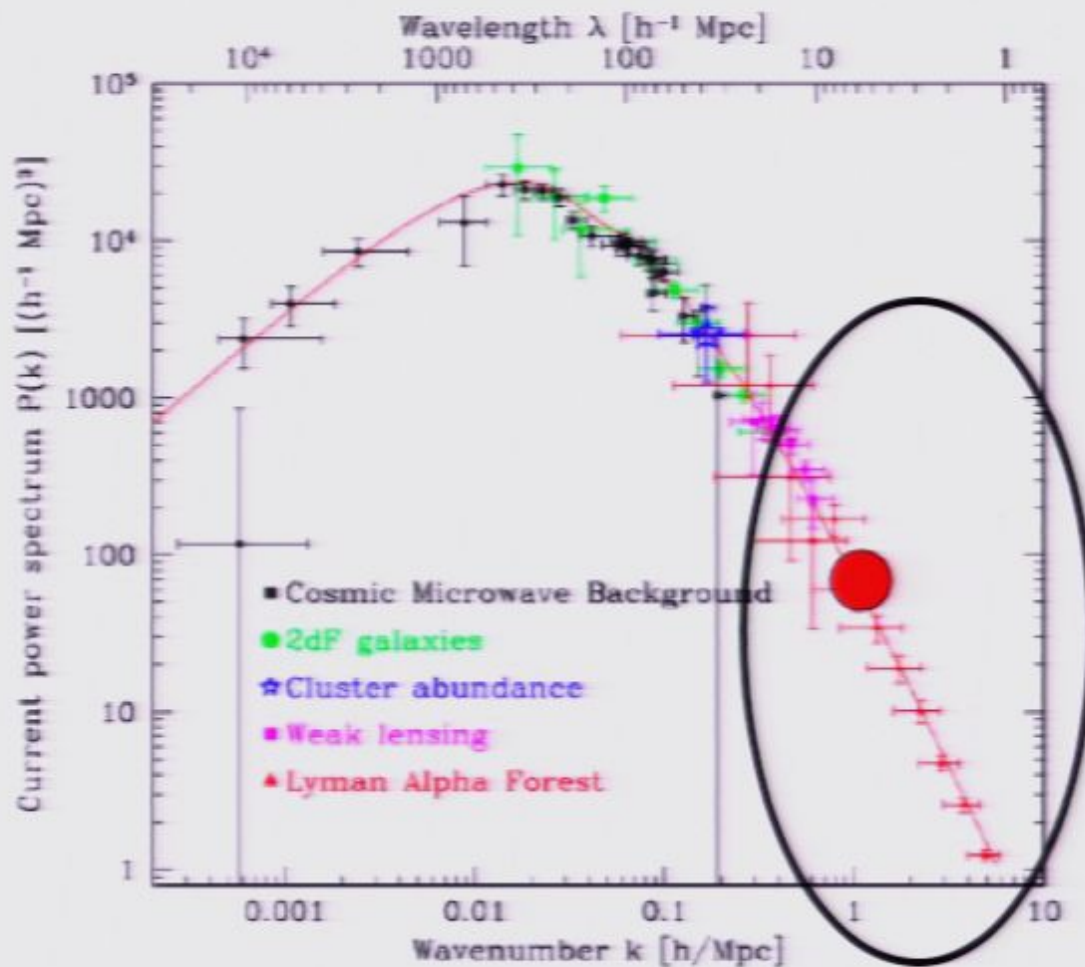
parameter	ALL DATA
r	< 0.22 (< 0.37)
α	$-0.015^{+0.012+0.023+0.036}_{-0.012-0.031-0.029}$
N_{ν}^{eff}	$5.3^{+0.4+2.1+3.8}_{-0.6-1.7-2.5}$
$\sum m_{\nu}$	$< 0.17\text{eV}$ ($< 0.32\text{eV}$)
m_s	$< 0.26\text{eV}$ ($< 0.43\text{eV}$)
Ω_k	$-0.003^{+0.0060+0.0109+0.0157}_{-0.0061-0.0122-0.0180}$
w	$-1.040^{+0.063+0.124+0.178}_{-0.063-0.130-0.208}$
$A_{\text{iso,bar}}$	$-0.06^{+0.18+0.35+0.50}_{-0.18-0.34-0.55}$
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$G\mu$	$< 2.3 \times 10^{-7}$ ($< 2.9 \times 10^{-7}$)

Running of spectral index

Sum of neutrino masses

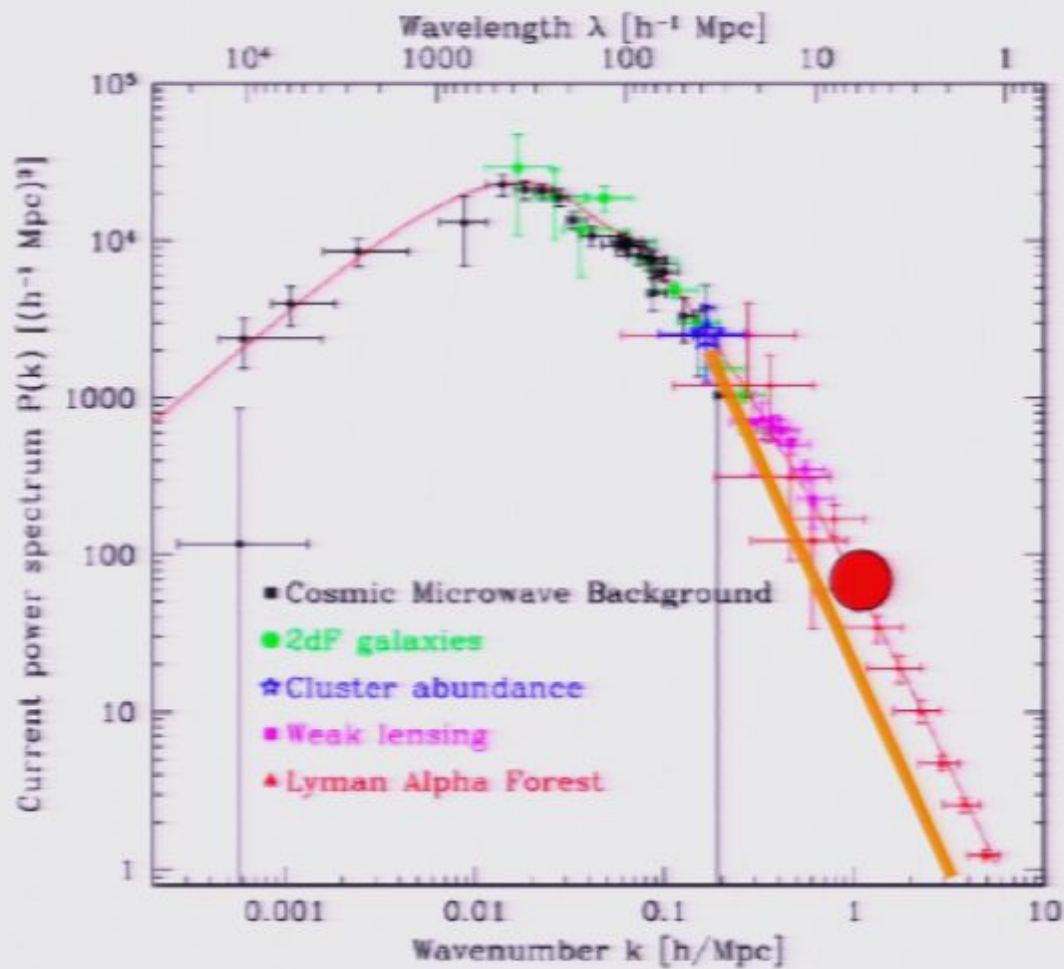
Table 1: Parameter constraints for the simplest model plus one parameter. Limits are probabilities corresponding to 1, 2 and 3 sigma; when only upper limits are given, these are at 95% and 99.9%..

Scales of various LSS probes



(out of date figure by
Max Tegmark)

Scales of various LSS probes



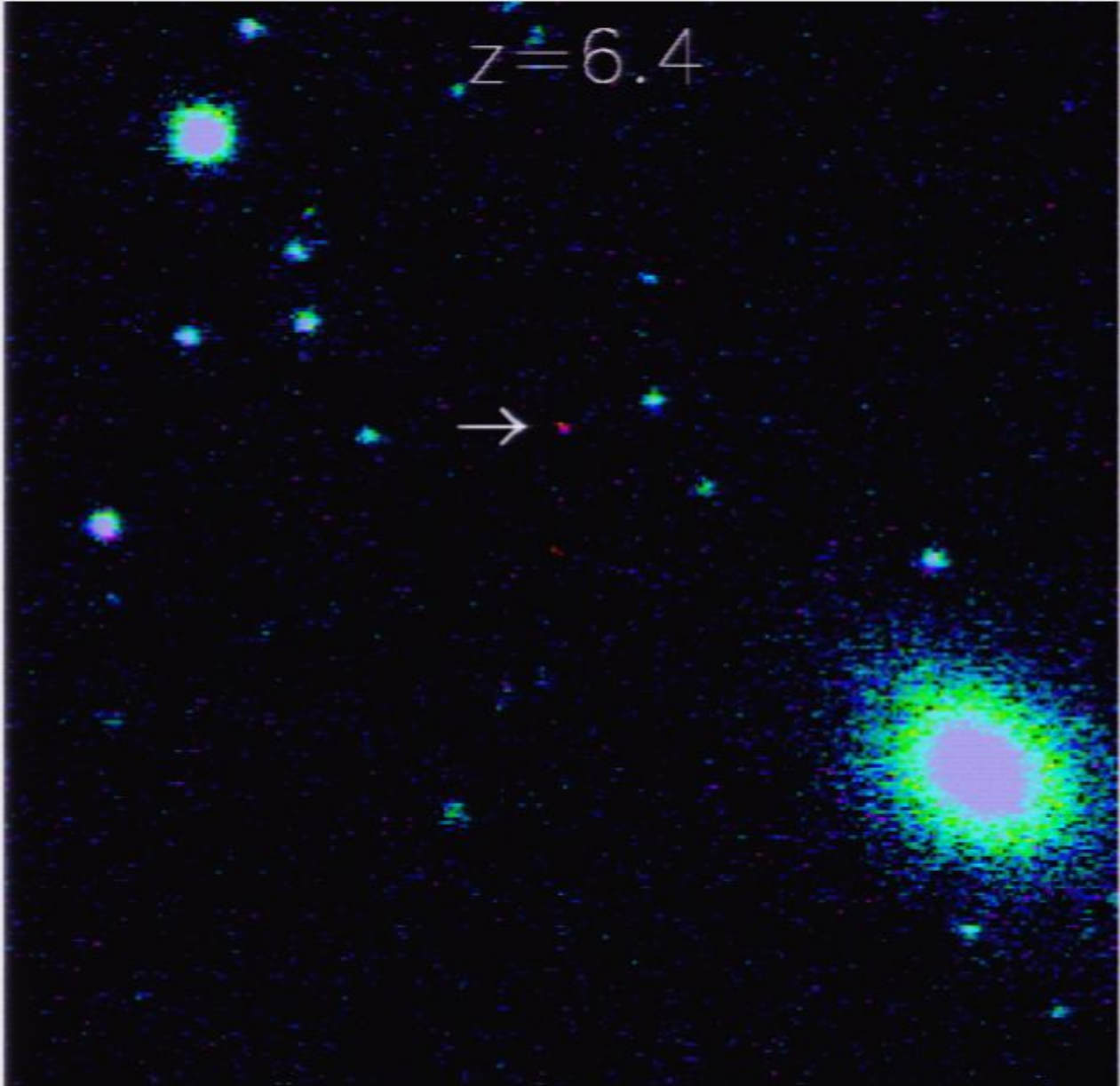
(out of date figure by Max Tegmark)

So, What Do We Believe?

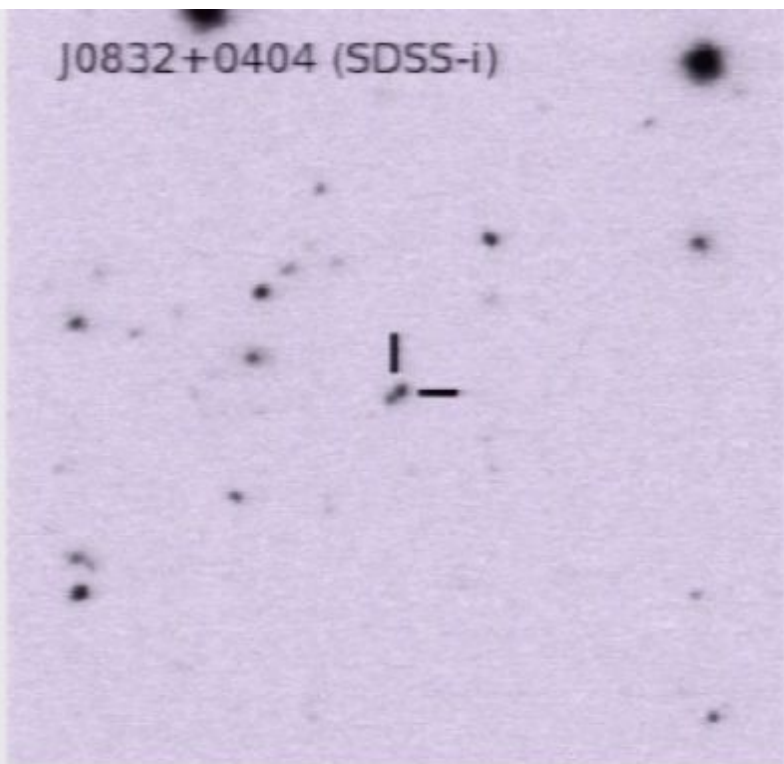
- Good work done! But ...
- Running of spectral index, if poorly motivated in theory, *may not be needed*, though Ly α data “like” it.
- Similarly: “heavy” neutrinos are down for the count, but not out of the game!

Astrophysics

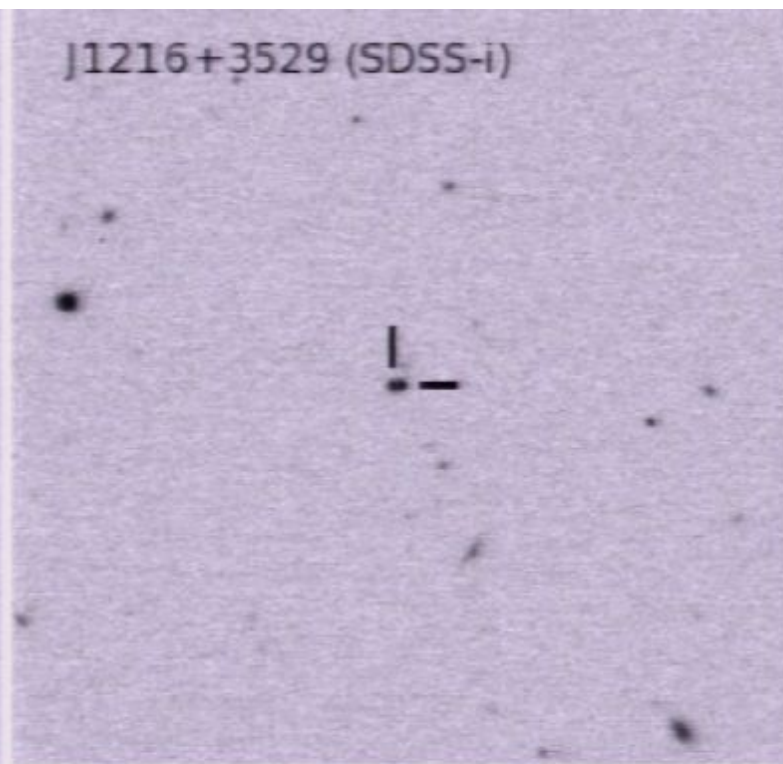
- Galaxies and Quasars are interesting in their own right.
- Big survey also = rare events
 - Gravitational lensing: Dark Matter made “visible”!
 - Very distant quasars (Astronomer’s bragging rights)



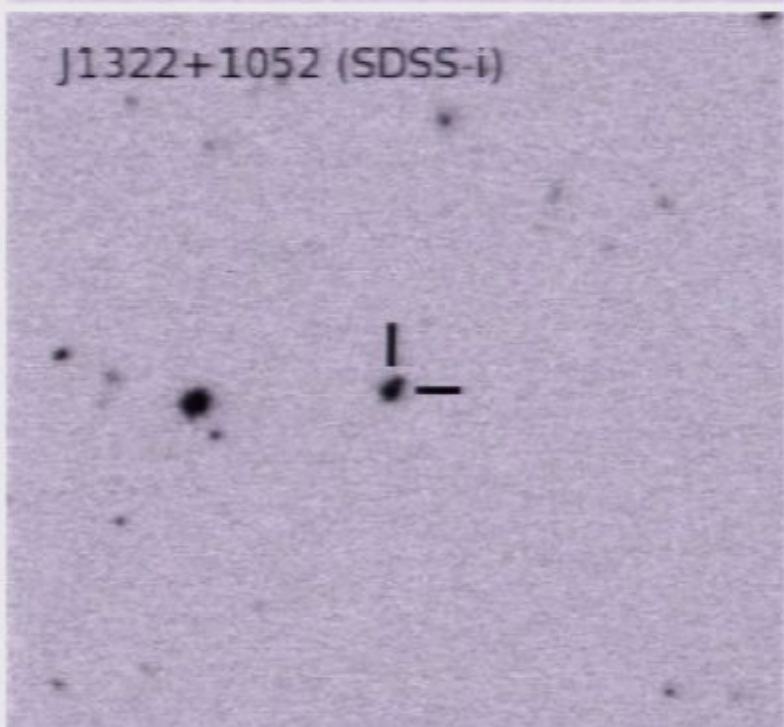
J0832+0404 (SDSS-i)



J1216+3529 (SDSS-i)



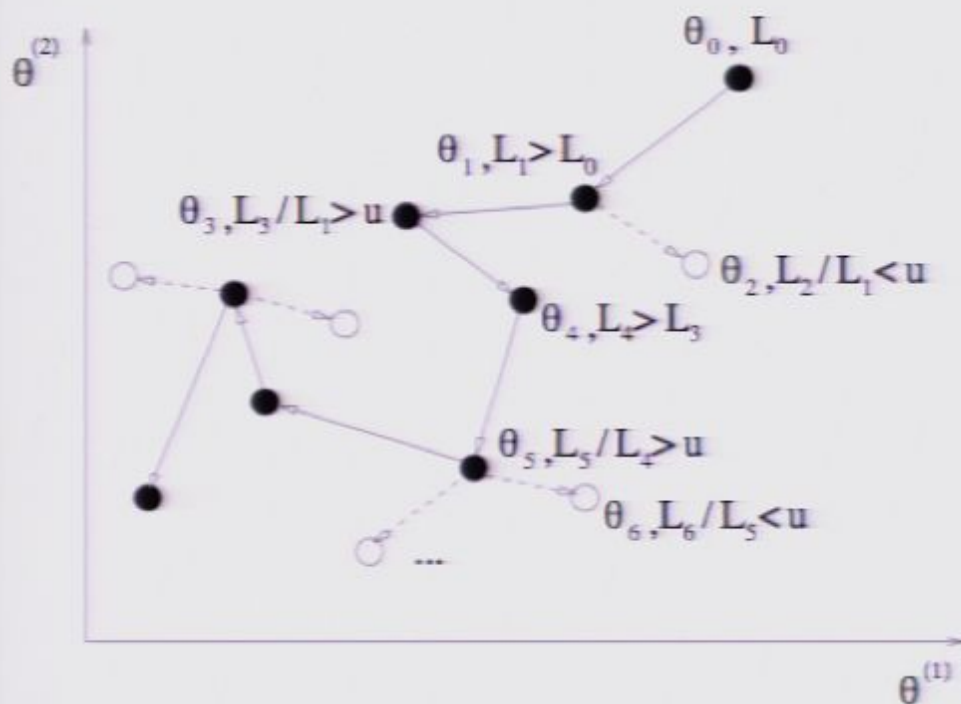
J1322+1052 (SDSS-i)



J1524+4409 (SDSS-i)



Extra Material: Markov Chain Monte Carlo



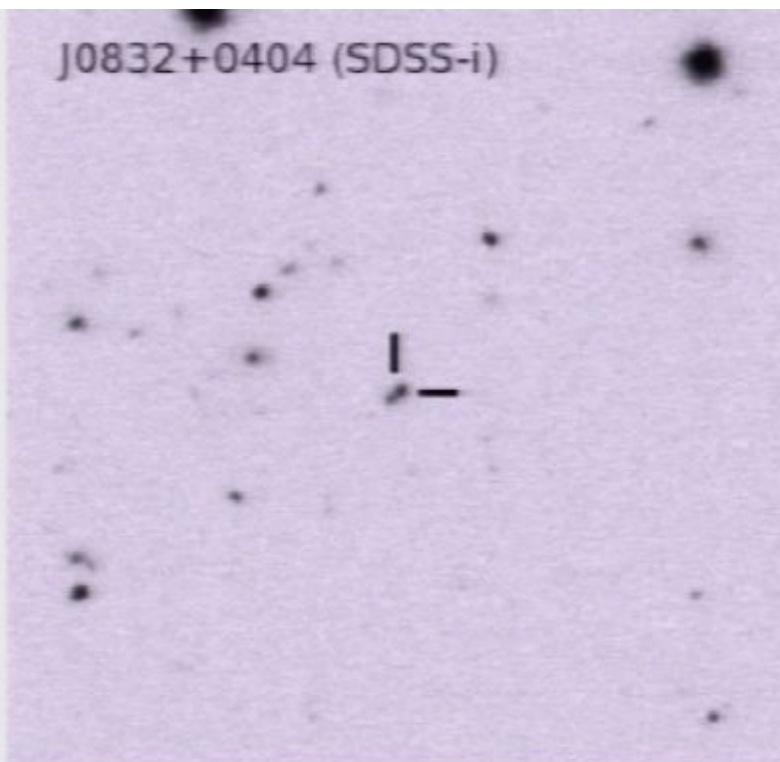
- Markov Chain: given probability distribution $p(q)$
 - Step 0: Guess Model Parameters, q
 - Step $n+1$: Use Rule, $q(q|q_n)$ to guess new parameters
 - Calculate

$$\alpha(\theta'|\theta_n) = \min \left\{ \frac{p(\theta')p(z|\theta')q(\theta_n|\theta')}{p(\theta_n)p(z|\theta_n)q(\theta'|\theta_n)}, 1 \right\}$$

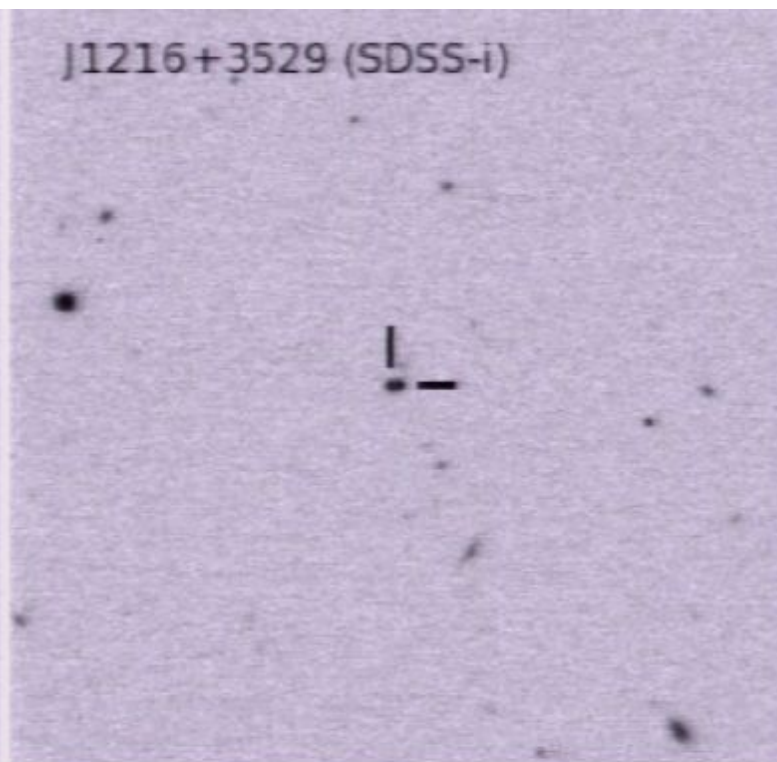
- Draw
- If $u < a$, $u \in [0, 1]$
- Else, reject and try again

NB: Graph Represents a Modified Version of this Method

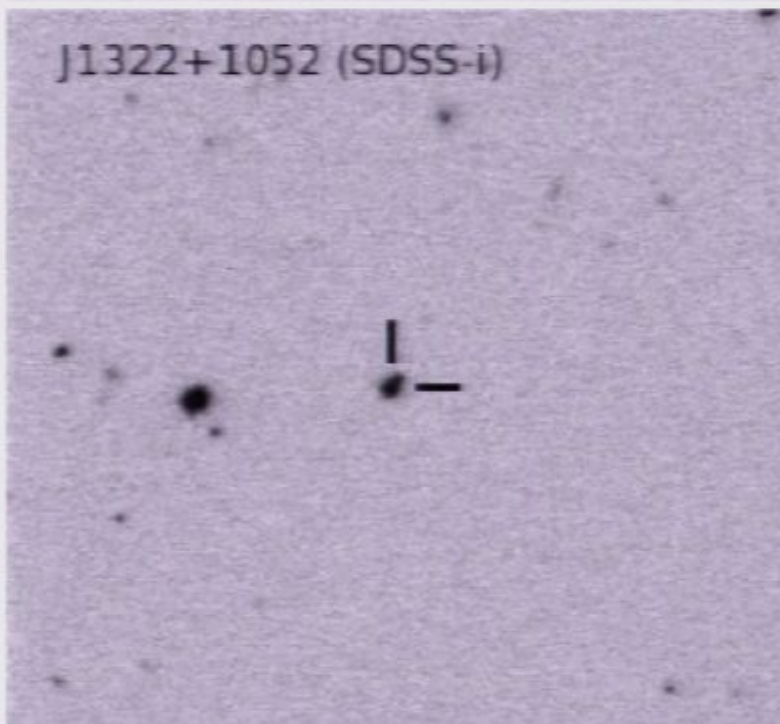
J0832+0404 (SDSS-i)



J1216+3529 (SDSS-i)



J1322+1052 (SDSS-i)



J1524+4409 (SDSS-i)

