Title: From the Biggest Things to the Biggest Bang

Date: Jul 22, 2011 07:00 AM

URL: http://pirsa.org/11070099

Abstract: Assuming that you are really (really) strong, what are the biggest objects in the Universe that hold together enough that you could throw them? What are they made of and why are they so big? In this talk, I will show how studies of the large scale structure of the Universe enable us to reconstruct the initial conditions at the Big-Bang and test the fundamental laws of physics. Among other things, scientist are trying to test one of the most provocative idea of modern physics: the possibility that these huge "things" actually originated from quantum fluctuations smaller than anything we have ever detected!

From the Biggest Things to the Biggest Bang

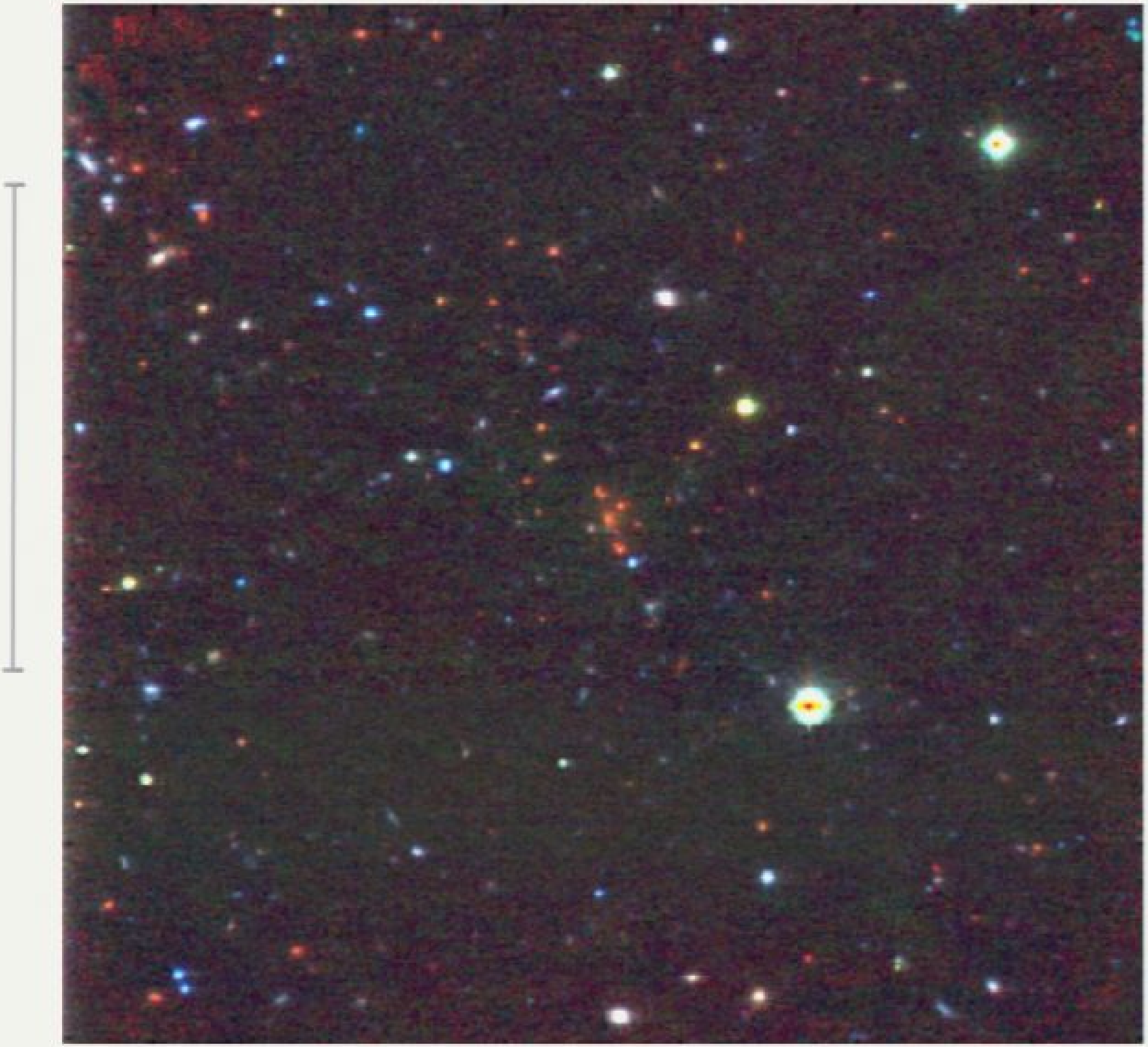
Louis Leblond

... and to the biggest questions

Observe 1.

- we will observe the biggest things in three different ways.

XMMUJ2235.3+2557 Visible

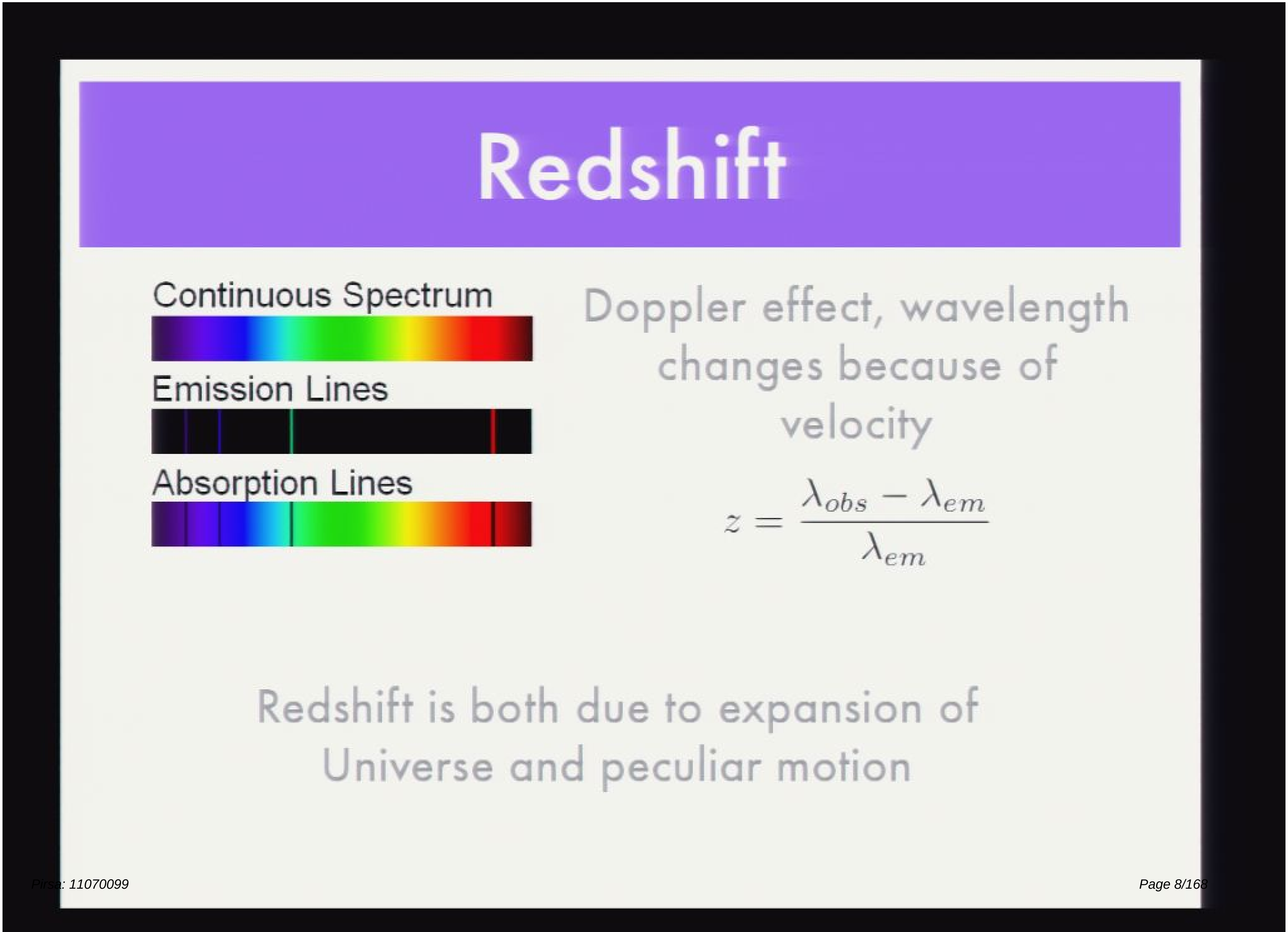


Galaxy Clusters

- 10-1000 galaxies appear to be held together by some kind of gravitational attraction.

- Galaxies have a typical mass of $10^{11} M_{\odot}$

~ 30 Kpc $\sim 10^{17}$ km



Redshift

Continuous Spectrum

Emission Lines

Absorption Lines

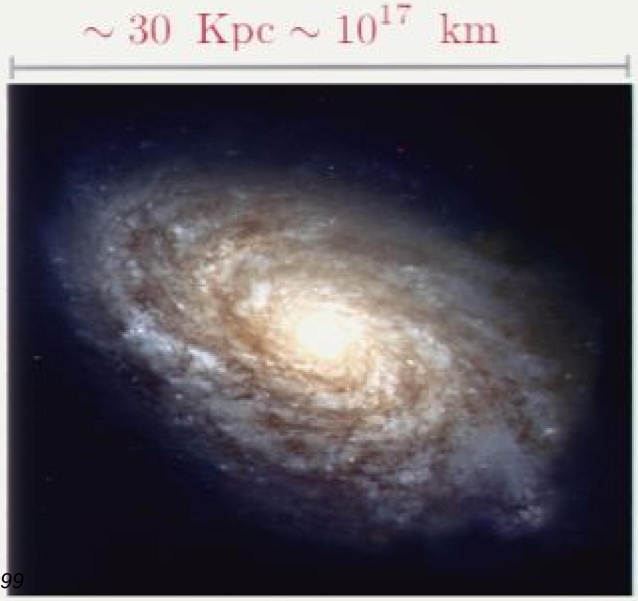
Doppler effect, wavelength changes because of velocity

$$z = \frac{\lambda_{obs} - \lambda_{em}}{\lambda_{em}}$$

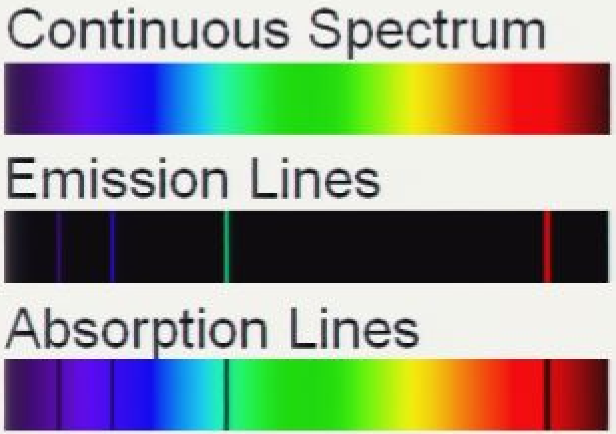
Redshift is both due to expansion of Universe and peculiar motion

Galaxy Clusters

- 10-1000 galaxies appear to be held together by some kind of gravitational attraction.
- Galaxies have a typical mass of $10^{11} M_{\odot}$



Redshift



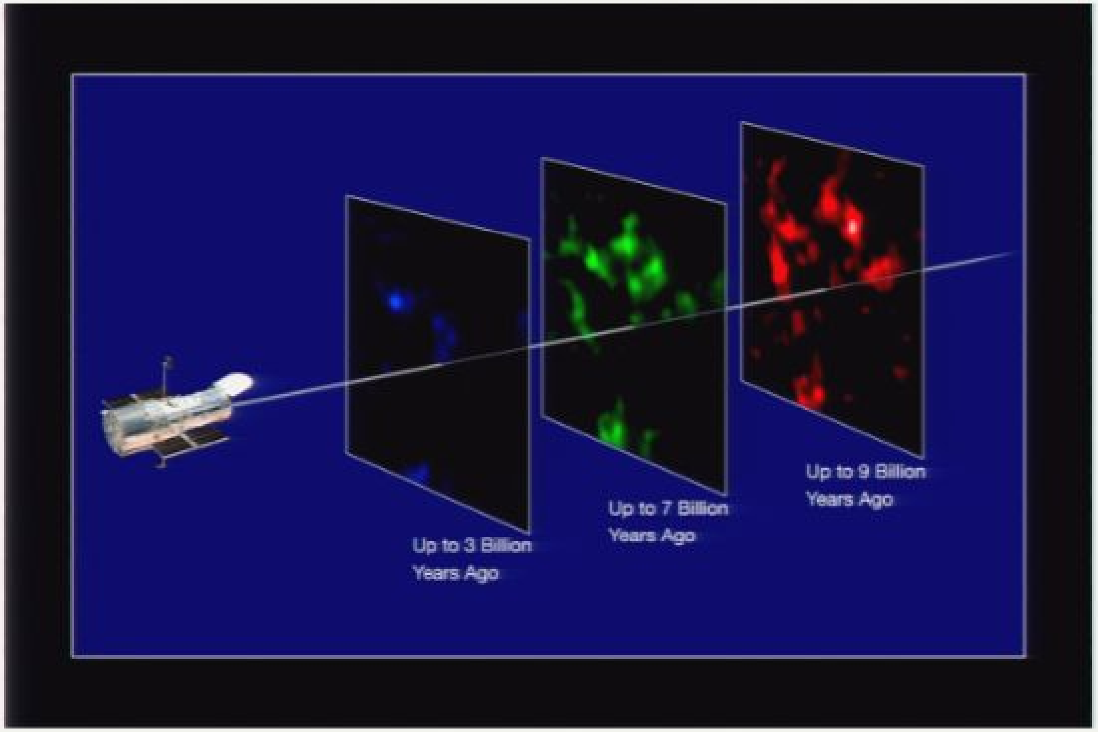
Doppler effect, wavelength changes because of velocity

$$z = \frac{\lambda_{obs} - \lambda_{em}}{\lambda_{em}}$$

Redshift is both due to expansion of Universe and peculiar motion

Redshift

- XMMUJ2235.3+2557 z=1.4



$$z > 0.1$$

expansion dominate over peculiar velocities

The biggest things are close by

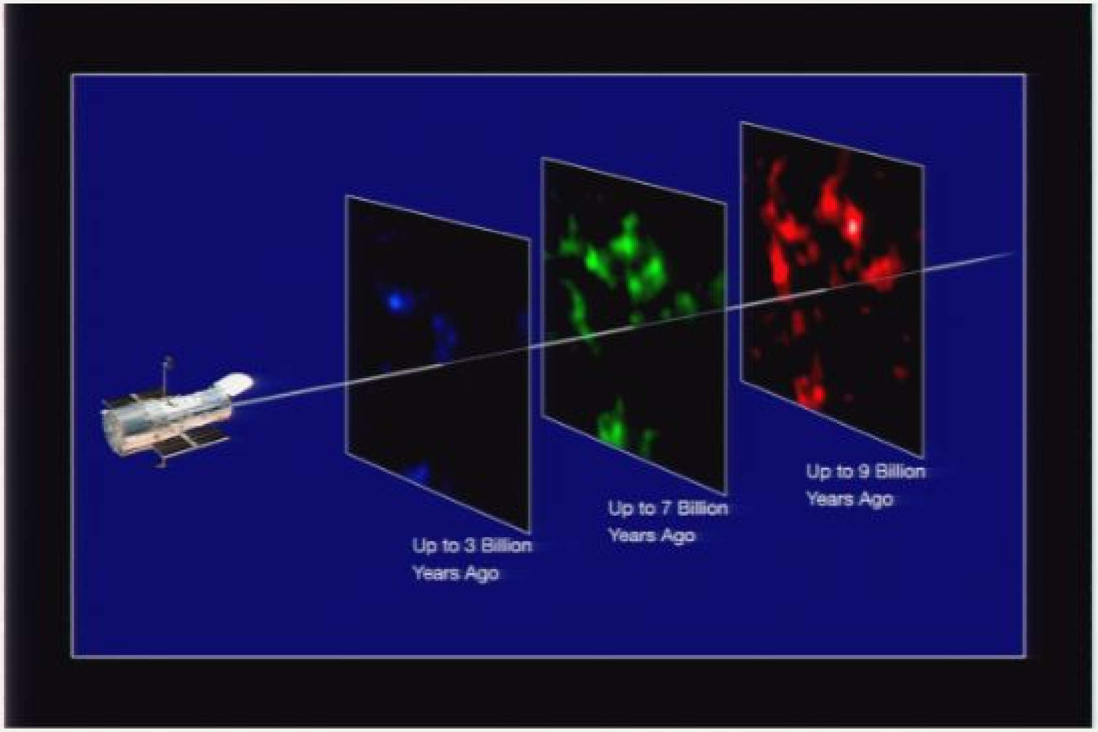
- quasar and GRB (small galaxies) have been observed up to redshift of $z = 7$
    - 770 millions year after Big-Bang, 12.9 billions for the light to reach us.
- Fun facts, at redshift of $z > 1.407$, recession velocity of galaxies is greater than the speed of light!

Measured

Assume a cosmological model ΛCDM

Redshift

- XMMUJ2235.3+2557 z=1.4



$$z > 0.1$$

expansion dominate over peculiar velocities

The biggest things are close by

- quasar and GRB (small galaxies) have been observed up to redshift of $z = 7$
    - 770 millions year after Big-Bang, 12.9 billions for the light to reach us.
- Fun facts, at redshift of $z > 1.407$, recession velocity of galaxies is greater than the speed of light!

Measured

Assume a cosmological model ΛCDM

Peculiar velocities of Galaxy

- by measuring relative redshift we can figure their peculiar velocities. Spread of velocities for a typical cluster is around 800-1000 km/s

$$v_e = \sqrt{\frac{2GM}{r}}$$

- speed is too high. The galaxies cannot be bound.

1000 galaxies @ $10^{11} M_{\odot}$ r G

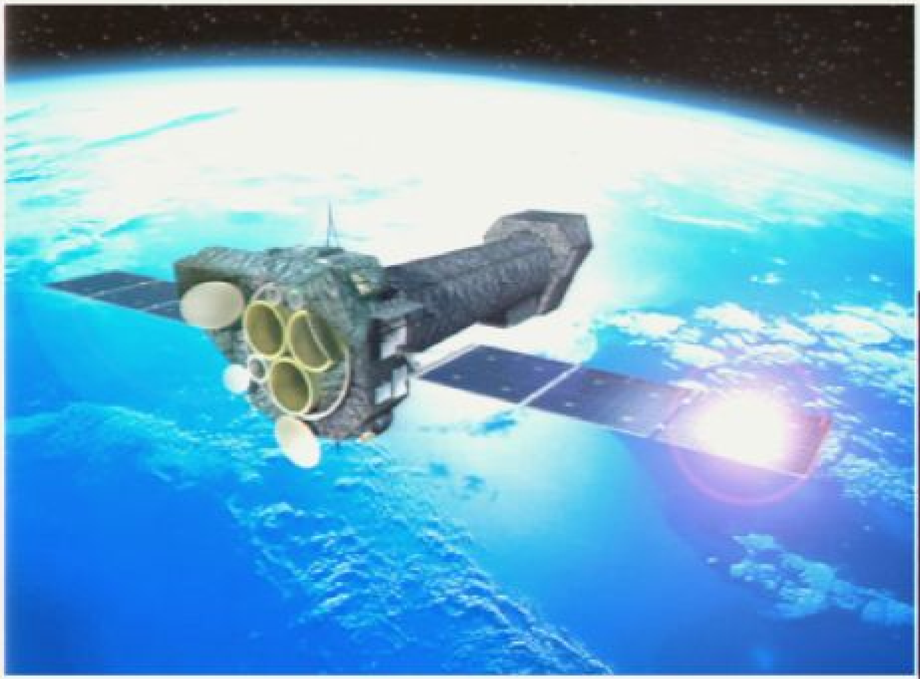
$\sim 10^{45}$ kg $\sim 10^{20}$ km $\sim 10^{-20} \frac{\mathrm{km}^3}{\mathrm{kg\ s}^2}$

First Puzzle

- Galaxies should not be bound, they move to fast. Either
    - we are missing mass
    - or our formula is wrong (or maybe G is wrong?)

$$v_e = \sqrt{\frac{2GM}{r}}$$

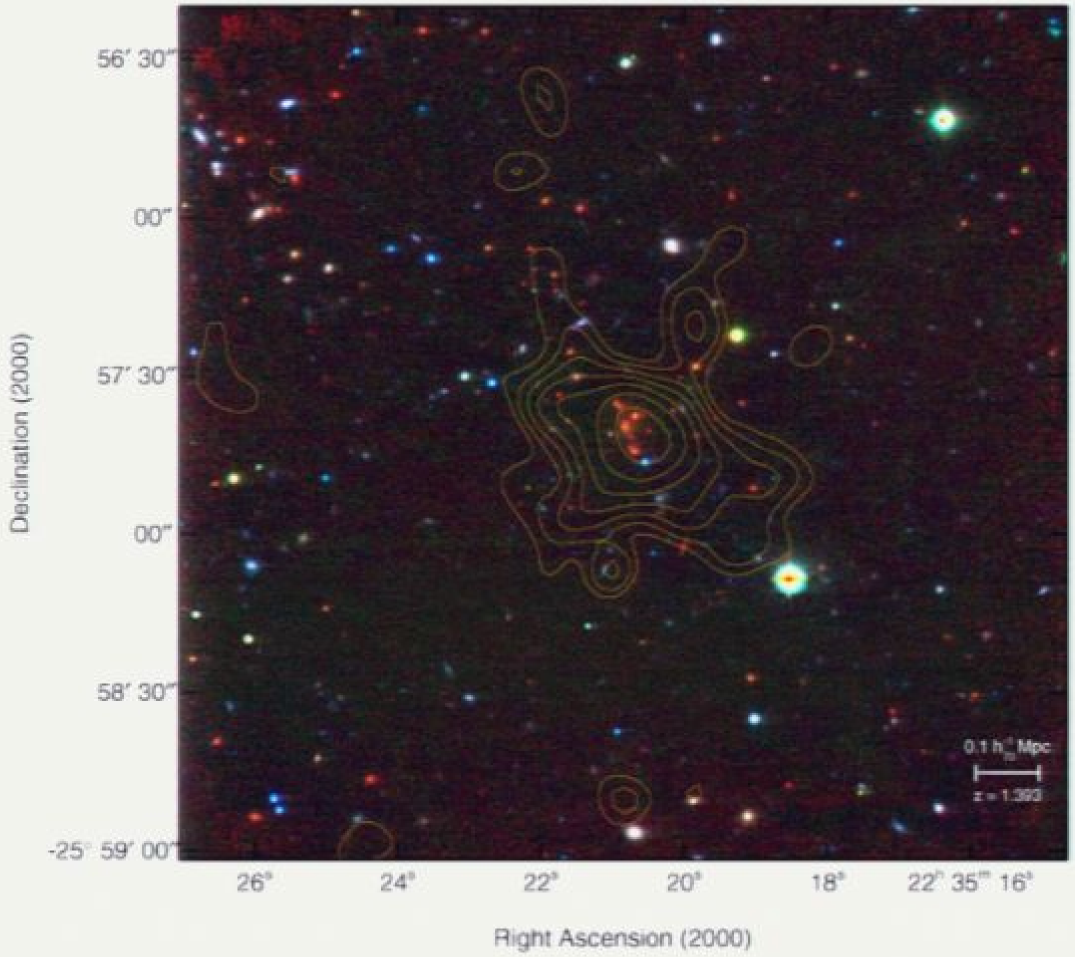
Observe 2. X-Rays



← ESA, XMM-Newton

NASA, Chandra →

XMMUJ2235.3+2557 X-rays contour



XMMUJ2235.3+2557

X-rays

XMMUJ2235.3+2557

- Was discovered as an extended x-rays source in archival XMM-Newton.
- X-rays is from an intergalactic gas known as intercluster gas.
- The gas is very hot ... 10^7-10^8 K

Mass of Gas = 2 x Mass of galaxies

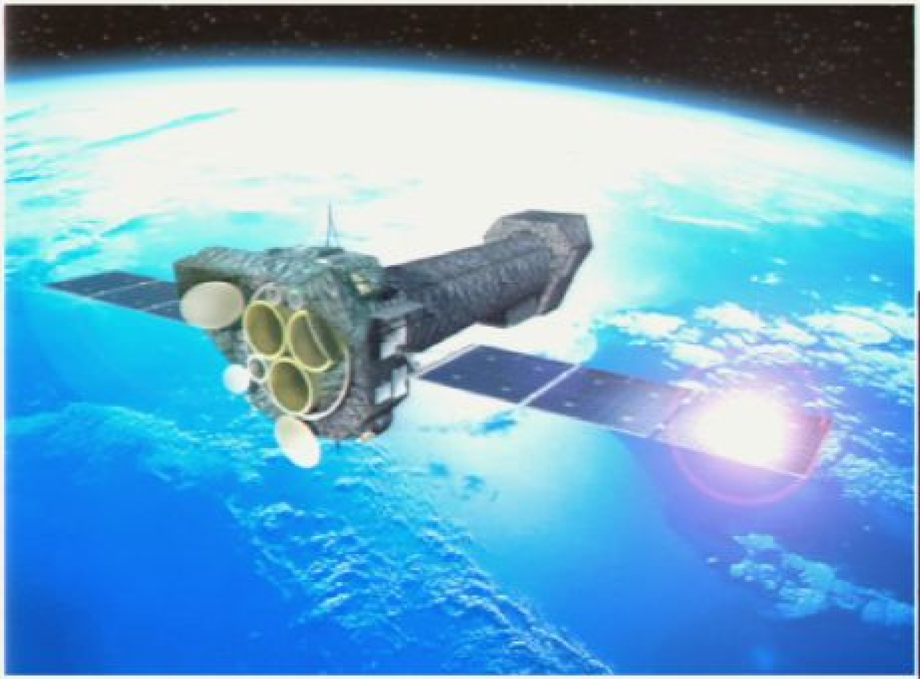
Still mass missing

First Puzzle

- Galaxies should not be bound, they move to fast. Either
  - we are missing mass
  - or our formula is wrong (or maybe G is wrong?)

$$v_e = \sqrt{\frac{2GM}{r}}$$

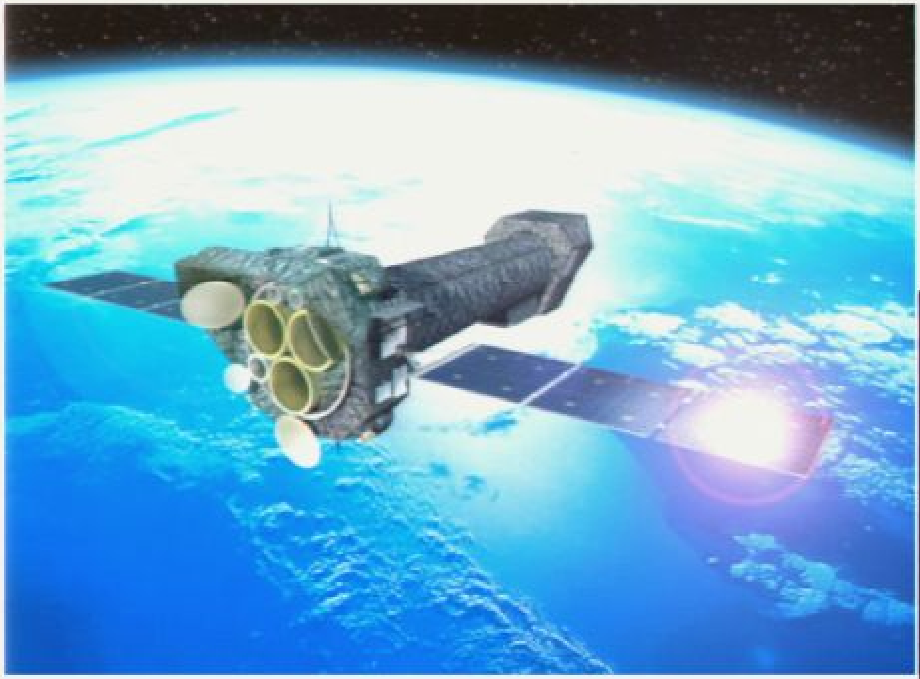
Observe 2. X-Rays



← ESA, XMM-Newton

NASA, Chandra →

Observe 2. X-Rays



← ESA, XMM-Newton

NASA, Chandra →

XMMUJ2235.3+2557

- Was discovered as an extended x-rays source in archival XMM-Newton.
- X-rays is from an intergalactic gas known as intercluster gas.
- The gas is very hot ... 10^7-10^8 K

Mass of Gas = 2 x Mass of galaxies

Still mass missing

Dark Matter

Gas is in approximate hydrostatic equilibrium with cluster gravitational field, we can estimate the total mass

Total Mass ≈ 6 x (mass of gas + galaxy)

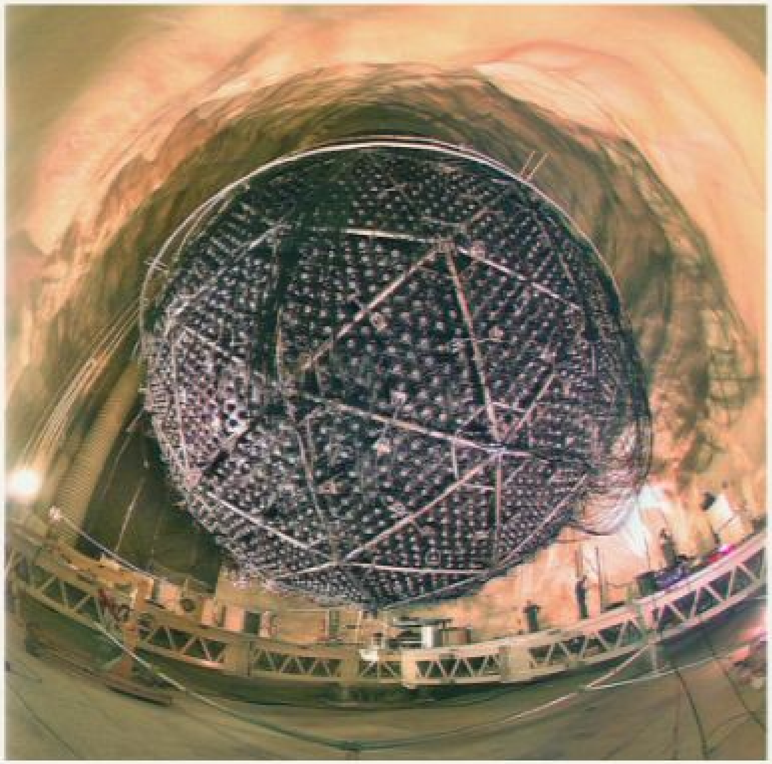
mass	
5%	galaxies
10%	gas
85%	dark matter

dark matter as seen using visible lights

dark matter also seems to be needed to exists inside galaxies

great, we can't see it… can we test it?

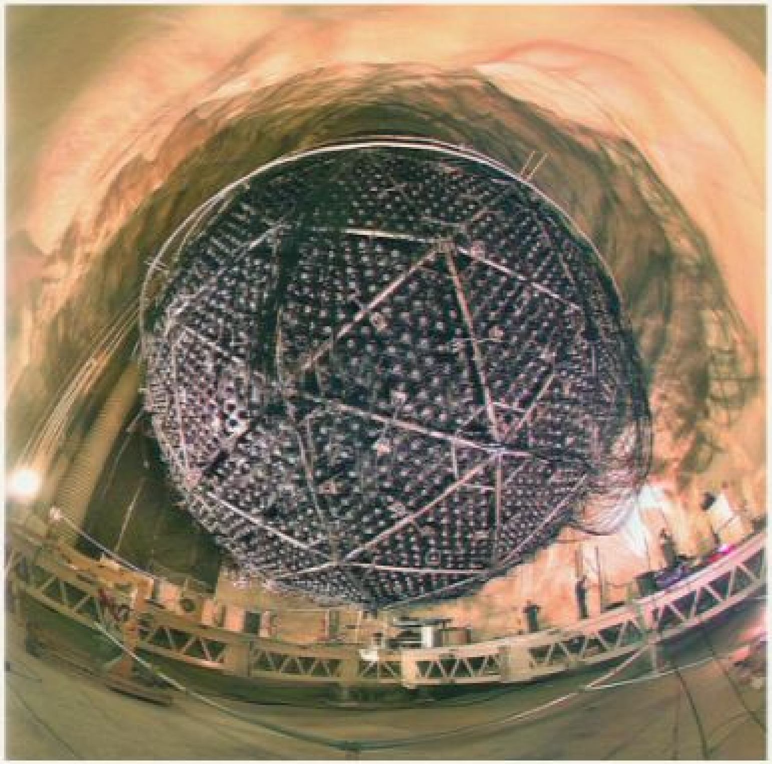
What is Dark Matter?



snolab

What is Dark Matter?

We don't know

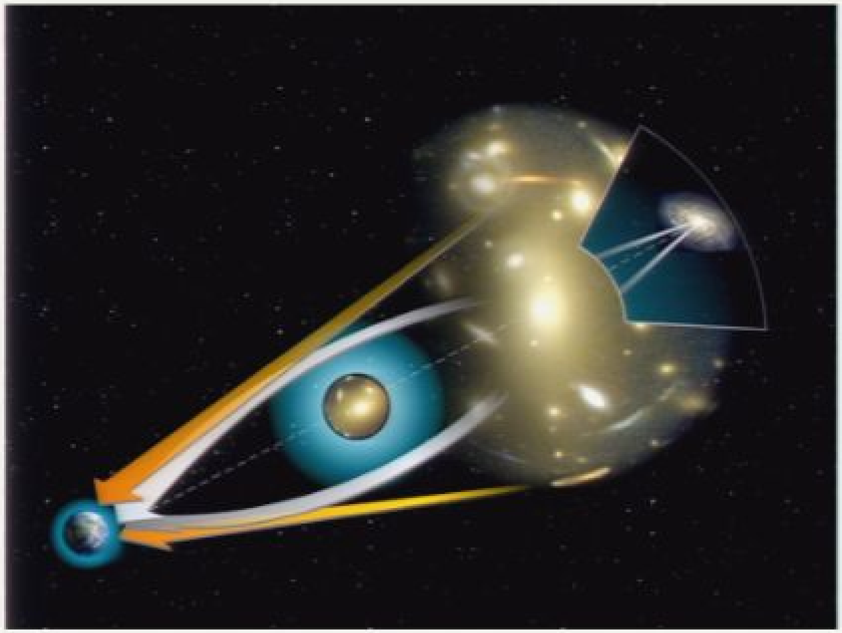


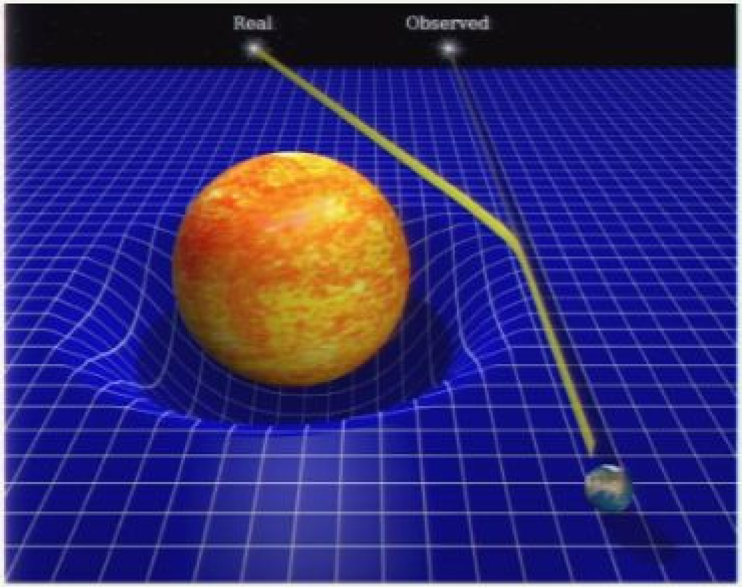
snolab

a serious contender is the hypothesis of a weakly interacting massive particle

Observe 3. Gravitational lensing

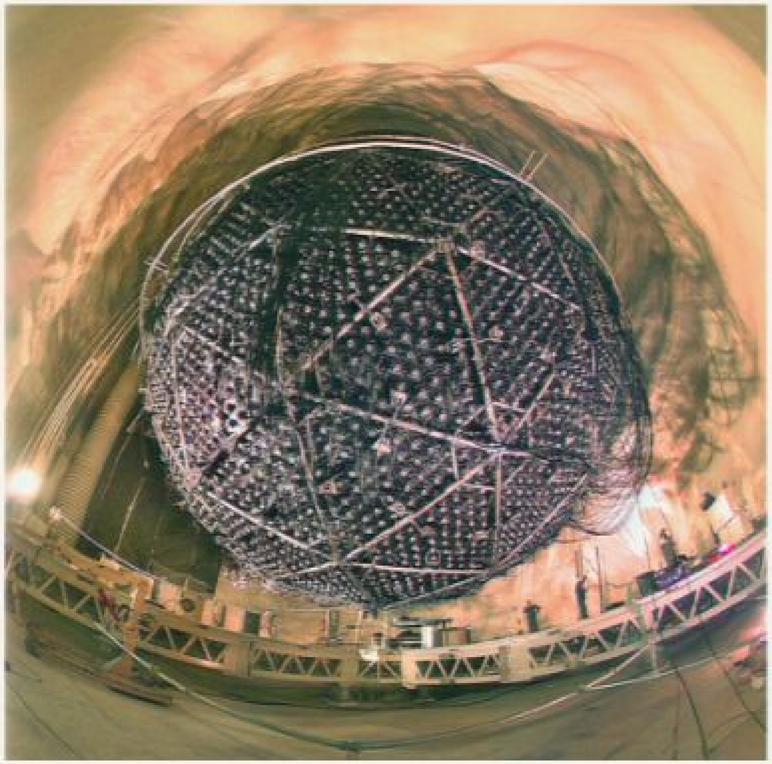
Strong Gravitational lensing





What is Dark Matter?

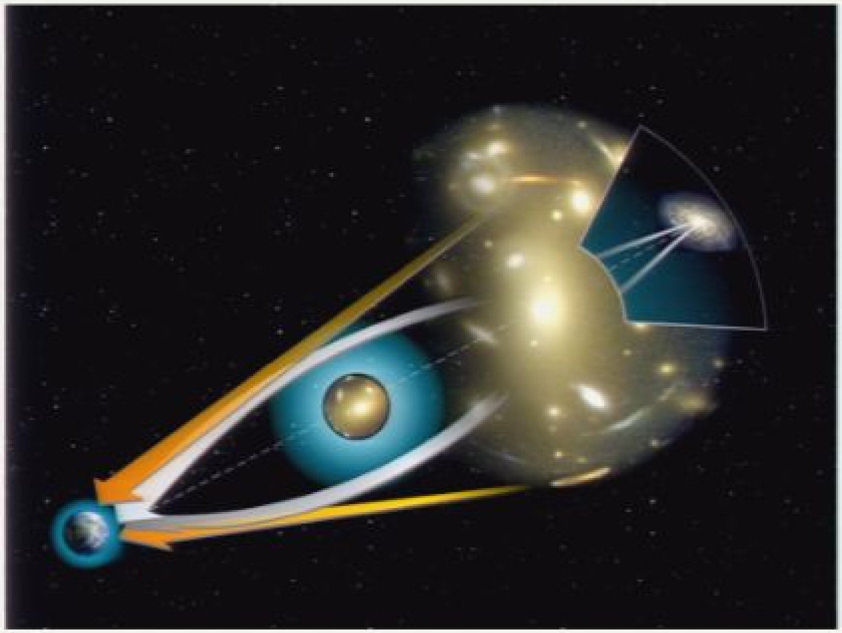
We don't know

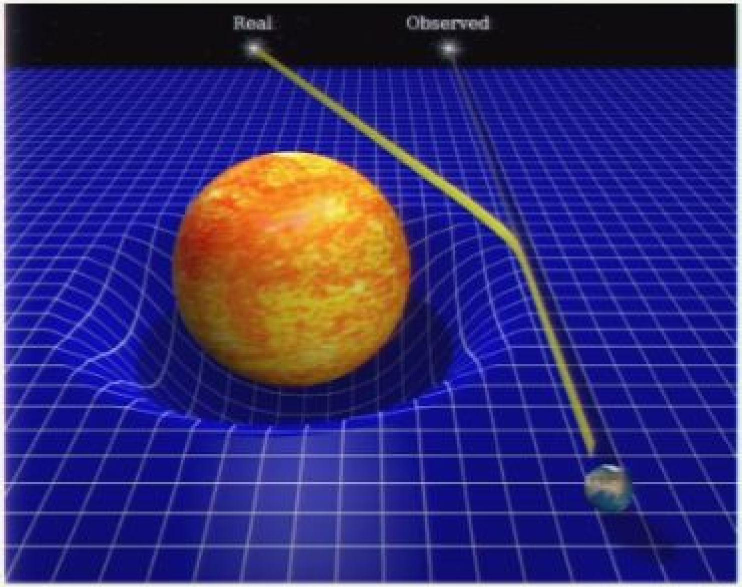


snolab

Observe 3. Gravitational lensing

Strong Gravitational lensing





J. Bézecourt et al.: Lensed galaxies in Abell 370 3

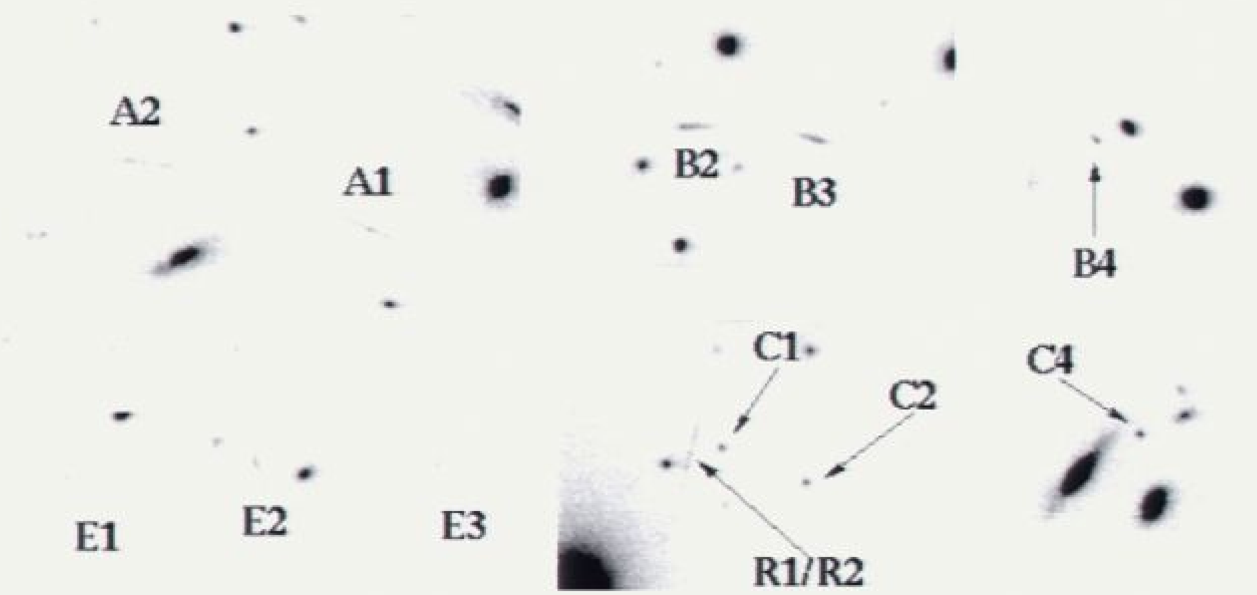
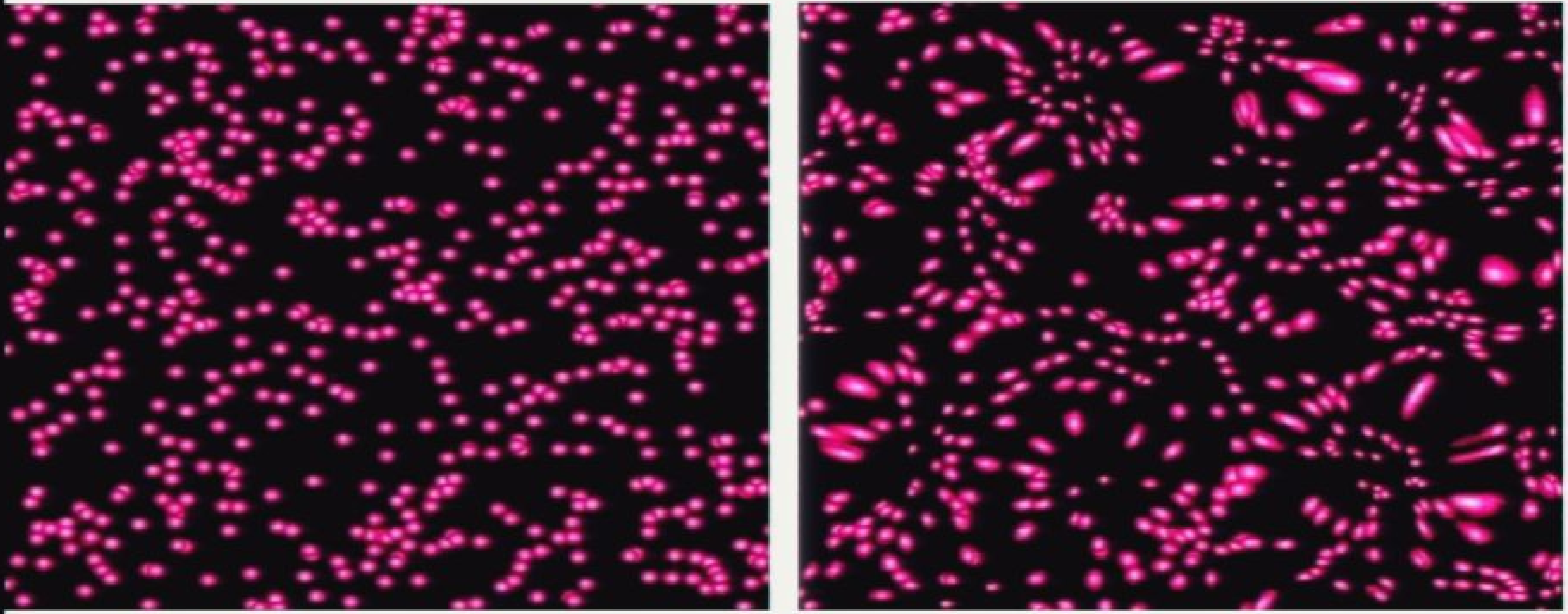


Fig. 1. Detailed view of the multiple image candidates detected in the WFPC2/F675W image. B2–B3–B4 is a triple image configuration, as well as C1–C2–C4. R1/R2 is a radial arc. E1–E2–E3 is also a triple configuration with a clear inversion of parity between E2 and E1/E3 (see text for more details).

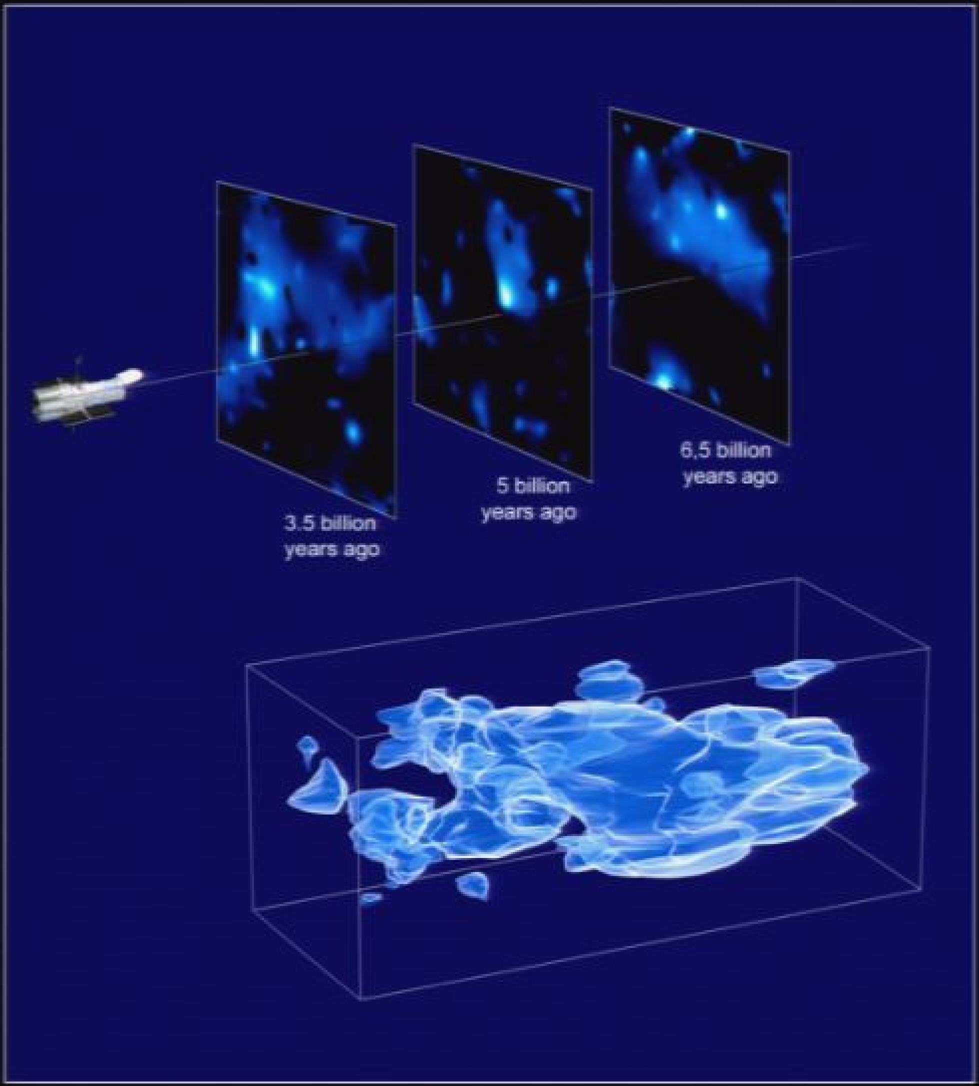
From strong gravitational lensing we can figure out the total mass in Abell 370

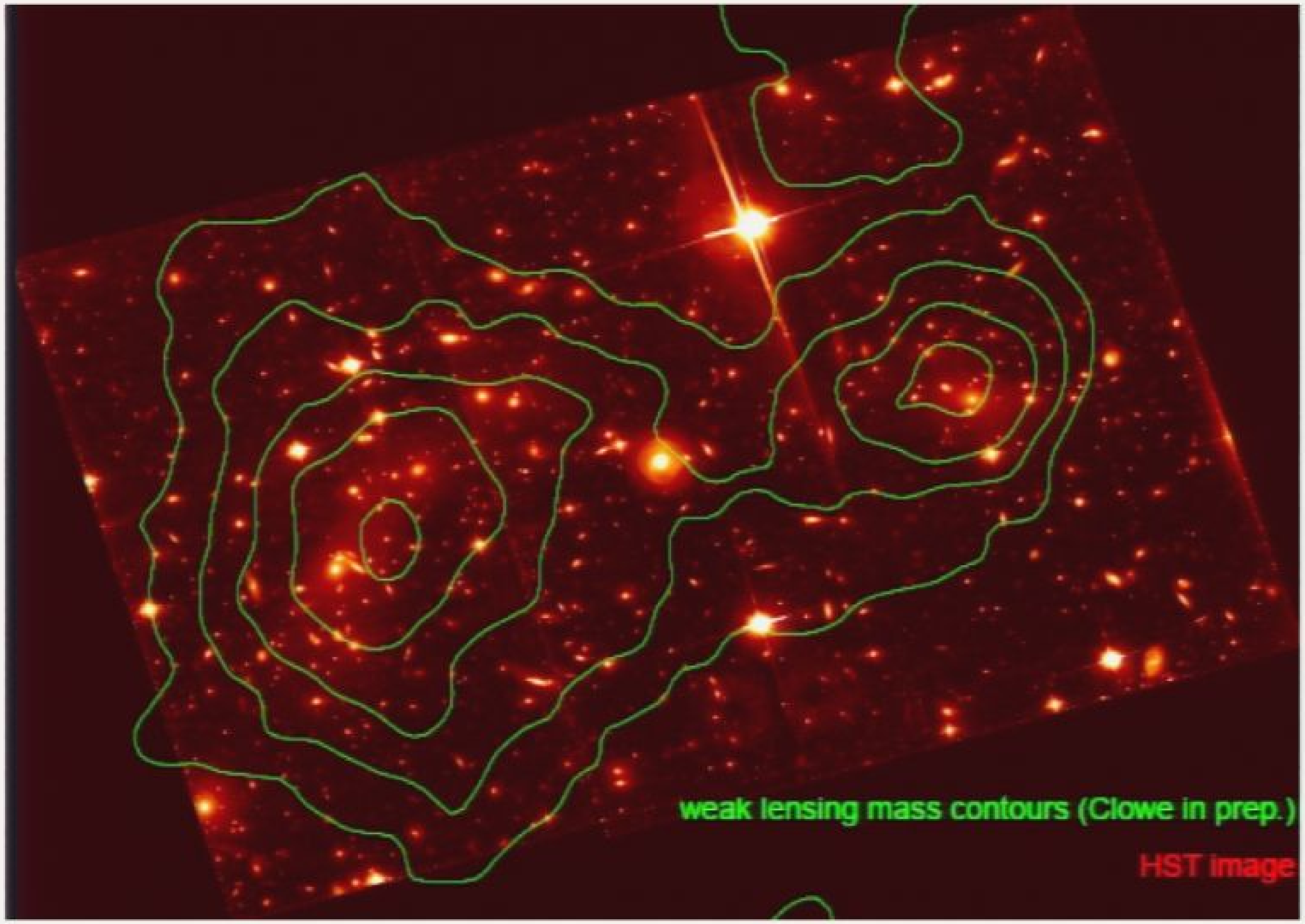
But we can do better

Weak Gravitational Lensing



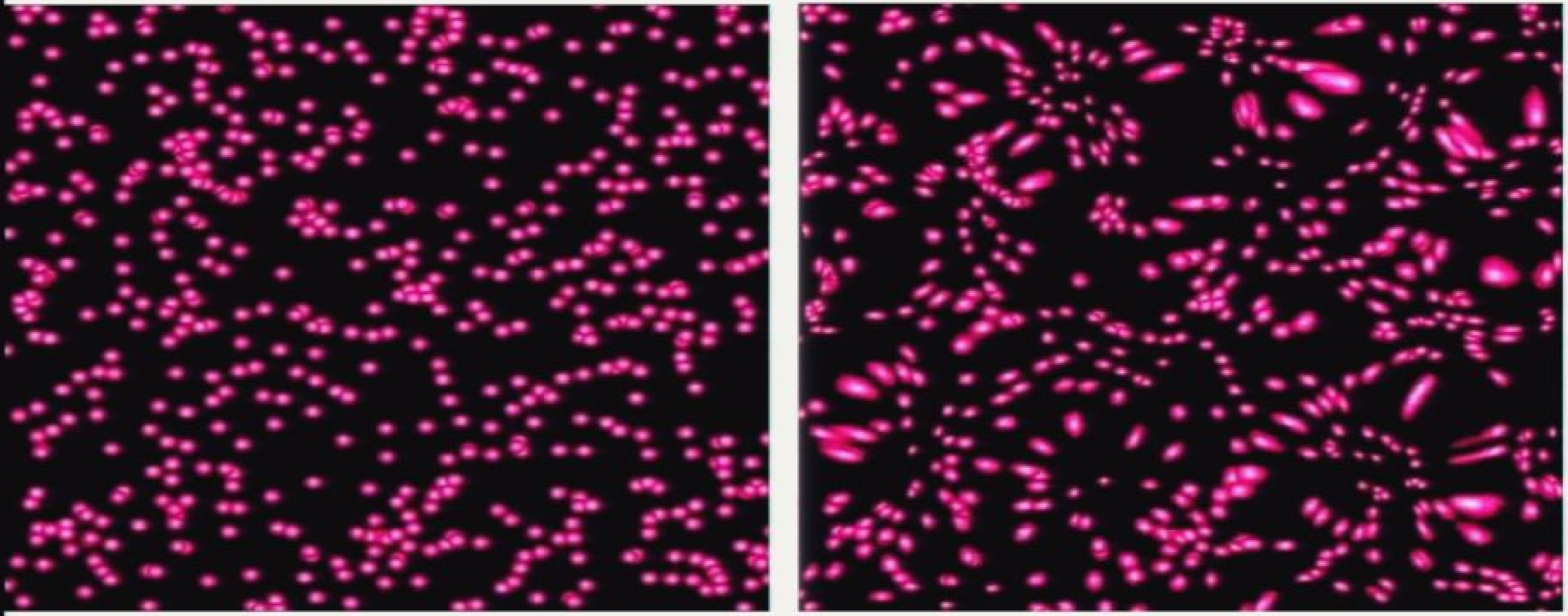
Gravitational lensing acts as a coordinate transformation that distorts the images of background objects (usually galaxies) near a foreground mass. The transformation can be split into two terms, the convergence and shear.


3.5 billion years ago
5 billion years ago
6,5 billion years ago

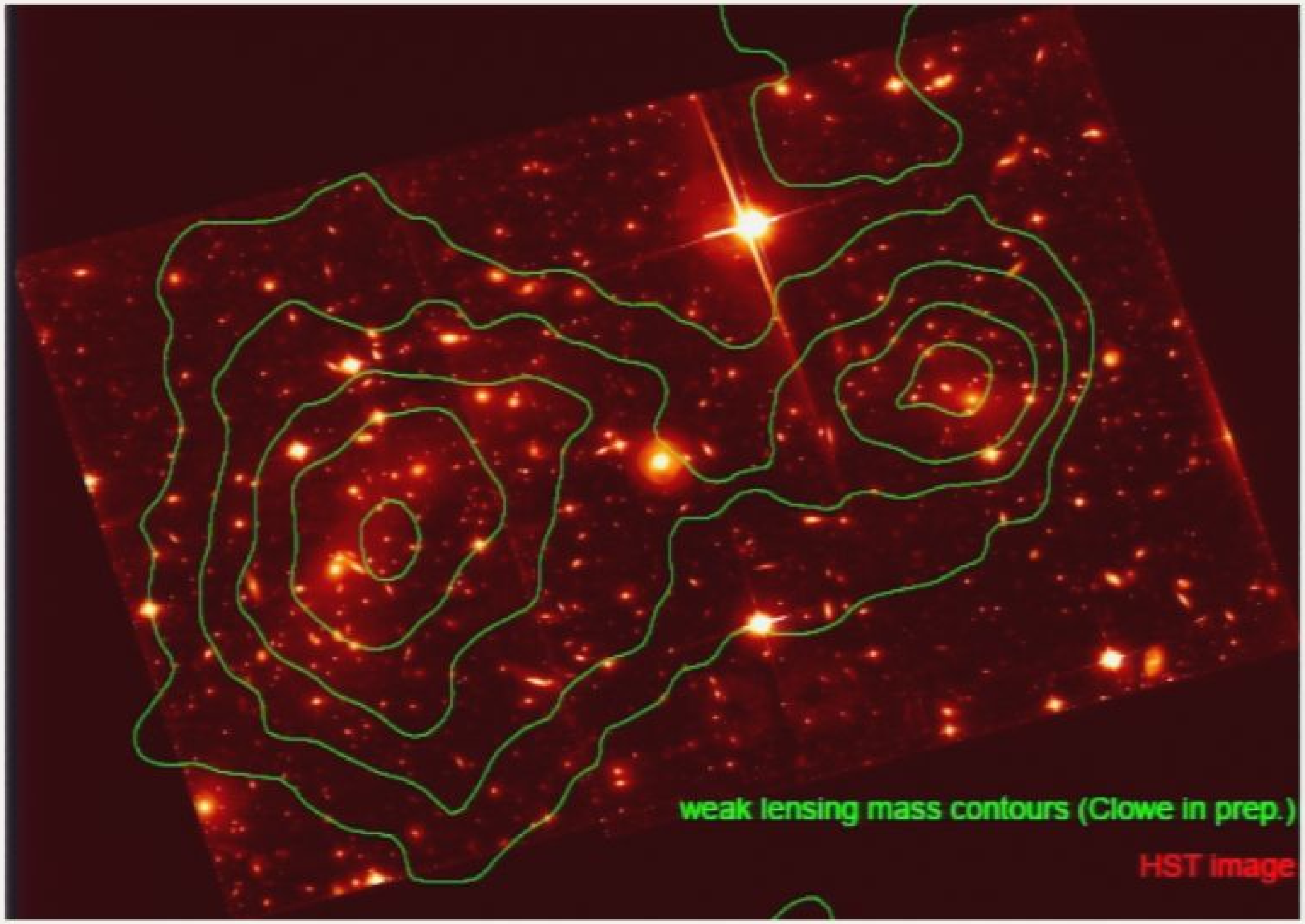

weak lensing mass contours (Clowe in prep.)
HST image

Coe et al

Weak Gravitational Lensing



Gravitational lensing acts as a coordinate transformation that distorts the images of background objects (usually galaxies) near a foreground mass. The transformation can be split into two terms, the convergence and shear.


weak lensing mass contours (Clowe in prep.)
HST image

The Bullet Cluster


Optical X-ray Gas


Optical
Dark Matter


Optical Dark Matter X-ray Gas

Cosmology: neglecting us

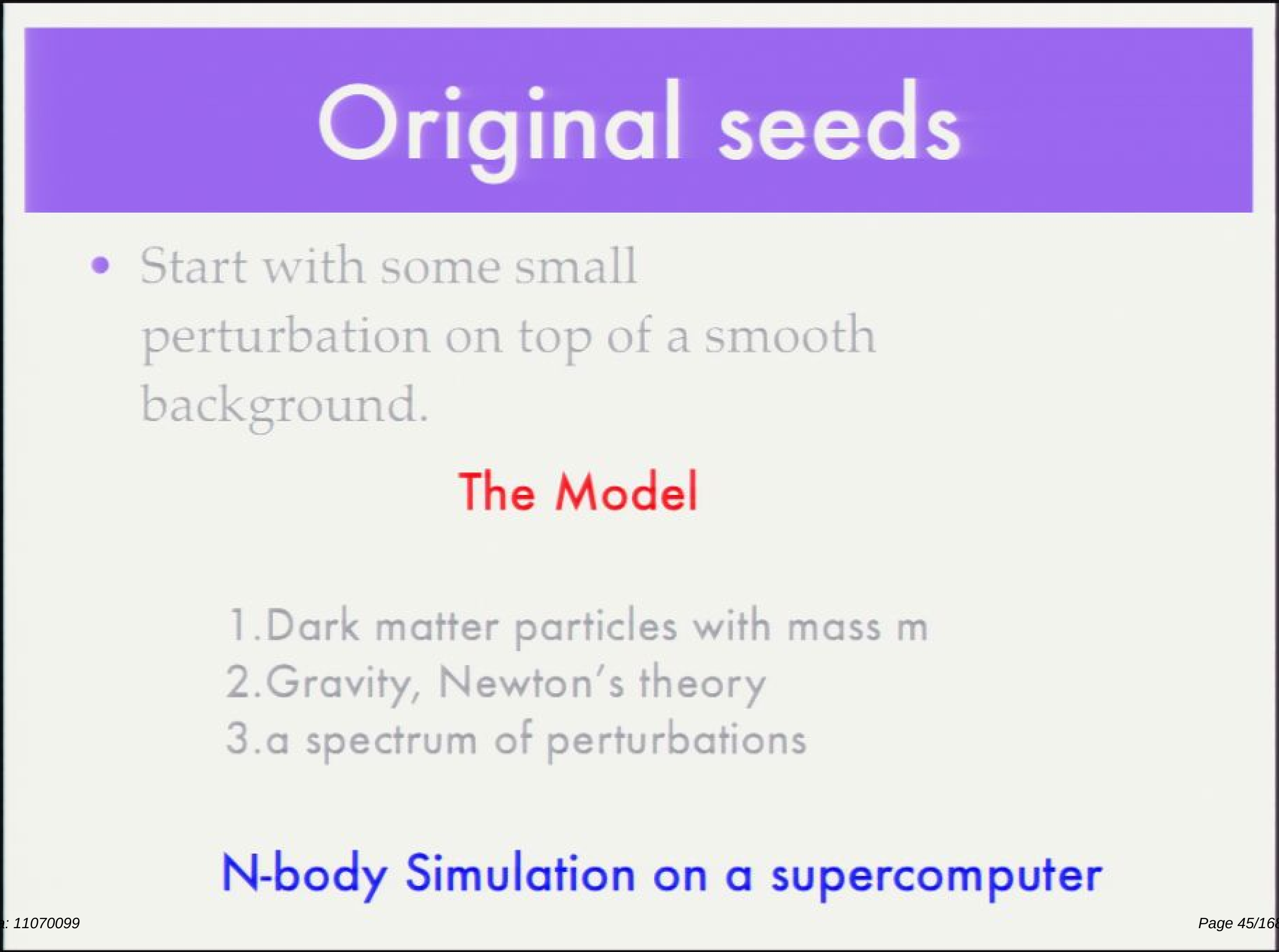
- Forget about baryons (only about 15 %). There is only dark matter.

ΛCDM

Cold Dark matter

Particle with no interaction with a mass

How do we get structure in the Universe?



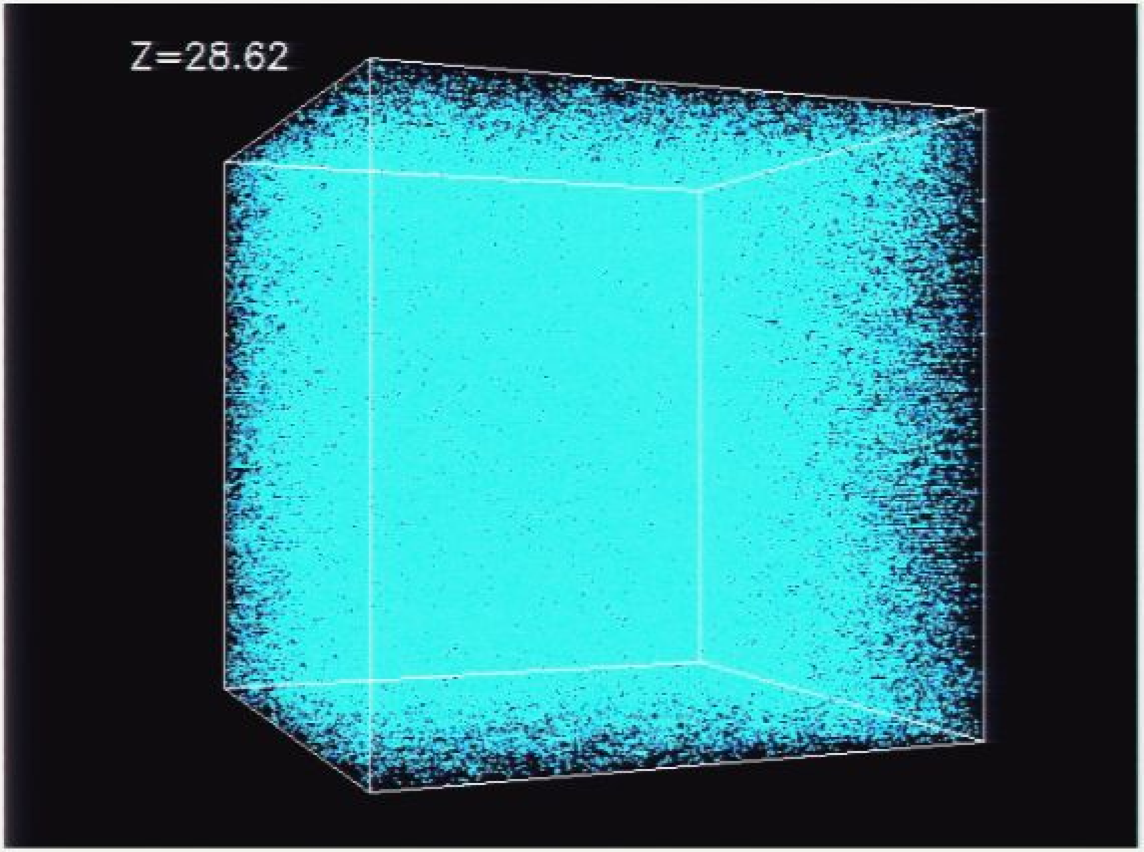
Original seeds

- Start with some small perturbation on top of a smooth background.

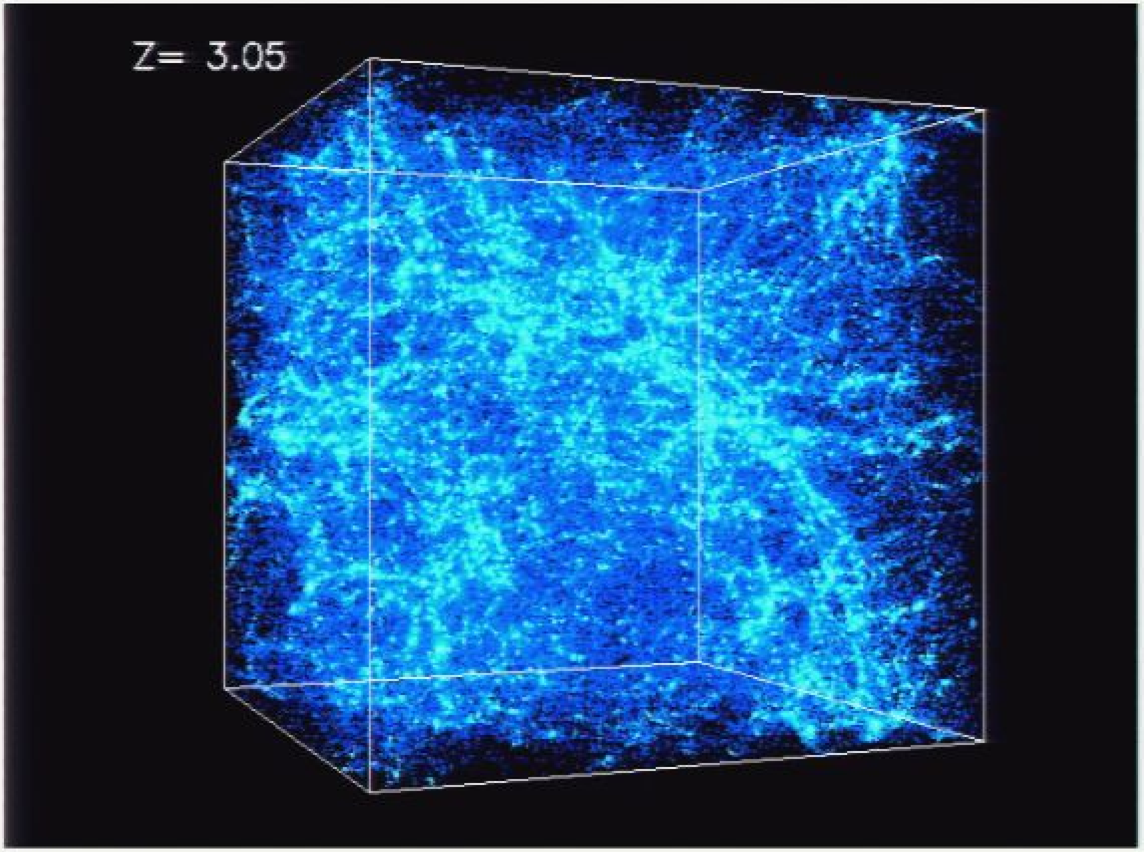
The Model

1. Dark matter particles with mass m
2. Gravity, Newton's theory
3. a spectrum of perturbations

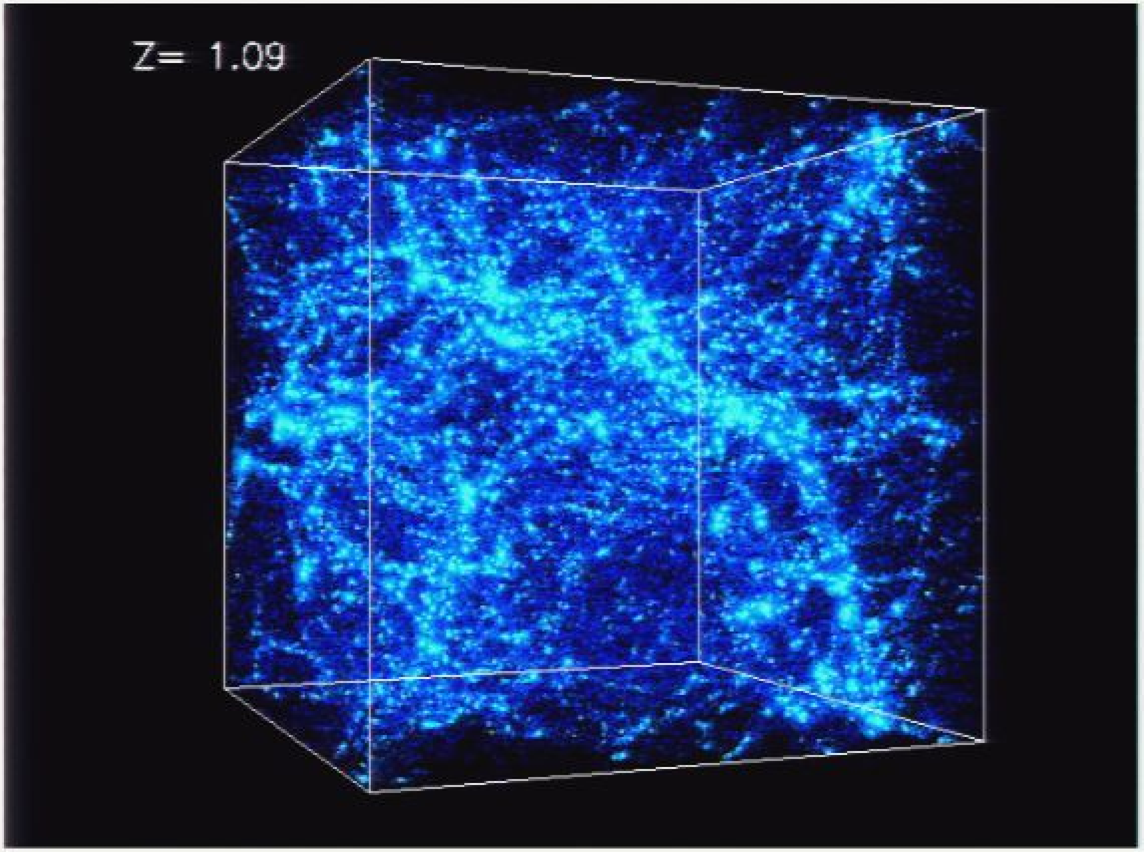
N-body Simulation on a supercomputer



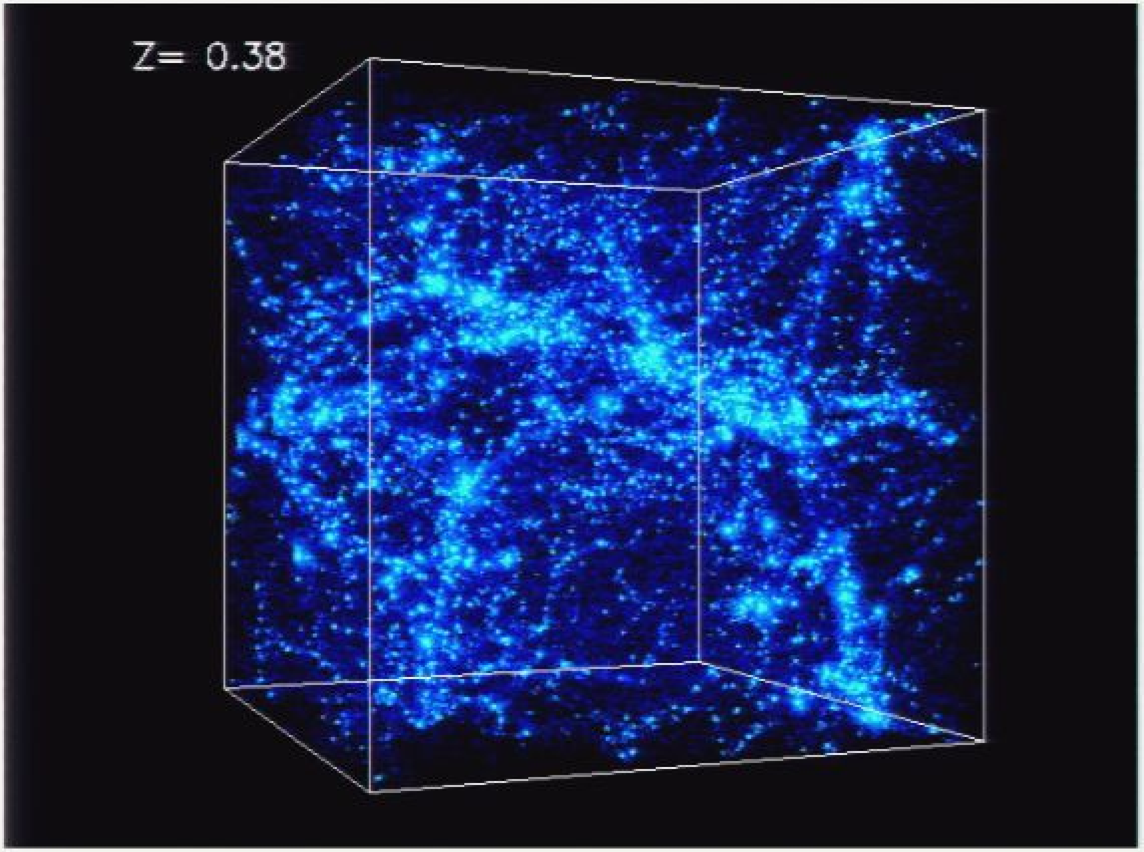
U. Chicago



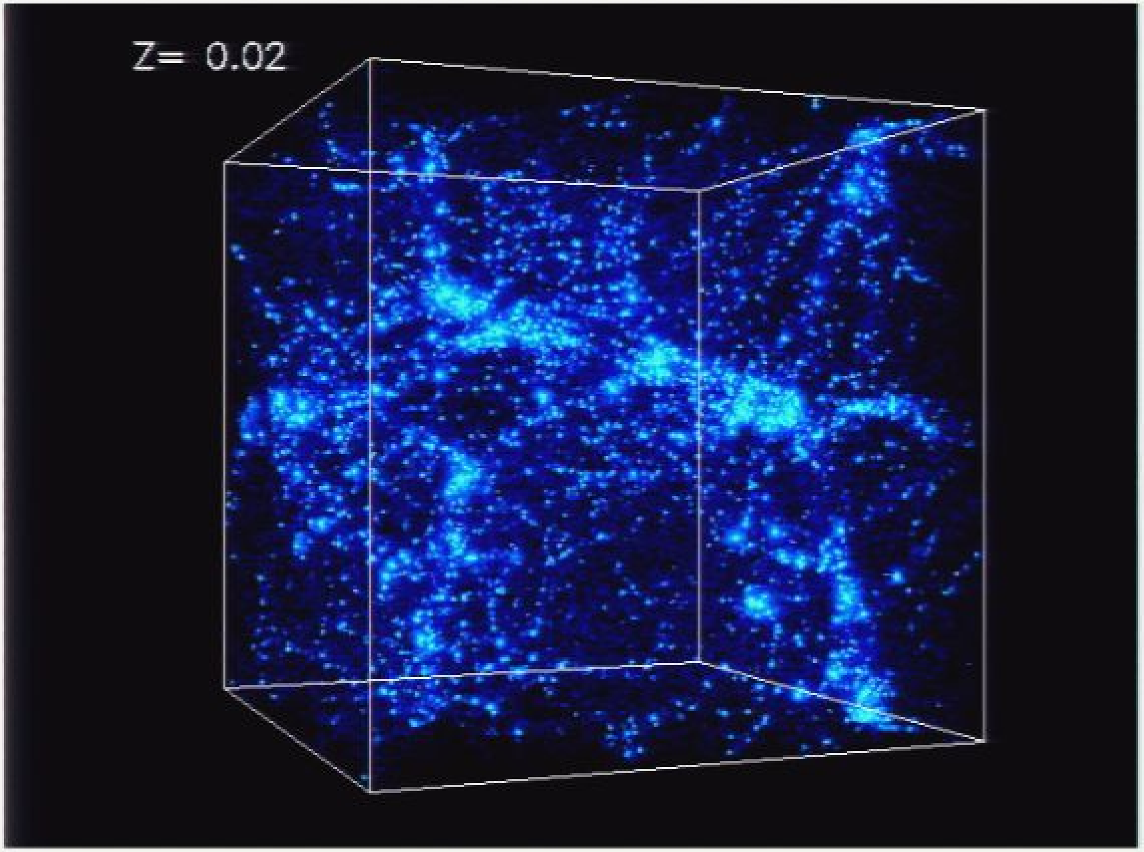
U. Chicago



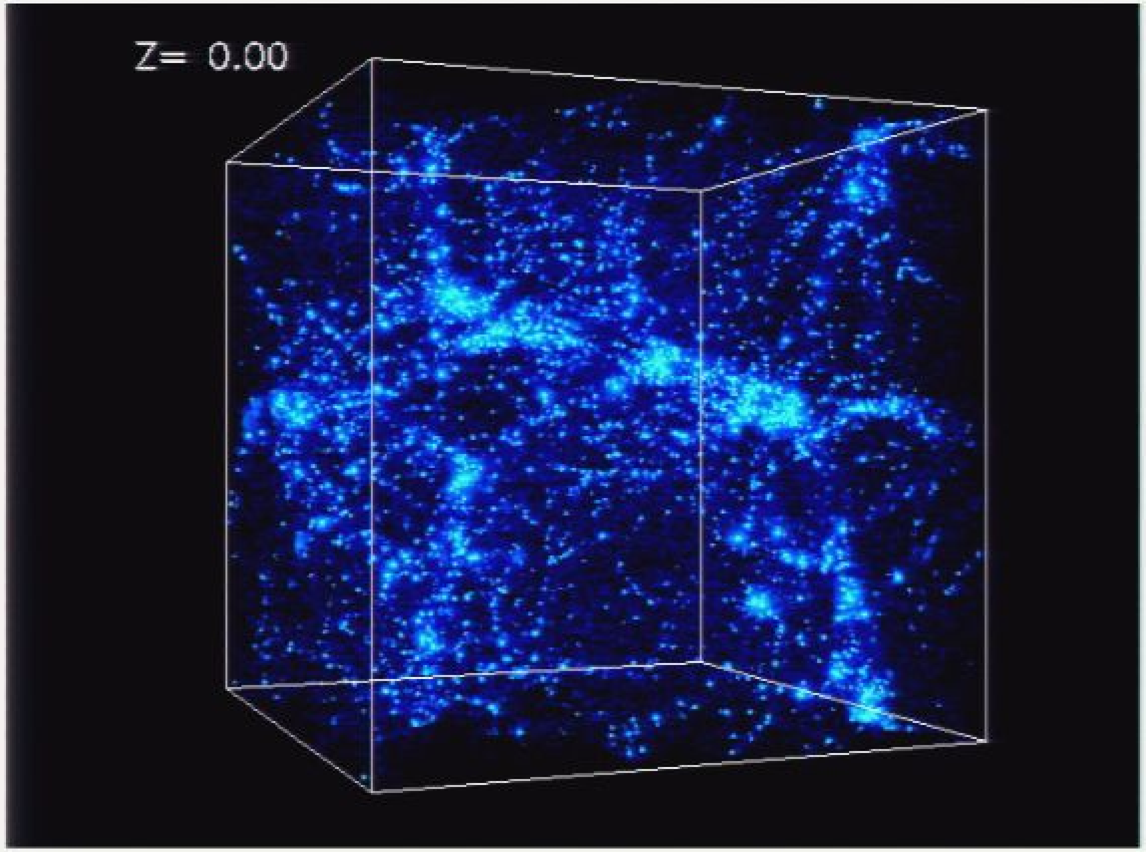
U. Chicago



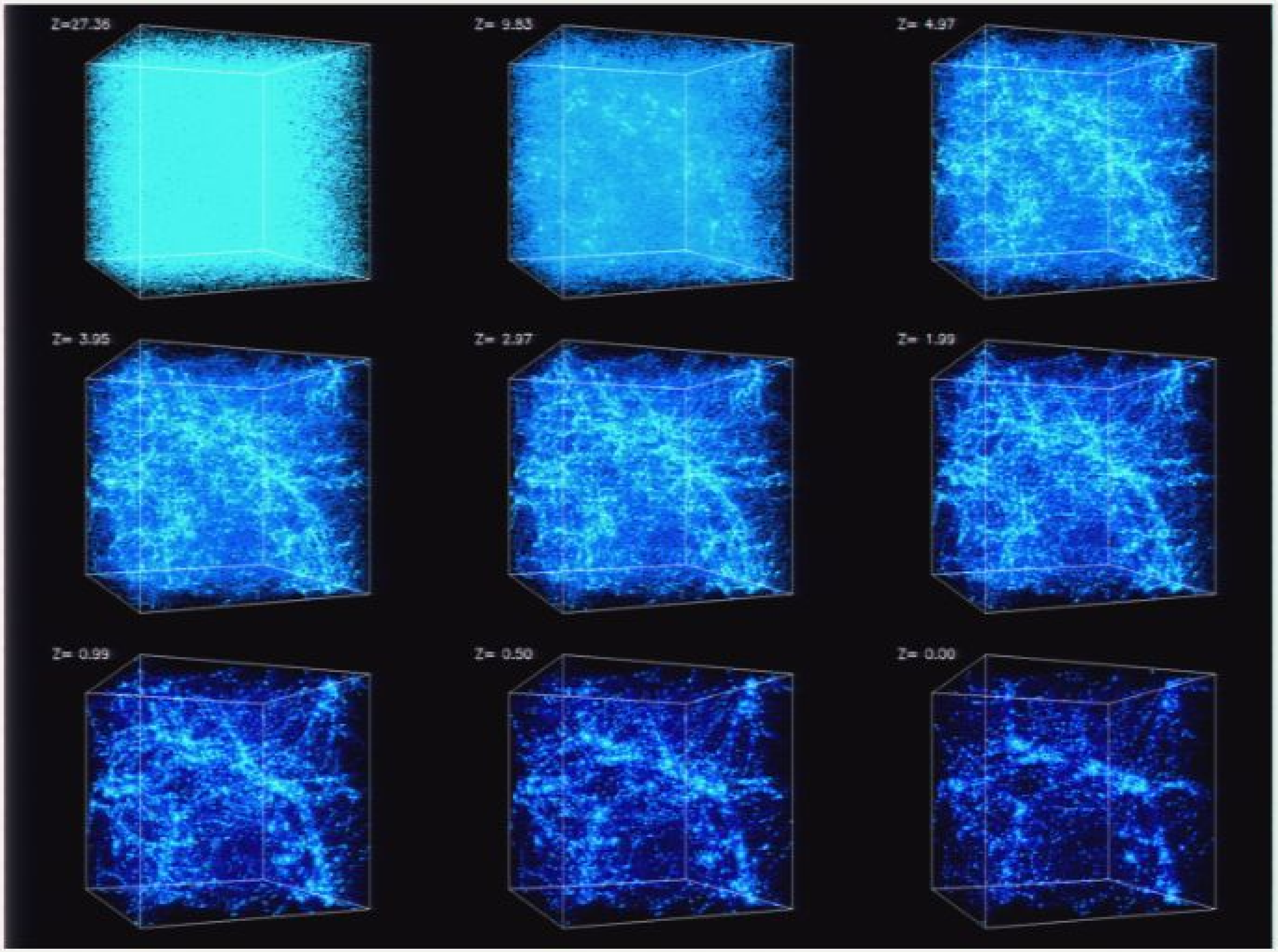
U. Chicago

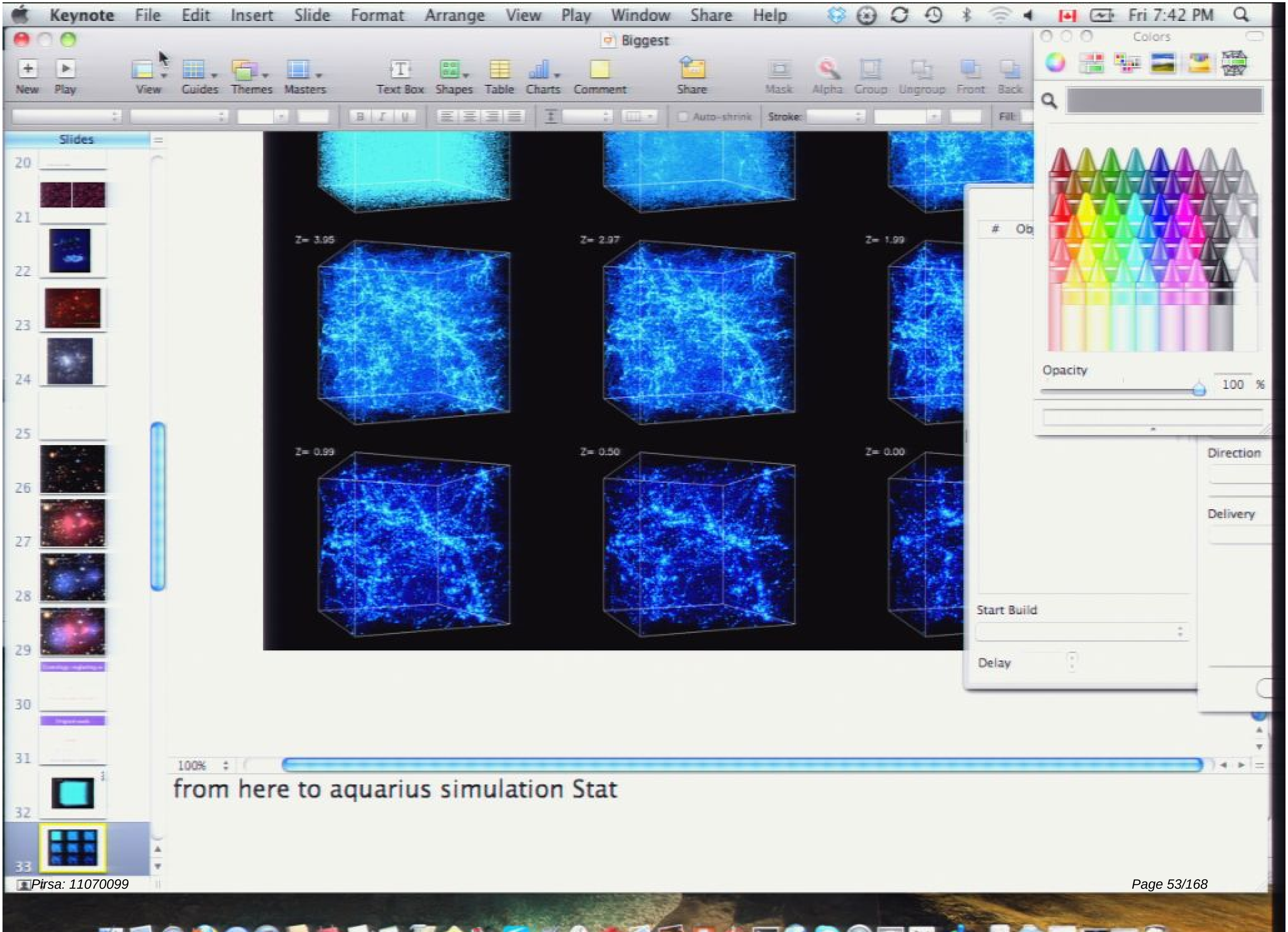


U. Chicago

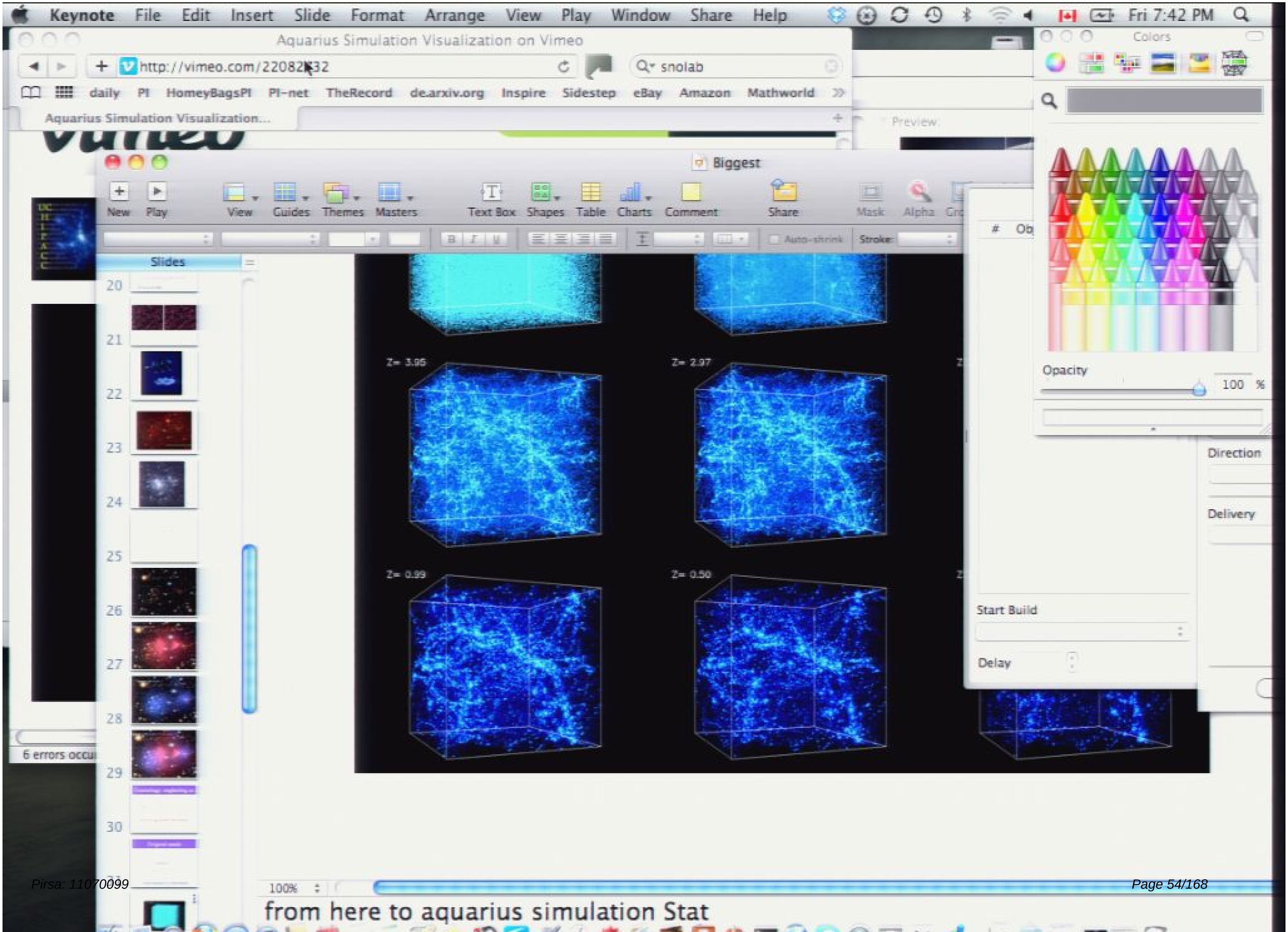


U. Chicago

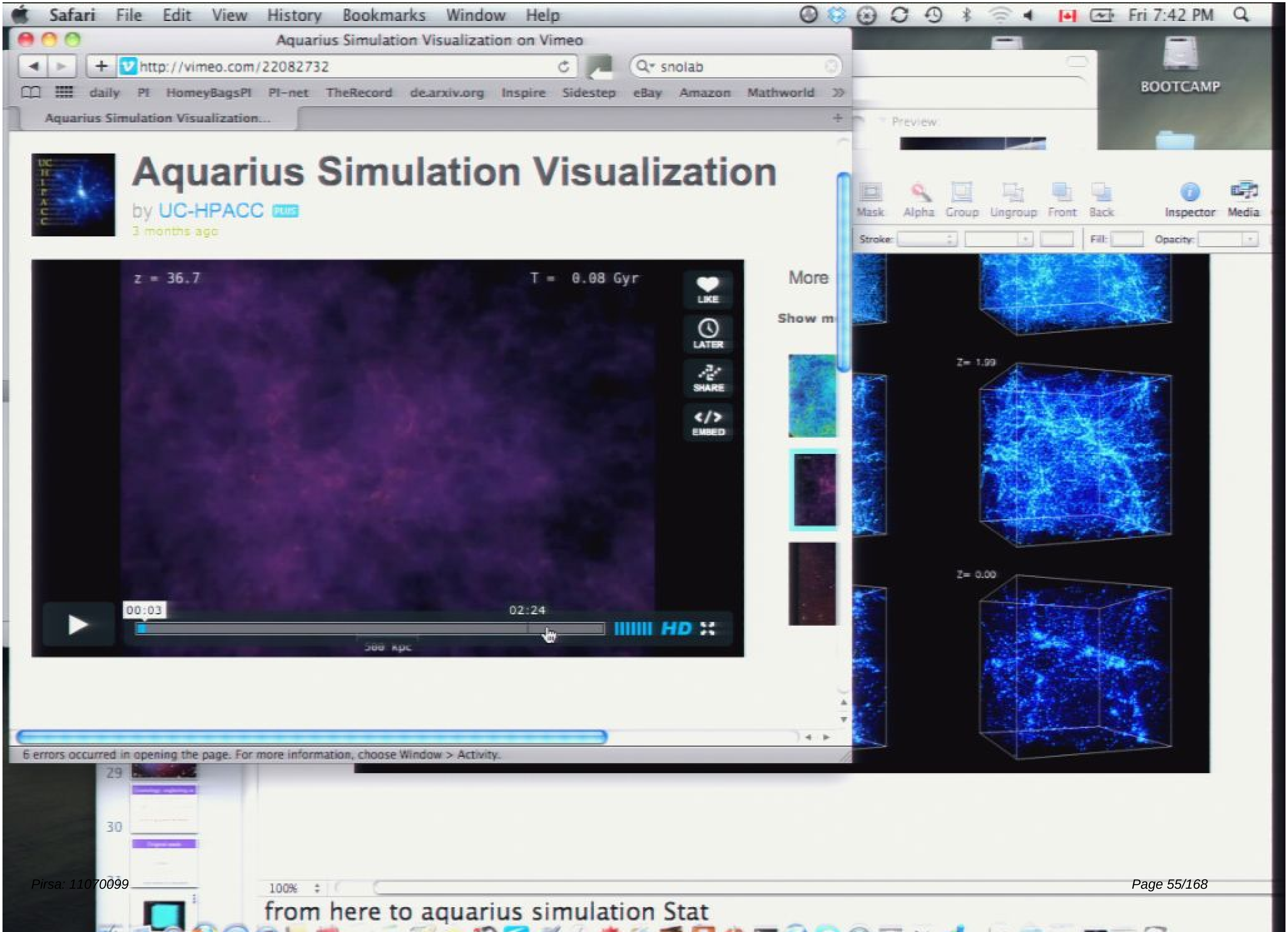

Z=27.36
Z= 9.83
Z= 4.97
Z= 3.95
Z= 2.97
Z= 1.99
Z= 0.99
Z= 0.50
Z= 0.00



from here to aquarius simulation Stat

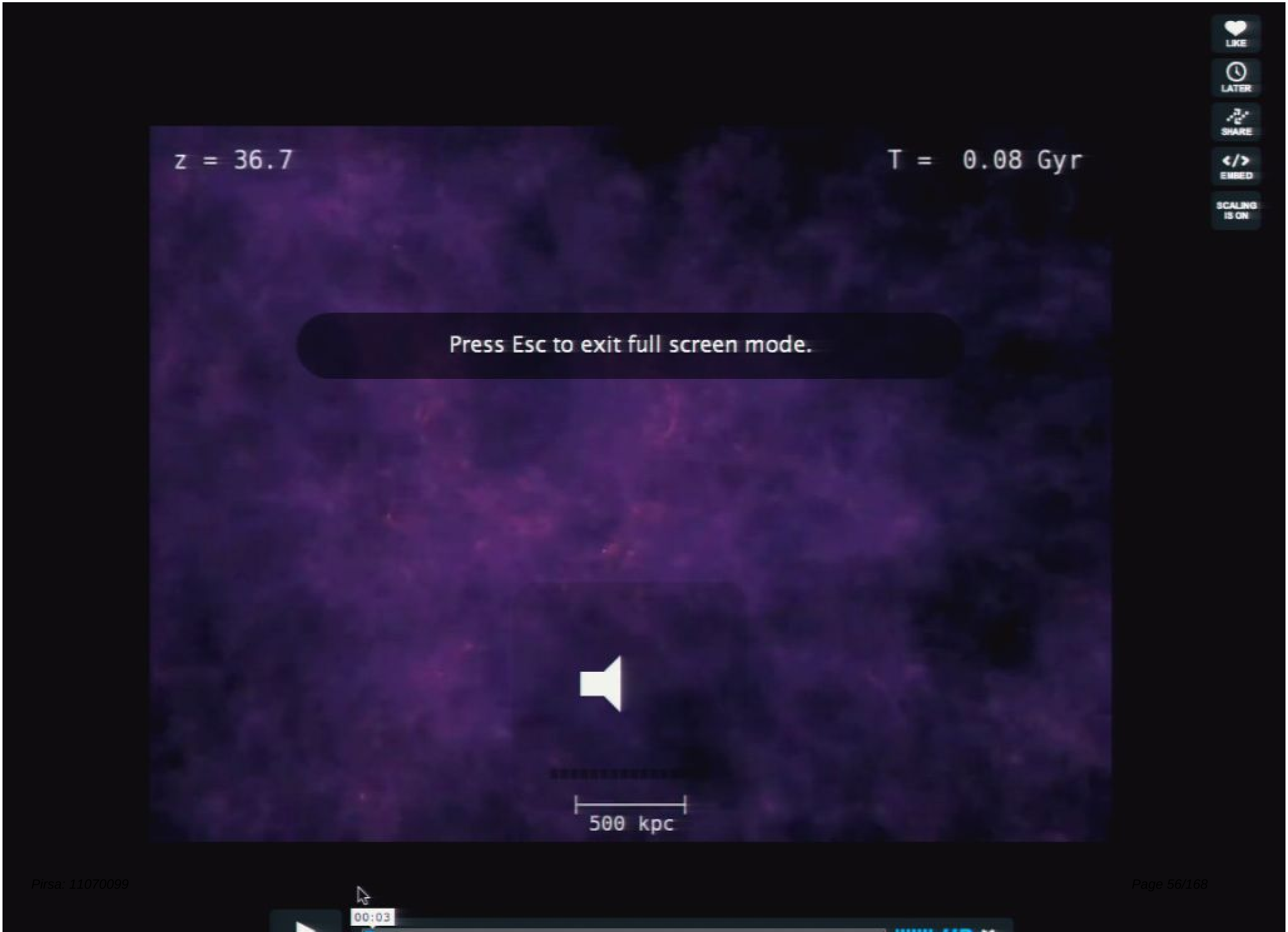


from here to aquarius simulation Stat

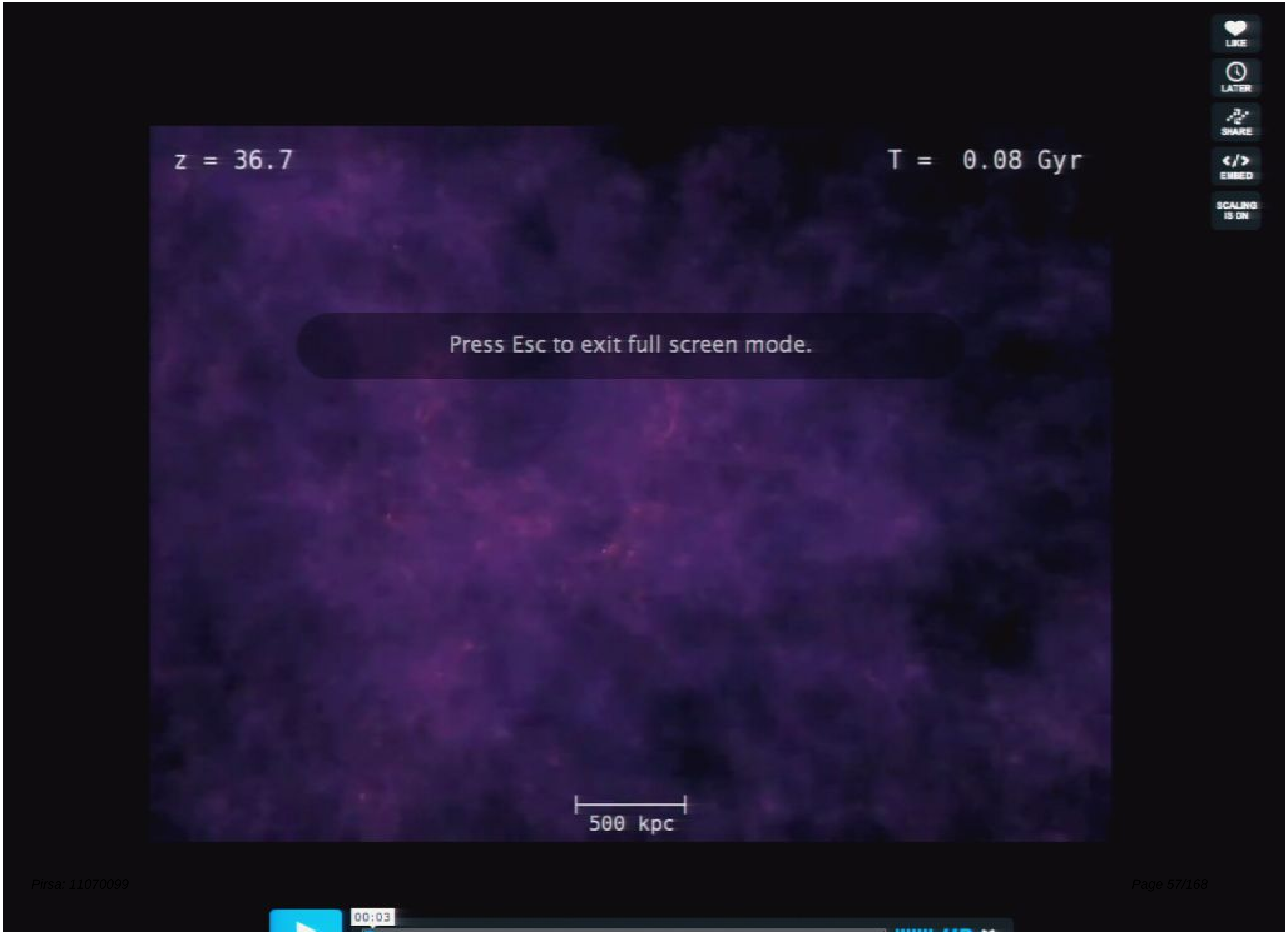


6 errors occurred in opening the page. For more information, choose Window > Activity.

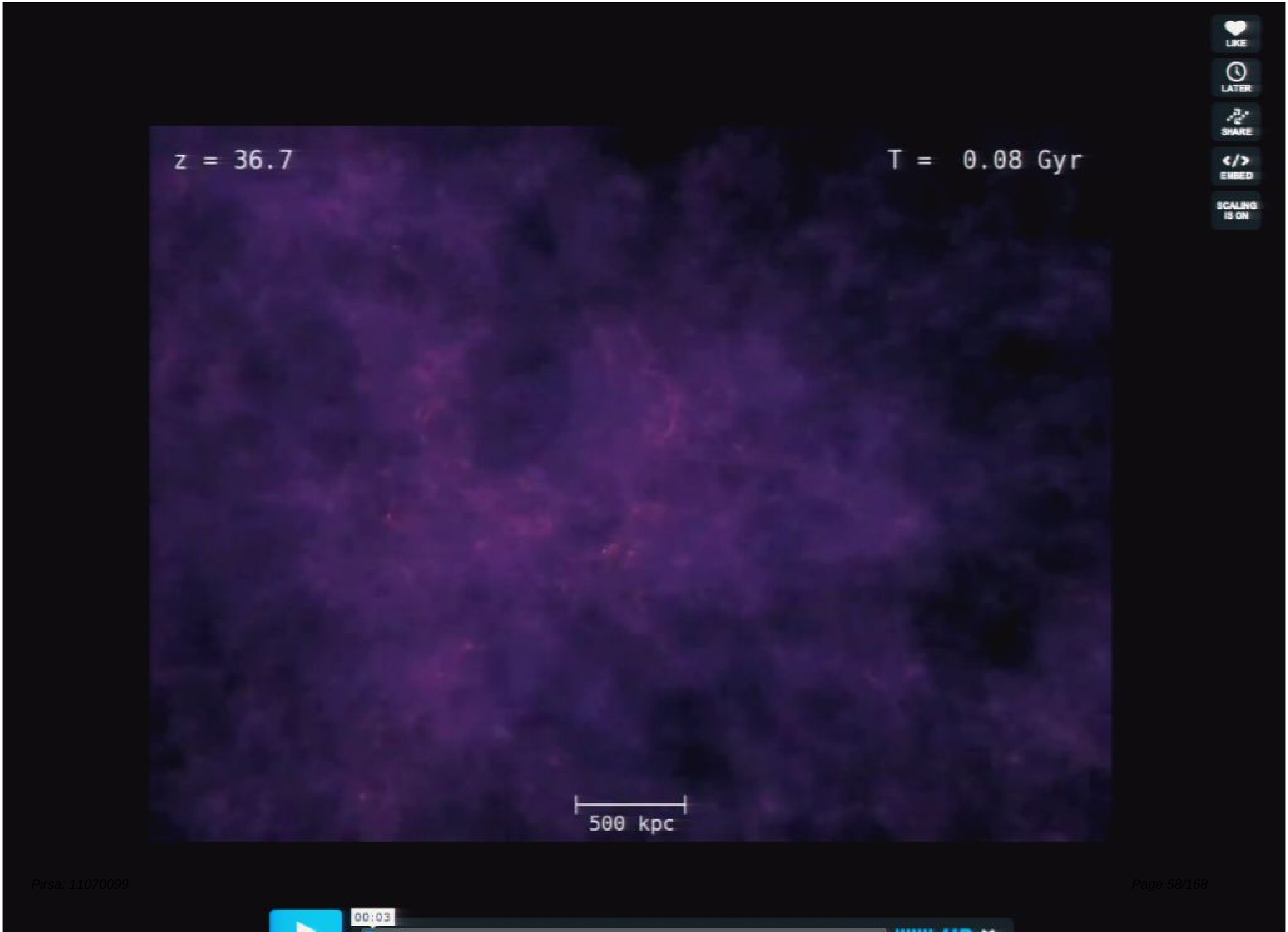
from here to aquarius simulation Stat

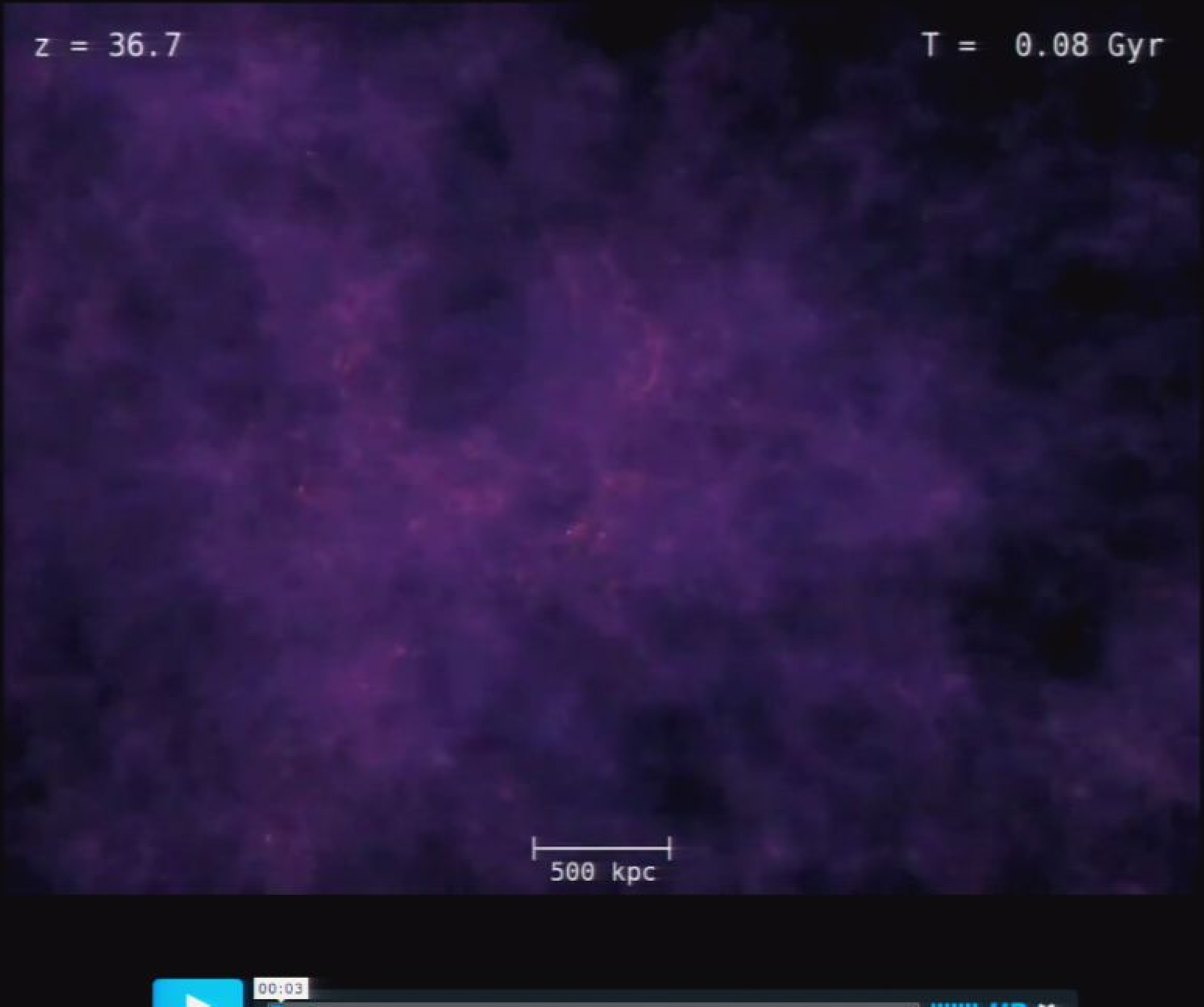


Press Esc to exit full screen mode.



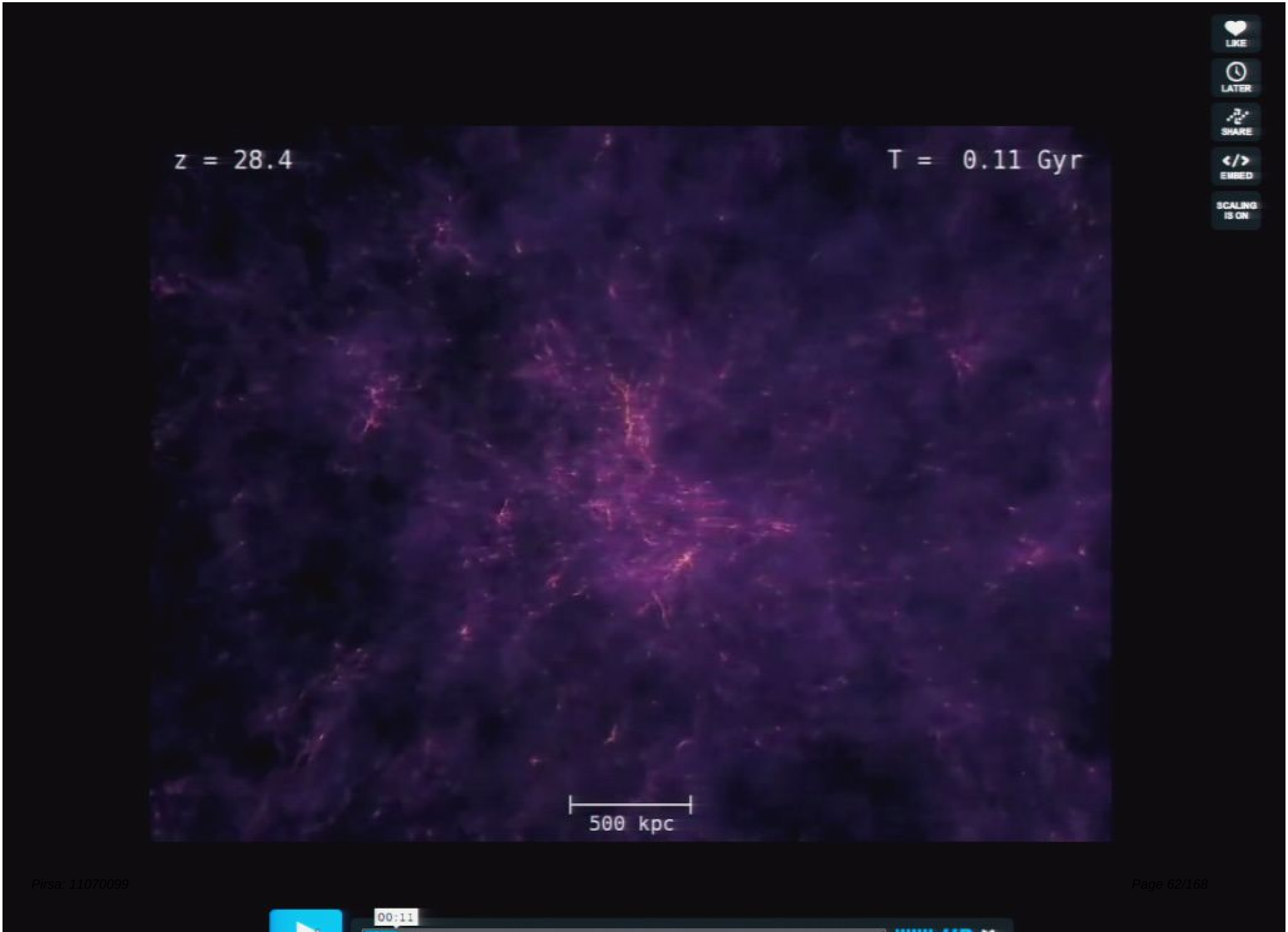
Press Esc to exit full screen mode.


z = 36.7
T = 0.08 Gyr
500 kpc
LIKE
LATER
SHARE
EMBED
SCALING IS ON
00:03


z = 36.7
T = 0.08 Gyr
500 kpc
00:03


z = 33.1
T = 0.09 Gyr
500 kpc


z = 30.0
T = 0.10 Gyr
500 kpc


z = 28.4
T = 0.11 Gyr
500 kpc
LIKE
LATER
SHARE
EMBED
SCALING IS ON
00:11
HD

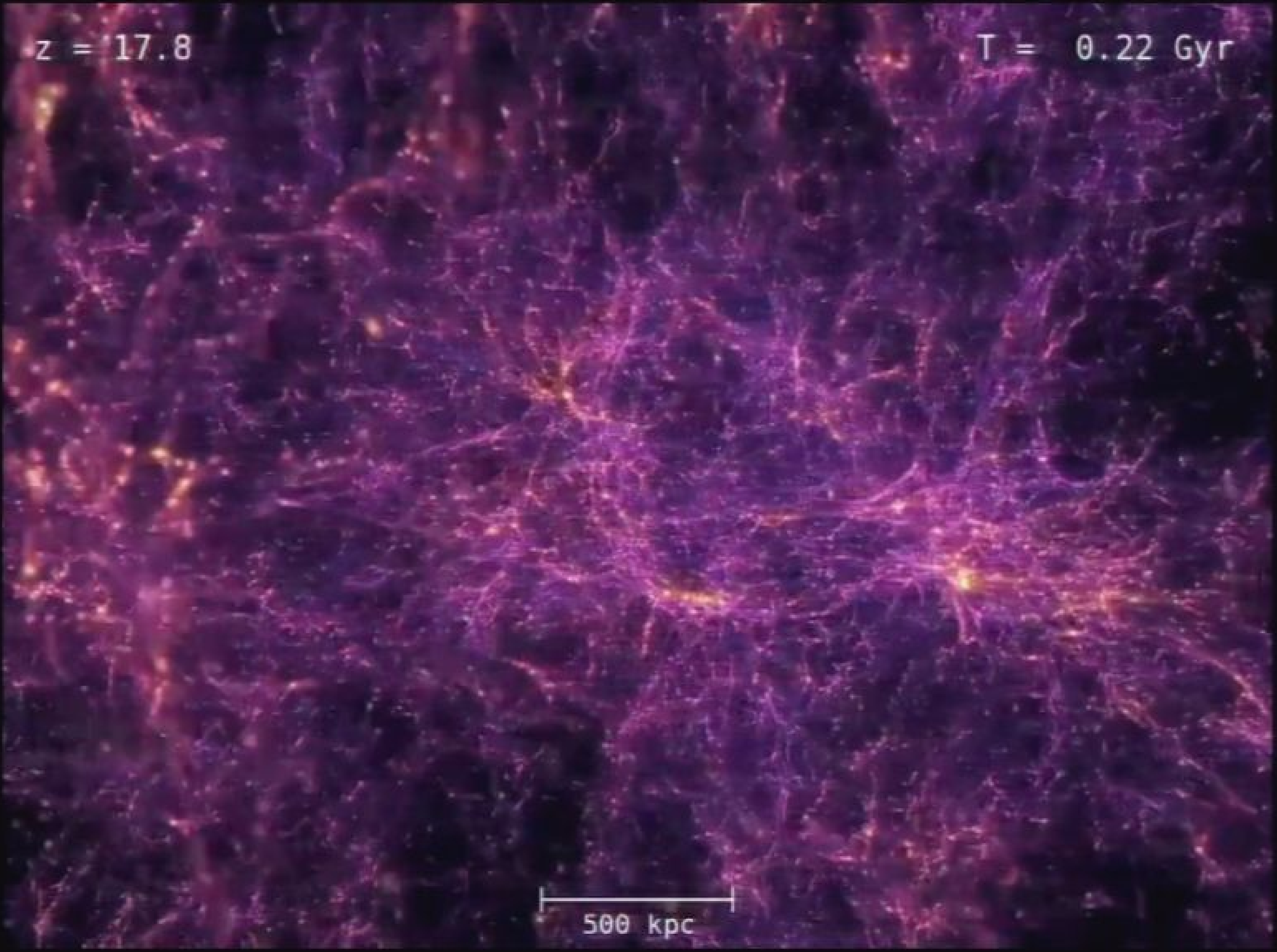
00:11

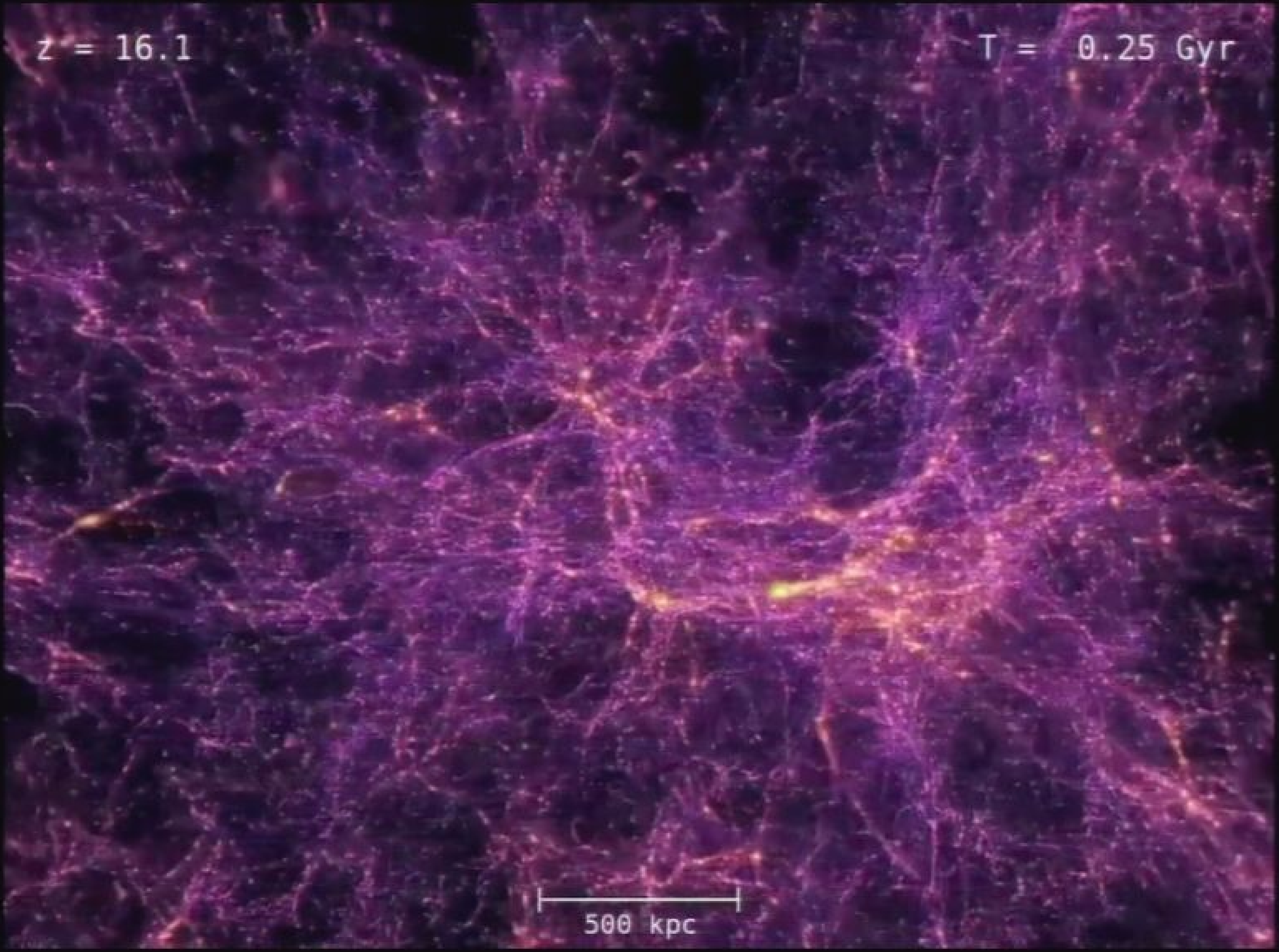

z = 26.0
T = 0.13 Gyr
500 kpc

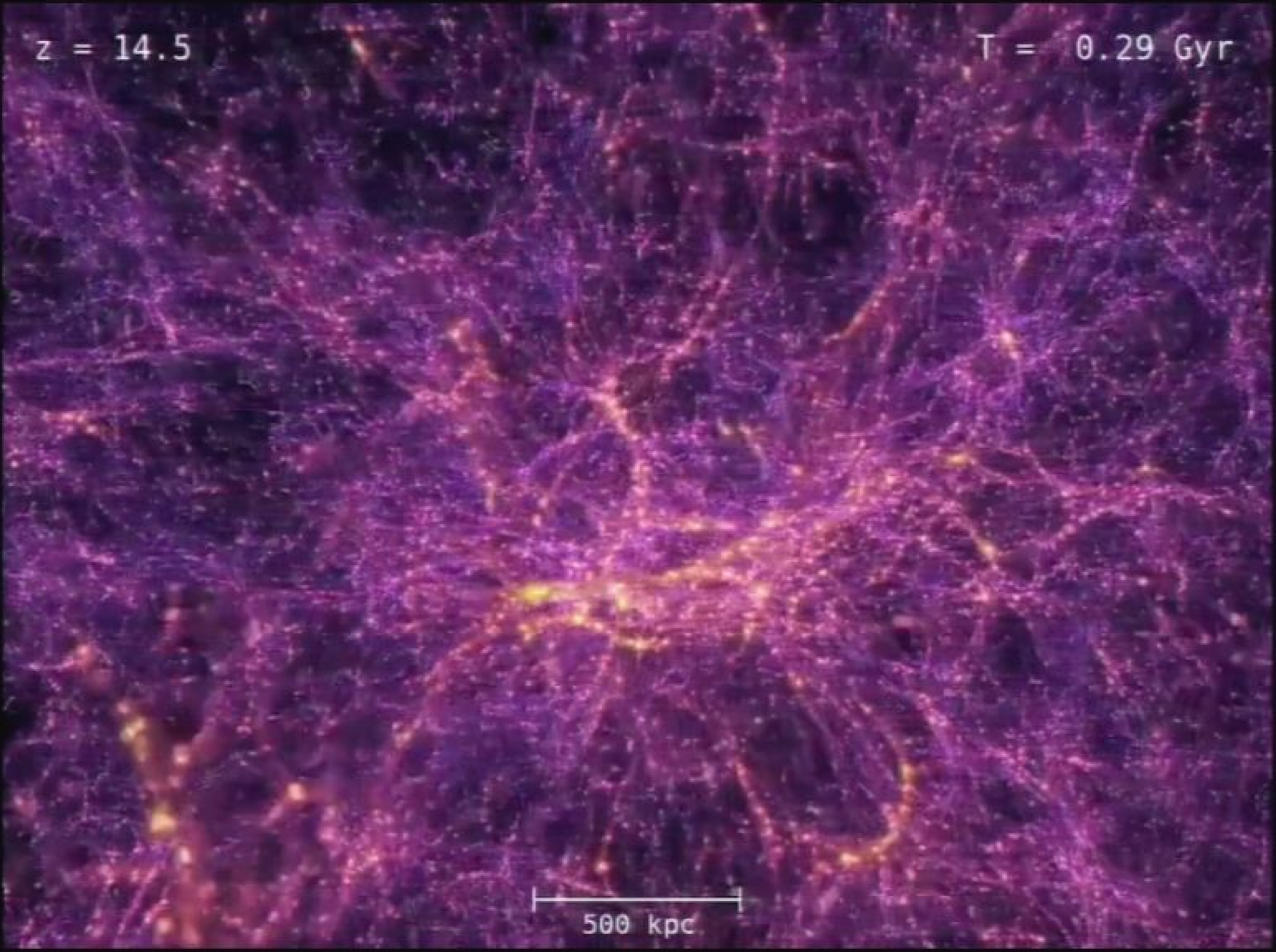

z = 23.7
T = 0.15 Gyr
500 kpc

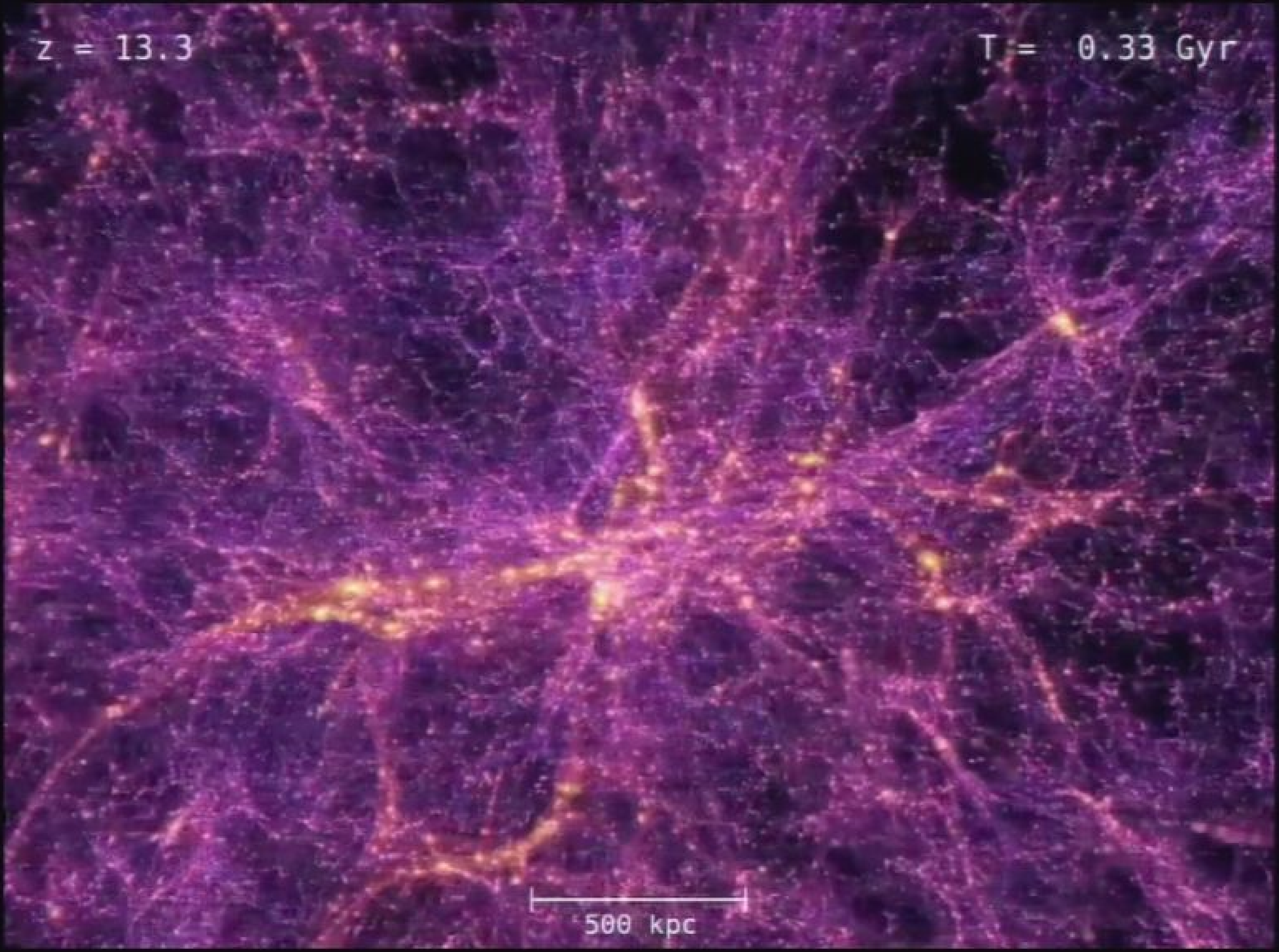

z = 21.5
T = 0.17 Gyr
500 kpc

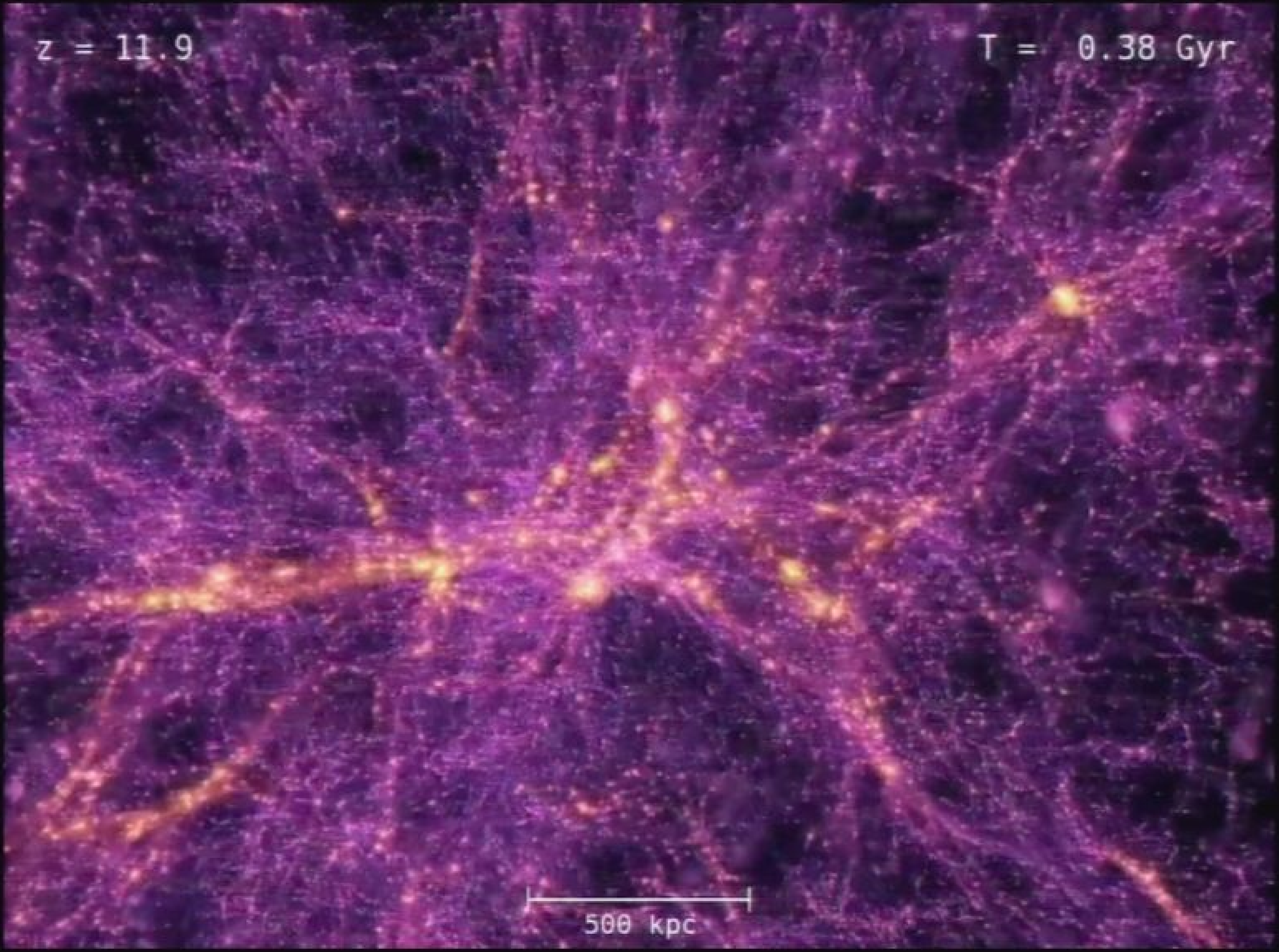

z = 19.4
T = 0.19 Gyr
500 kpc

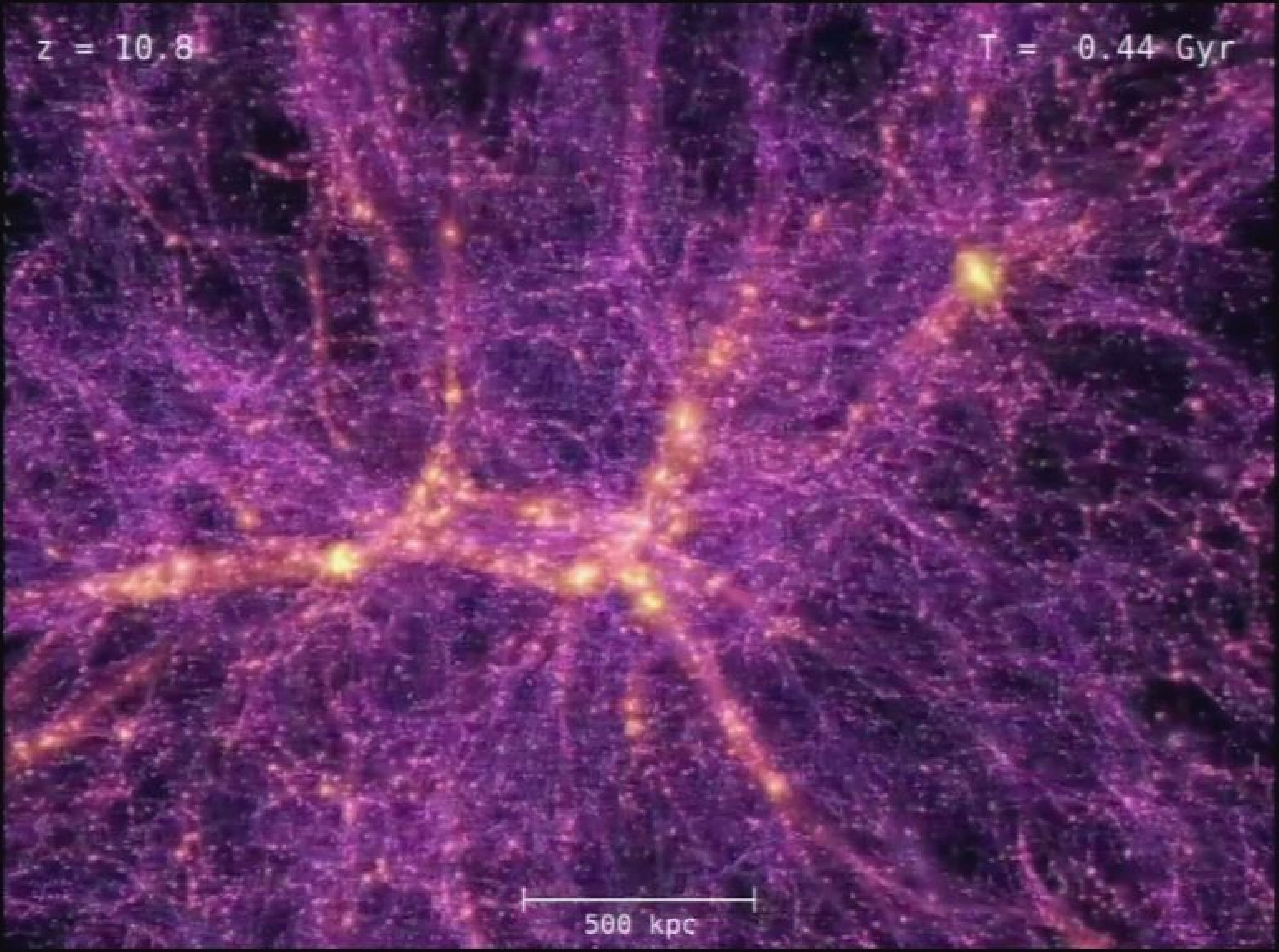

z = 17.8
T = 0.22 Gyr
500 kpc

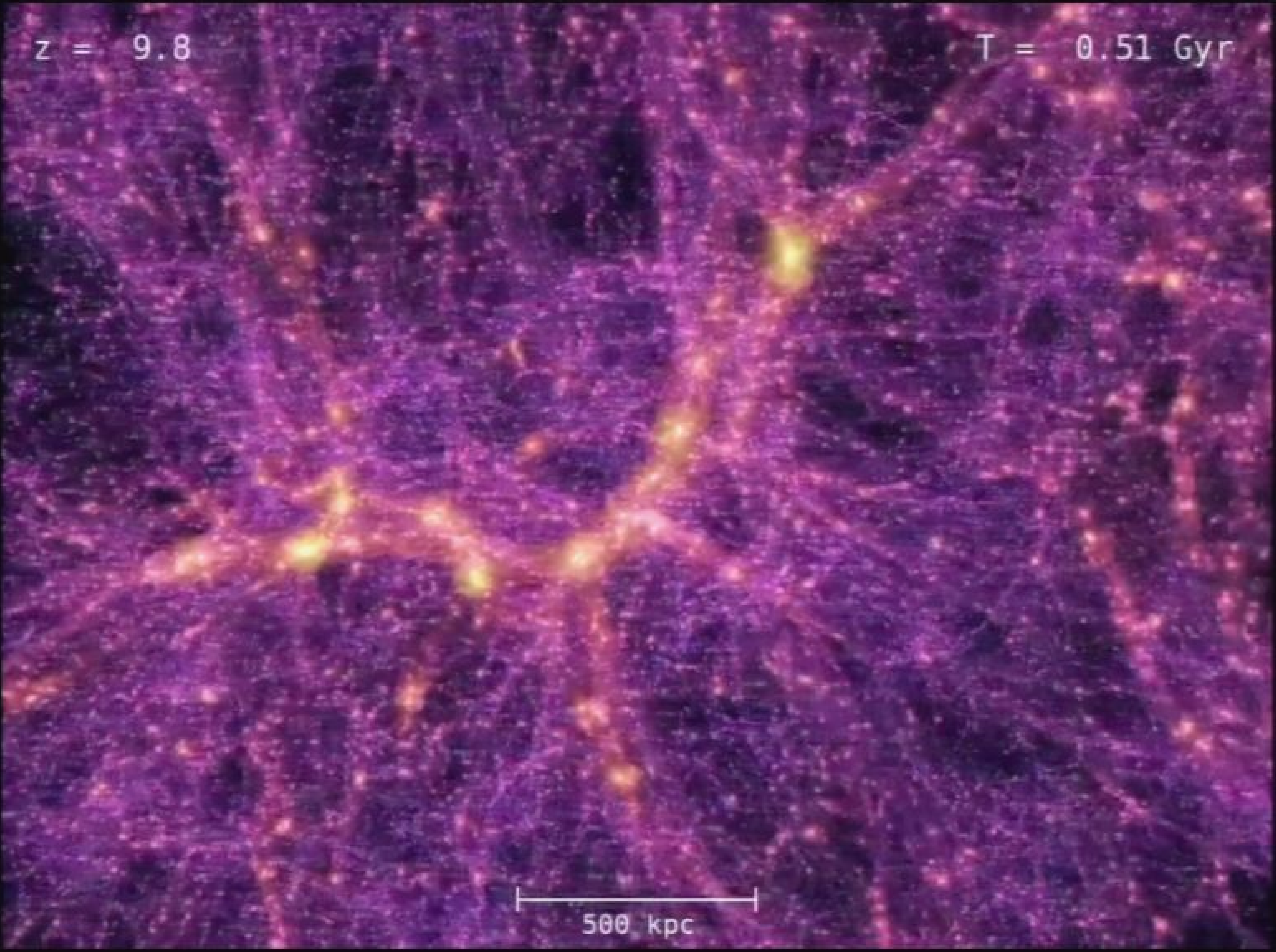

z = 16.1
T = 0.25 Gyr
500 kpc

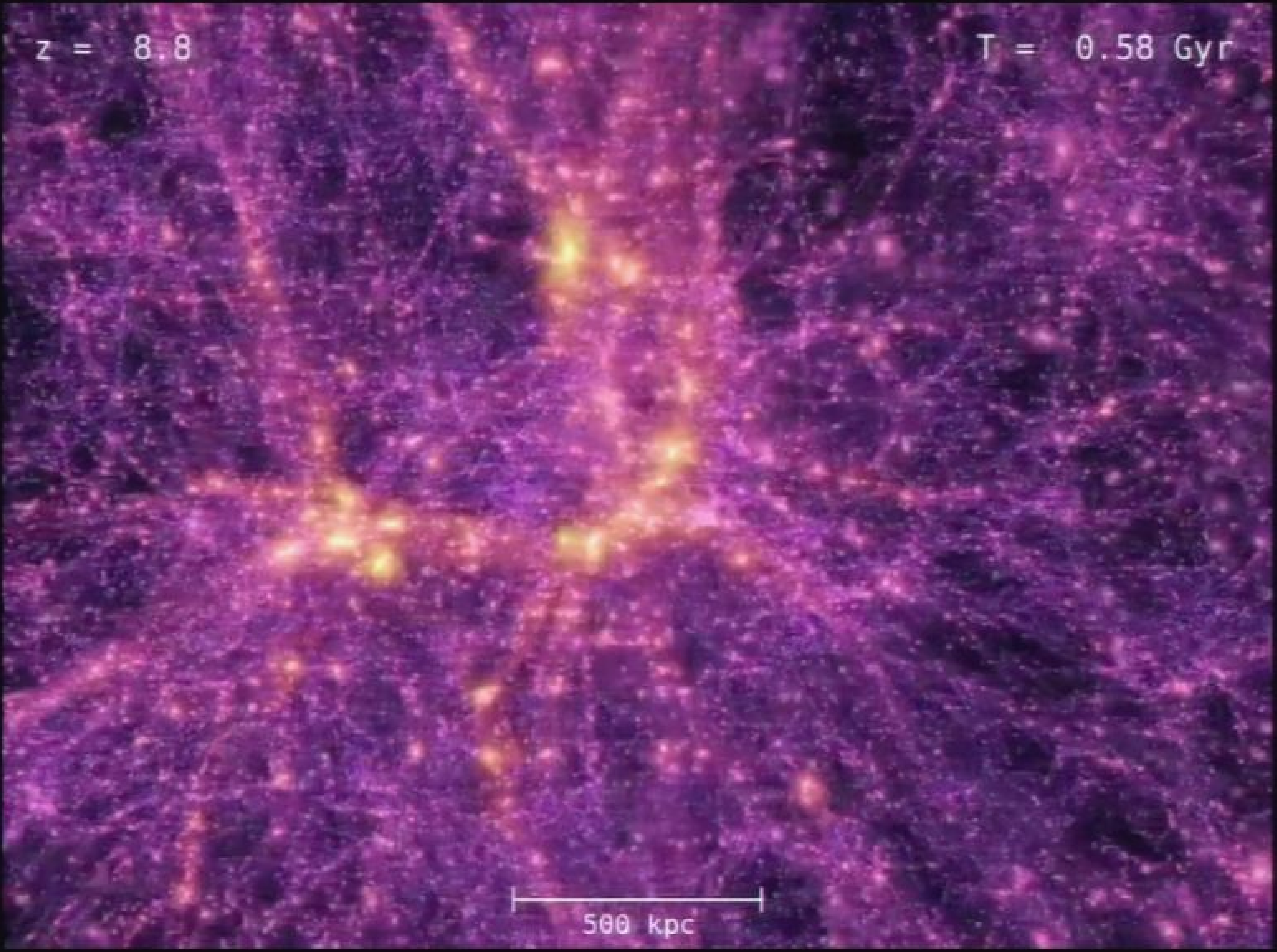

z = 14.5
T = 0.29 Gyr
500 kpc

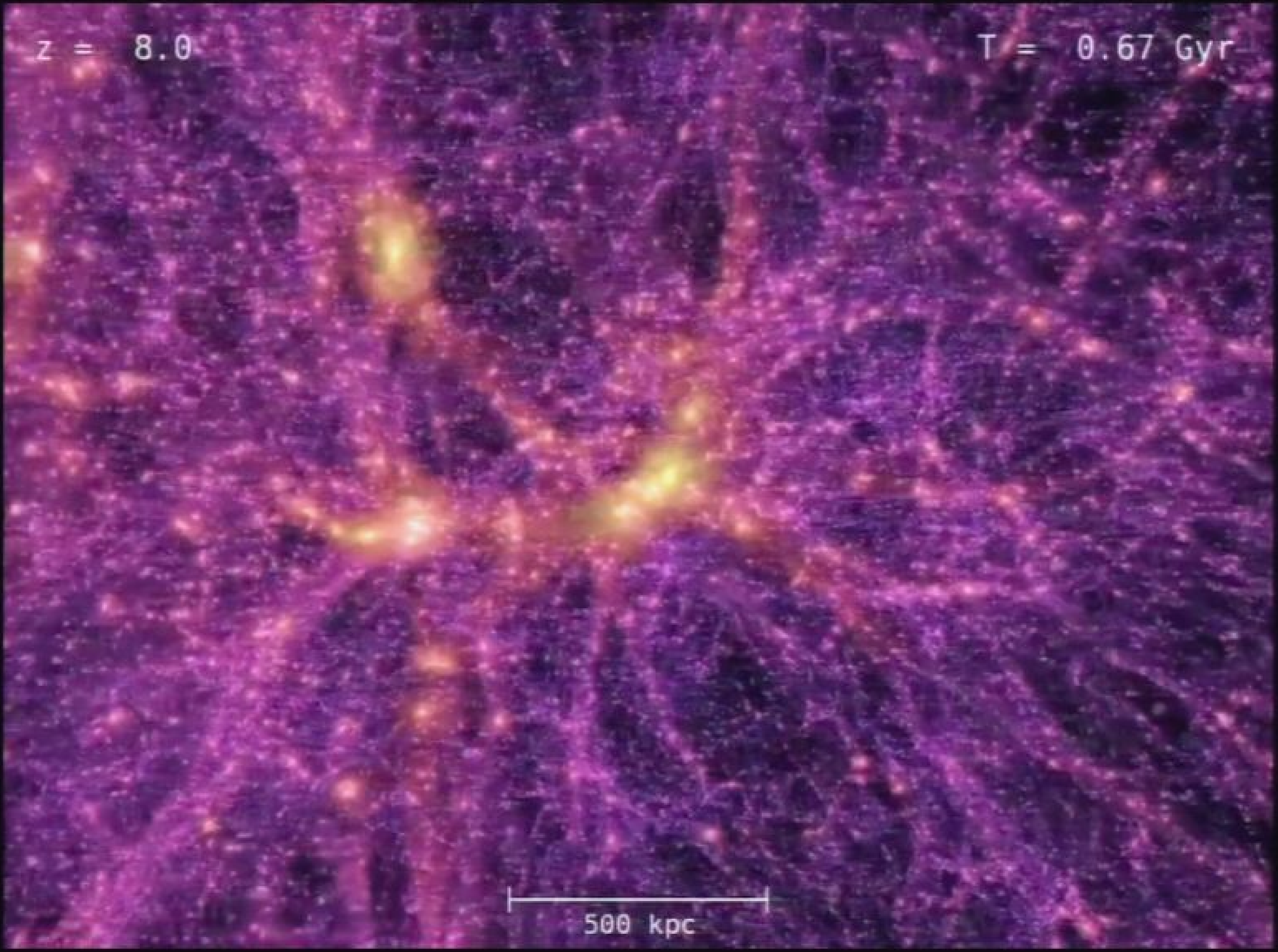

z = 13.3
T = 0.33 Gyr
500 kpc

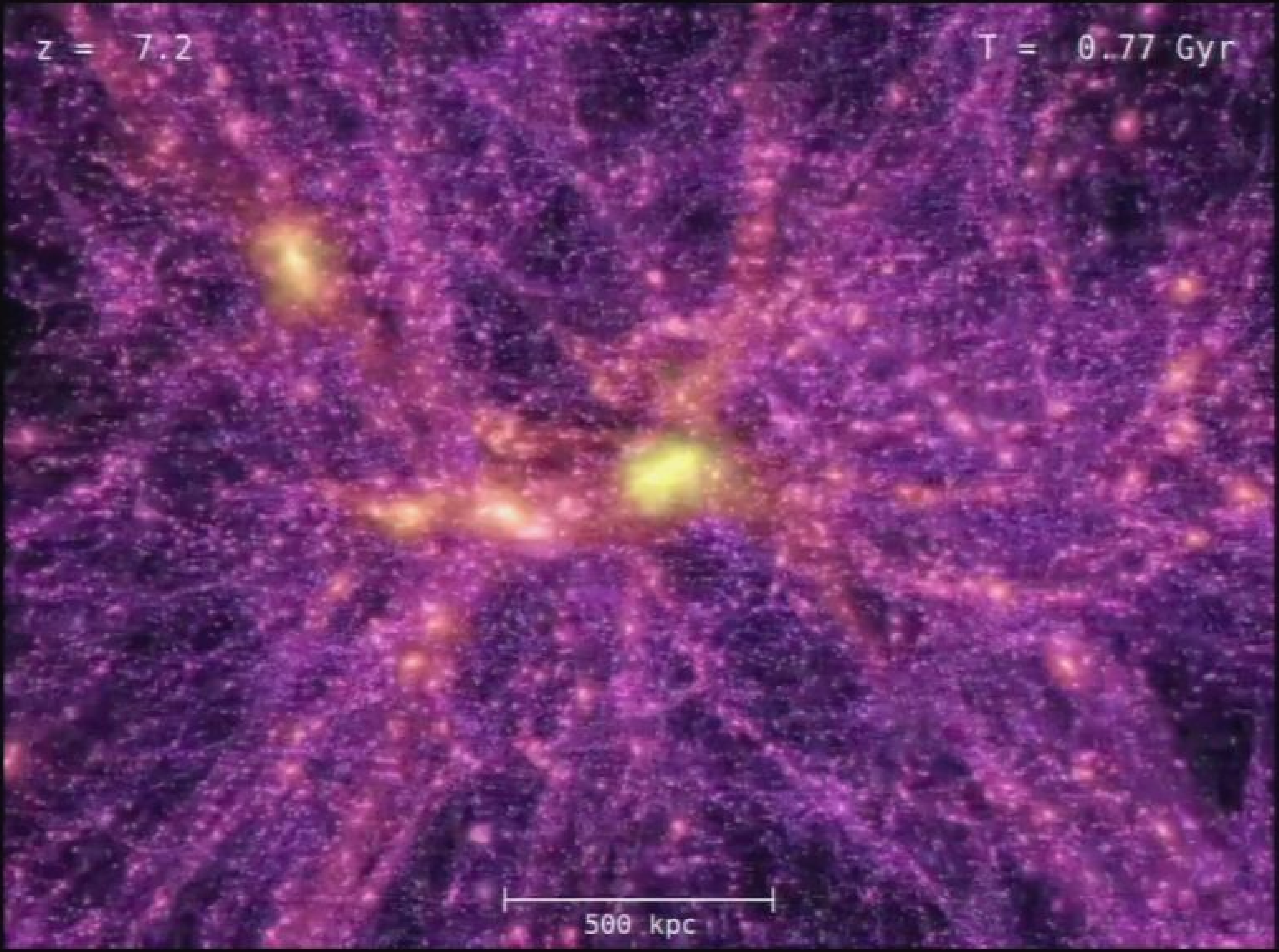

z = 11.9
T = 0.38 Gyr
500 kpc

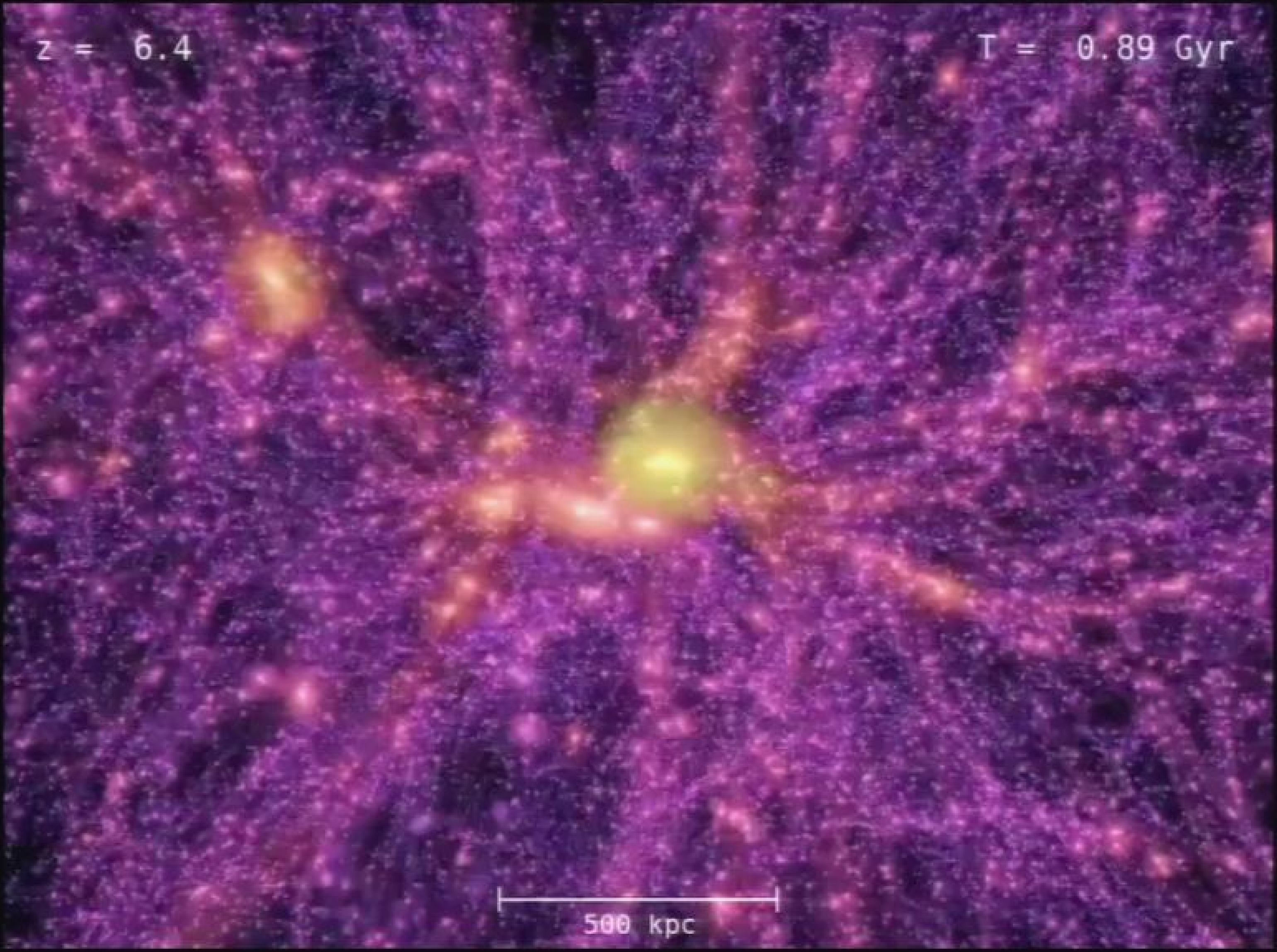

z = 10.8
T = 0.44 Gyr
500 kpc

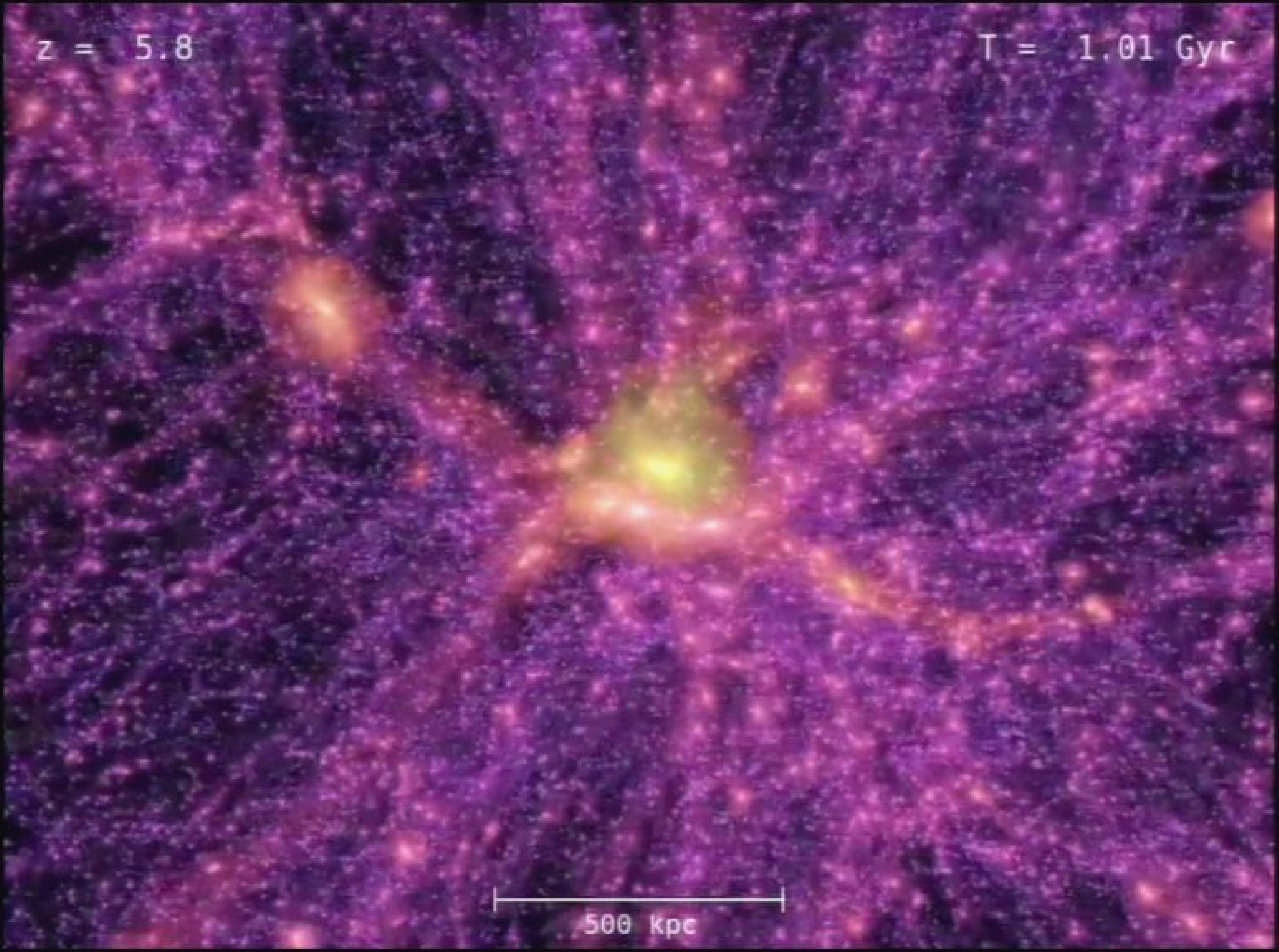

z = 9.8
T = 0.51 Gyr
500 kpc

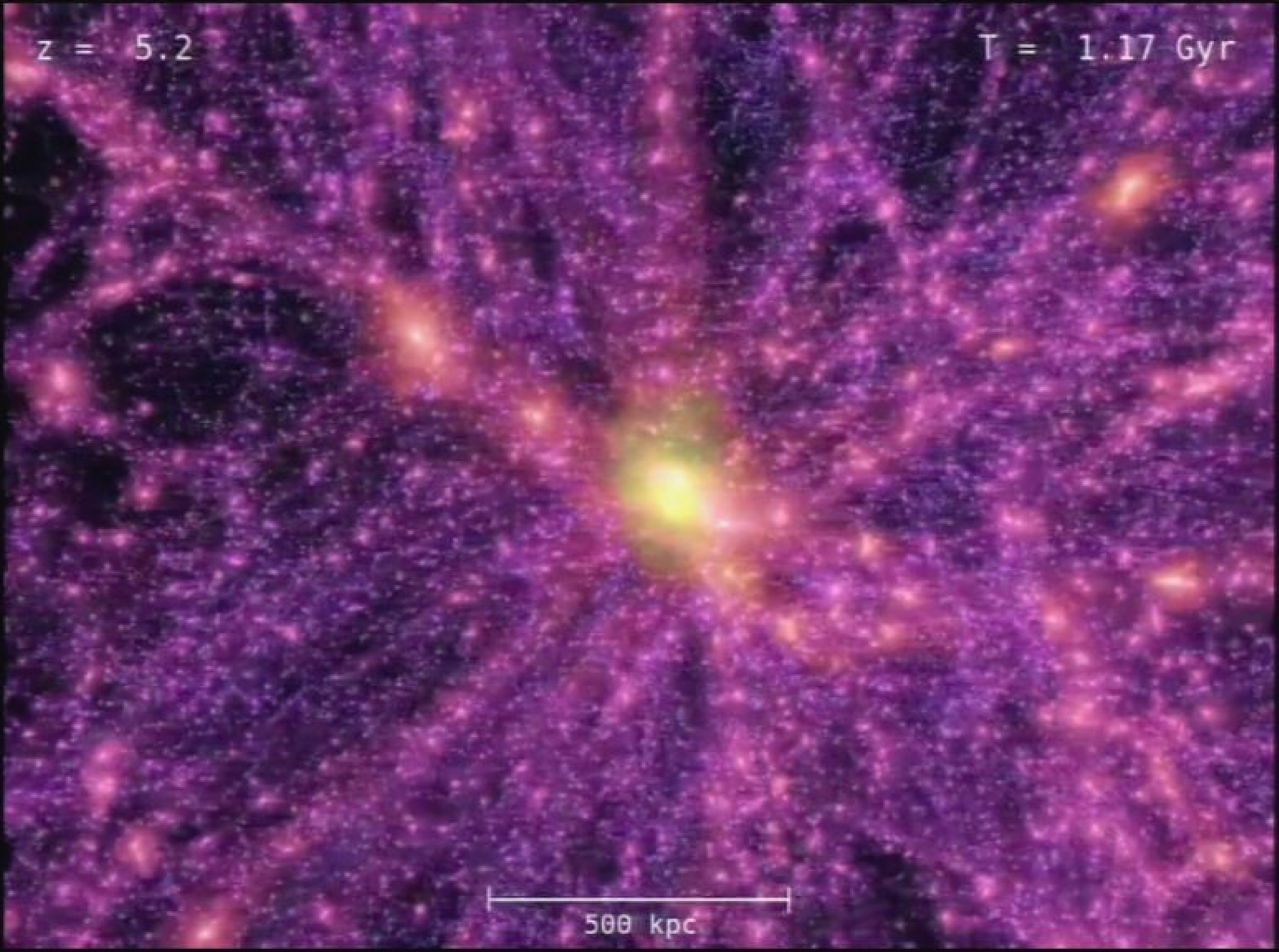

z = 8.8
T = 0.58 Gyr
500 kpc

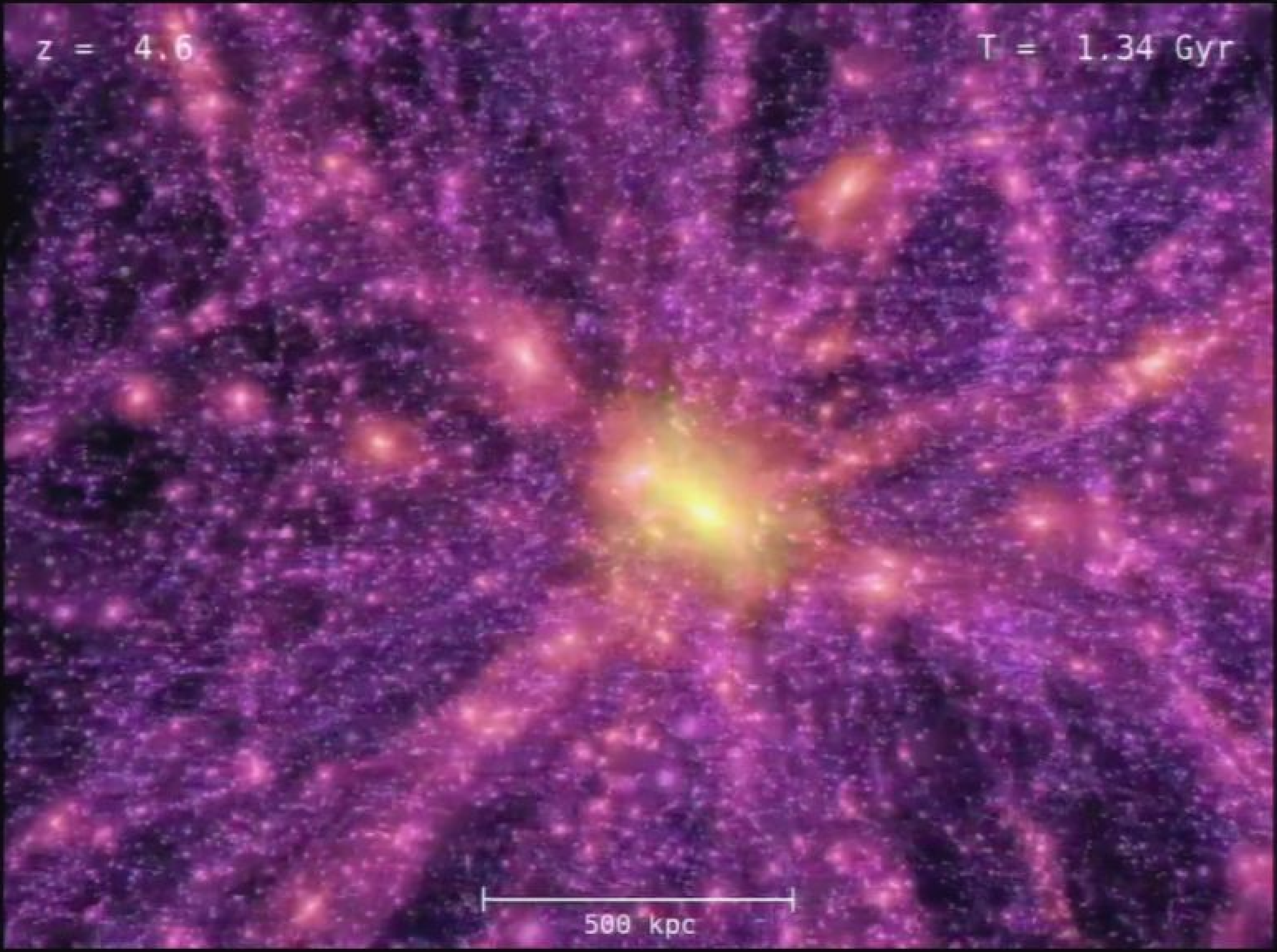

z = 8.0
T = 0.67 Gyr
500 kpc


z = 7.2
T = 0.77 Gyr
500 kpc


z = 6.4
T = 0.89 Gyr
500 kpc

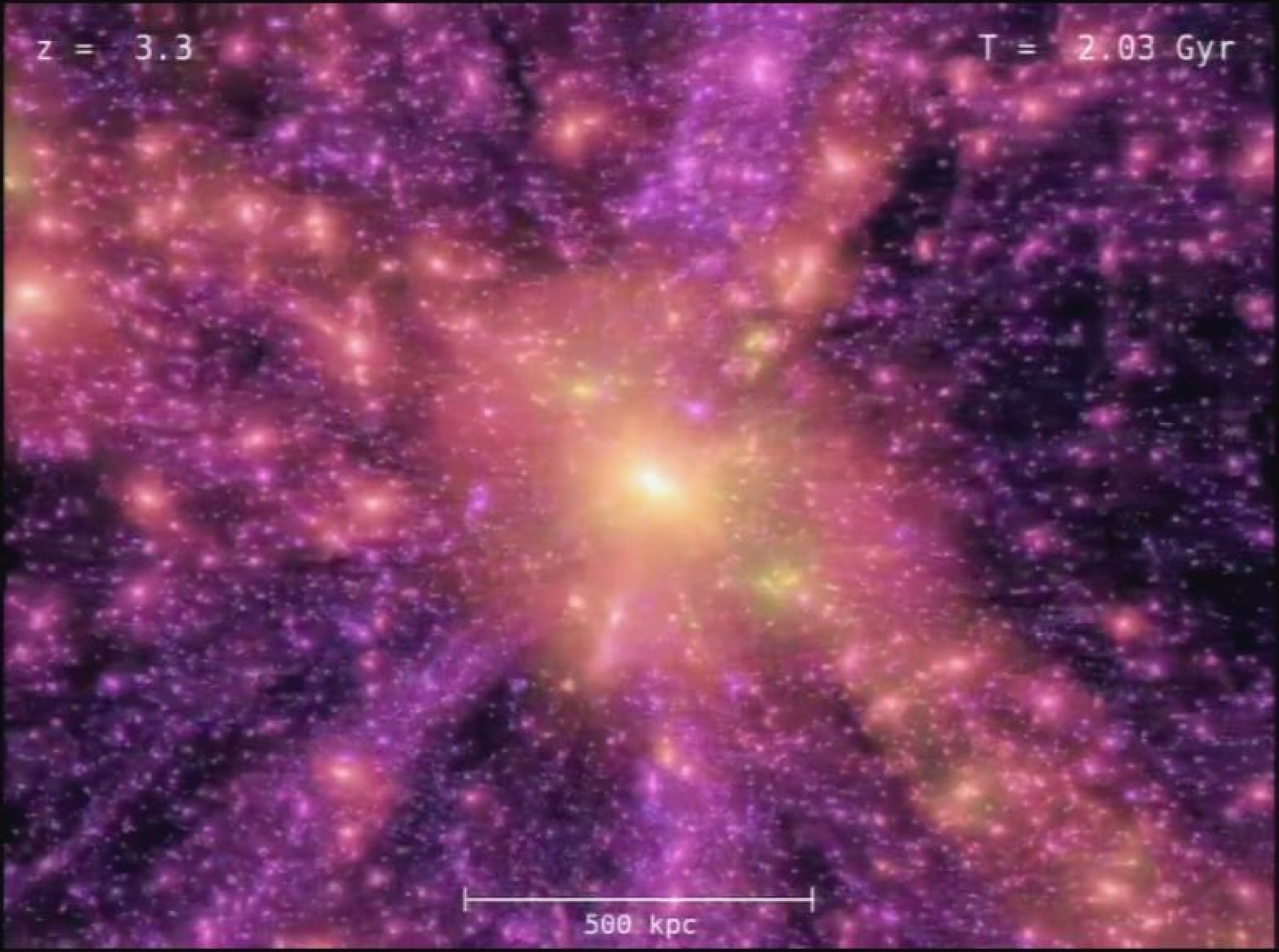

z = 5.8
T = 1.01 Gyr
500 kpc

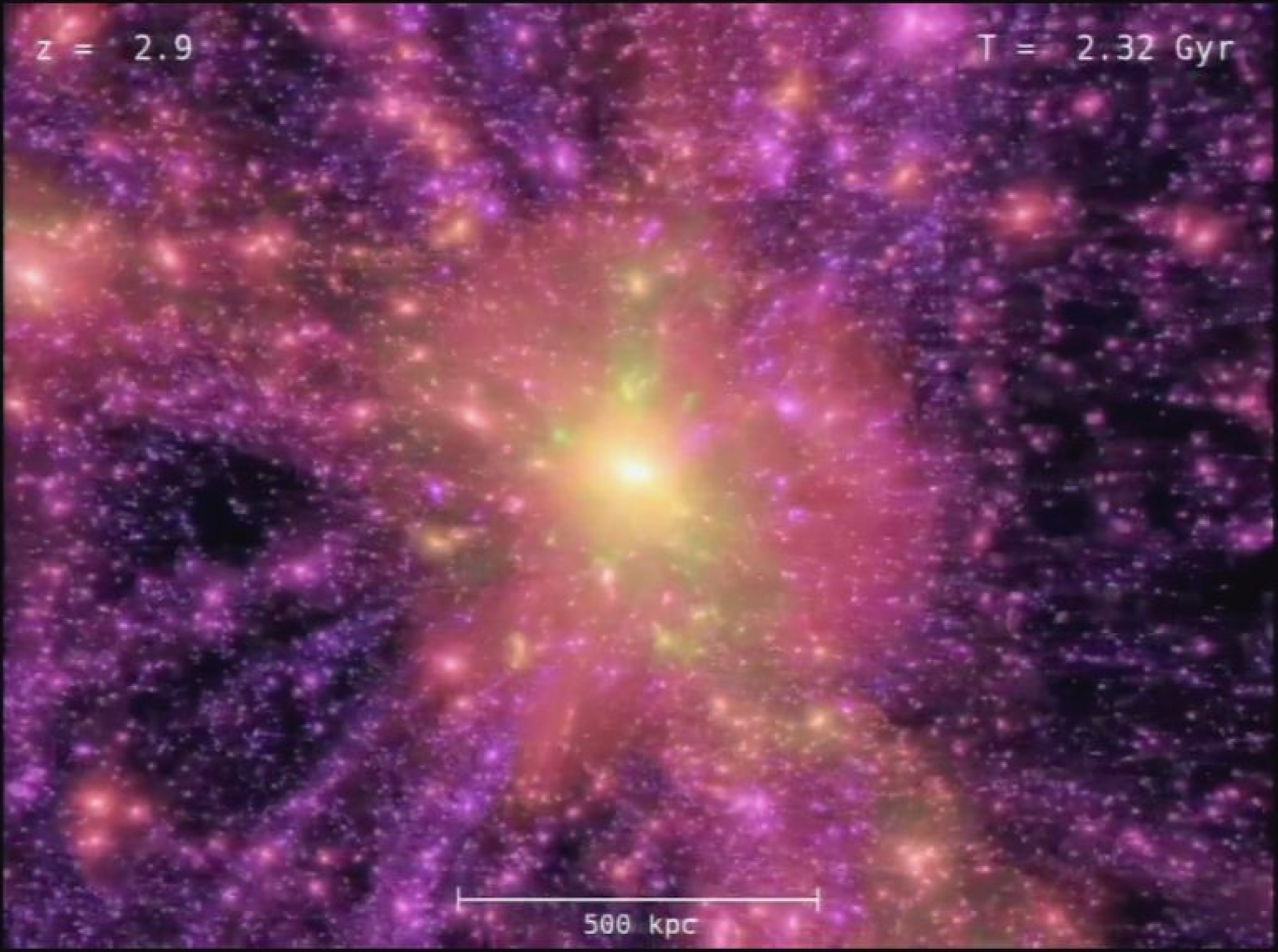

z = 5.2
T = 1.17 Gyr
500 kpc


z = 4.6
T = 1.34 Gyr
500 kpc


z = 4.1
T = 1.53 Gyr
500 kpc


z = 3.7
T = 1.76 Gyr
500 kpc


z = 3.3
T = 2.03 Gyr
500 kpc


z = 2.9
T = 2.32 Gyr
500 kpc

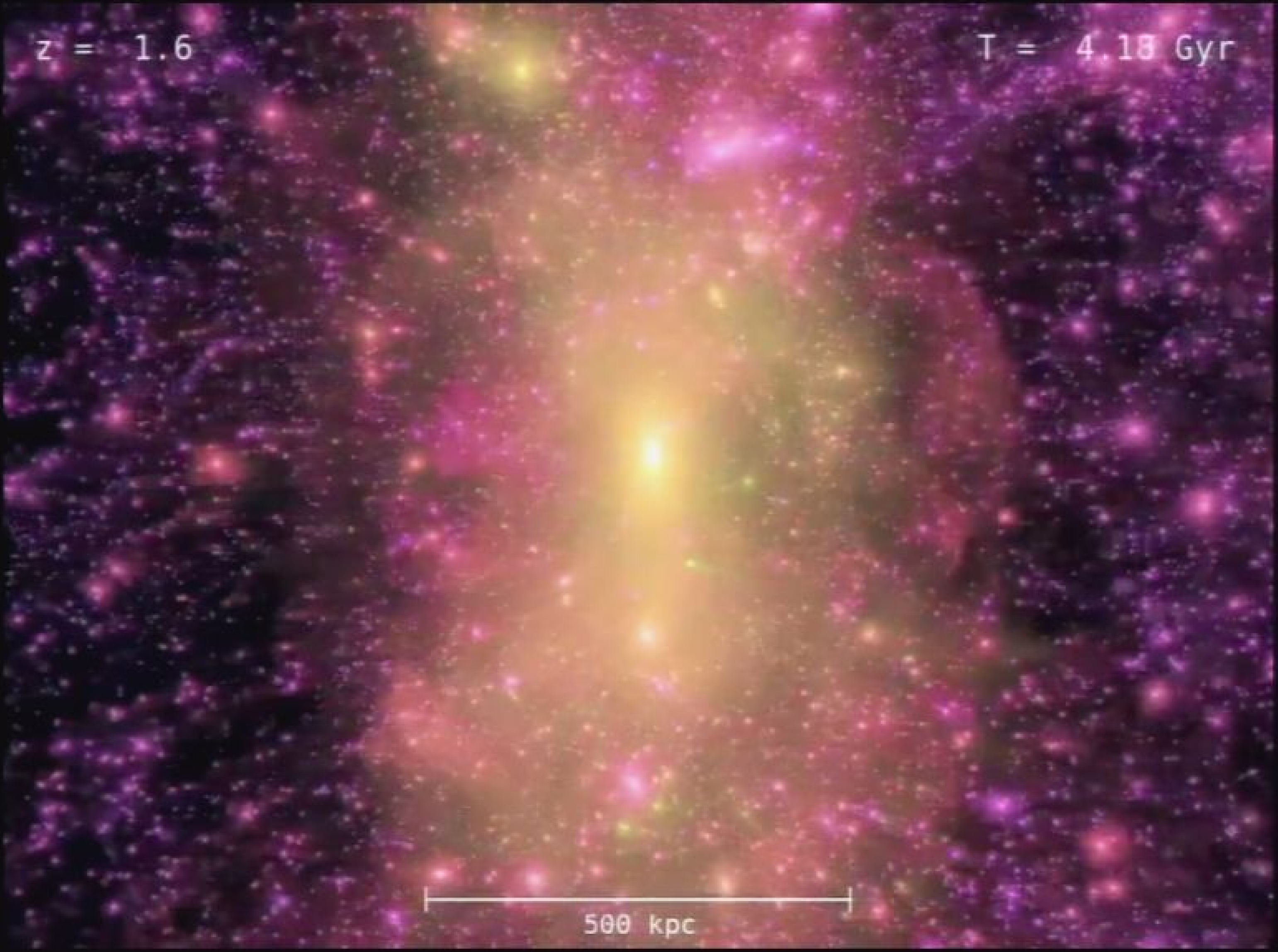

z = 2.6
T = 2.63 Gyr
500 kpc


z = 2.3
T = 2.93 Gyr
500 kpc


z = 2.1
T = 3.26 Gyr
500 kpc


z = 1.9
T = 3.54 Gyr
500 kpc


z = 1.7
T = 3.86 Gyr
500 kpc


z = 1.6
T = 4.18 Gyr
500 kpc

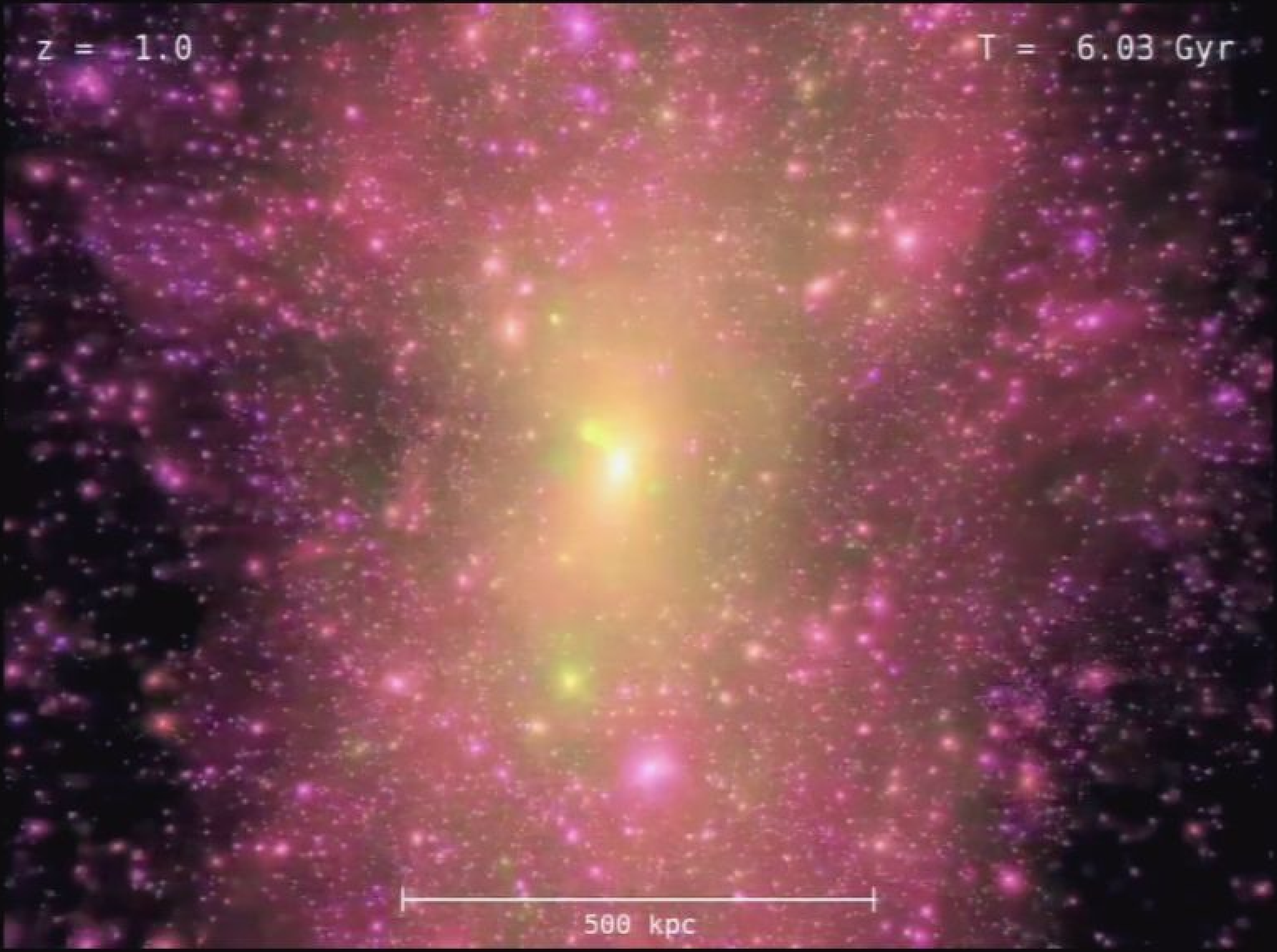

z = 1.5
T = 4.46 Gyr
500 kpc


z = 1.4
T = 4.79 Gyr
500 kpc


z = 1.2
T = 5.10 Gyr
500 kpc

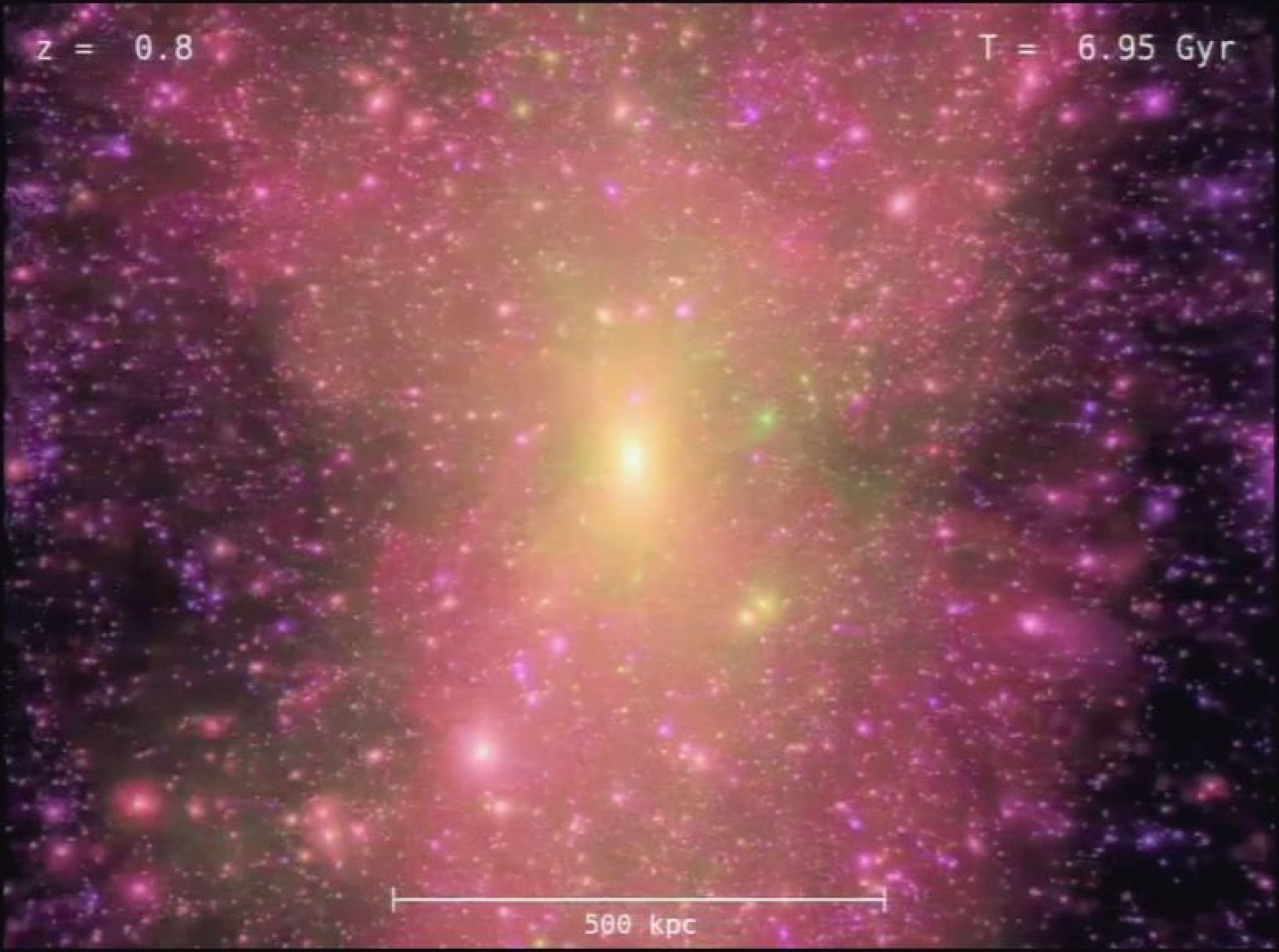

z = 1.2
T = 5.39 Gyr
500 kpc


z = 1.1
T = 5.70 Gyr
500 kpc


z = 1.0
T = 6.03 Gyr
500 kpc


z = 0.9
T = 6.32 Gyr
500 kpc


z = 0.9
T = 6.63 Gyr
500 kpc


z = 0.8
T = 6.95 Gyr
500 kpc


z = 0.7
T = 7.26 Gyr
500 kpc


z = 0.7
T = 7.56 Gyr
500 kpc


z = 0.6
T = 7.87 Gyr
500 kpc


z = 0.6
T = 8.18 Gyr
500 kpc

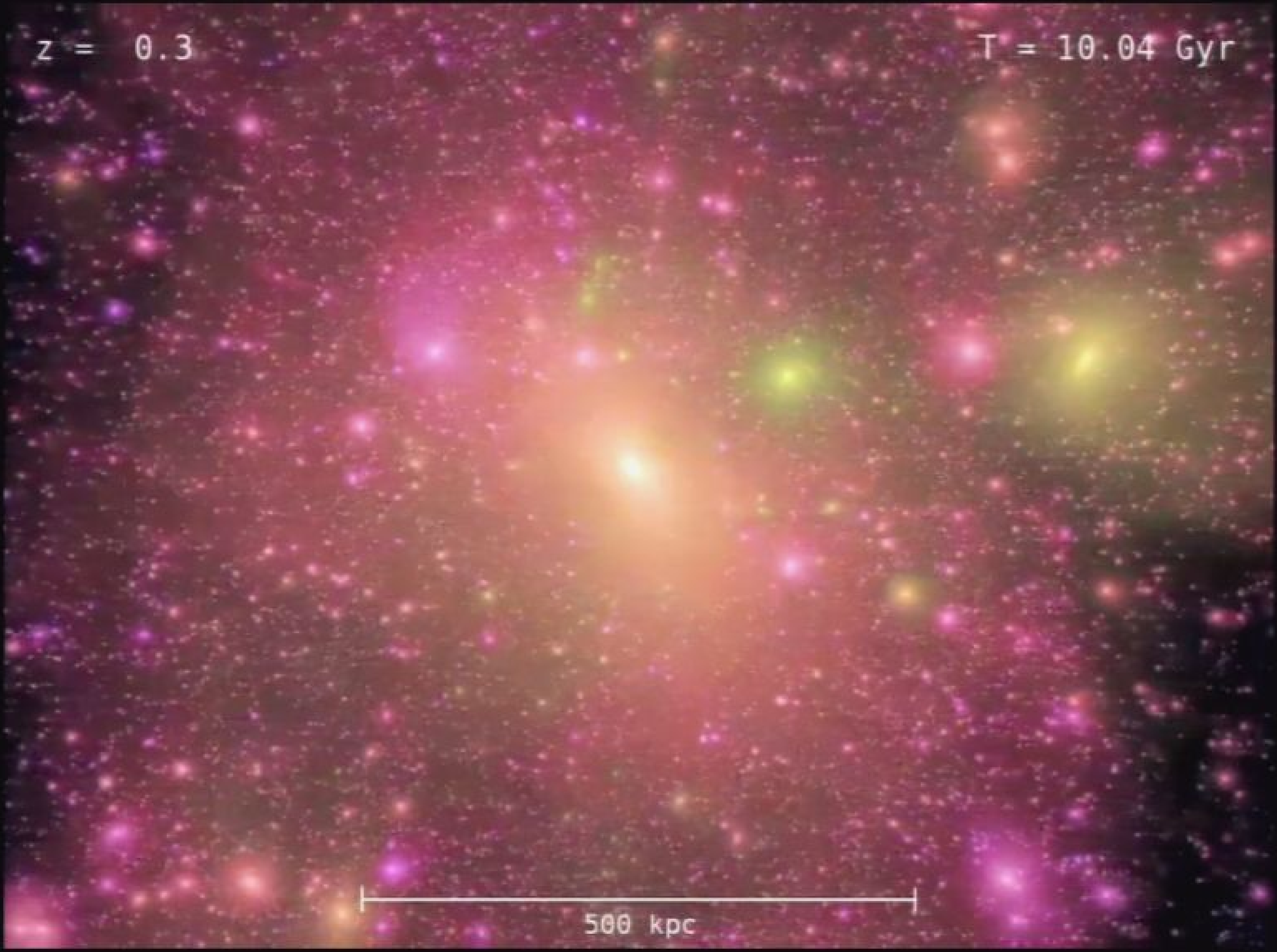

z = 0.5
T = 8.51 Gyr
500 kpc

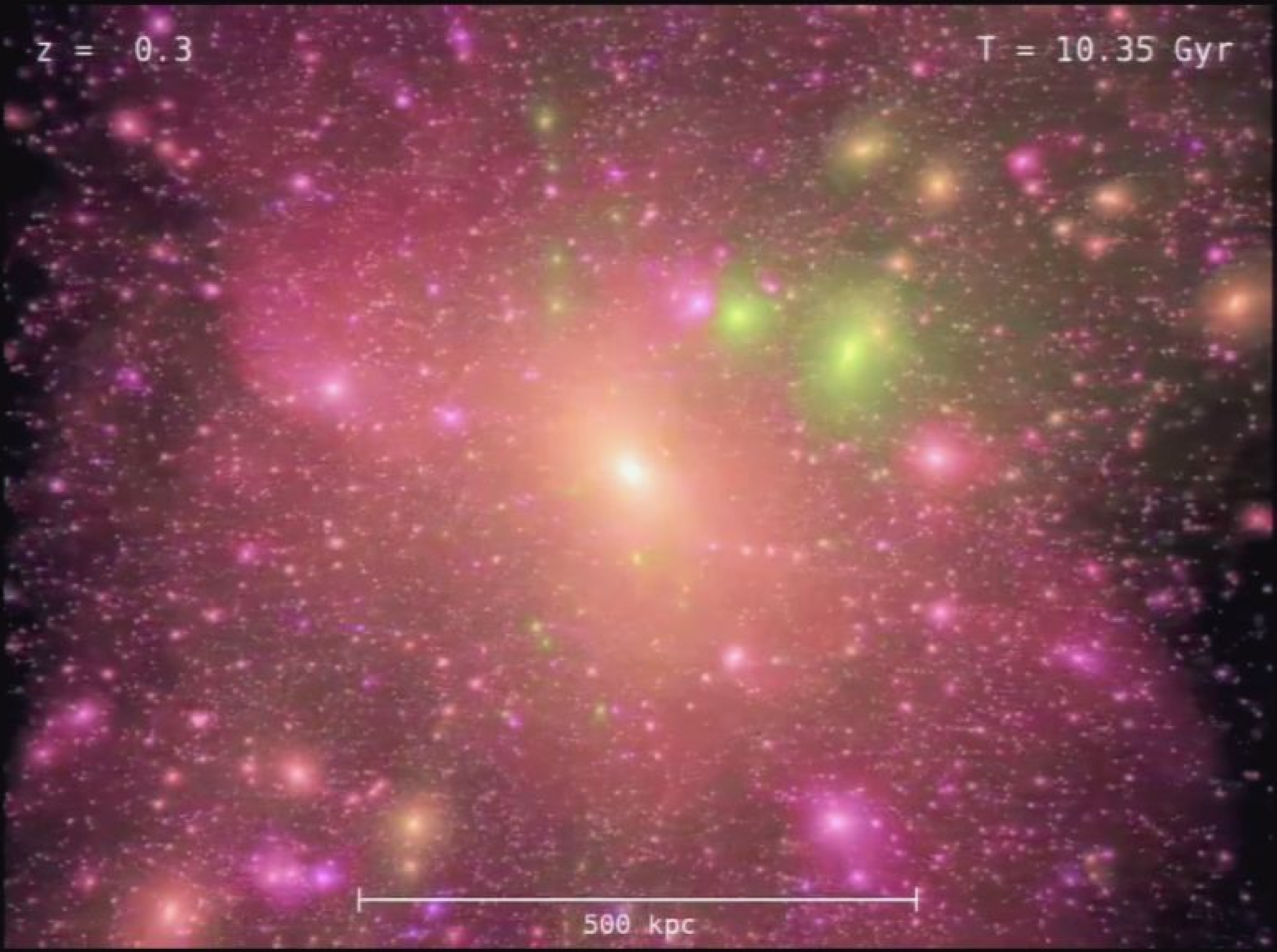

z = 0.5
T = 8.79 Gyr
500 kpc

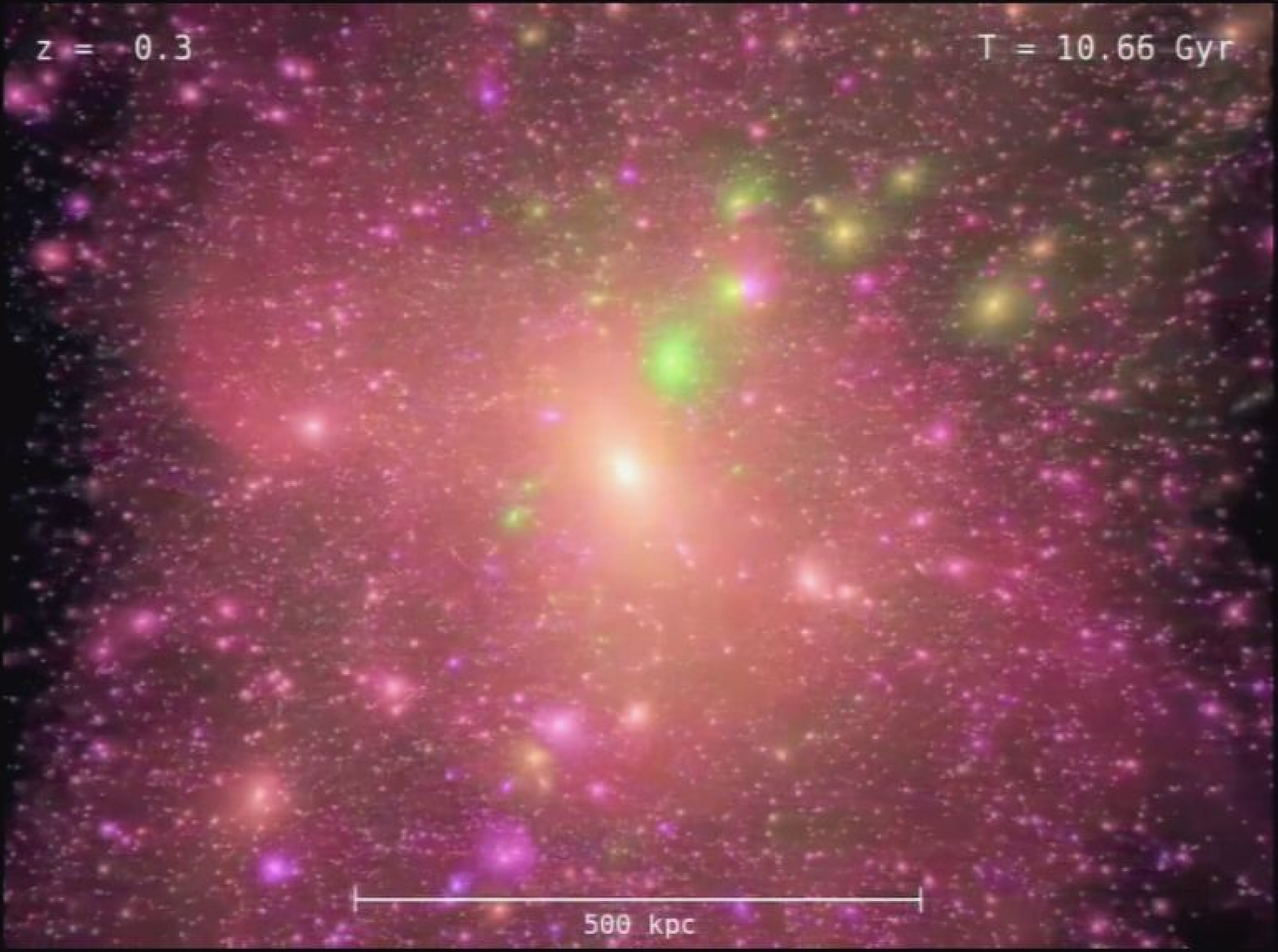

z = 0.4
T = 9.10 Gyr
500 kpc

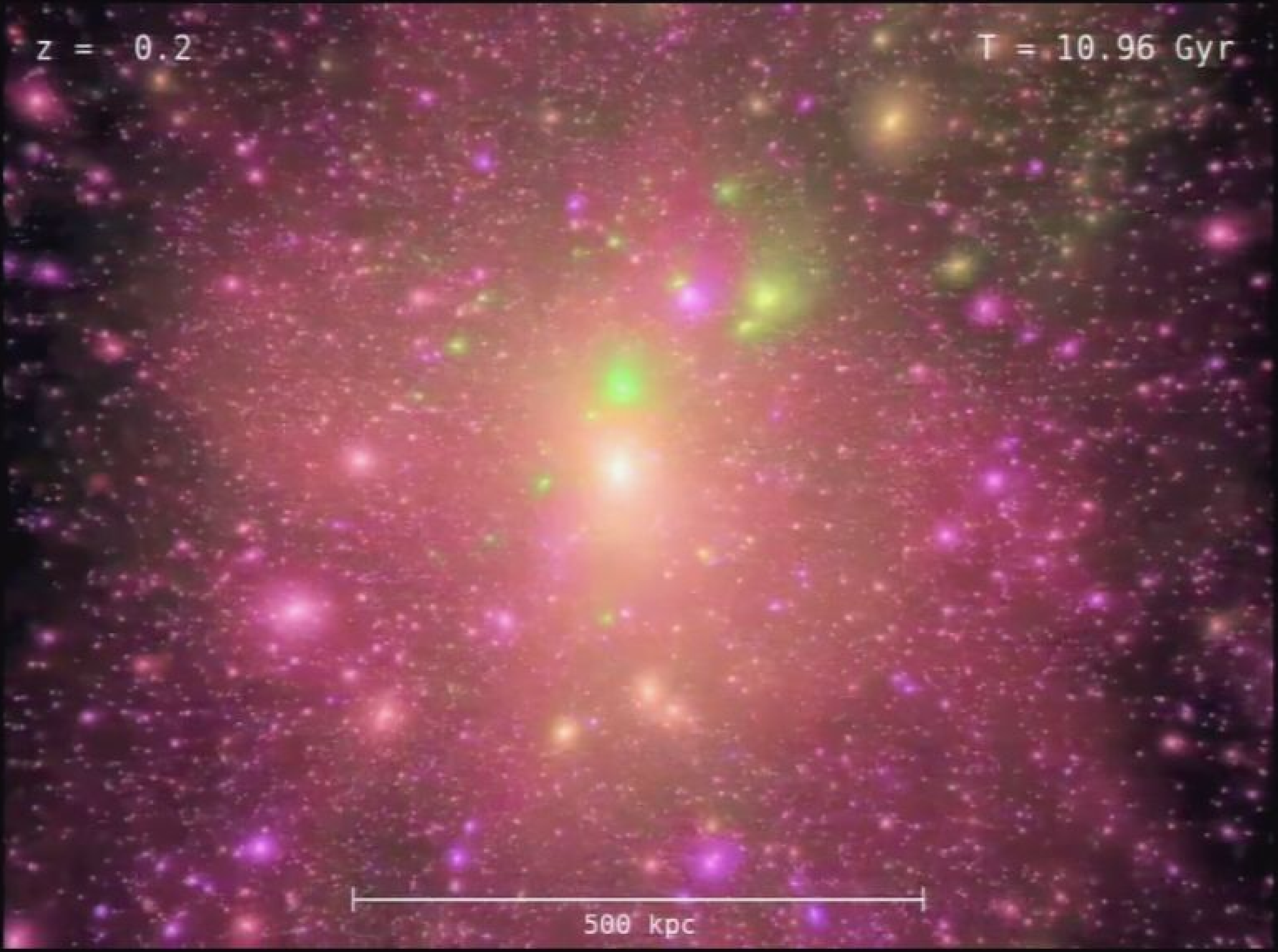

z = 0.4
T = 9.43 Gyr
500 kpc


z = 0.4
T = 9.71 Gyr
500 kpc

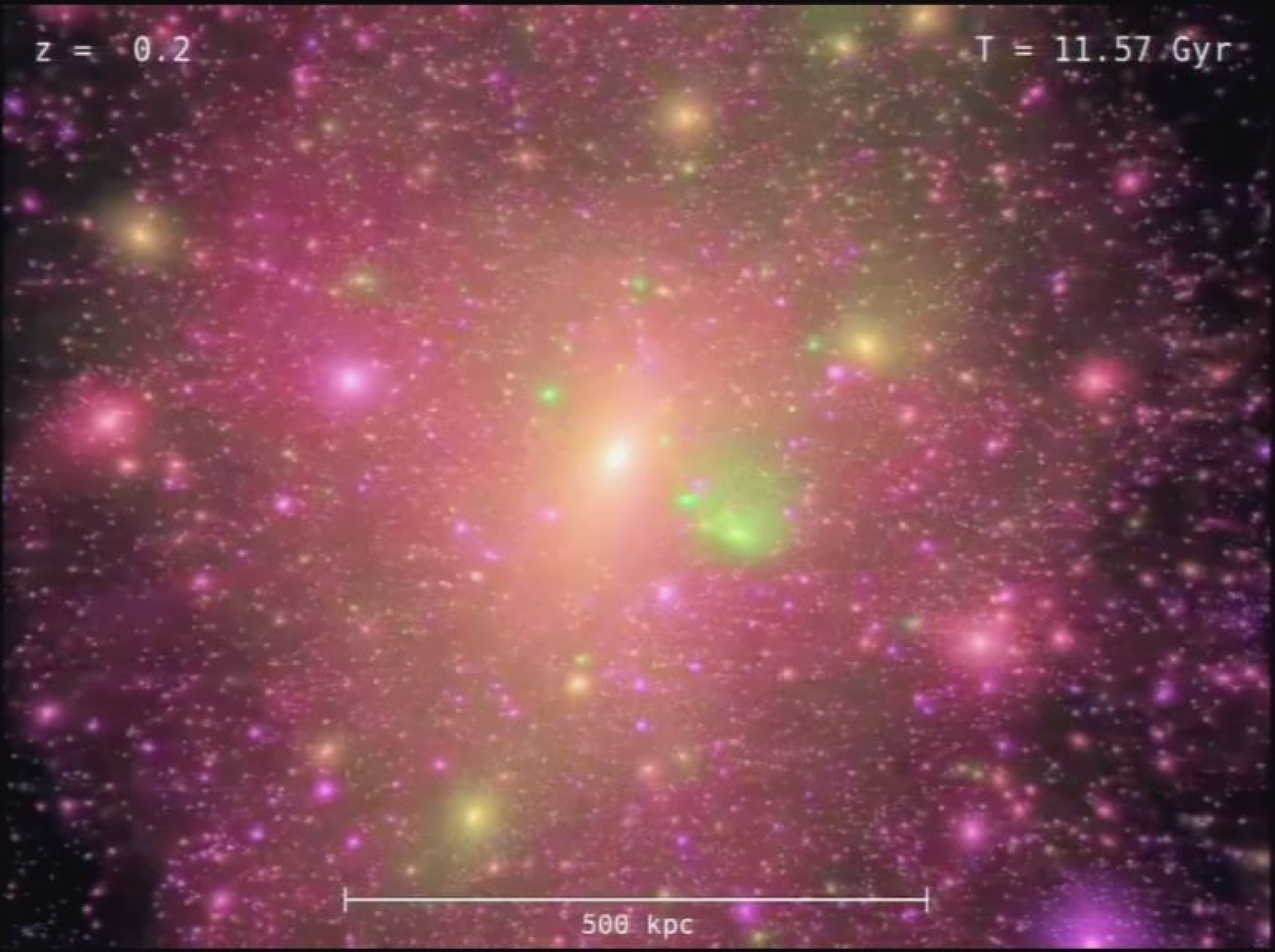

z = 0.3
T = 10.04 Gyr
500 kpc


z = 0.3
T = 10.35 Gyr
500 kpc


z = 0.3
T = 10.66 Gyr
500 kpc


z = 0.2
T = 10.96 Gyr
500 kpc


z = 0.2
T = 11.27 Gyr
500 kpc


z = 0.2
T = 11.57 Gyr
500 kpc


z = 0.1
T = 11.88 Gyr
500 kpc

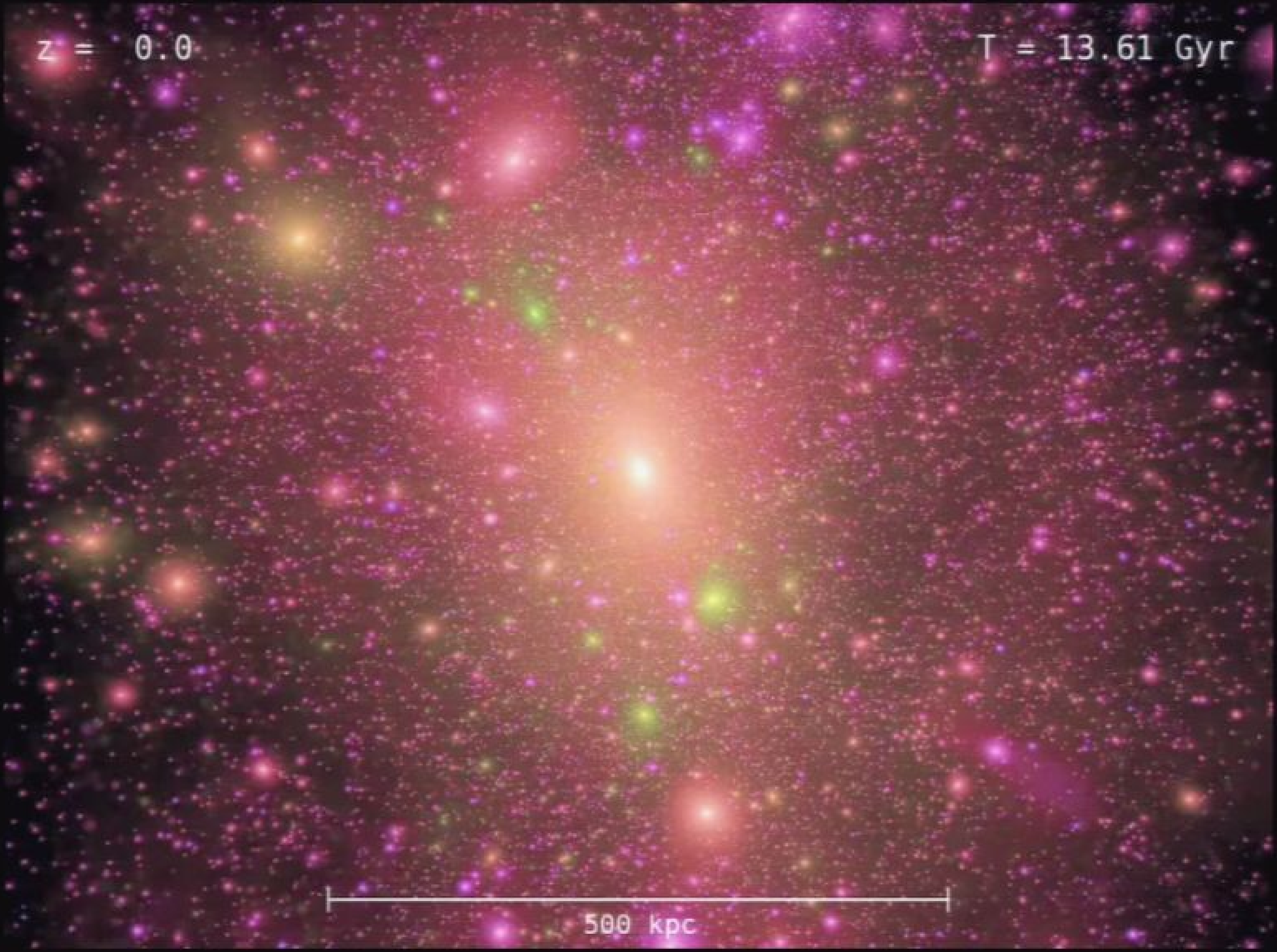

z = 0.1
T = 12.20 Gyr
500 kpc


z = 0.1
T = 12.52 Gyr
500 kpc

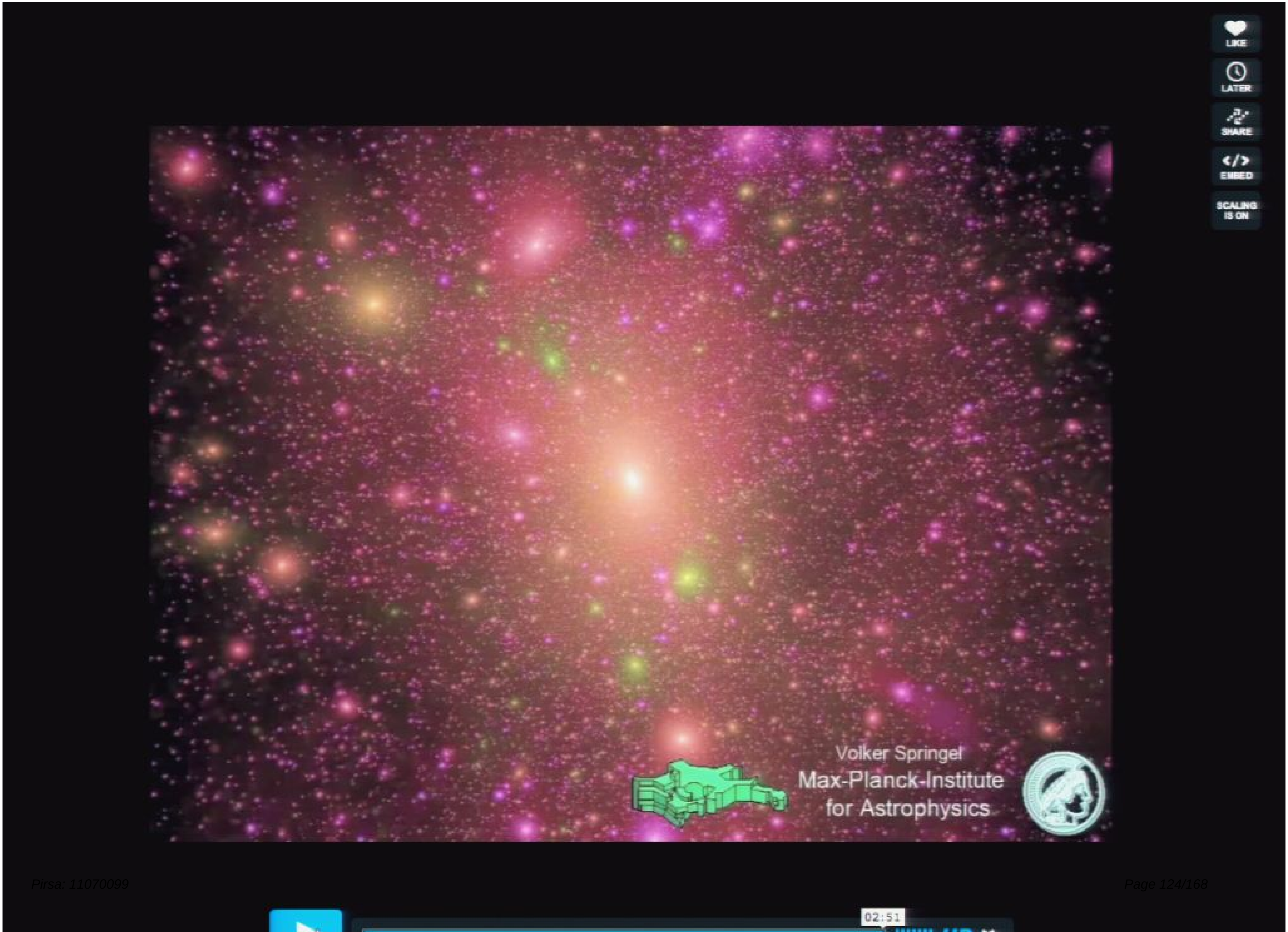

z = 0.1
T = 12.81 Gyr
500 kpc


z = 0.0
T = 13.12 Gyr
500 kpc


z = 0.0
T = 13.43 Gyr
500 kpc

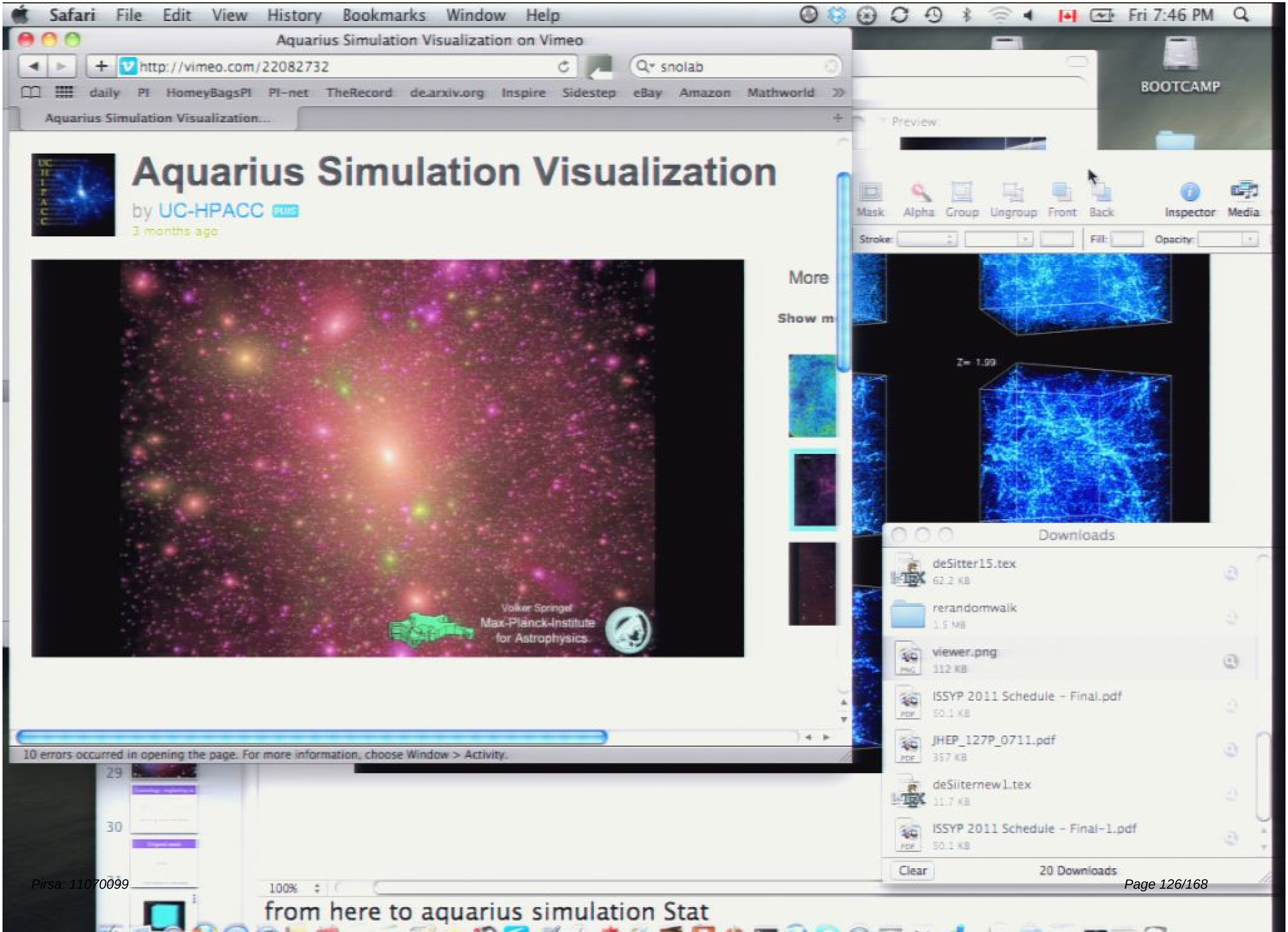

z = 0.0
T = 13.61 Gyr
500 kpc


Volker Springel
Max-Planck-Institute
for Astrophysics


LIKE
LATER
SHARE
EMBED
SCALING IS ON
Volker Springel
Max-Planck-Institute
for Astrophysics
02:51


Volker Springel
Max-Planck-Institute
for Astrophysics


02:51



Aquarius Simulation Visualization

by UC-HPACC PLUS

3 months ago

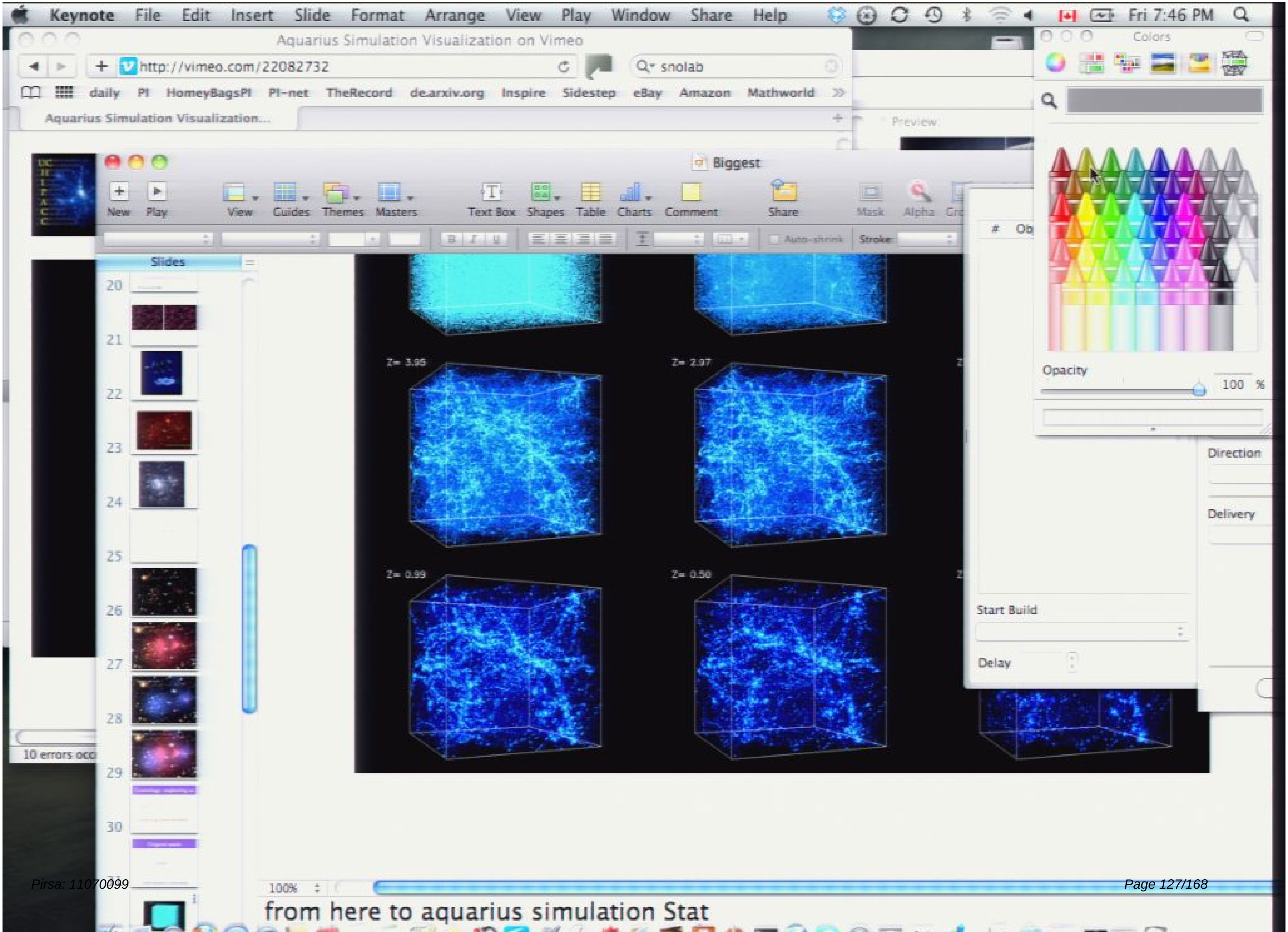
10 errors occurred in opening the page. For more information, choose Window > Activity.

Downloads

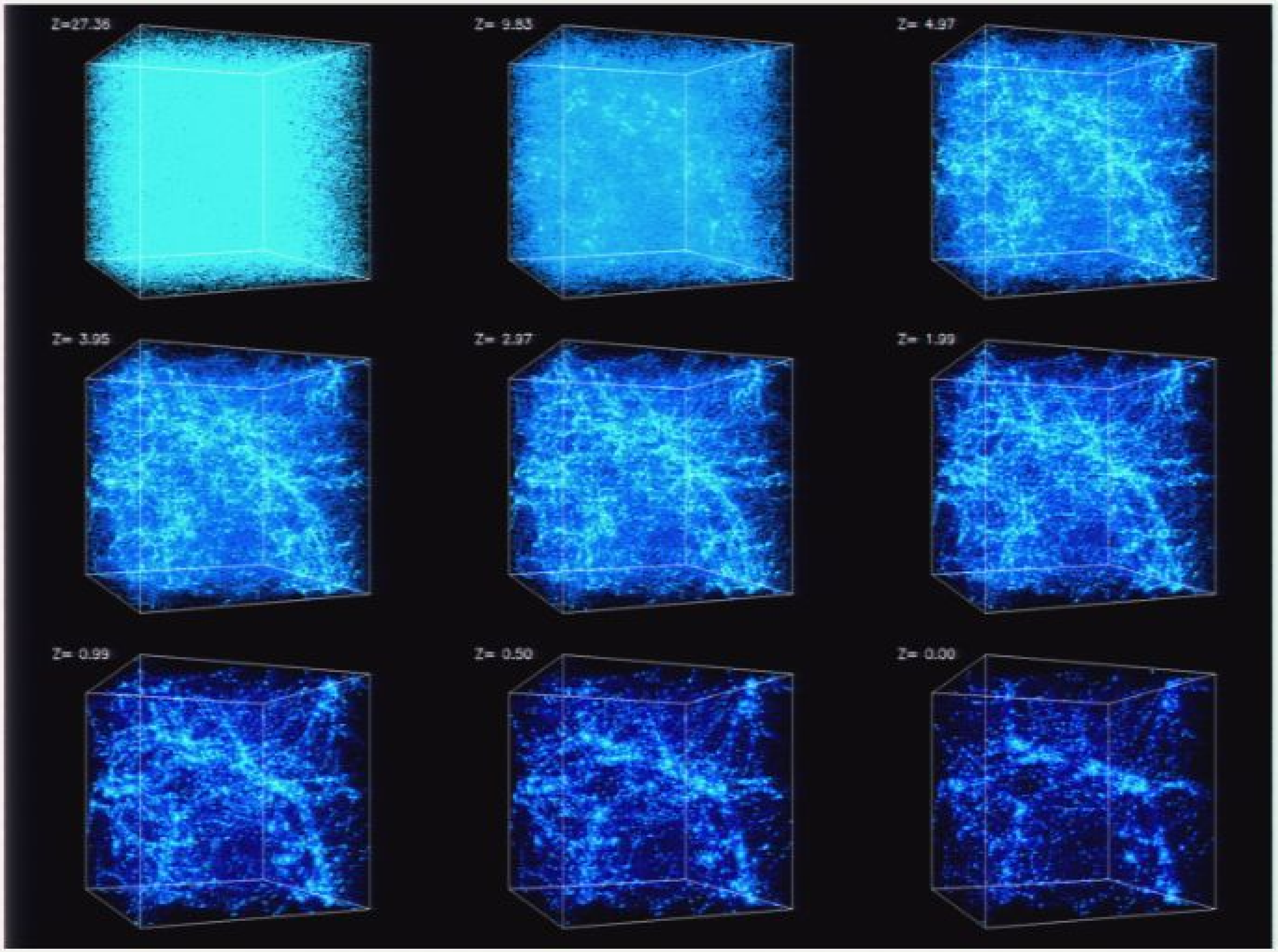
deSitter15.tex 62.2 KB
rerandomwalk 1.5 MB
viewer.png 112 KB
ISSYP 2011 Schedule - Final.pdf 50.1 KB
JHEP_127P_0711.pdf 357 KB
deSiiternew1.tex 11.7 KB
ISSYP 2011 Schedule - Final-1.pdf 50.1 KB

Clear 20 Downloads

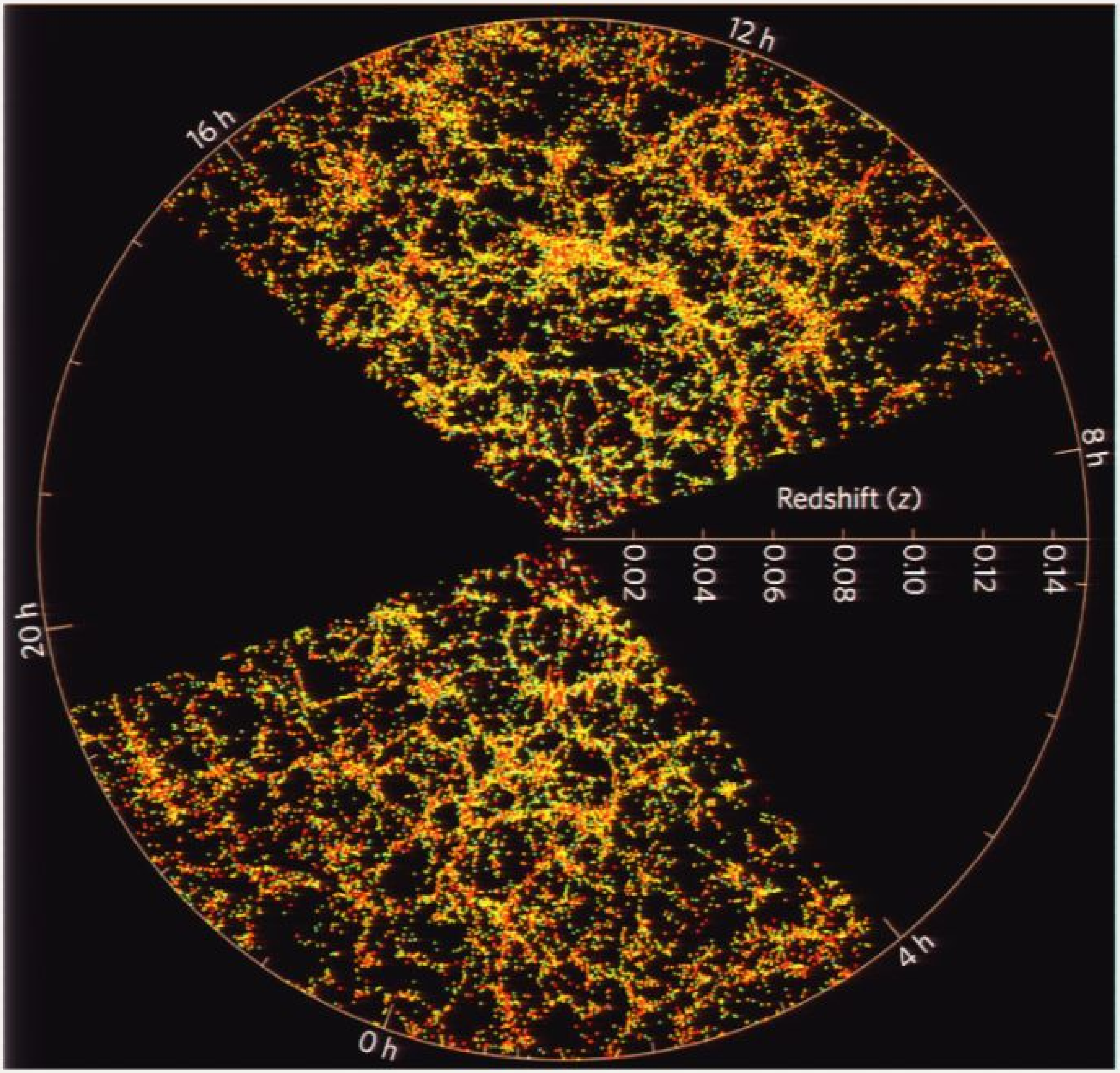
from here to aquarius simulation Stat



from here to aquarius simulation Stat


Z=27.36
Z= 9.83
Z= 4.97
Z= 3.95
Z= 2.97
Z= 1.99
Z= 0.99
Z= 0.50
Z= 0.00

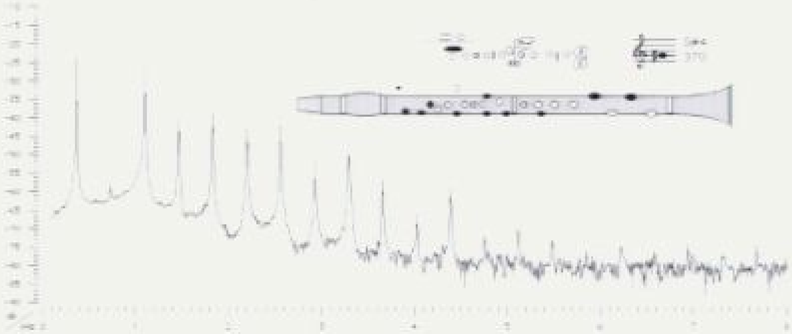
SDSS



Harmonics

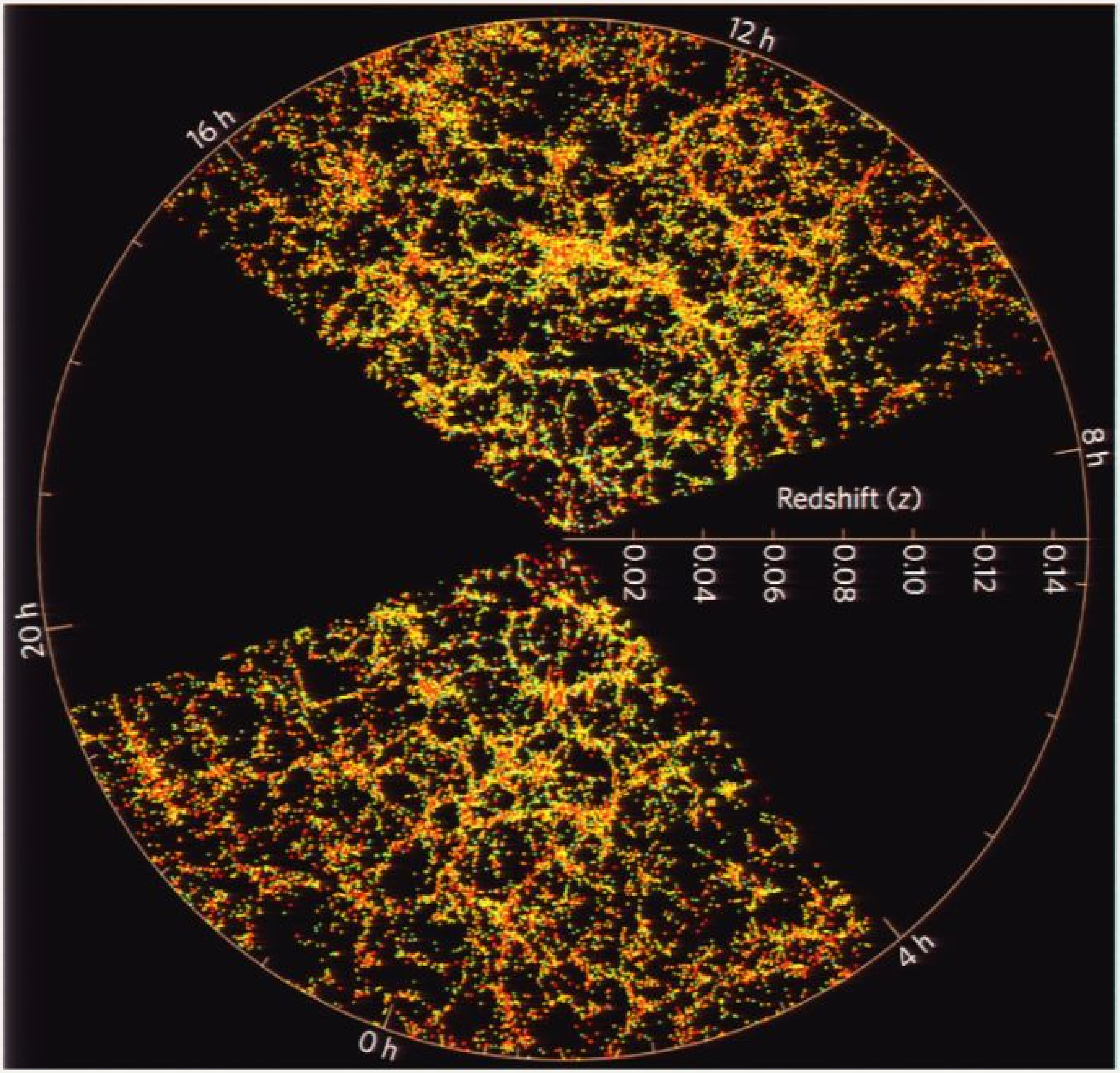
- Decompose into Harmonics

Sound of clarinet



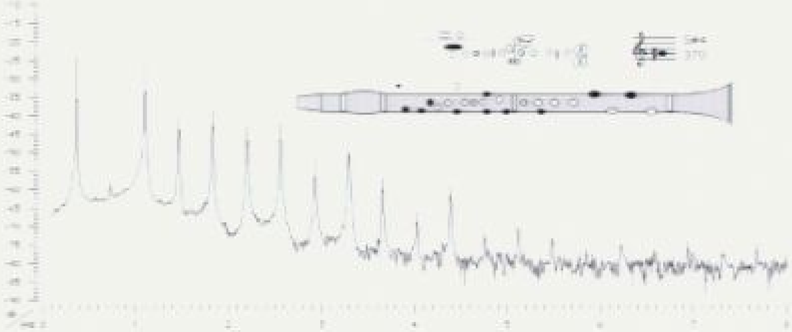
Credit: Mark Whittle, University of Virginia

SDSS



Harmonics

- Decompose into Harmonics



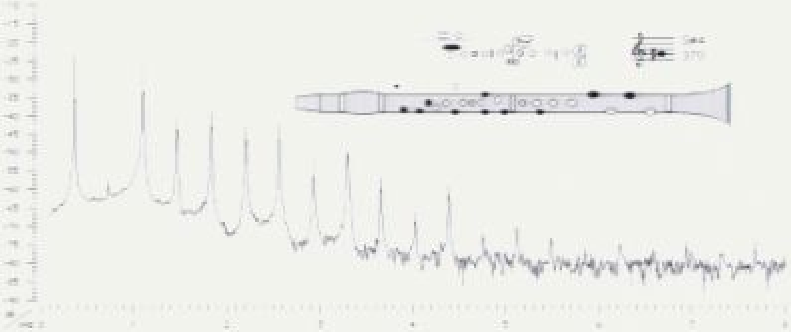
Sound of clarinet

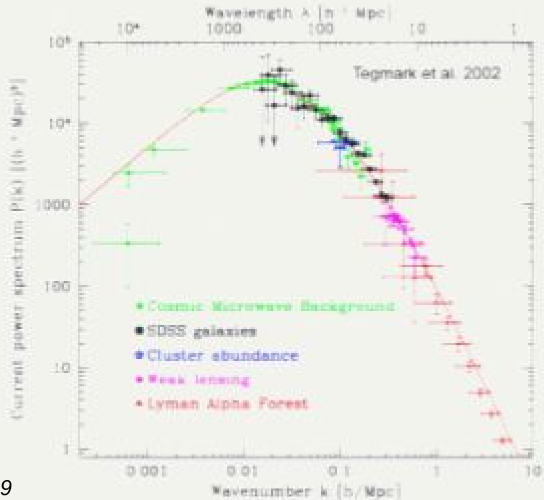
Credit: Mark Whittle, University of Virginia

Harmonics

- Decompose into Harmonics

Sound of clarinet



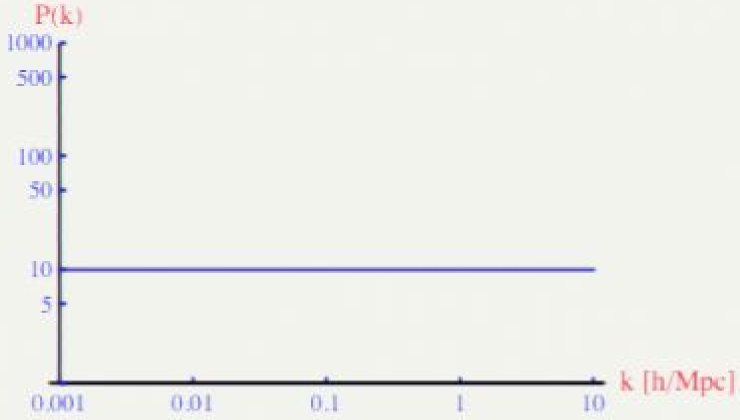


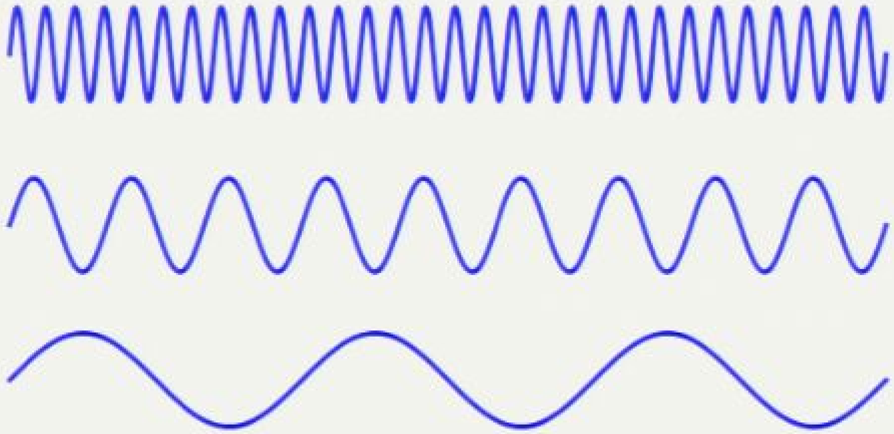
Sound of dark matter

Credit: Mark Whittle, University of Virginia

Scale Invariance

Perturbations in gravitational potential. All wavelength, amplitude for each wave is drawn from a gaussian with variance 10^{-5}





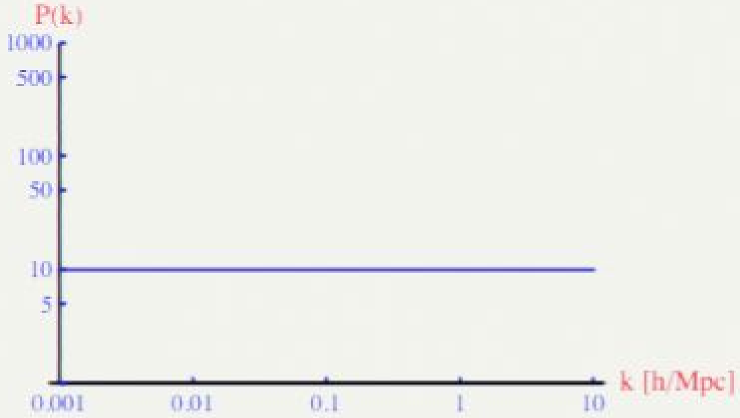
When the wave enter the horizon, dark matter falls in

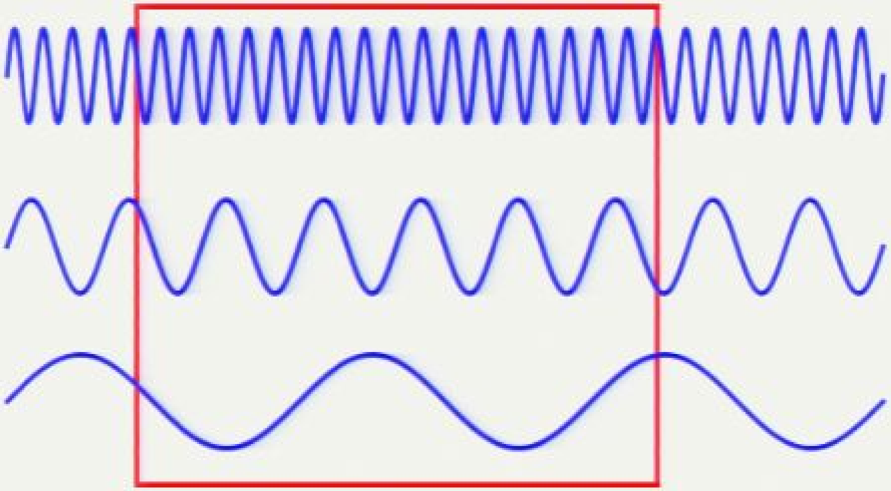
Perturbations grow

$$\Phi \propto \frac{\delta\rho}{\rho}$$

Scale Invariance

Perturbations in gravitational potential. All wavelength, amplitude for each wave is drawn from a gaussian with variance 10^{-5}





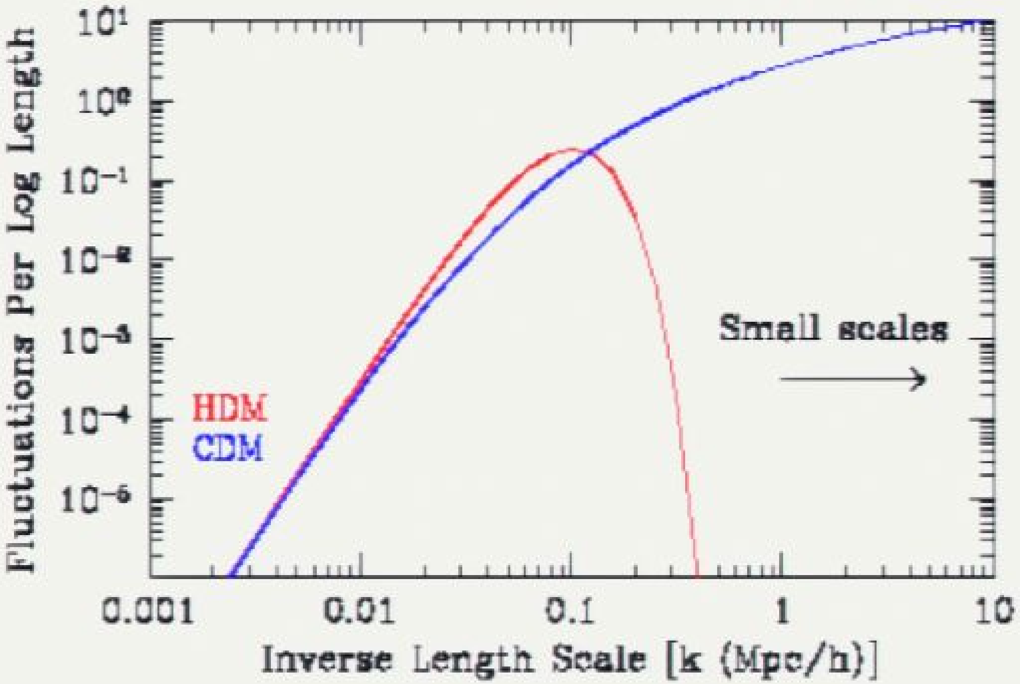
When the wave enter the horizon, dark matter falls in

Perturbations grow

$$\Phi \propto \frac{\delta\rho}{\rho}$$

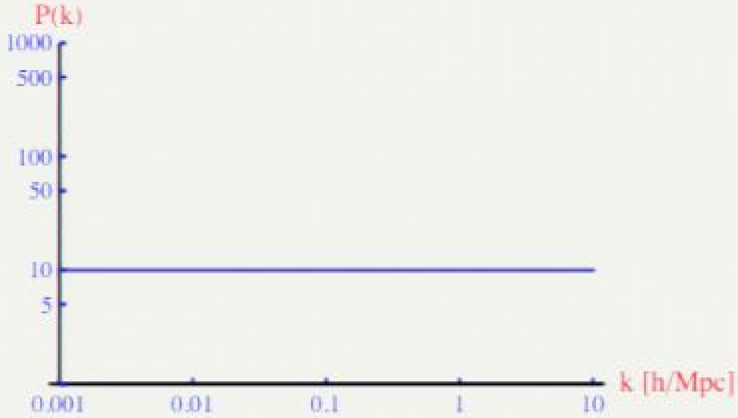
Linear theory: just matter

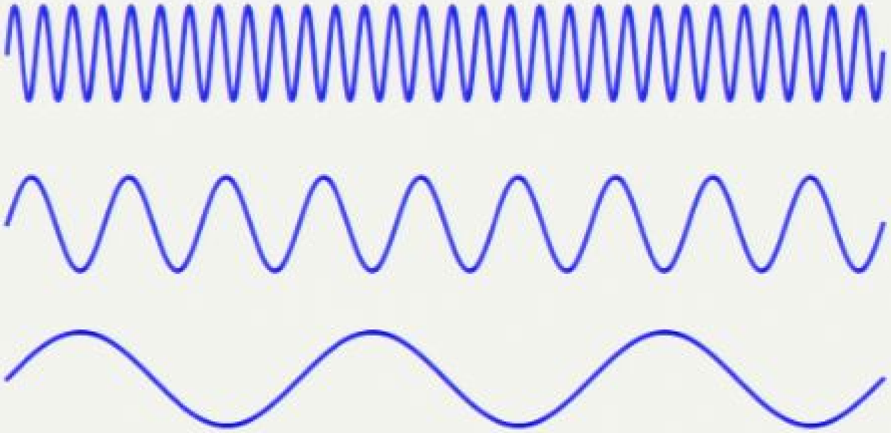
Small scale have grown for longer because they entered first



Scale Invariance

Perturbations in gravitational potential. All wavelength, amplitude for each wave is drawn from a gaussian with variance 10^{-5}





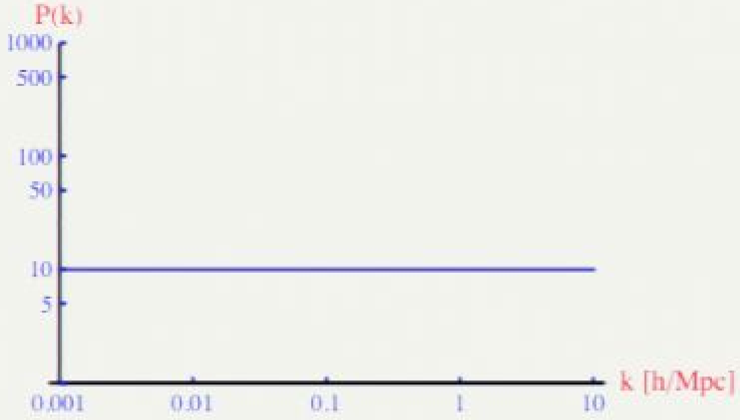
When the wave enter the horizon, dark matter falls in

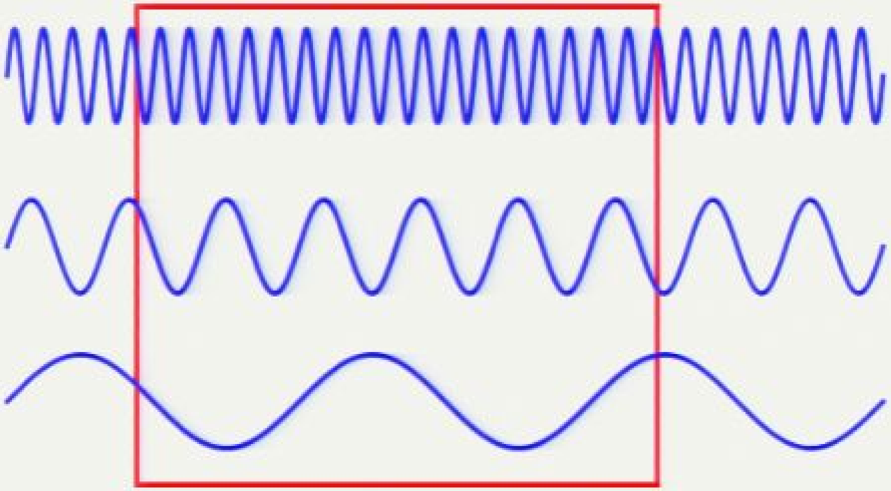
Perturbations grow

$$\Phi \propto \frac{\delta\rho}{\rho}$$

Scale Invariance

Perturbations in gravitational potential. All wavelength, amplitude for each wave is drawn from a gaussian with variance 10^{-5}





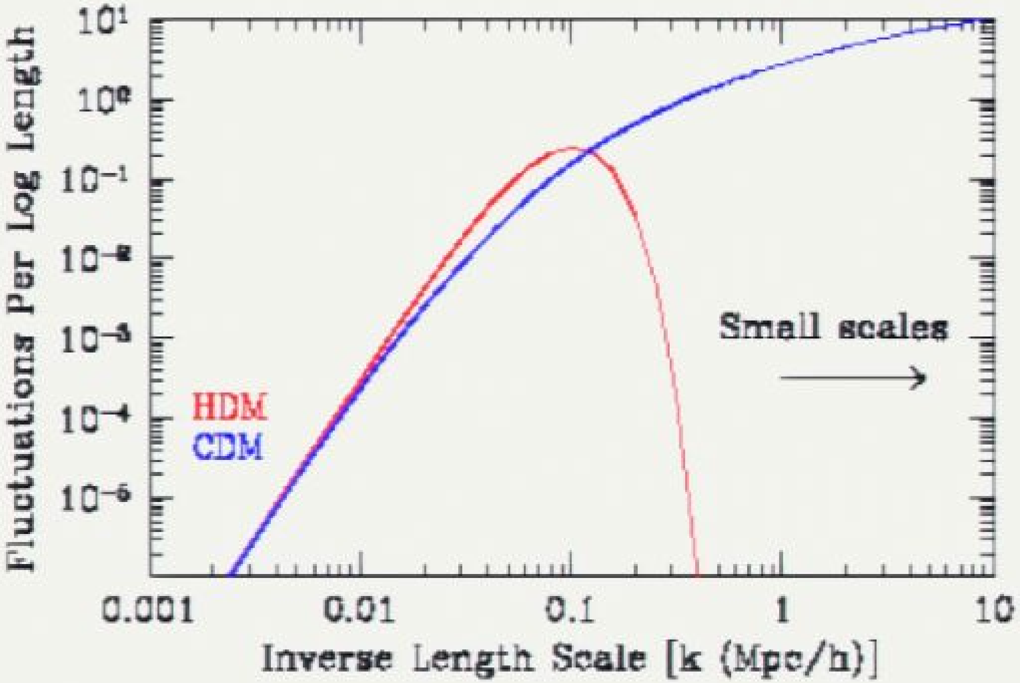
When the wave enter the horizon, dark matter falls in

Perturbations grow

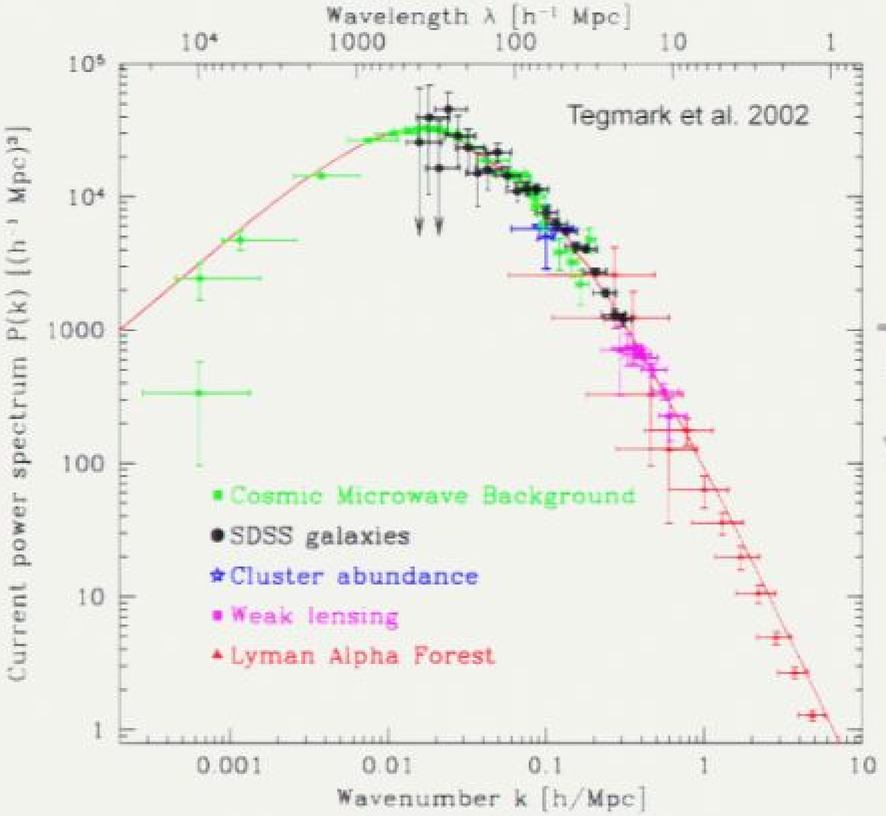
$$\Phi \propto \frac{\delta\rho}{\rho}$$

Linear theory: just matter

Small scale have grown for longer because they entered first



Radiation decreases power



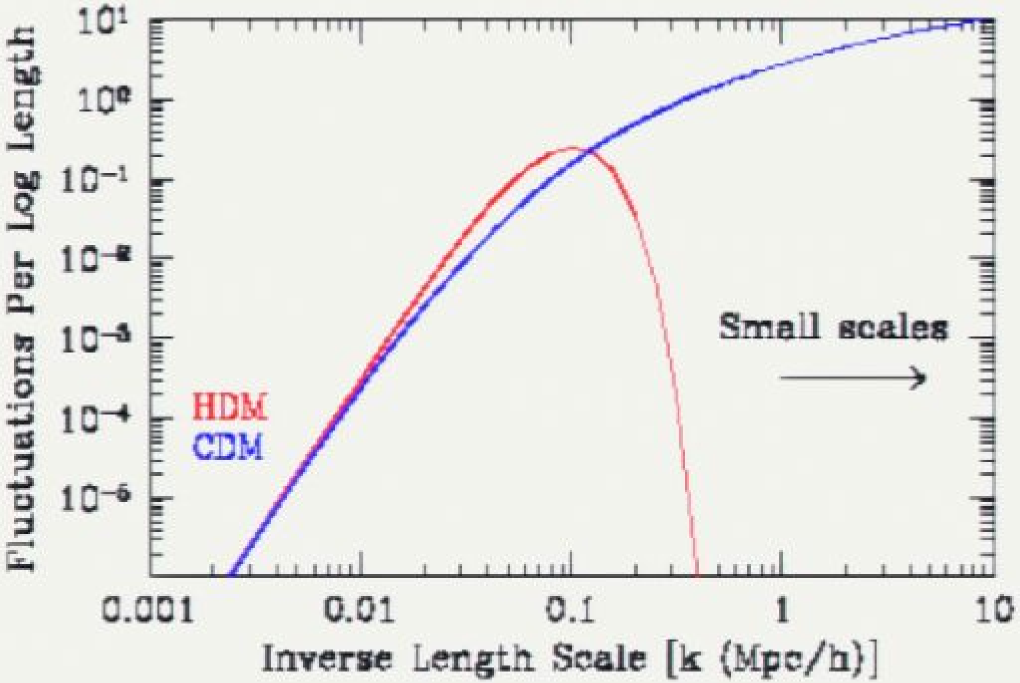
Power is decreased on small scale.

Those modes entered back when radiation dominated pressure decreases

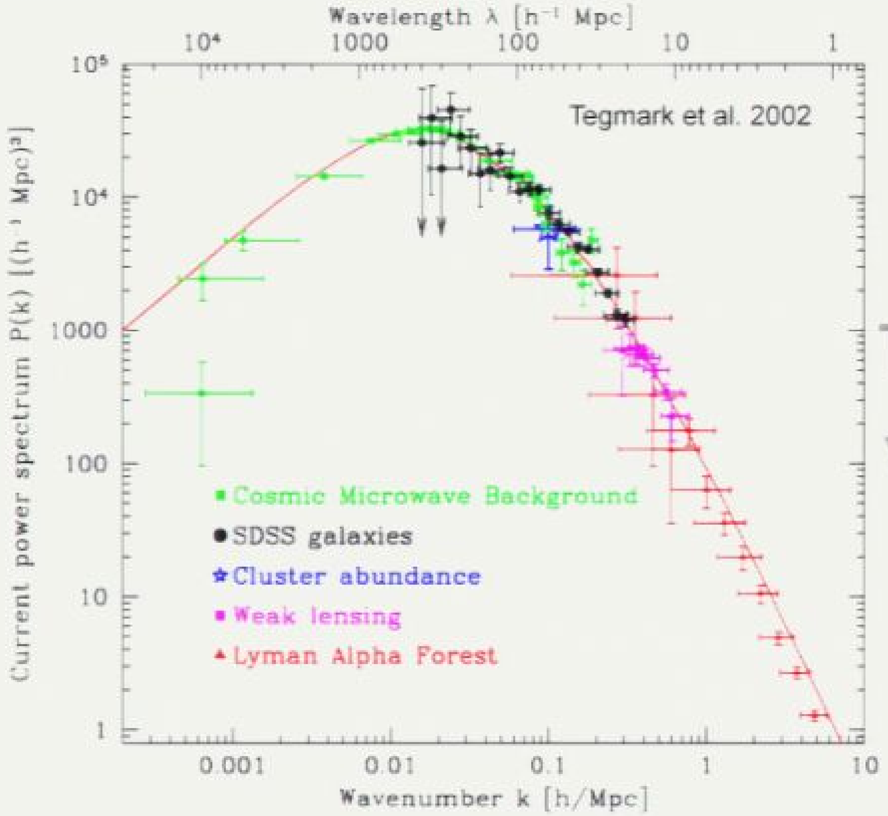
one more step,
we don't see the overall field,
we see collapsed objects

Linear theory: just matter

Small scale have grown for longer because they entered first



Radiation decreases power



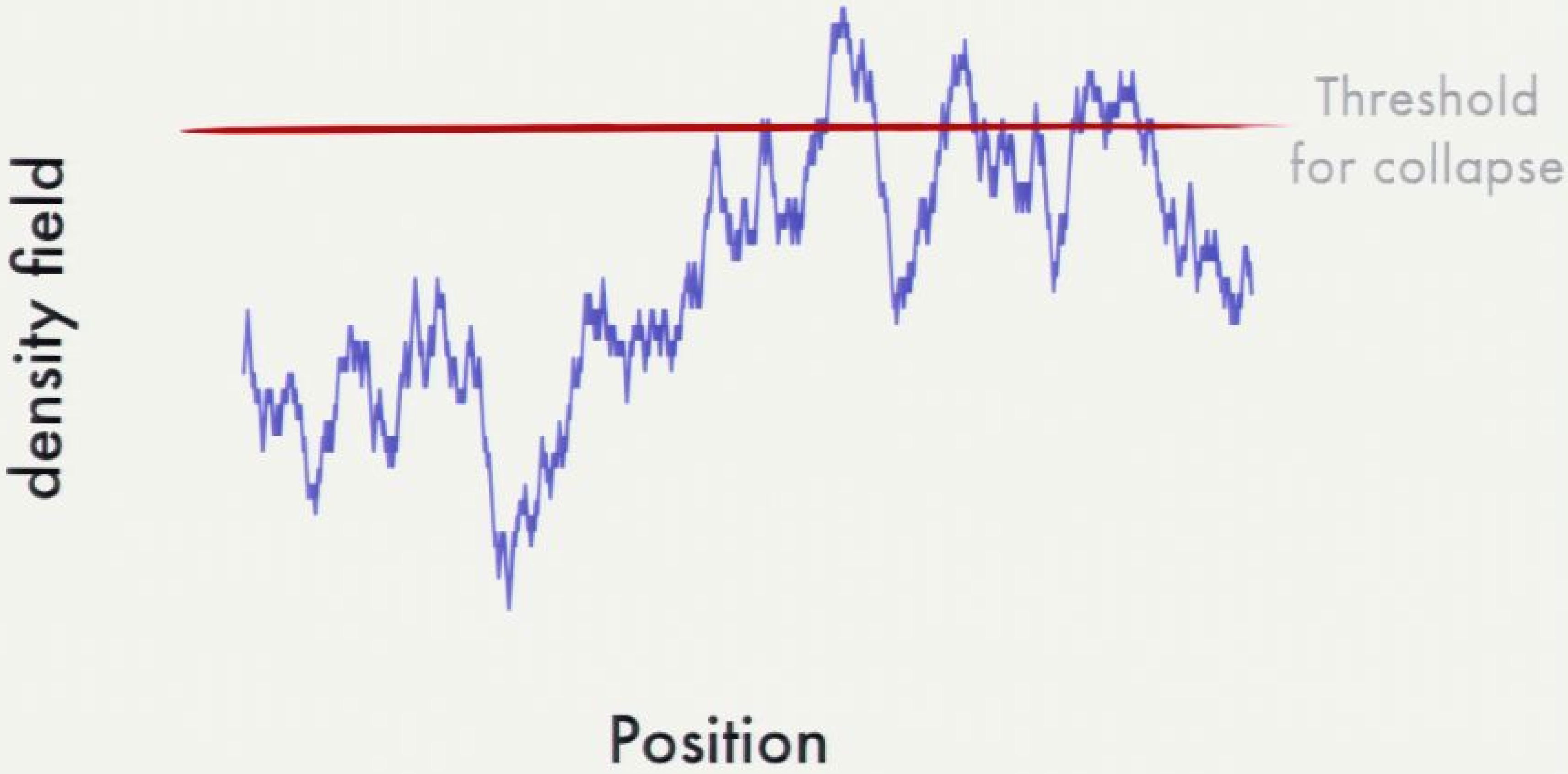
Power is decreased on small scale.

Those modes entered back when radiation dominated pressure decreases

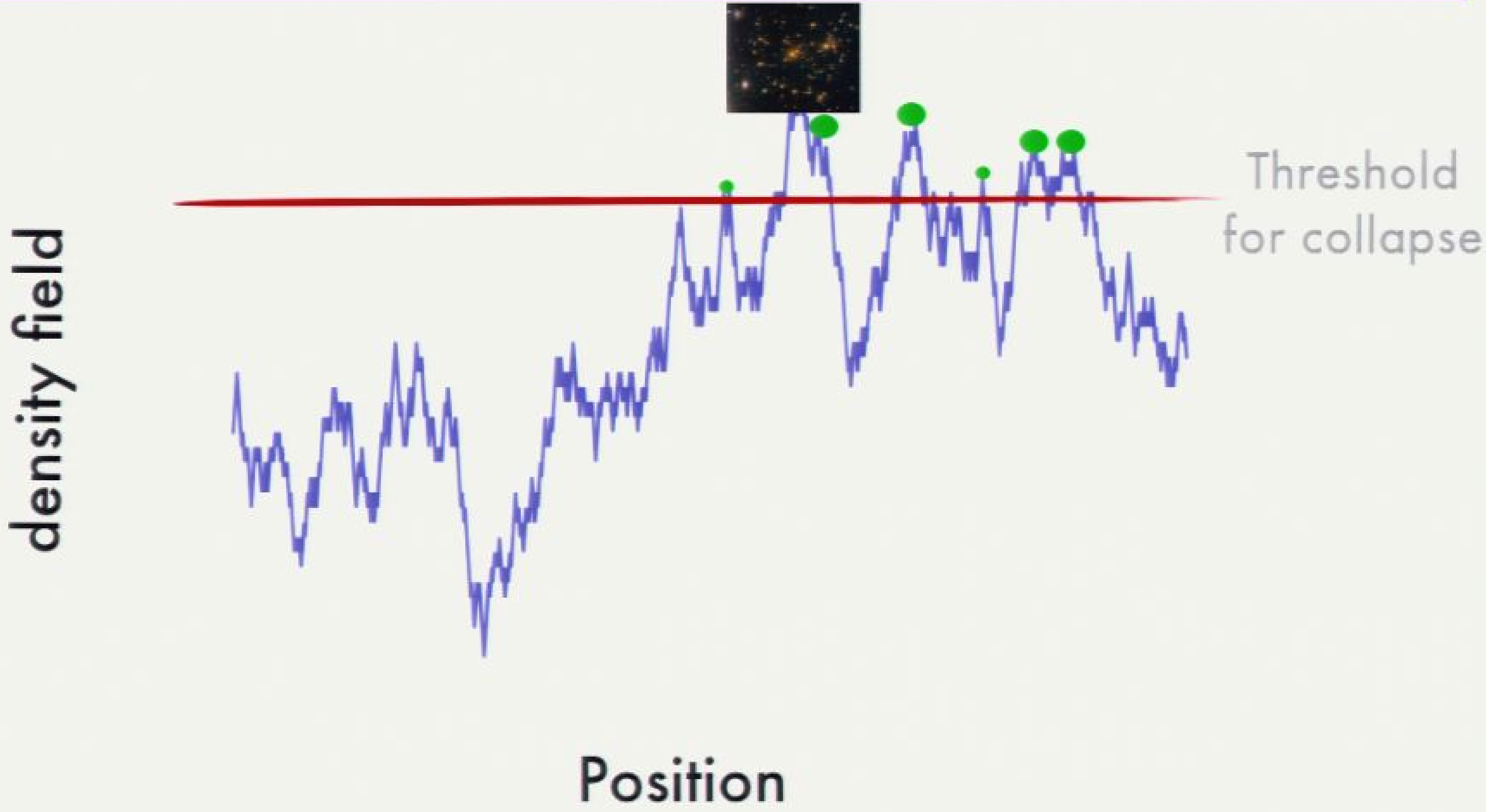
one more step,
we don't see the overall field,
we see collapsed objects

Collapsed Objects

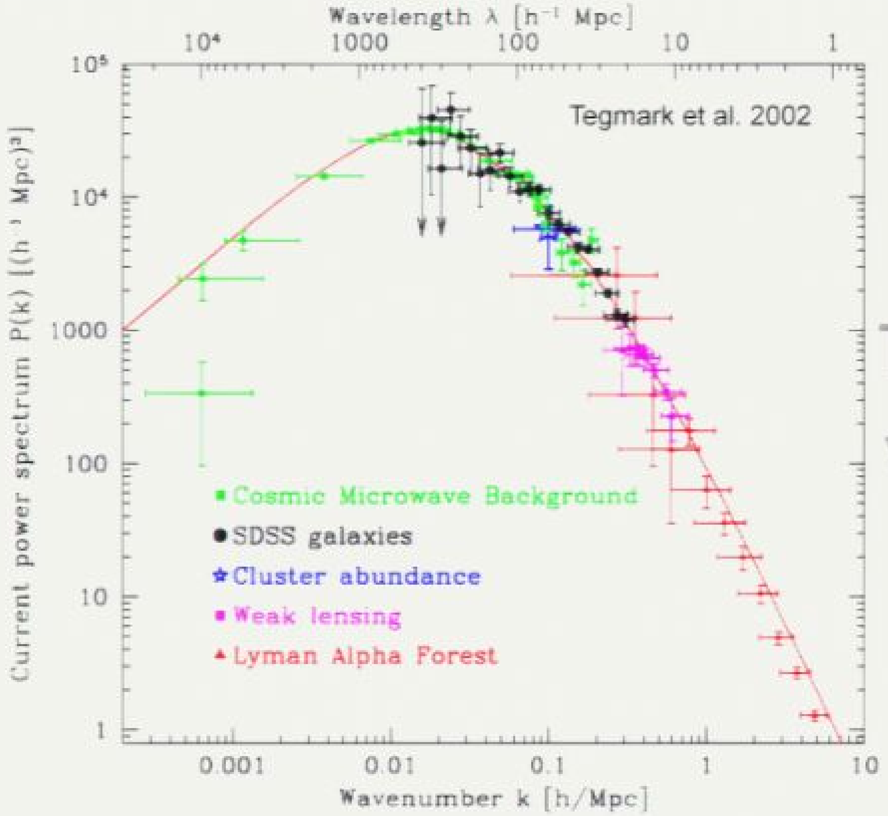
Collapsed Objects



Collapsed Objects



Radiation decreases power



Power is decreased on small scale.

Those modes entered back
when radiation dominated
pressure decreases

one more step,
we don't see the overall field,
we see collapsed objects

Collapsed objects are rare

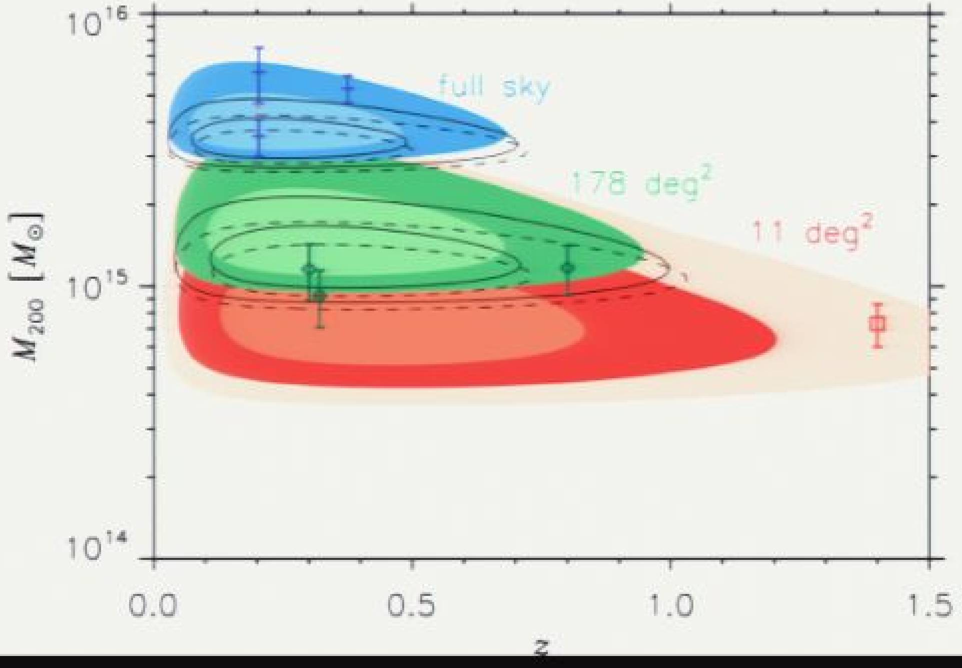
Collapsed objects are coming only from the tail of the probability distribution function

What is the probability of seeing the big objects given our best models for cosmology?

ΛCDM

Collapsed objects are rare

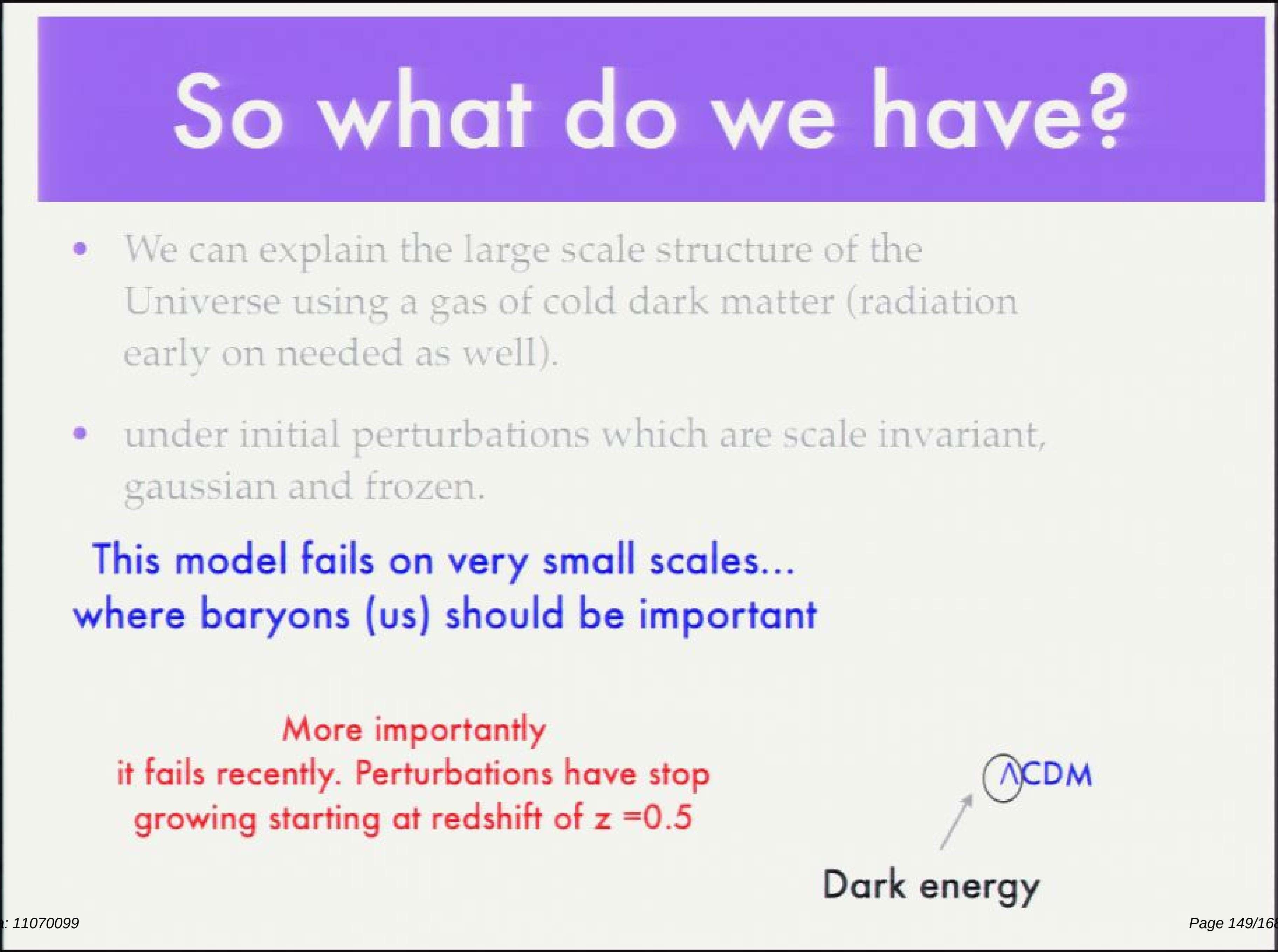
Collapsed objects are coming only from the tail of the probability distribution function



What is the probability of seeing the big objects given our best models for cosmology?

ΛCDM

Holz, Perlmutter



So what do we have?

- We can explain the large scale structure of the Universe using a gas of cold dark matter (radiation early on needed as well).
- under initial perturbations which are scale invariant, gaussian and frozen.

This model fails on very small scales...
where baryons (us) should be important

More importantly
it fails recently. Perturbations have stop
growing starting at redshift of z =0.5

ΛCDM

Dark energy

So what do we have?

- We can explain the large scale structure of the Universe using a gas of cold dark matter (radiation early on needed as well).
- under initial perturbations which are scale invariant, gaussian and frozen.

This model fails on very small scales... where baryons (us) should be important

More importantly
it fails recently. Perturbations have stop
growing starting at redshift of z =0.5

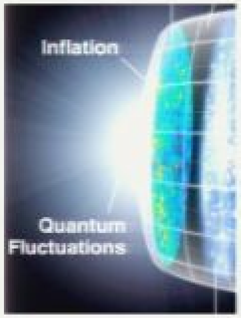
ΛCDM

Dark energy

Why? Why? Why?

- Why gaussian initial conditions?
- Why scale invariant?
- Why frozen on superhorizon scales?

Inflation



- era of dark energy early (very high energy)
- Spacetime is in accelerated expansion very very fast
- small quantum fluctuation are amplified and their wavelength stretched
- when inflation ends, the perturbations have been laid down.

Start with a smooth patch

dark energy Λ

$$l \sim [10^{-25}cm, 10^{-29}cm]$$

many models smaller than that

bound from data

Inflate!

Our horizon, anything outside that circle is unobservable unless it comes back in

Quantum fluctuations (perturbations of the metric) are amplified and grow

Cooling

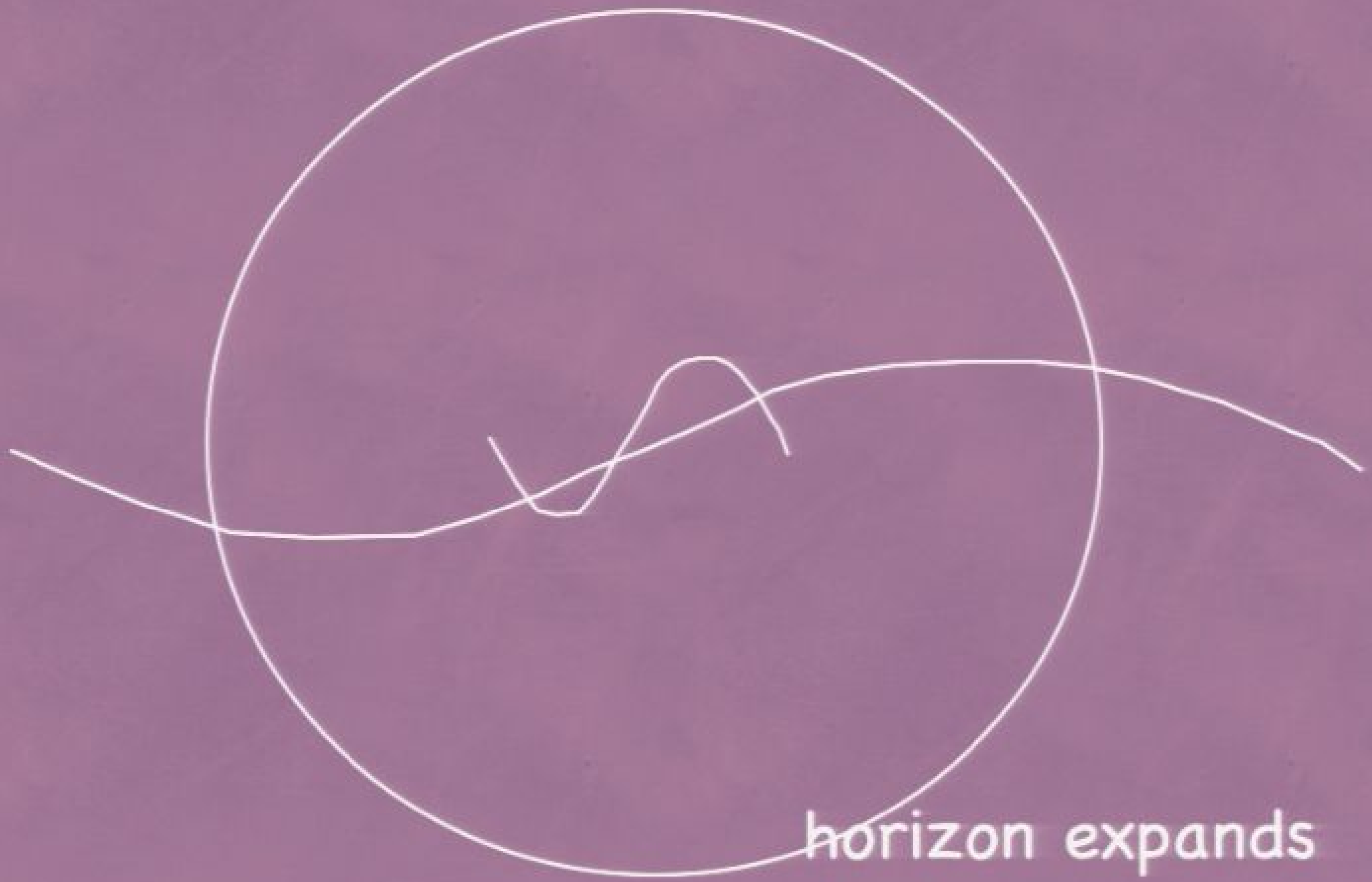
horizon expands
perturbations come back in
the horizon

Quantum fluctuations
(perturbations of the metric)
are amplified and grow

Cooling

horizon expands
perturbations come back in
the horizon

Cooling



horizon expands
perturbations come back in
the horizon

Dark matter

fall into potential well

Structure forms

Conclusion

- the biggest things are big

Conclusion

- but don't worry, we have a theory

Conclusion

- but don't worry, we have a theory

ΛCDM

Conclusion

- but don’t worry, we have a theory

ΛCDM

And its great because it works well
and because it may be wrong

- but don't worry, we have a theory

ΛCDM

And its great because it works well
and because it may be wrong

Conclusion

- but don't worry, we have a theory

ΛCDM

And its great because it works well
and because it may be wrong