Title: First stars and dark matter

Date: Jun 08, 2008 09:30 AM

URL: http://pirsa.org/08060015

Abstract:

Outline

- Briefly summarize current understanding of 1st formation in standard CDM.
- 1st formation in WDM.

- First stars: first generation of stars, PoP III stars, primordial stars

  They were formed out of primordial gas -- without metals and dust

Environment different from normal star formation today!

Why we care the first stars and its IMF so much?

- The first generation of starts created the first light to reionize our Universe and created heavy elements required for the subsequent normal star formation and galaxy assembly.
- Metal production is sensitive to IMF.
  - [8, 25] solar mass SNE exploration and a neutron stars.
  - [25, 40] Type II SNE and a BH.
  - [40, 140] collapse into BH directly.
  - [140, 260] pair-instability SNE.
  - [260--] collapse into a massive BH directory.

Woosley et al.

Simulate the formation of the first stars from first principle

- Known Cosmological parameters(?)
- Reproduce the growth of structure in the universe with computer
- Solve thermal history and non-equilibrium chemistry of primordial gas

Gas cooling at low temperature

- At T<10000k, H2 is the main coolant to dispose primordial gas entropy:
- Formation of H2
  - H_2^+ channel , dominates at z>200

$$H^+ + H \rightarrow H_2^+ + \gamma$$
$$H_2^+ + H \rightarrow H_2 + H^+$$

  - H- channel, dominates at z<200 and $N_H < 10^8 cm^{-3}$

$$H + e^- \rightarrow H^- + \gamma$$
$$H^- + H \rightarrow H_2 + e^-$$

  - 3 body reaction, very rapid reaction, dominates

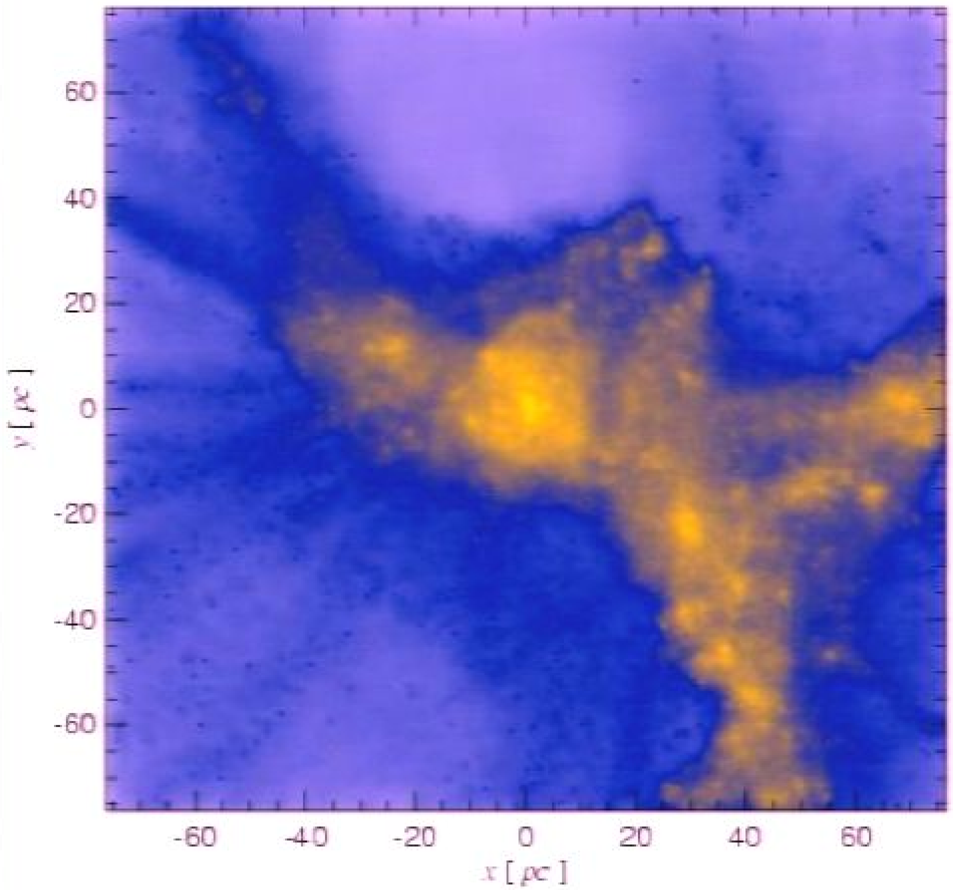
$N_H > 10^8 cm^{-3}$

$$H + H + H \rightarrow H_2 + H$$
$$H + H + H^2 \rightarrow H_2 + H_2$$

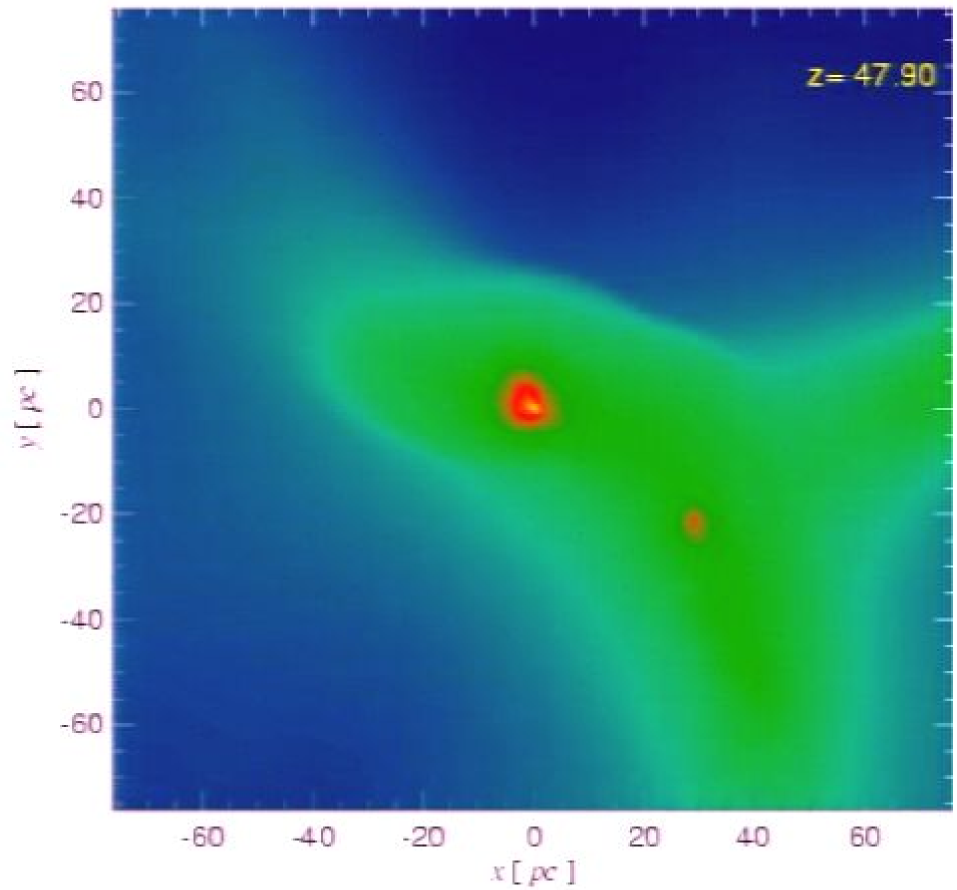
A general picture

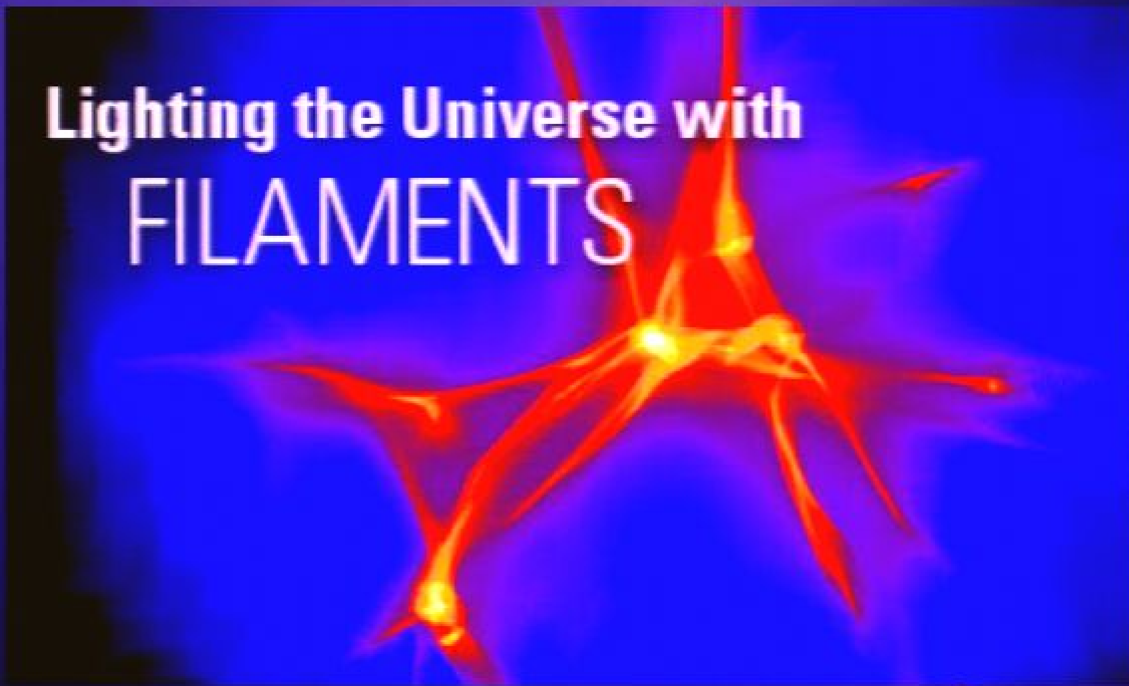
- Cosmological recombination at z ~1000.
- Nonlinear structure formation and assembly of dark halo.
- Virialization of 10^5 solar mass halos and H2 formation.
- Molecular cloud formation at the center of DM halos.
- Runaway collapse when a cloud gets large enough. (people called star formation).
- Collapsing core *does not fragment*, but forms a single massive star (but see Freese, Gondolo & Spolyar for a different story).

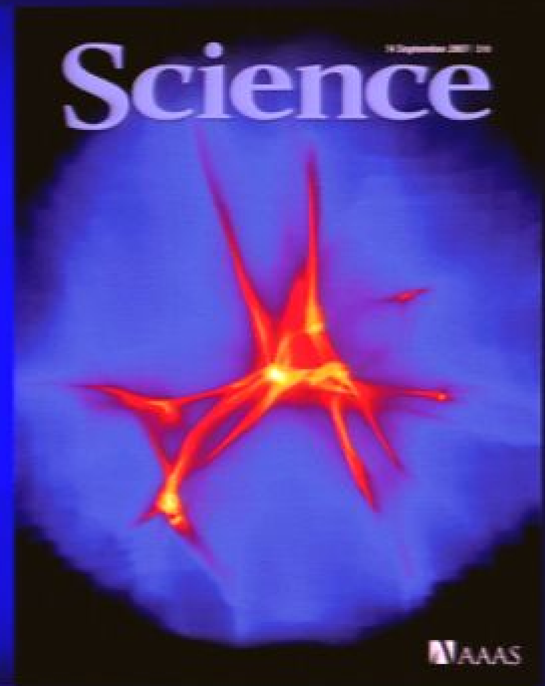
Dark matter



Gas density







Do properties of the first stars depend on nature of dark matter particles?

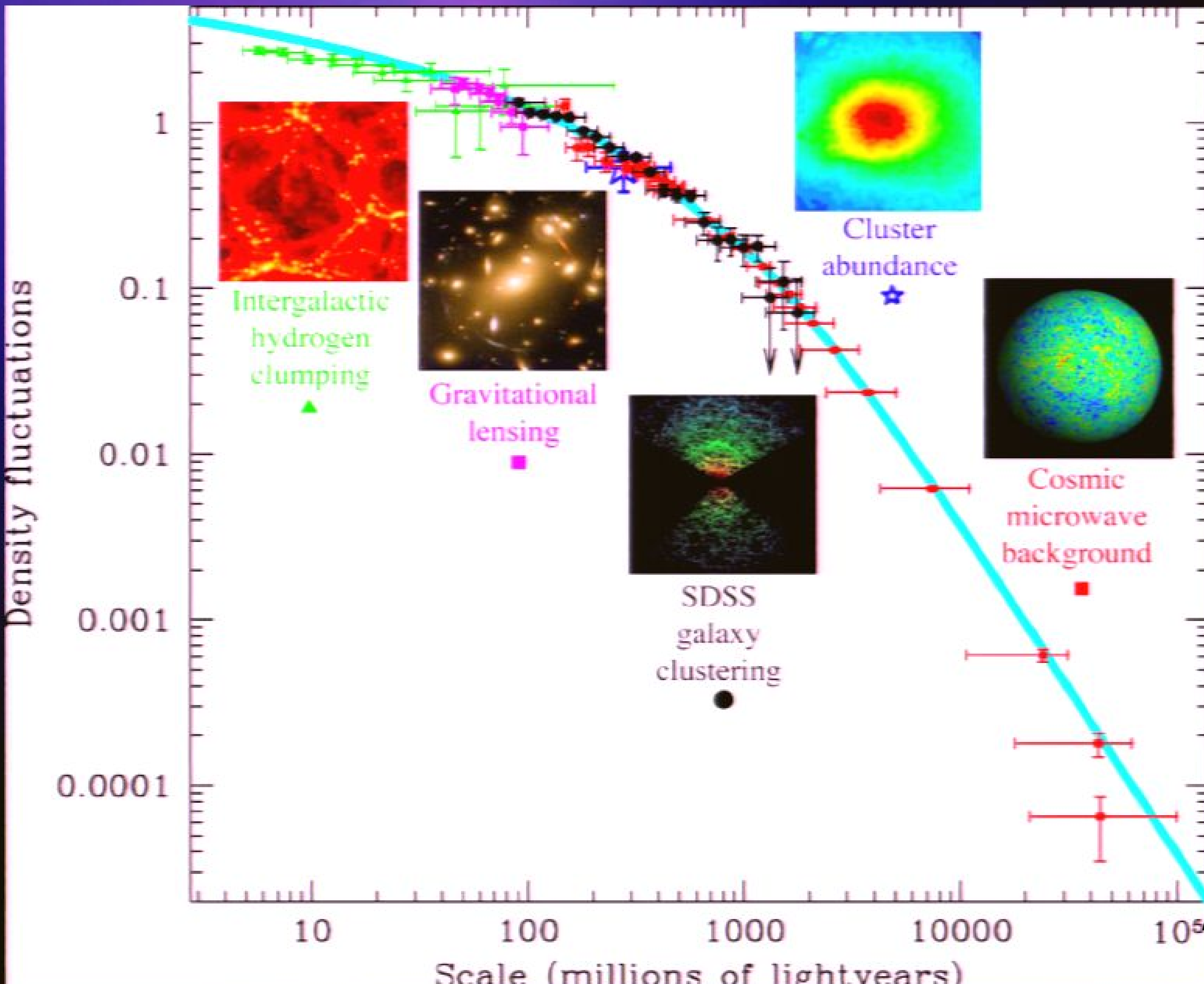
- Yes.
- Location.
- Formation path.
- Possibly IMF.

Gao & Theuns, 2007, Science, 317, 1527

Primordial star formation in WDM model

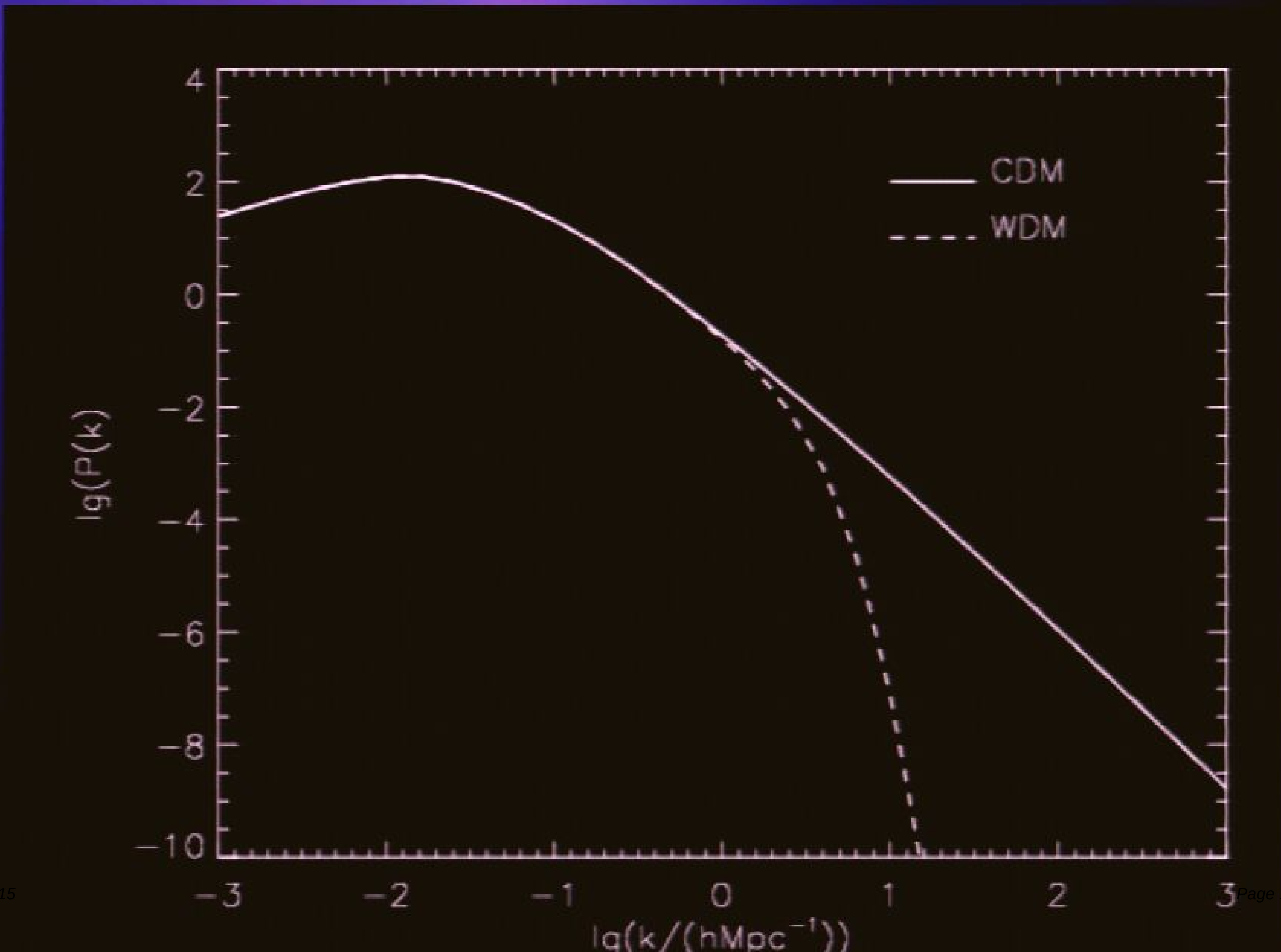
- Why warm dark matter model?

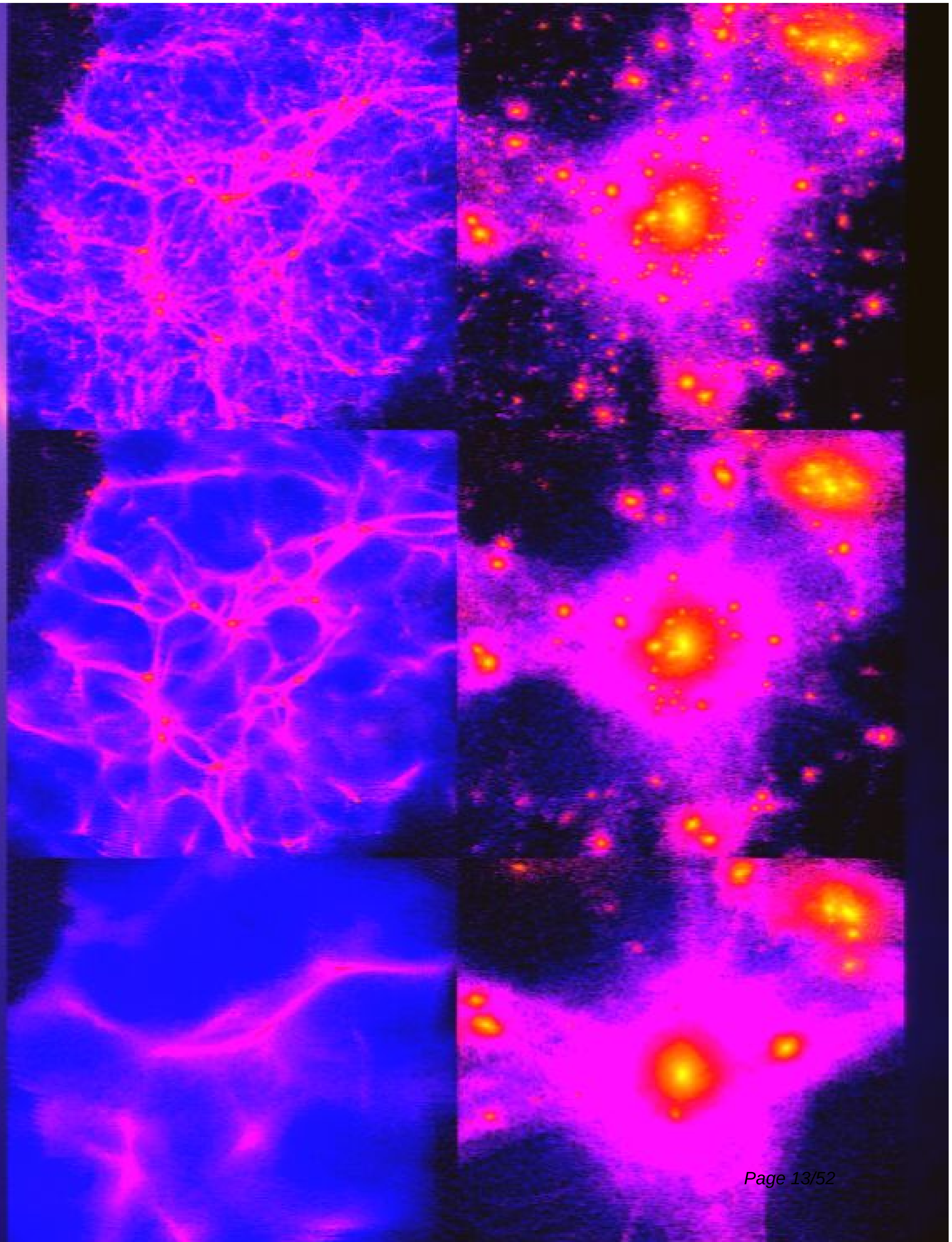
1. Small scale power spectrum of Universe is poorly constrained, so why not?
2. Central cusp of dwarf galaxy?.
3. No convincing model to explain the abundance of satellite in galaxies in the Local Group with CDM.
4. WDM is as good as CDM to interpret large scale distribution of galaxies.



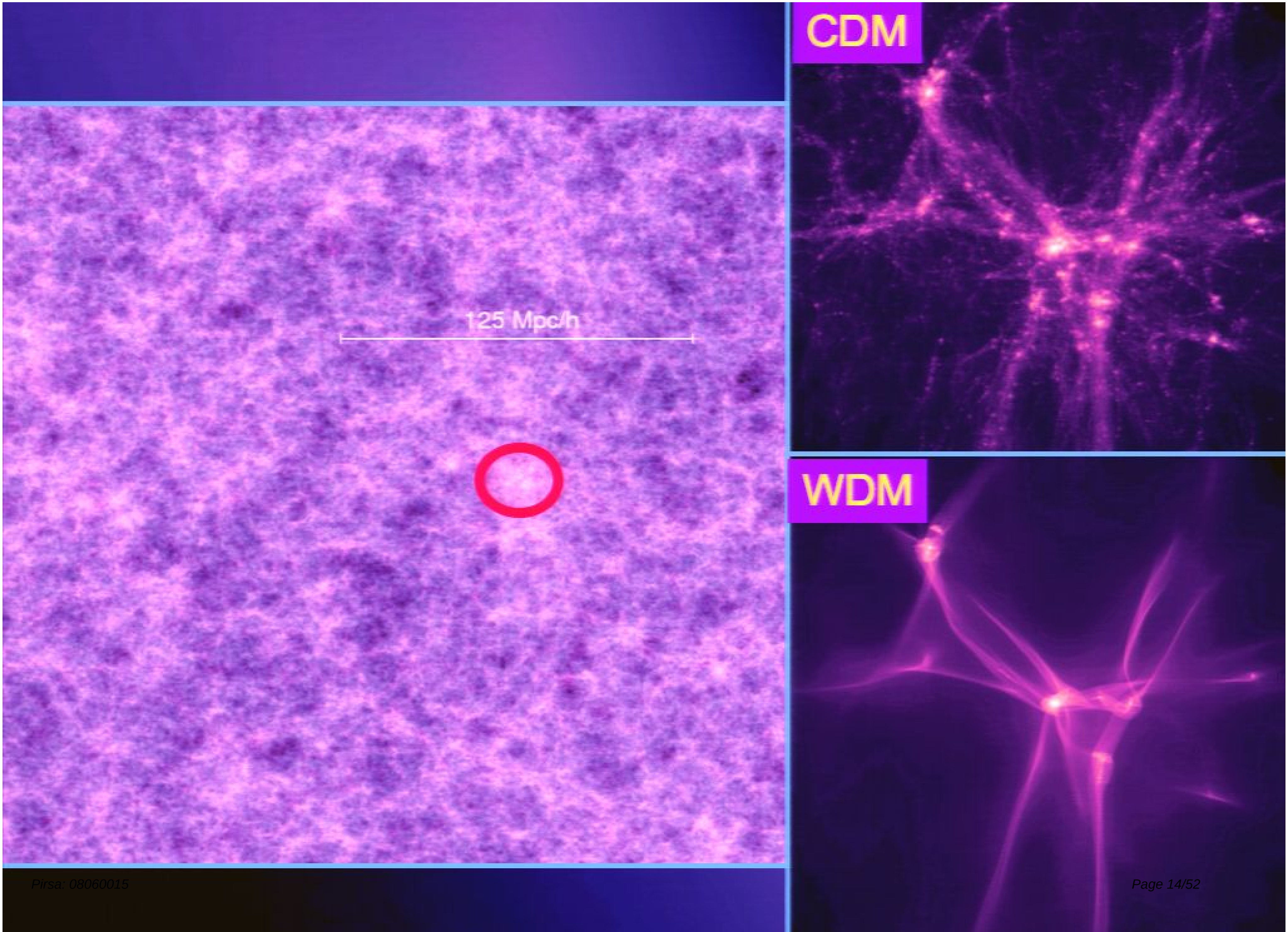
Density fluctuations
1
0.1
0.01
0.001
0.0001
10
100
1000
10000
Scale (millions of lightyears)
Intergalactic hydrogen clumping
Gravitational lensing
SDSS galaxy clustering
Cluster abundance
Cosmic microwave background

Power spectrum----CDM vs. WDM

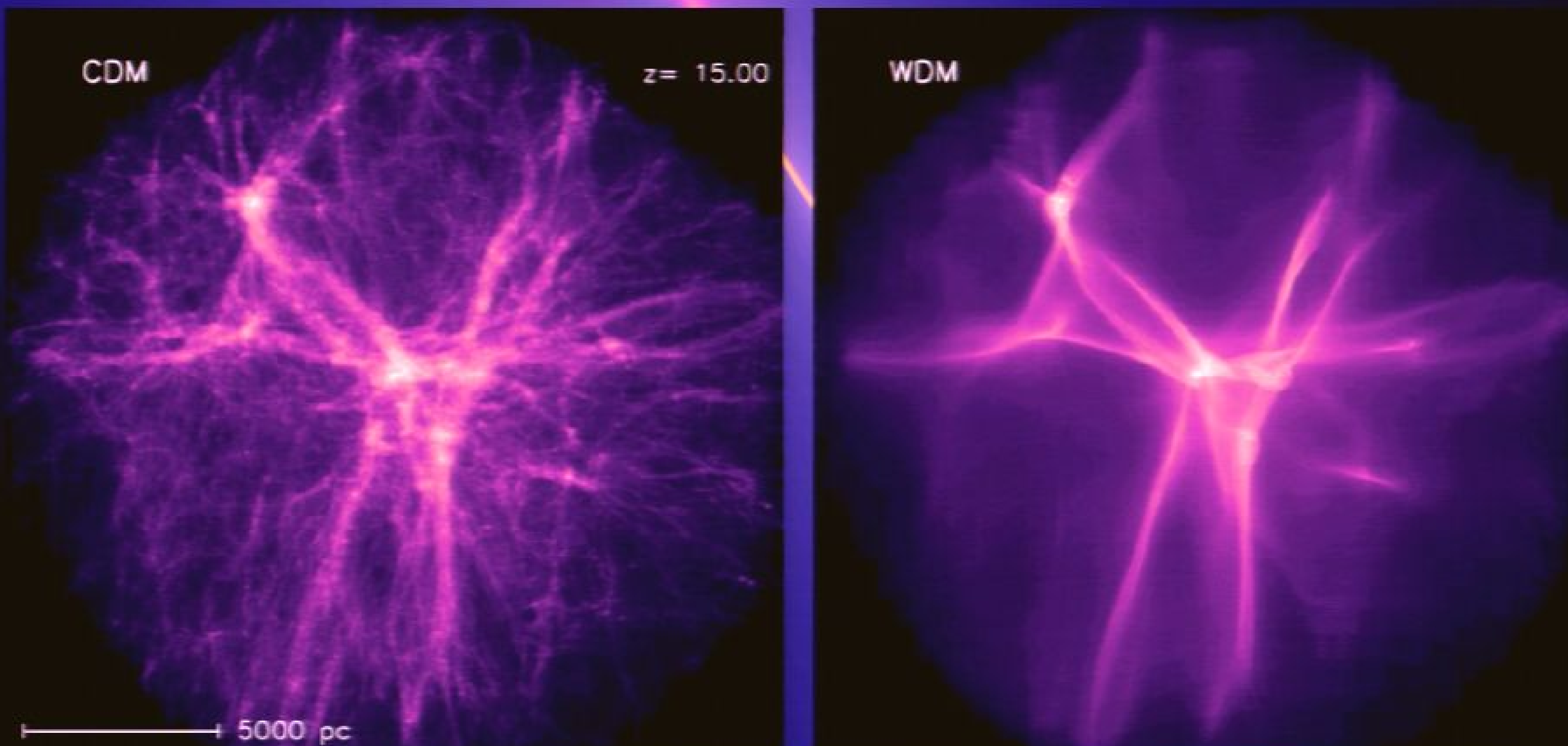




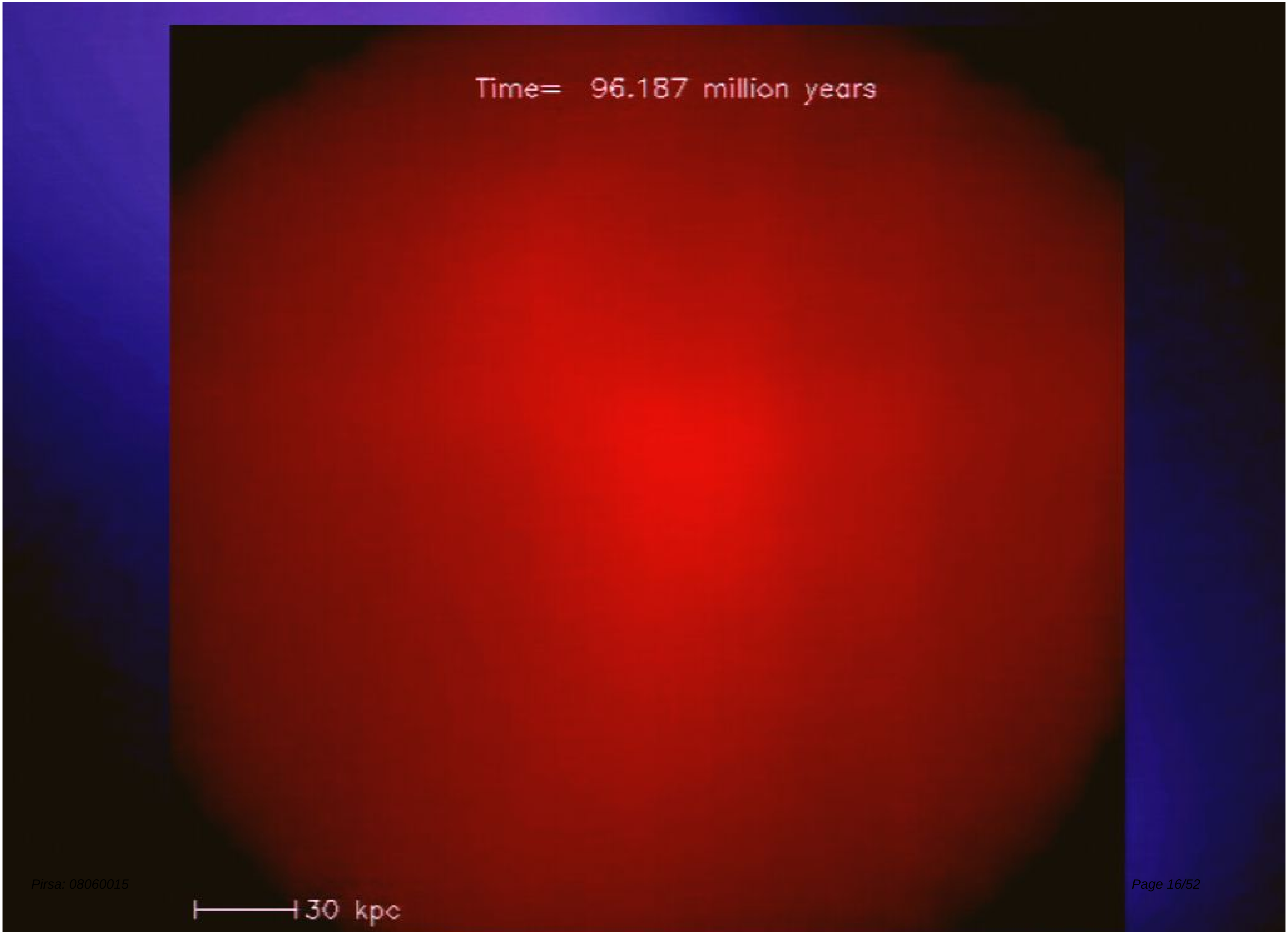
Simulations of Moore et al.

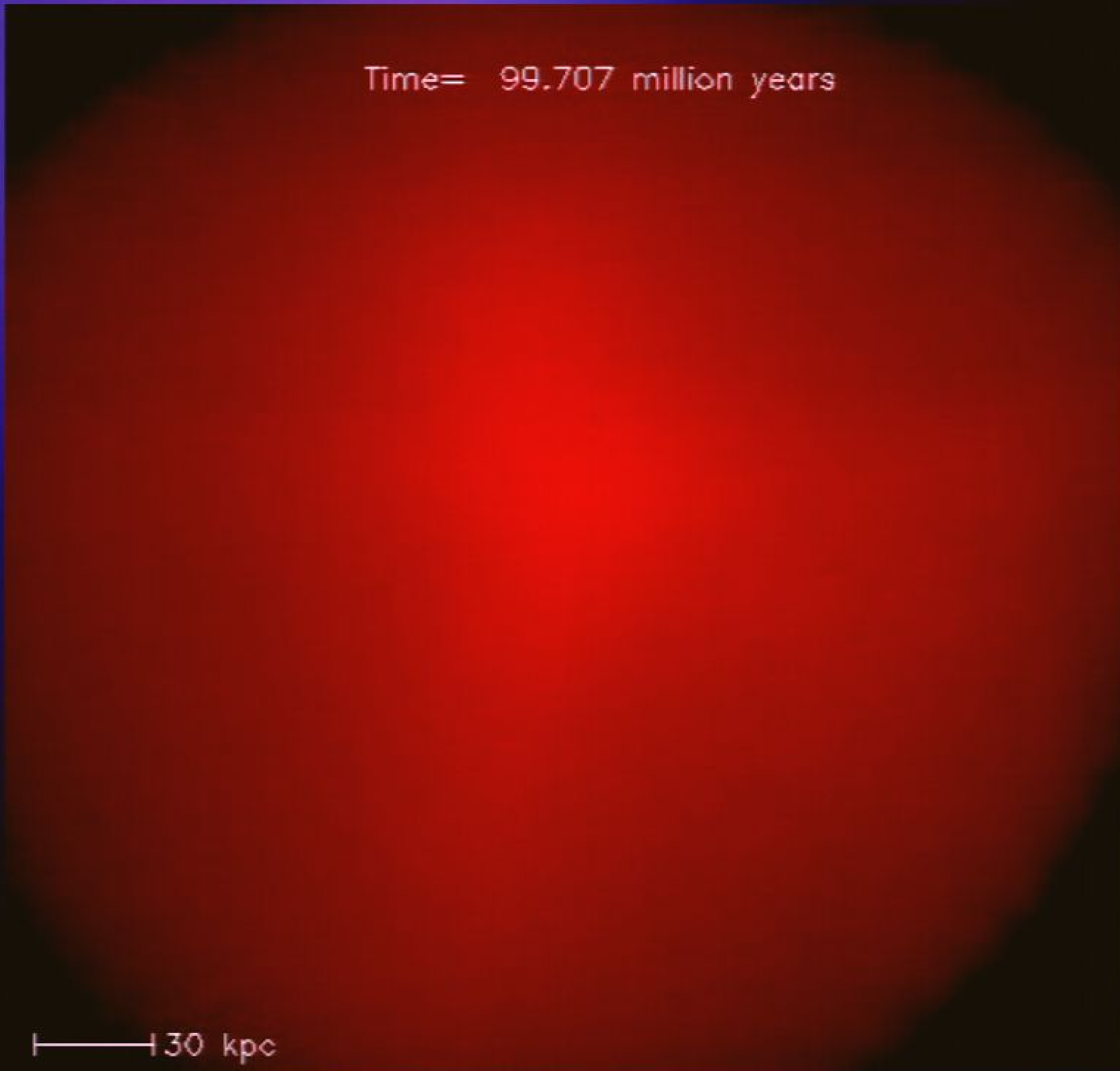

125 Mpc/h
CDM
WDM

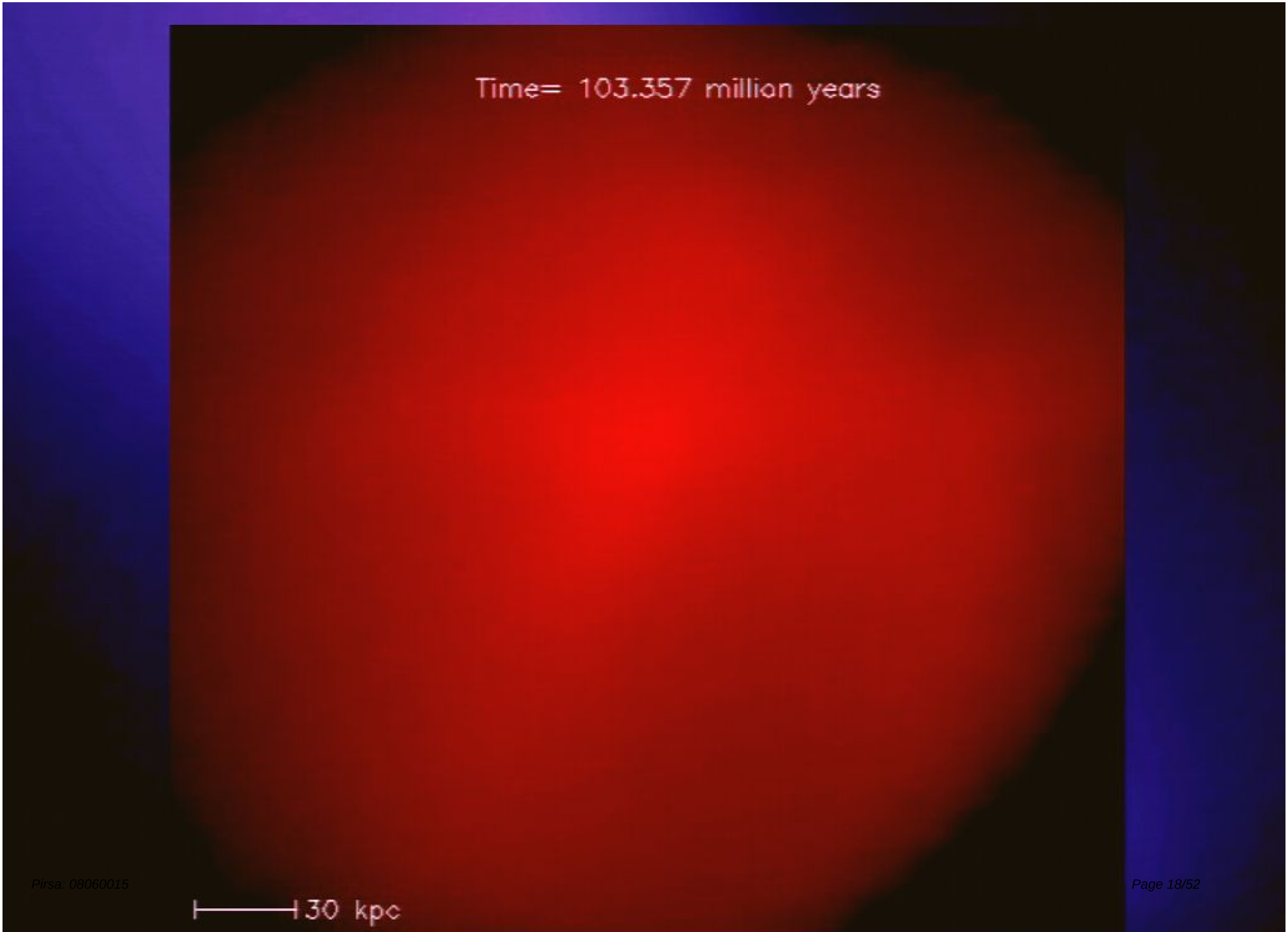
Structure formation is suppressed below dark matter particle free streaming scale.

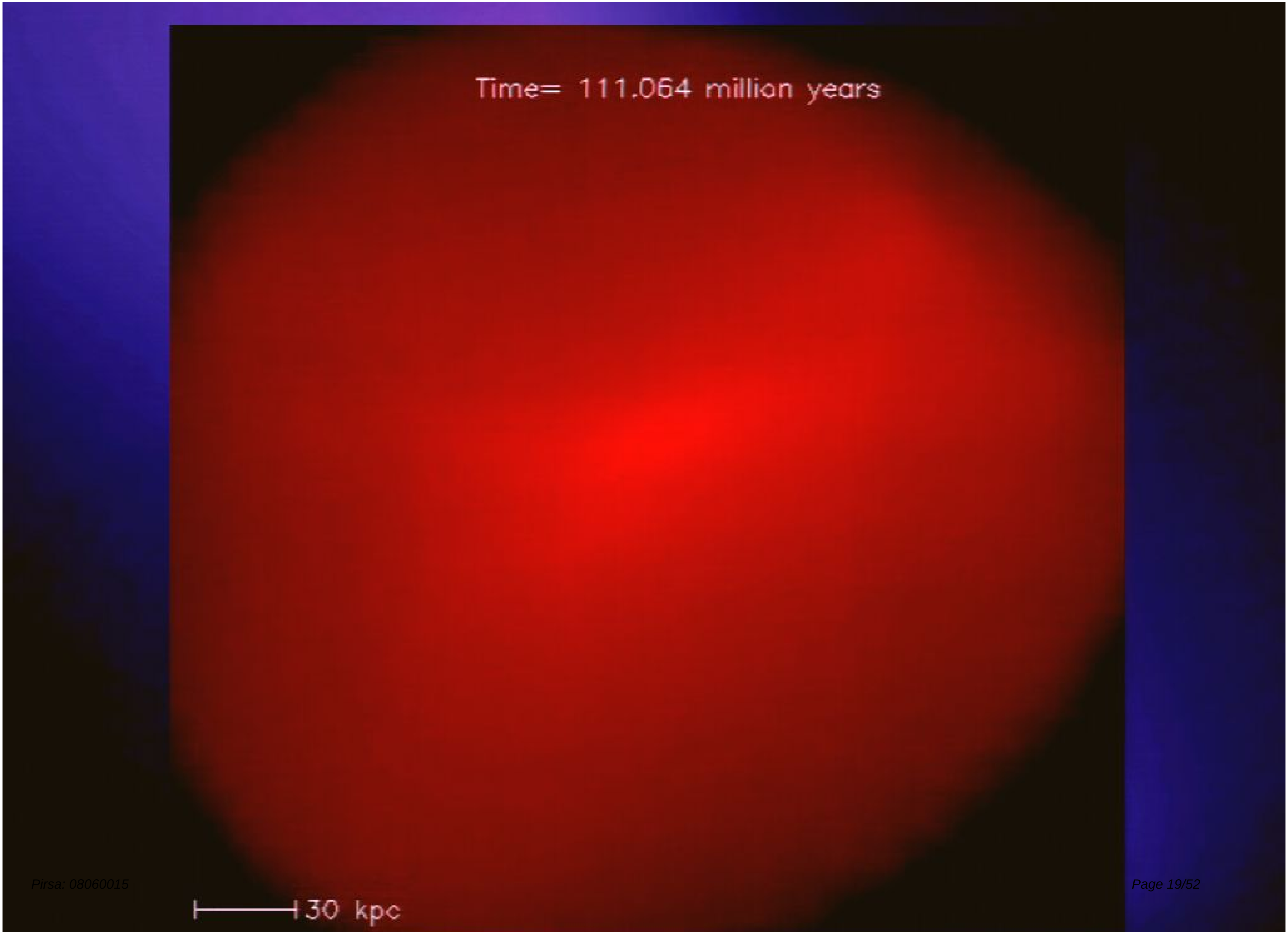


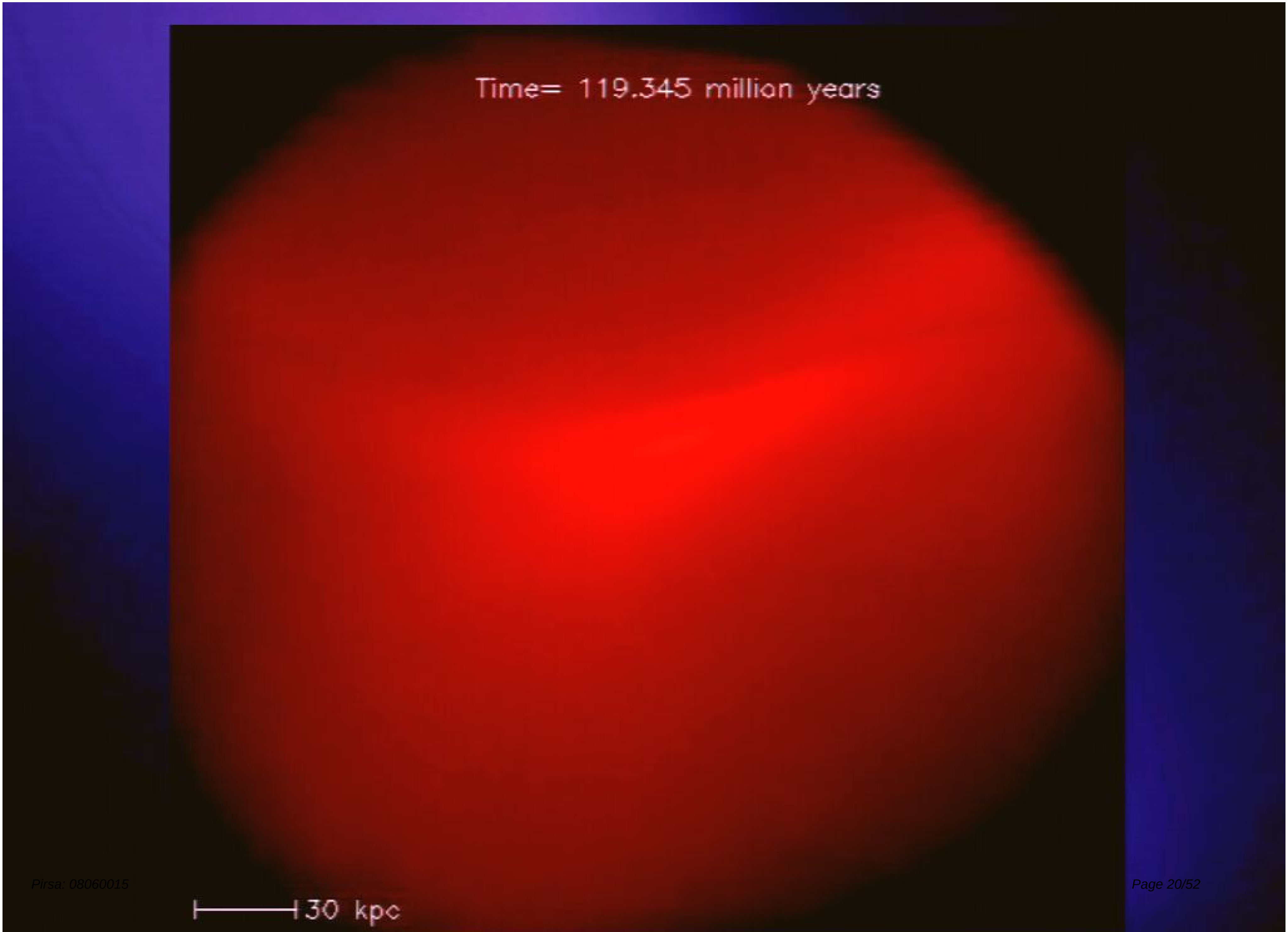
$M_{dm} = 3$ kev, $M_{fs} \sim 3 \times 10^8$ solar mases


Time= 96.187 million years
30 kpc

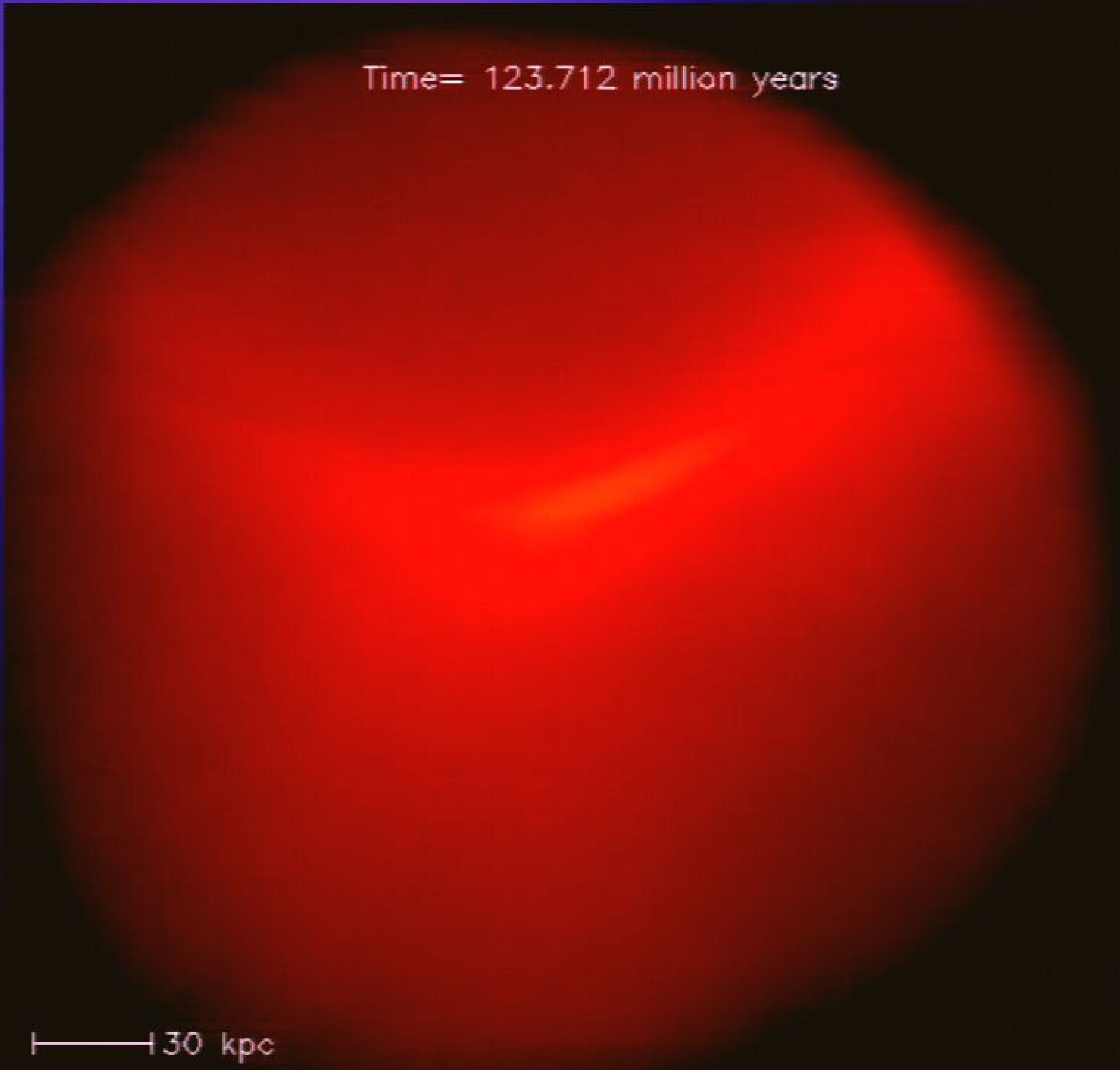

Time= 99.707 million years
30 kpc

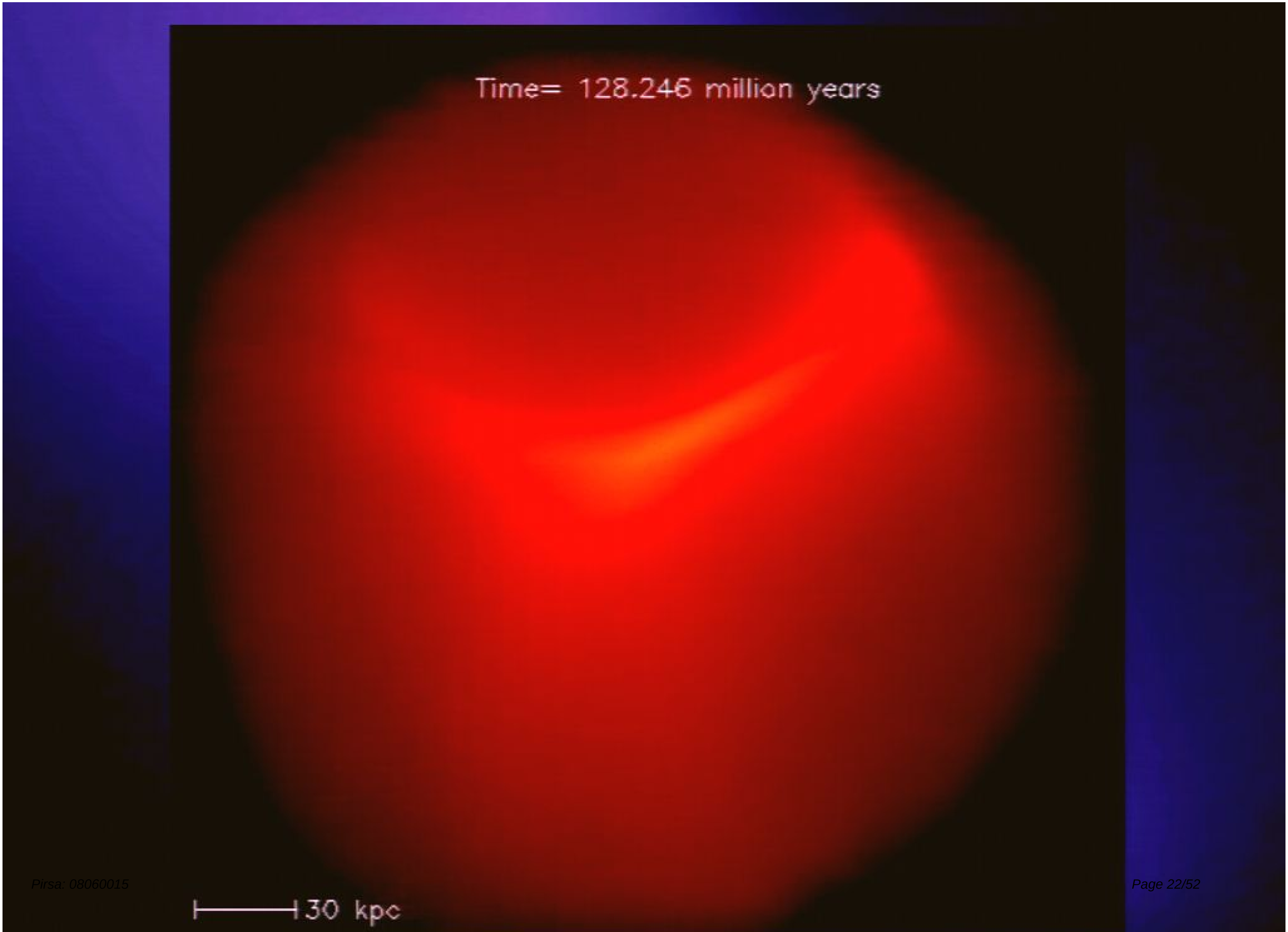

Time= 103.357 million years
30 kpc

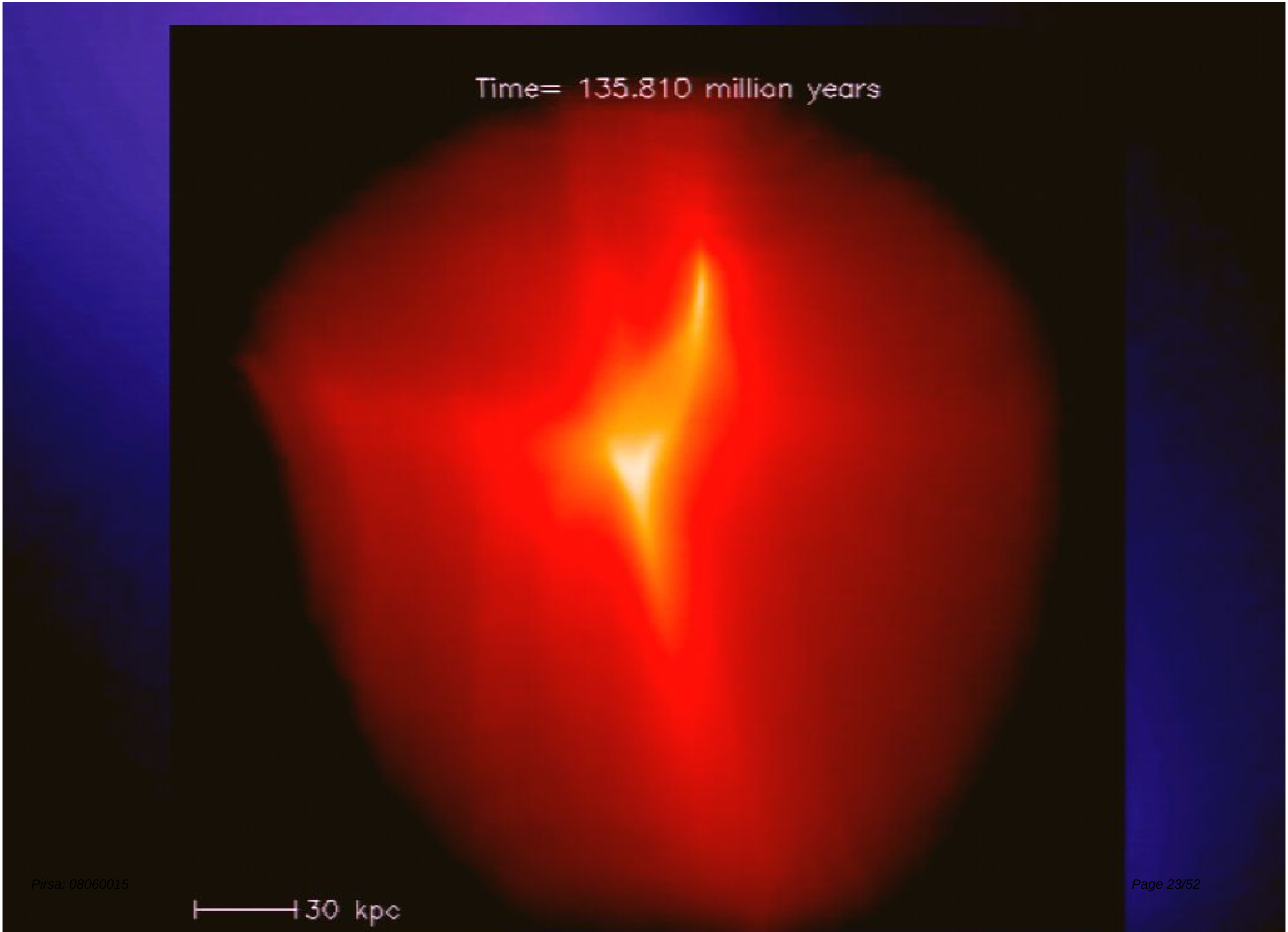

Time= 111.064 million years
30 kpc

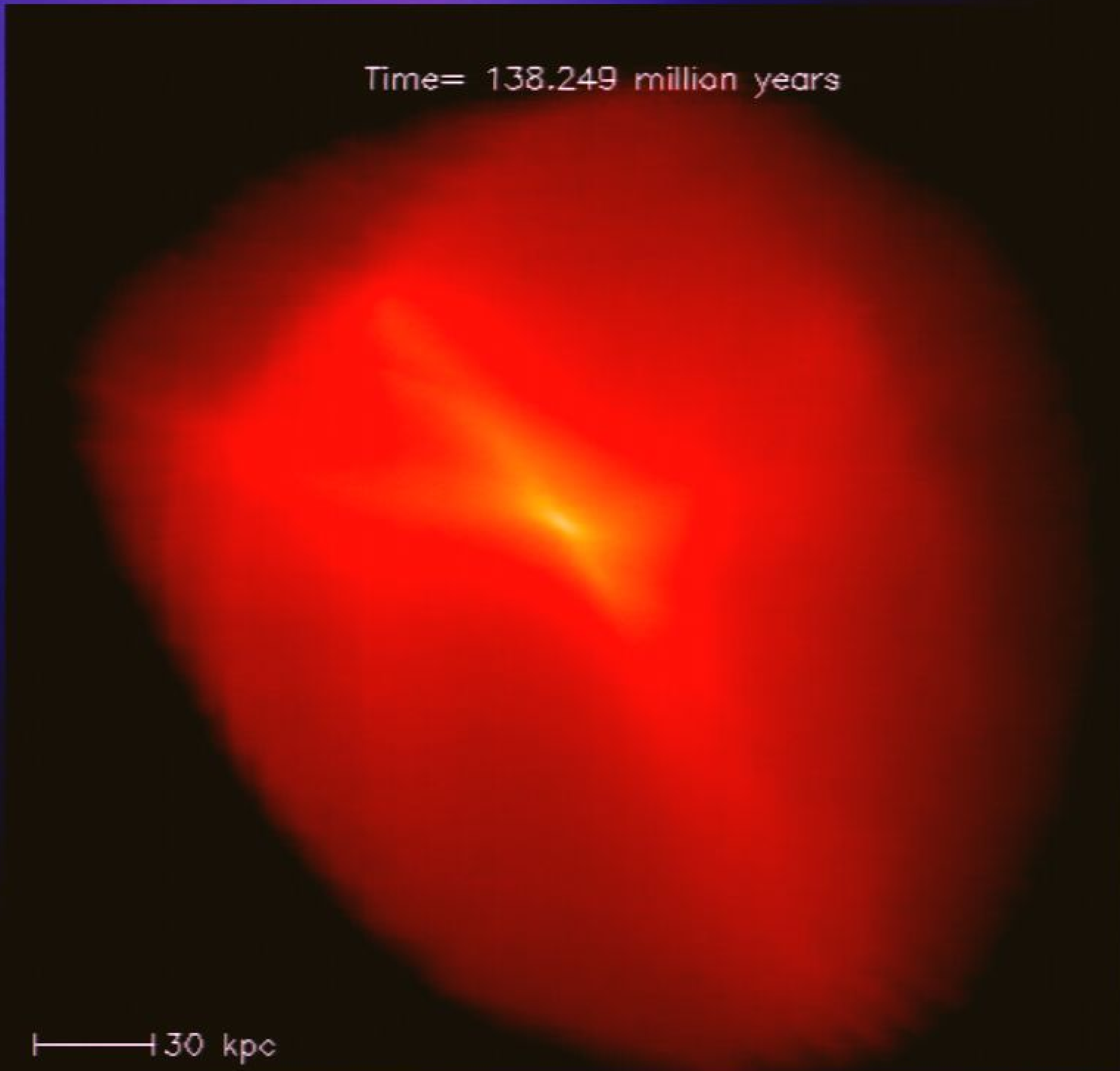


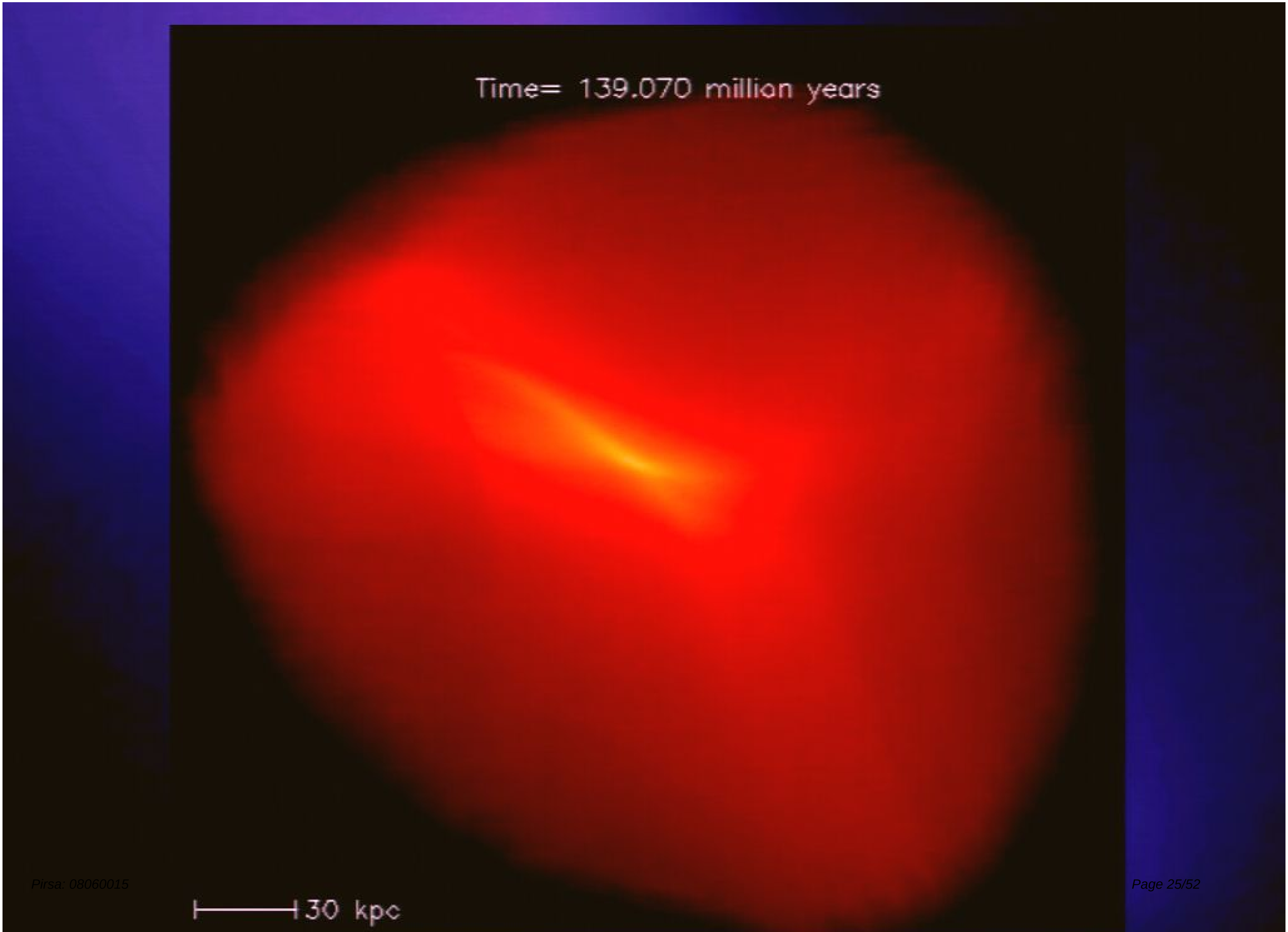
Time= 119.345 million years
30 kpc

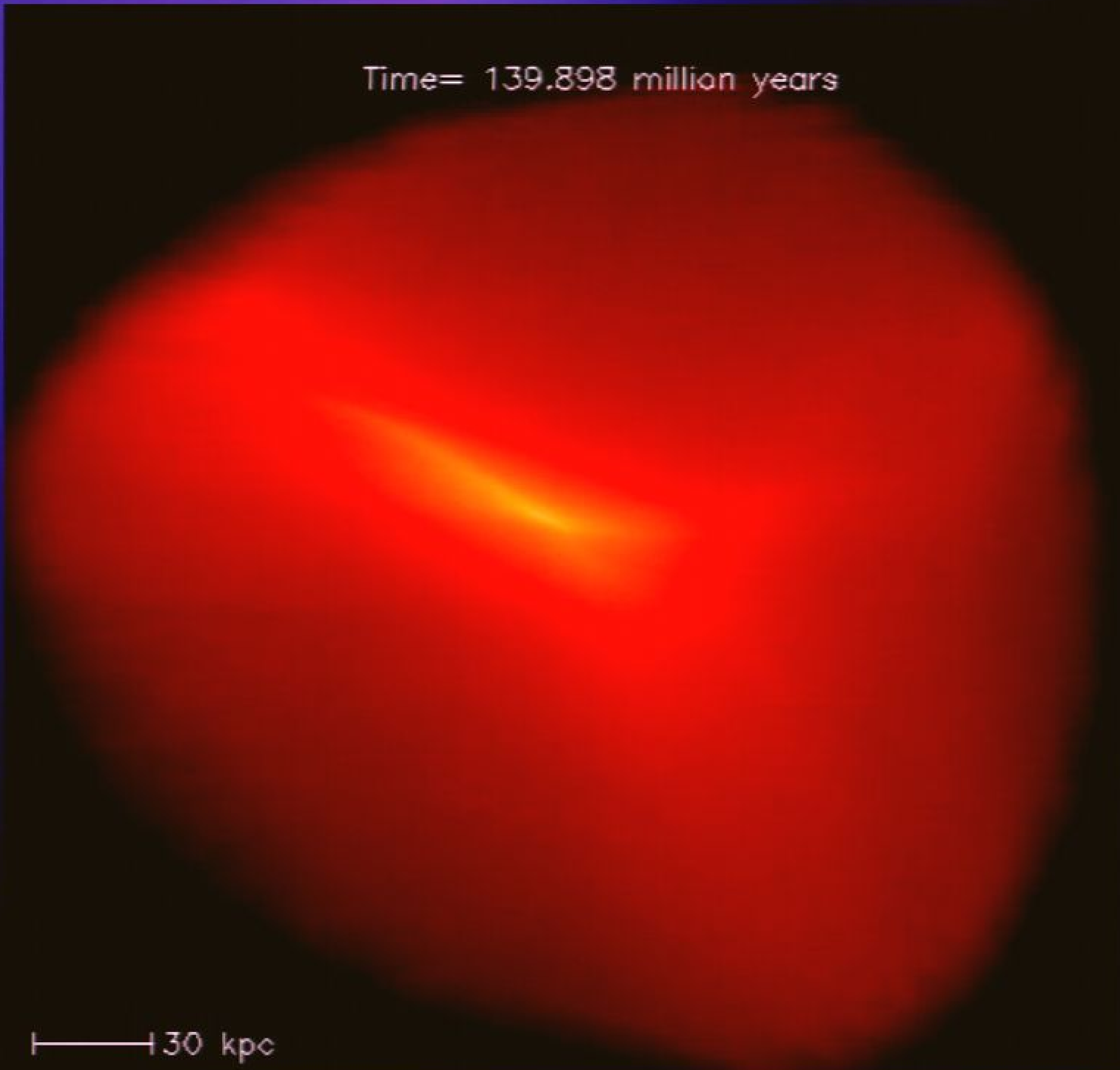

Time= 123.712 million years
30 kpc

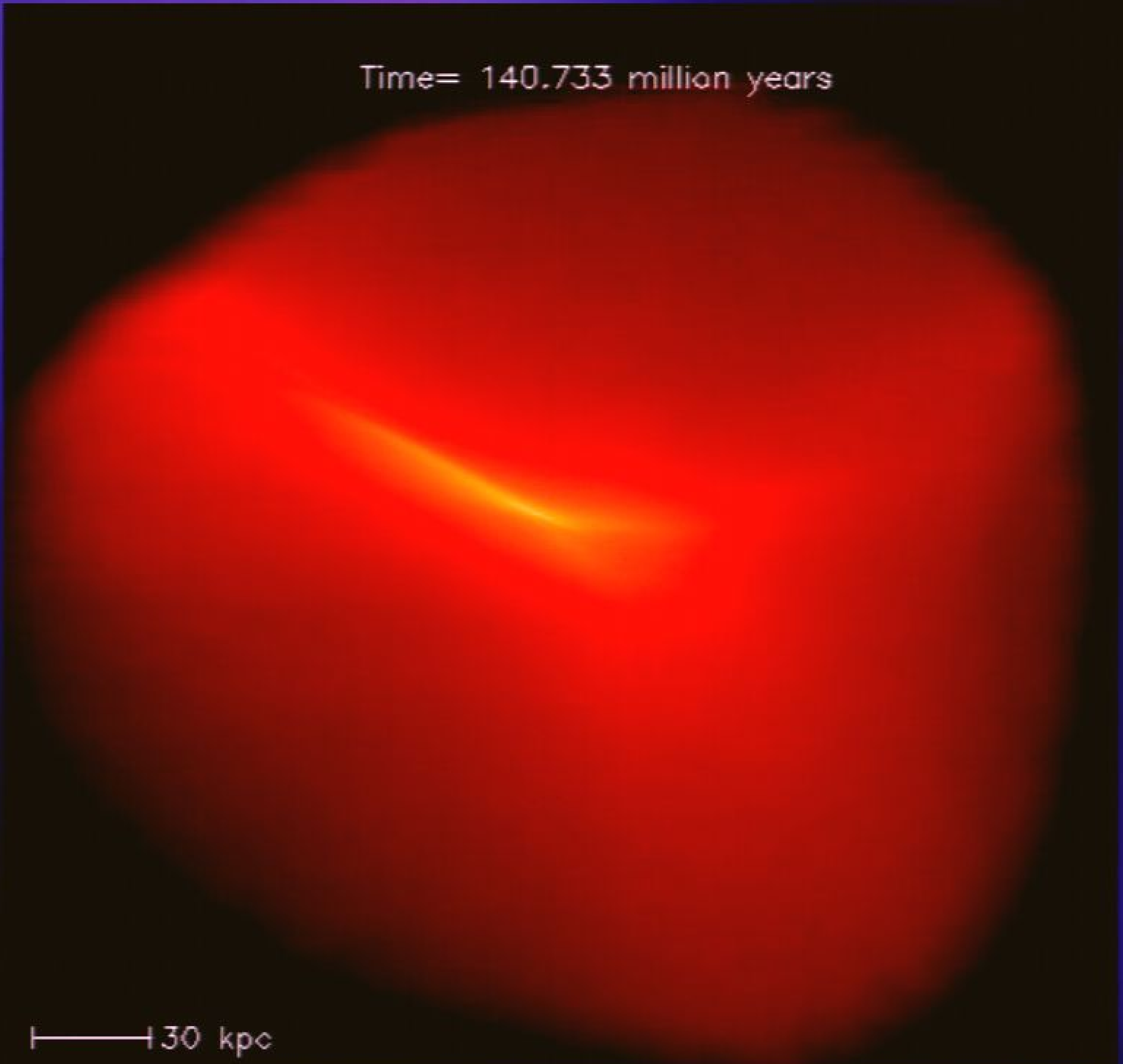

Time= 128.246 million years
30 kpc

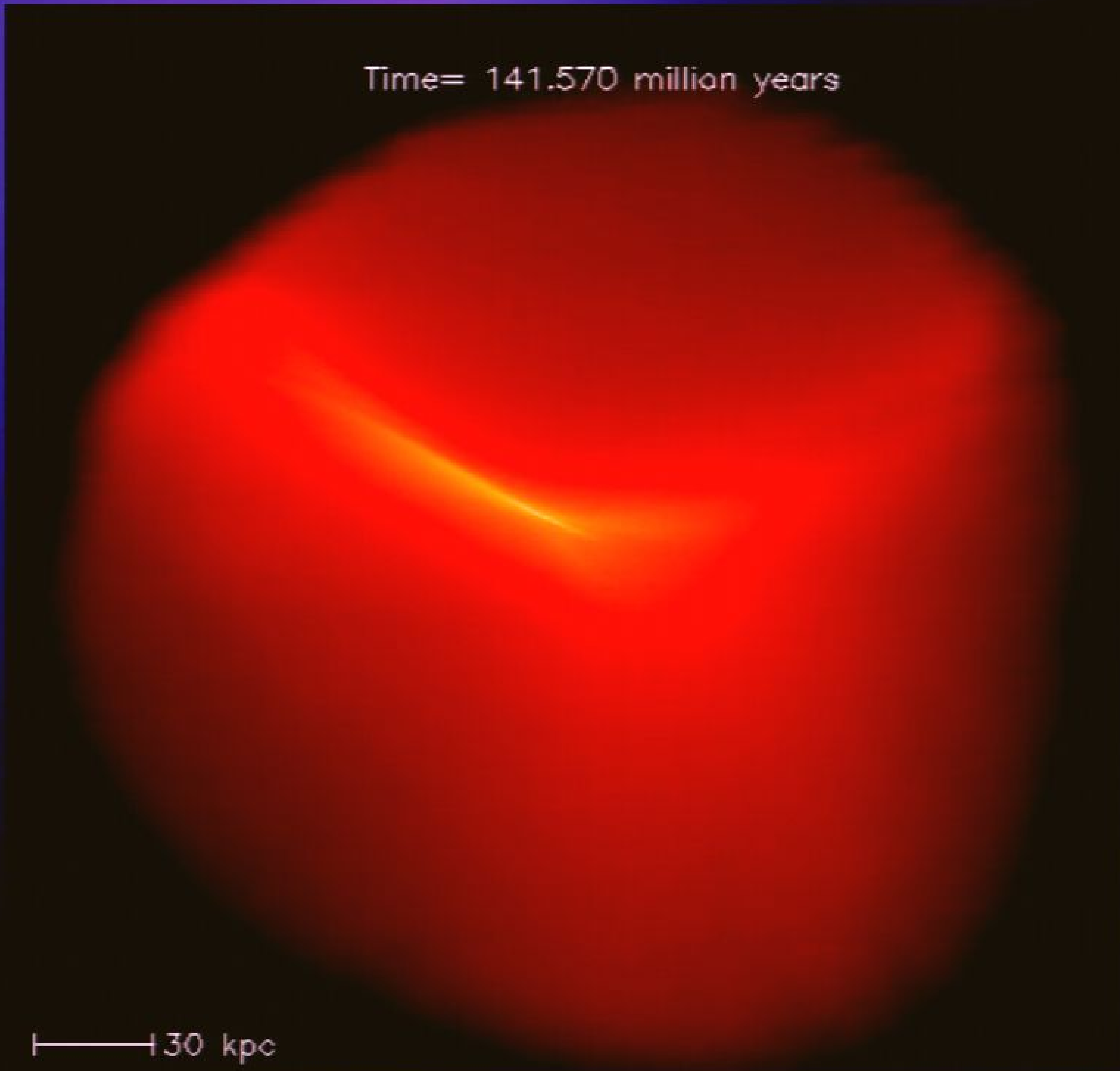

Time= 135.810 million years
30 kpc

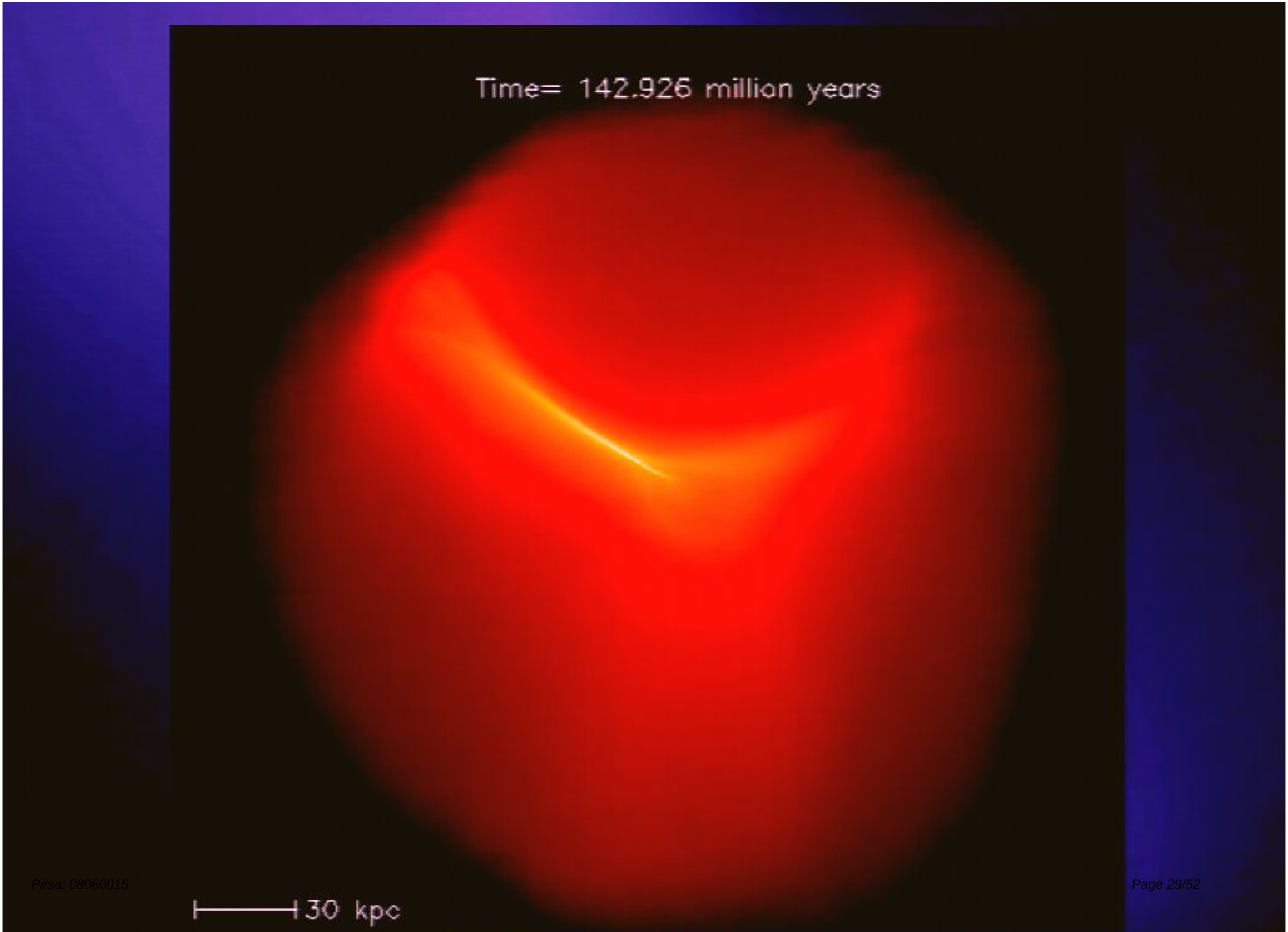

Time= 138.249 million years
30 kpc

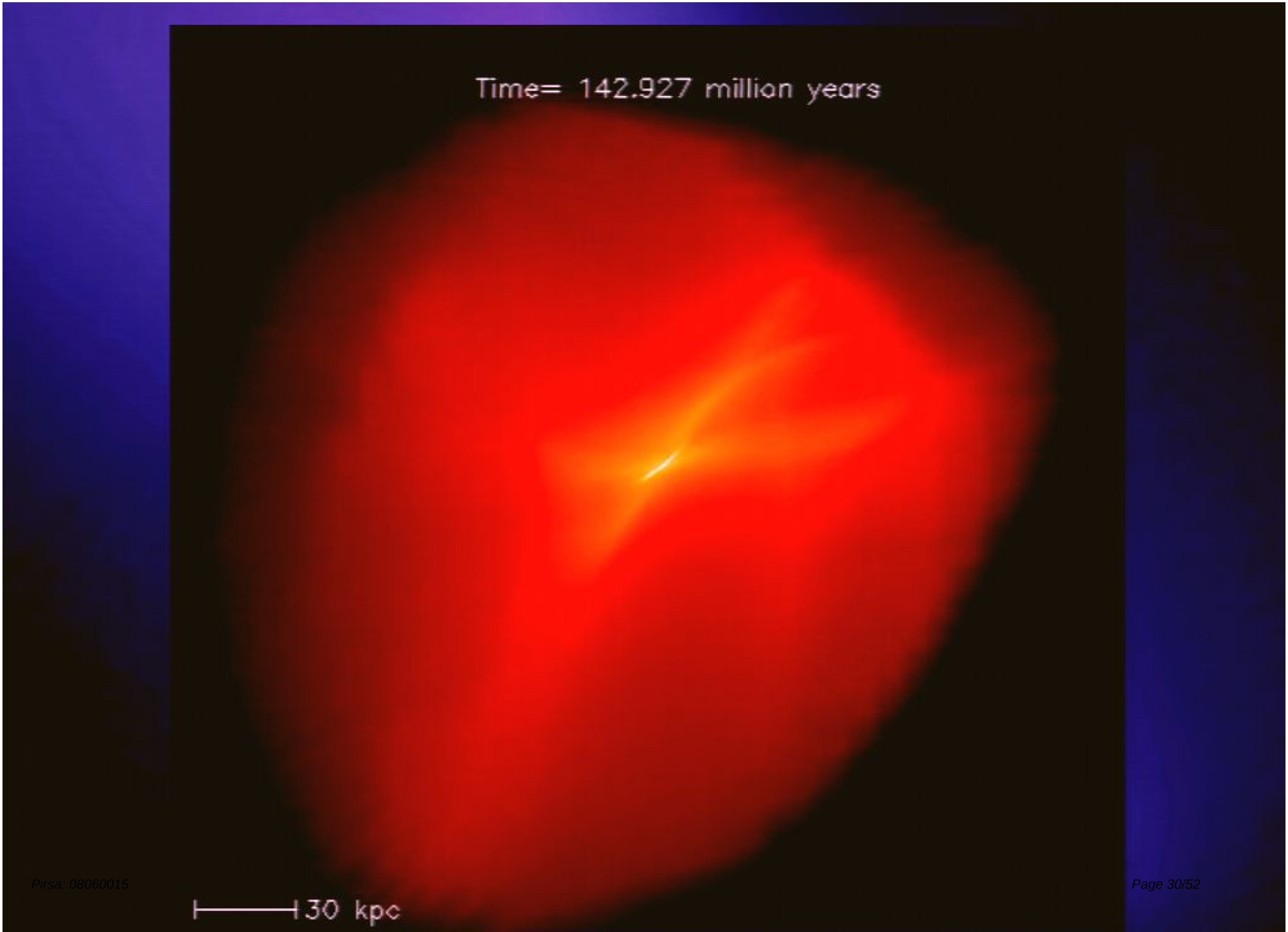

Time= 139.070 million years
30 kpc

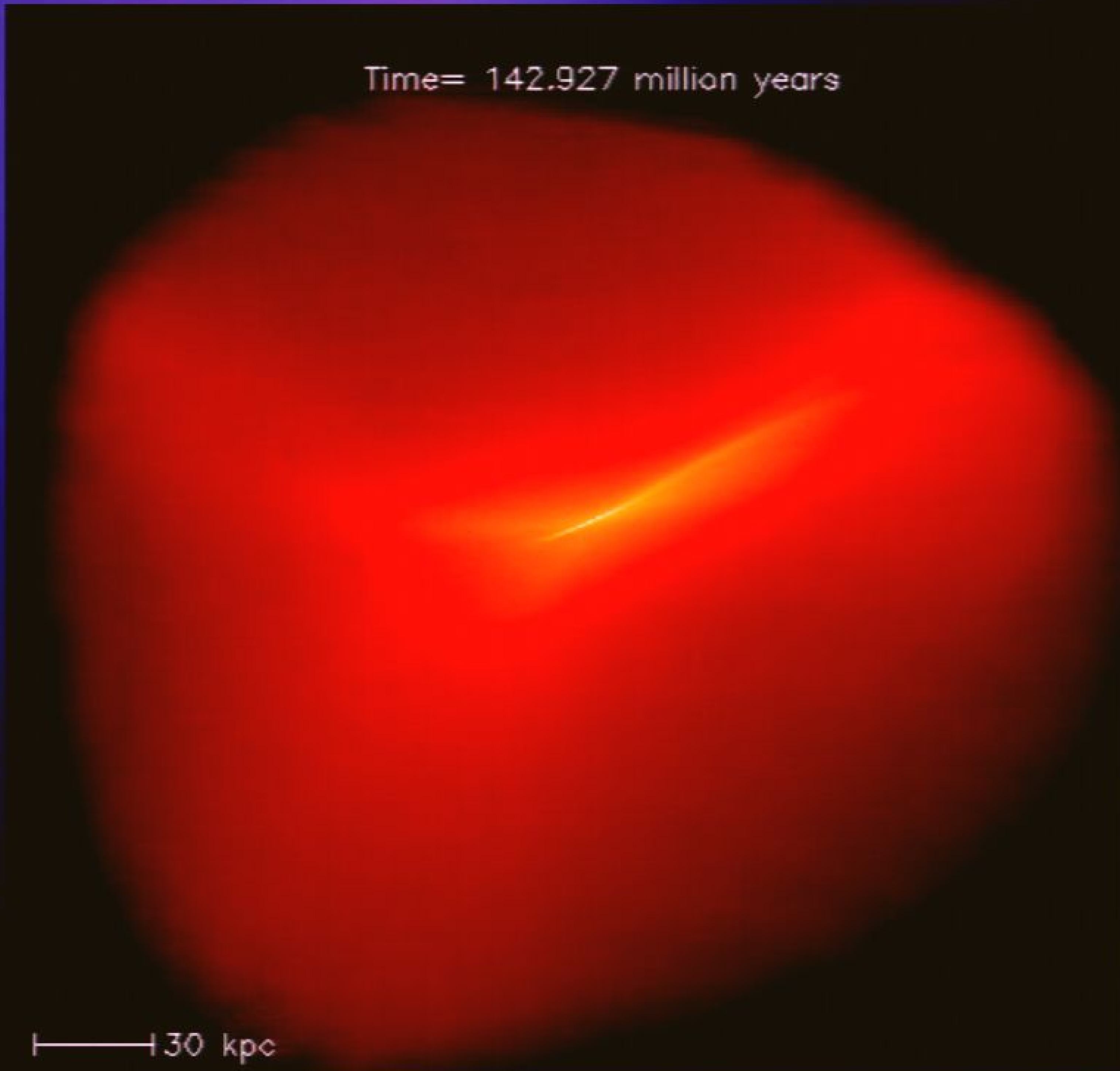

Time= 139.898 million years
30 kpc

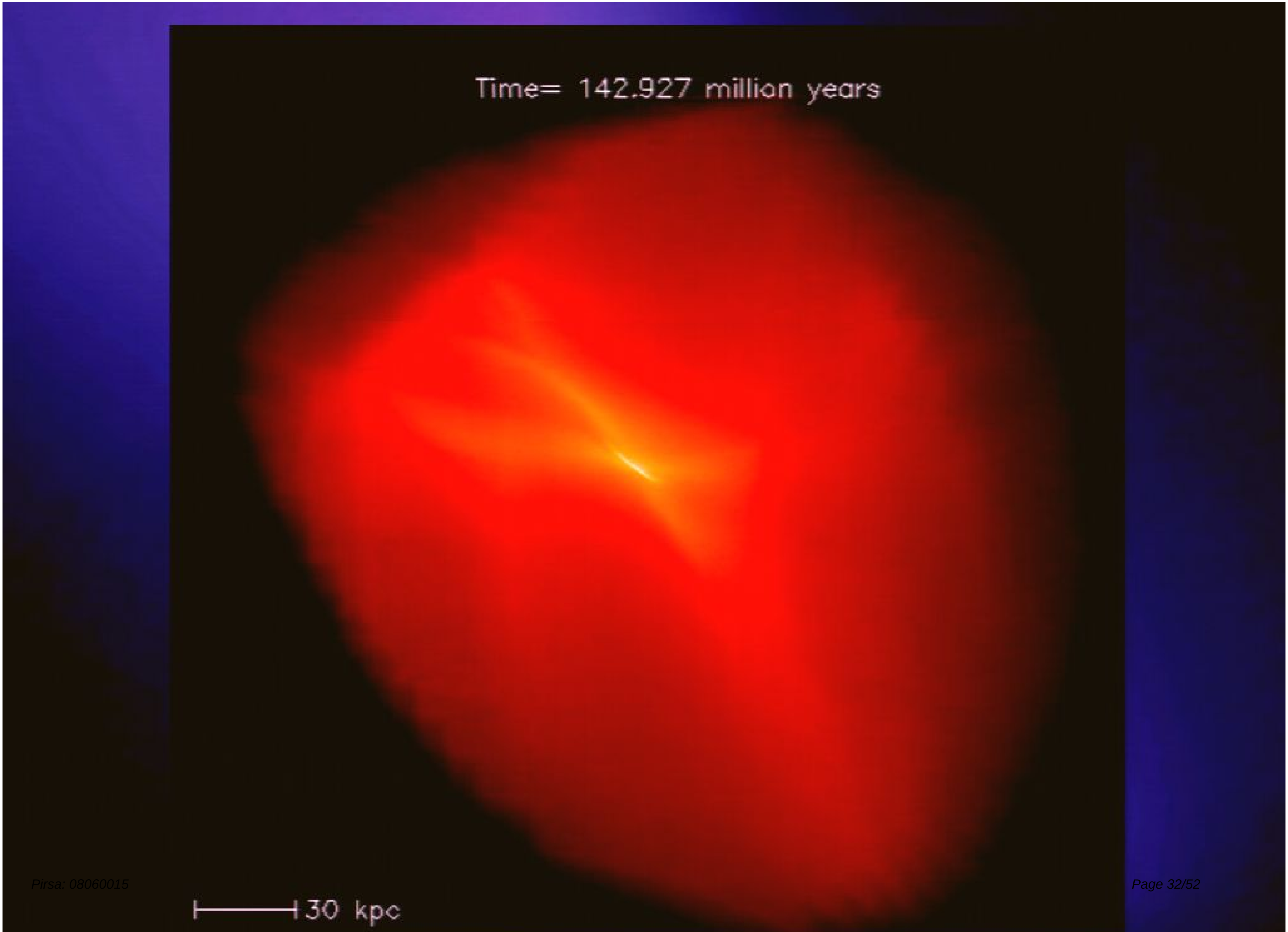

Time= 140.733 million years
30 kpc

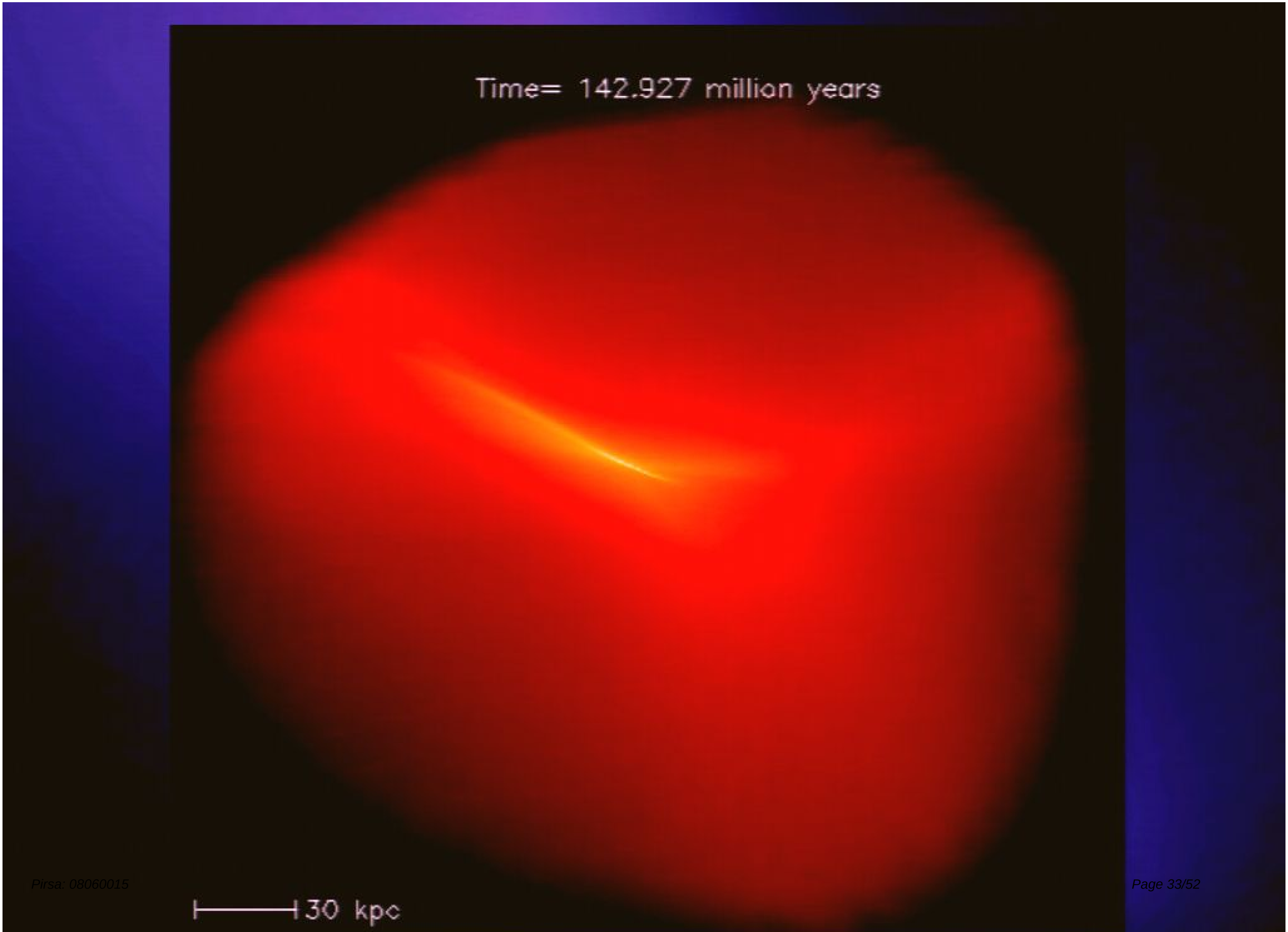

Time= 141.570 million years
30 kpc

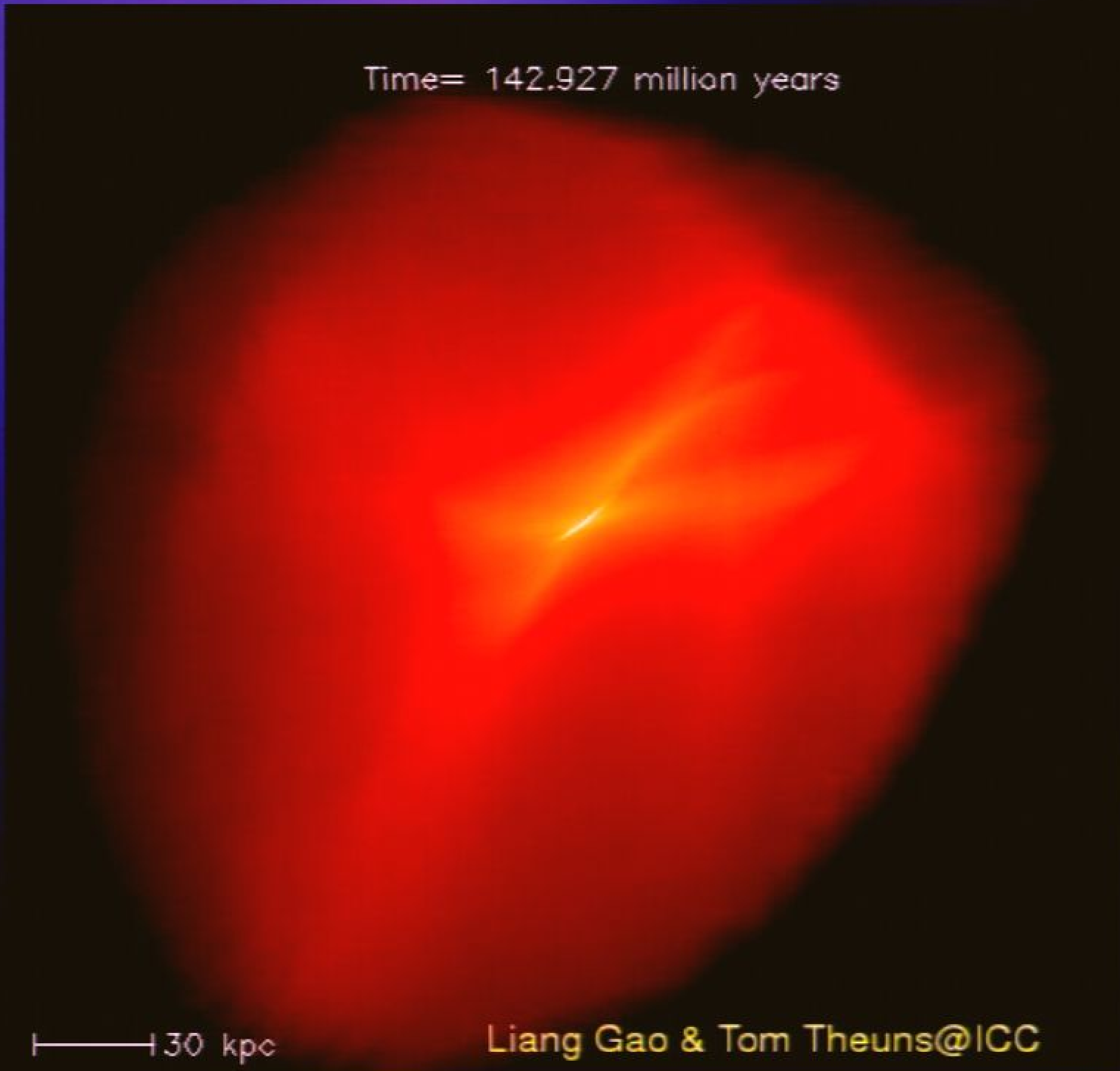

Time= 142.926 million years
30 kpc

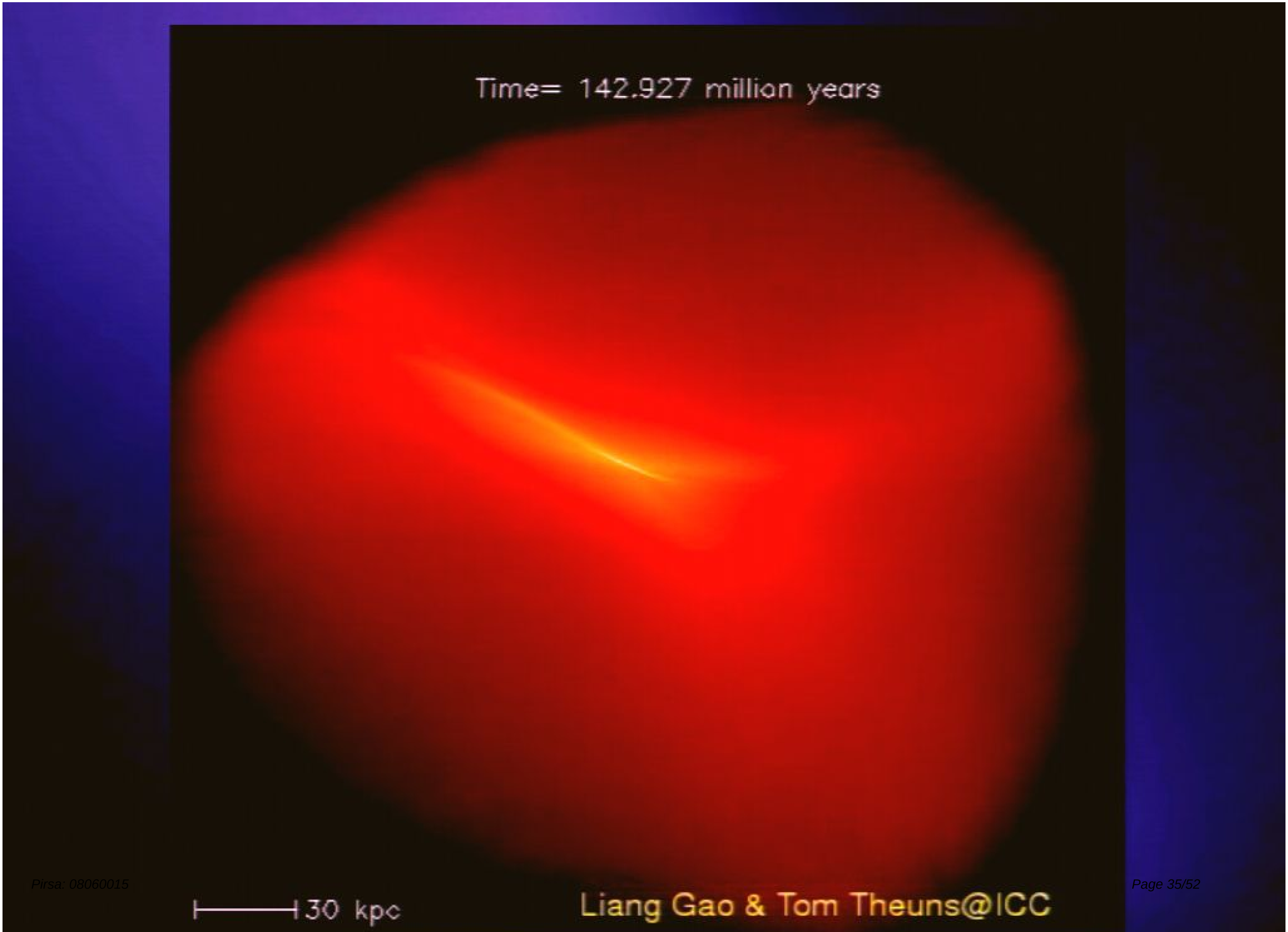

Time= 142.927 million years
30 kpc


Time= 142.927 million years
30 kpc


Time= 142.927 million years
30 kpc


Time= 142.927 million years
30 kpc


Time= 142.927 million years
30 kpc
Liang Gao & Tom Theuns@ICC



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30 kpc
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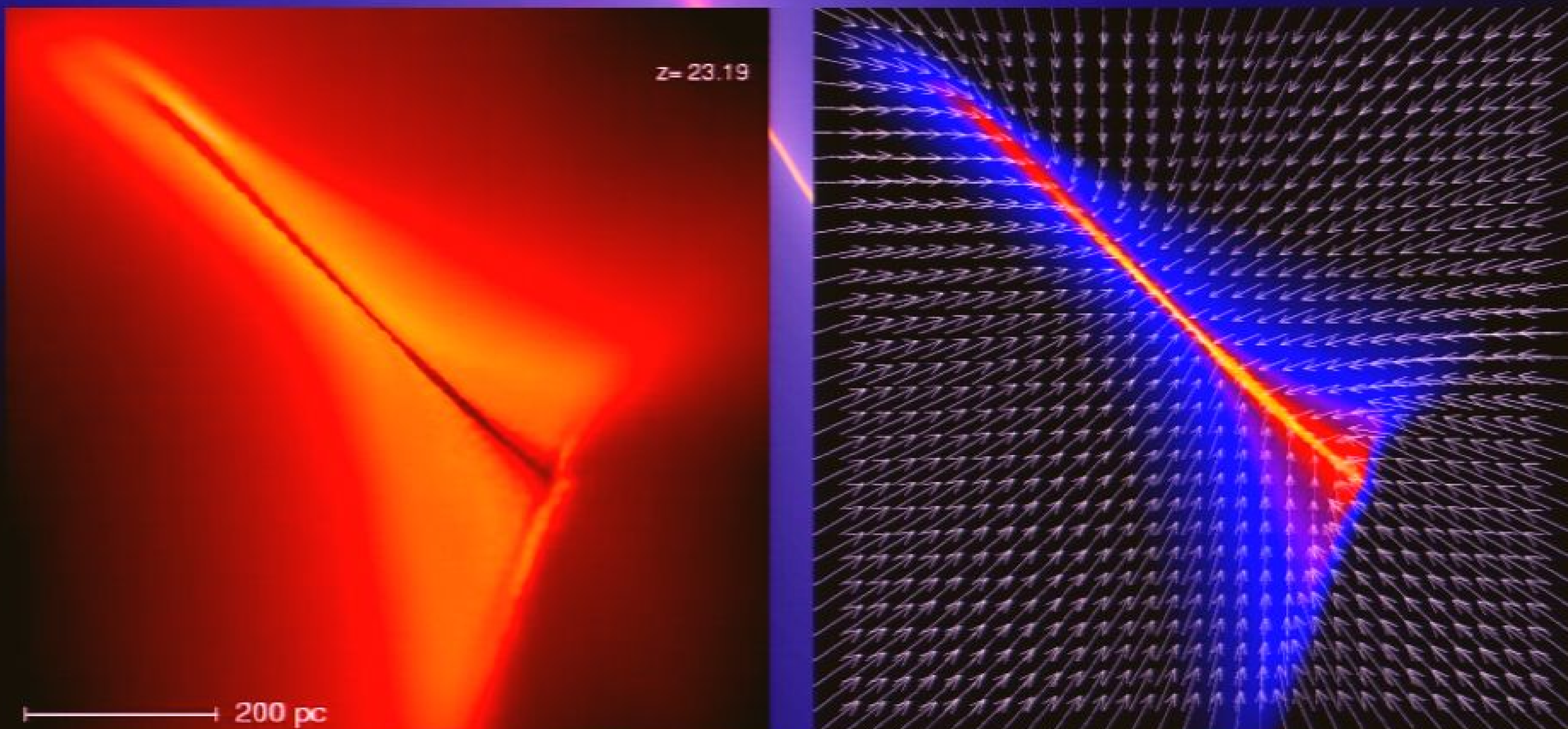
First structure in WDM



M_dm = 3 kev, M_fs ~ 3 x 10^8 solar mases

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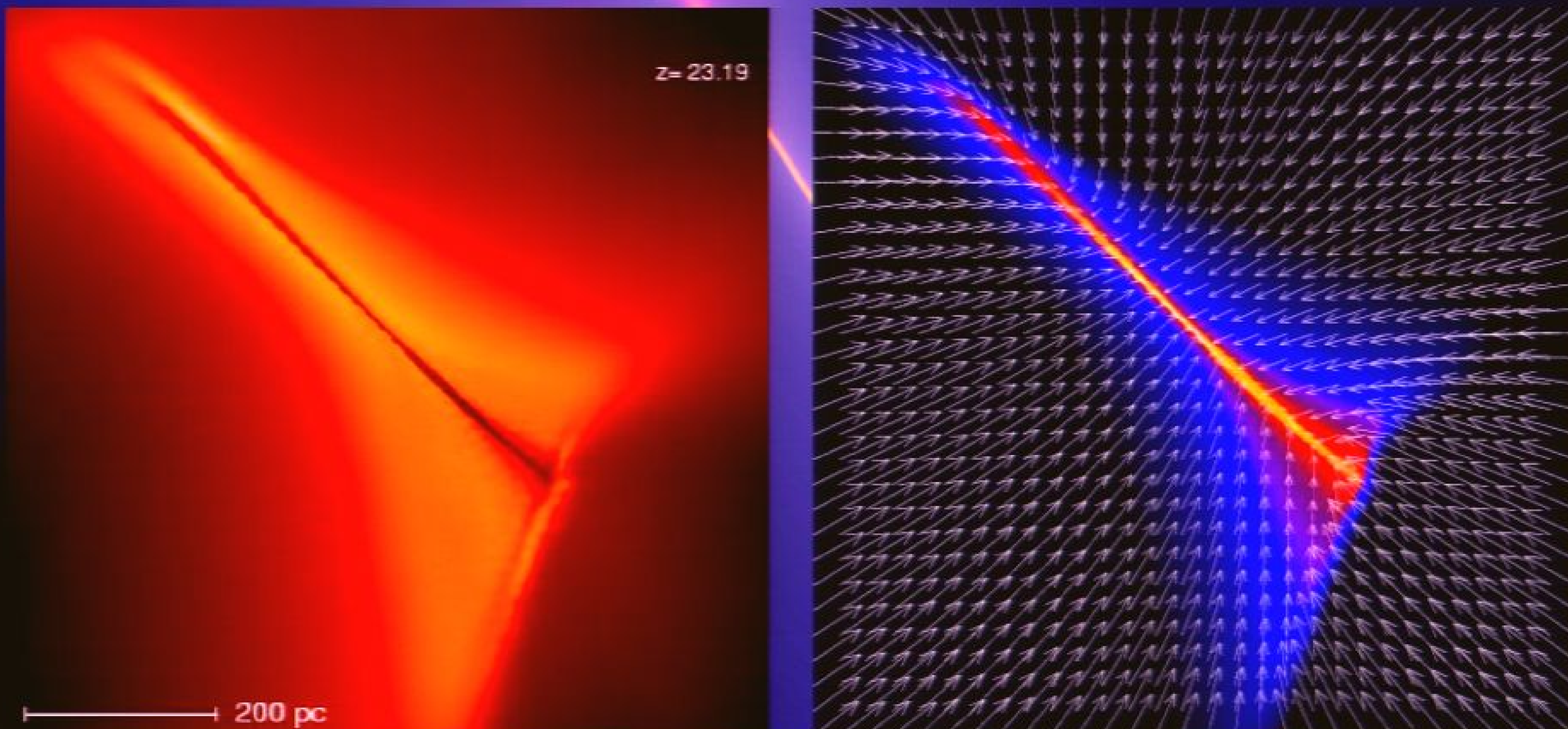

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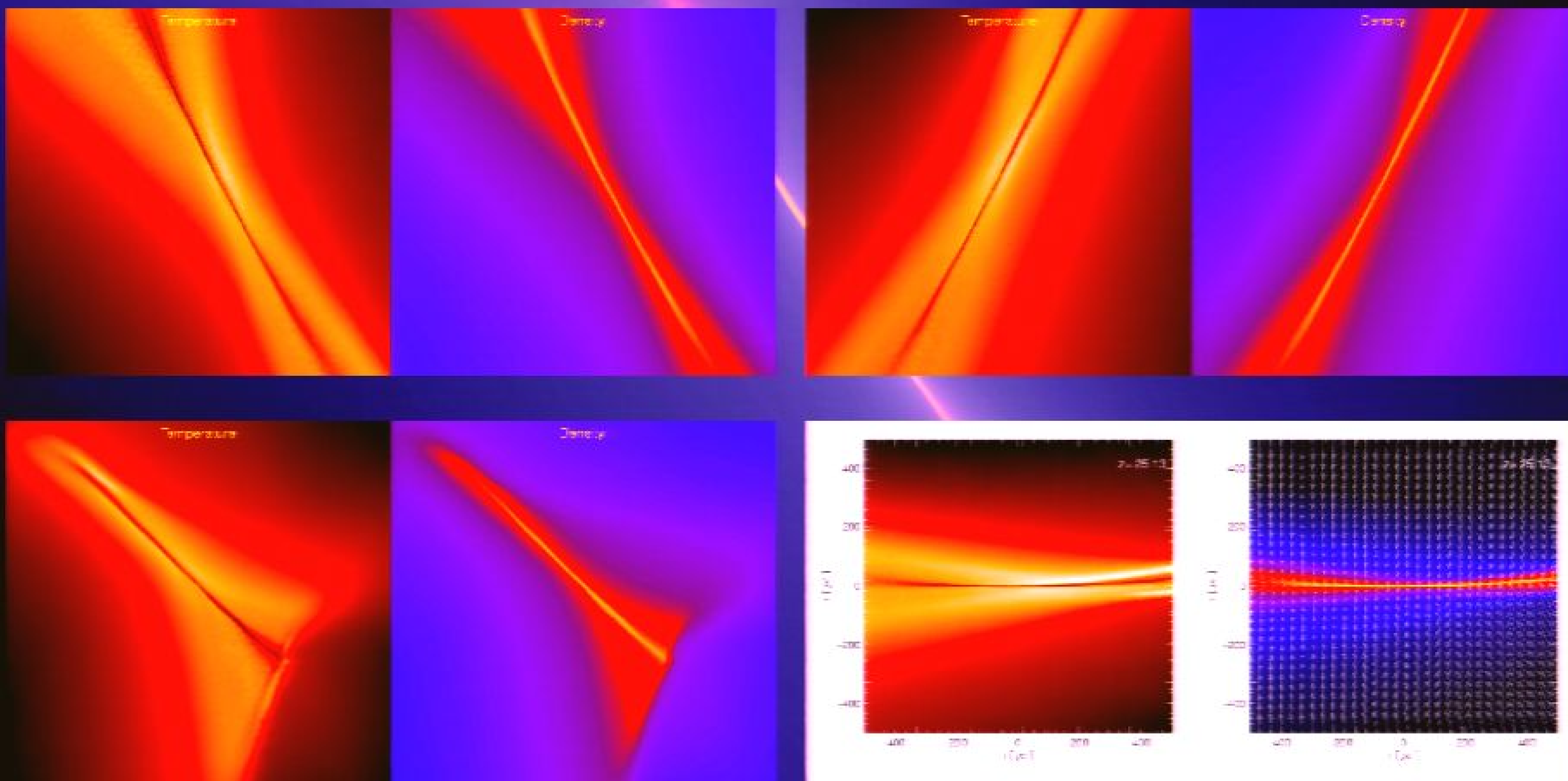
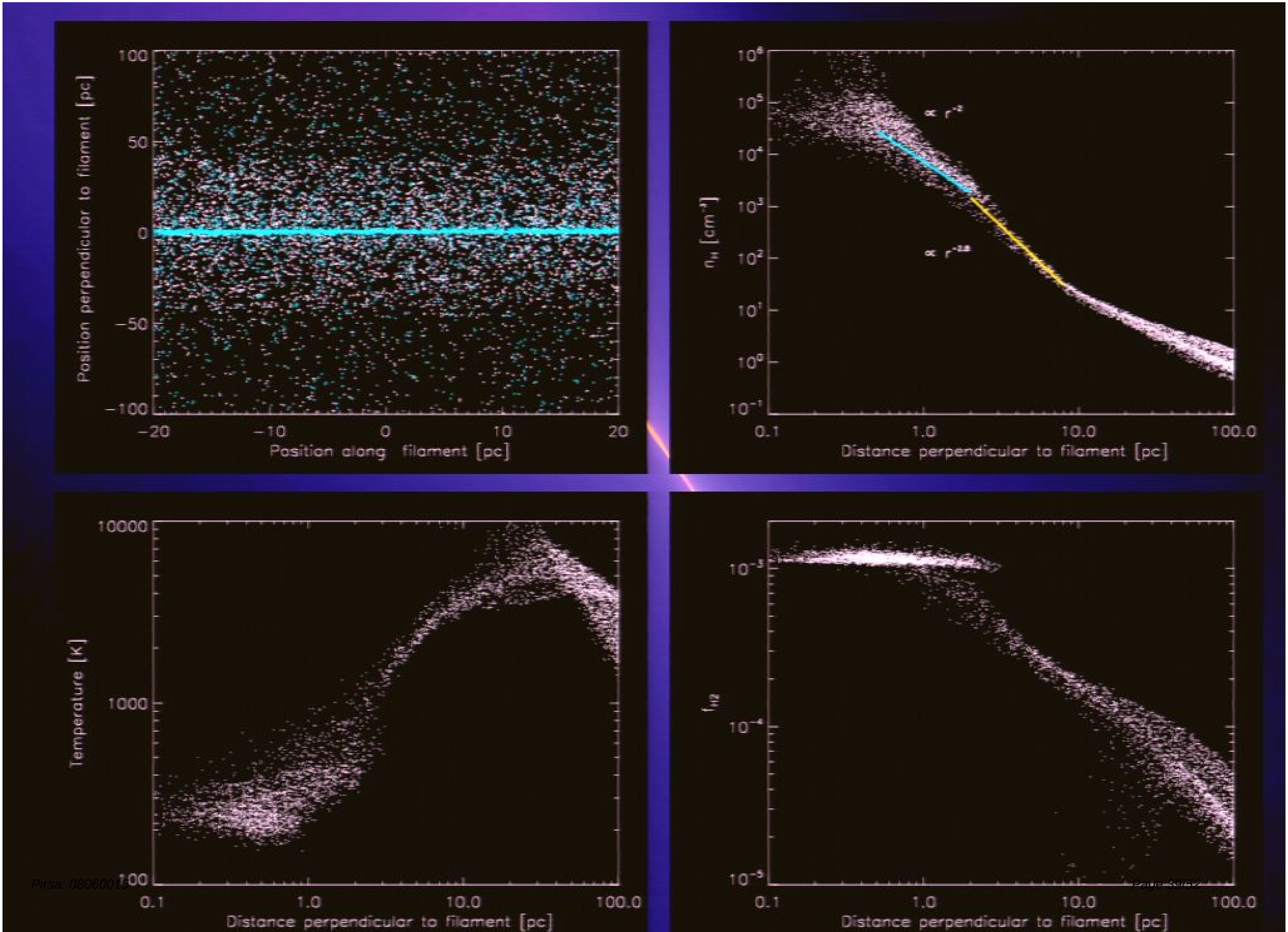
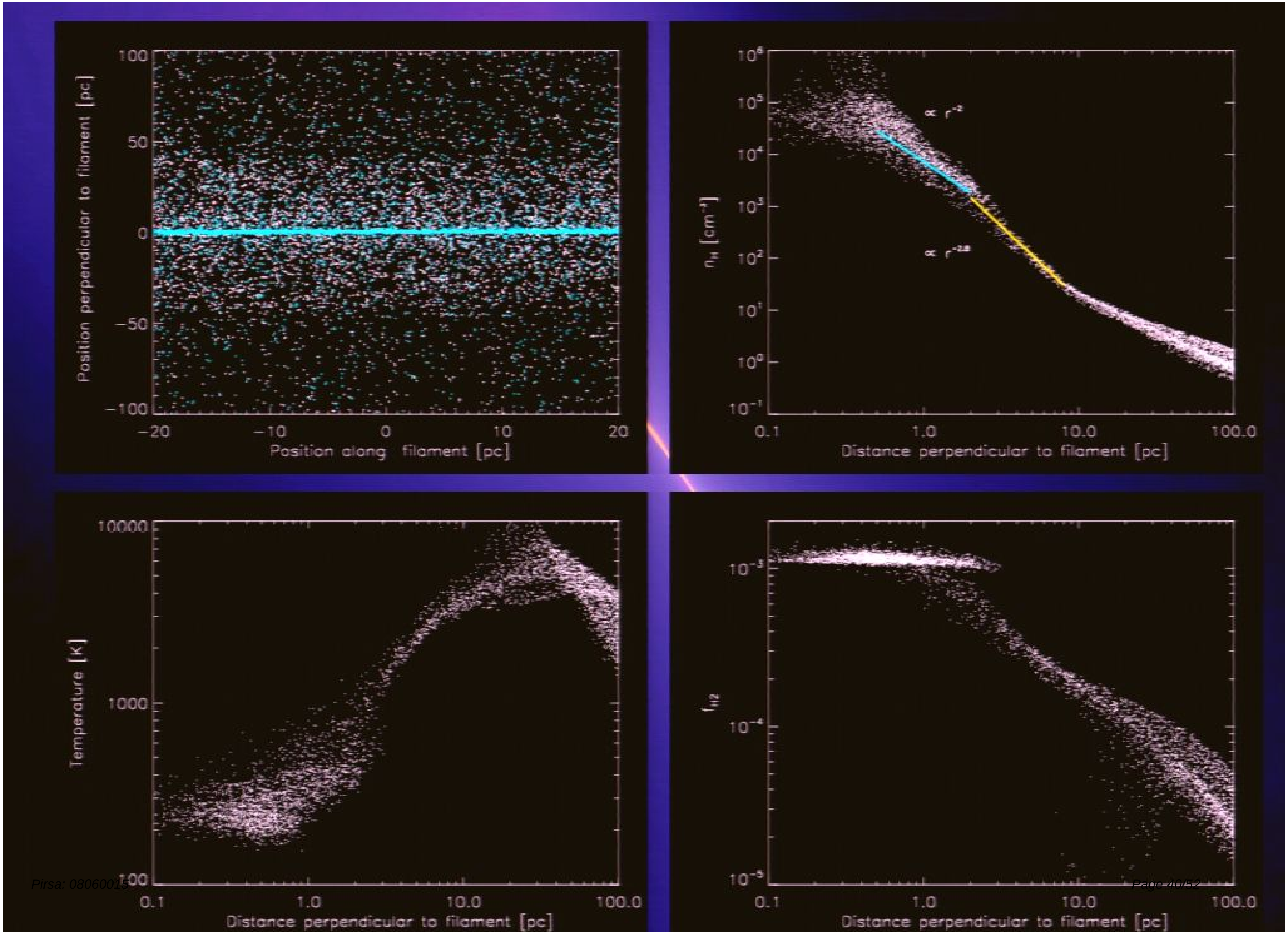
Structure of a filament




Position perpendicular to filament [pc]
Position along filament [pc]
n_H [cm^{-3}]
$\propto r^{-2}$
$\propto r^{-2.8}$
Distance perpendicular to filament [pc]
Temperature [K]
Distance perpendicular to filament [pc]
f_{H2}
Distance perpendicular to filament [pc]



Position perpendicular to filament [pc]
Position along filament [pc]
n_H [cm^{-3}]
$\propto r^{-2}$
Distance perpendicular to filament [pc]
Temperature [K]
Distance perpendicular to filament [pc]
f_{H2}
Distance perpendicular to filament [pc]

Linear analysis of stability of a general collapsing filament

- A filament is unstable to axis-symmetric perturbations of wavelength greater than about 2 times the filament diameter, when the line mass

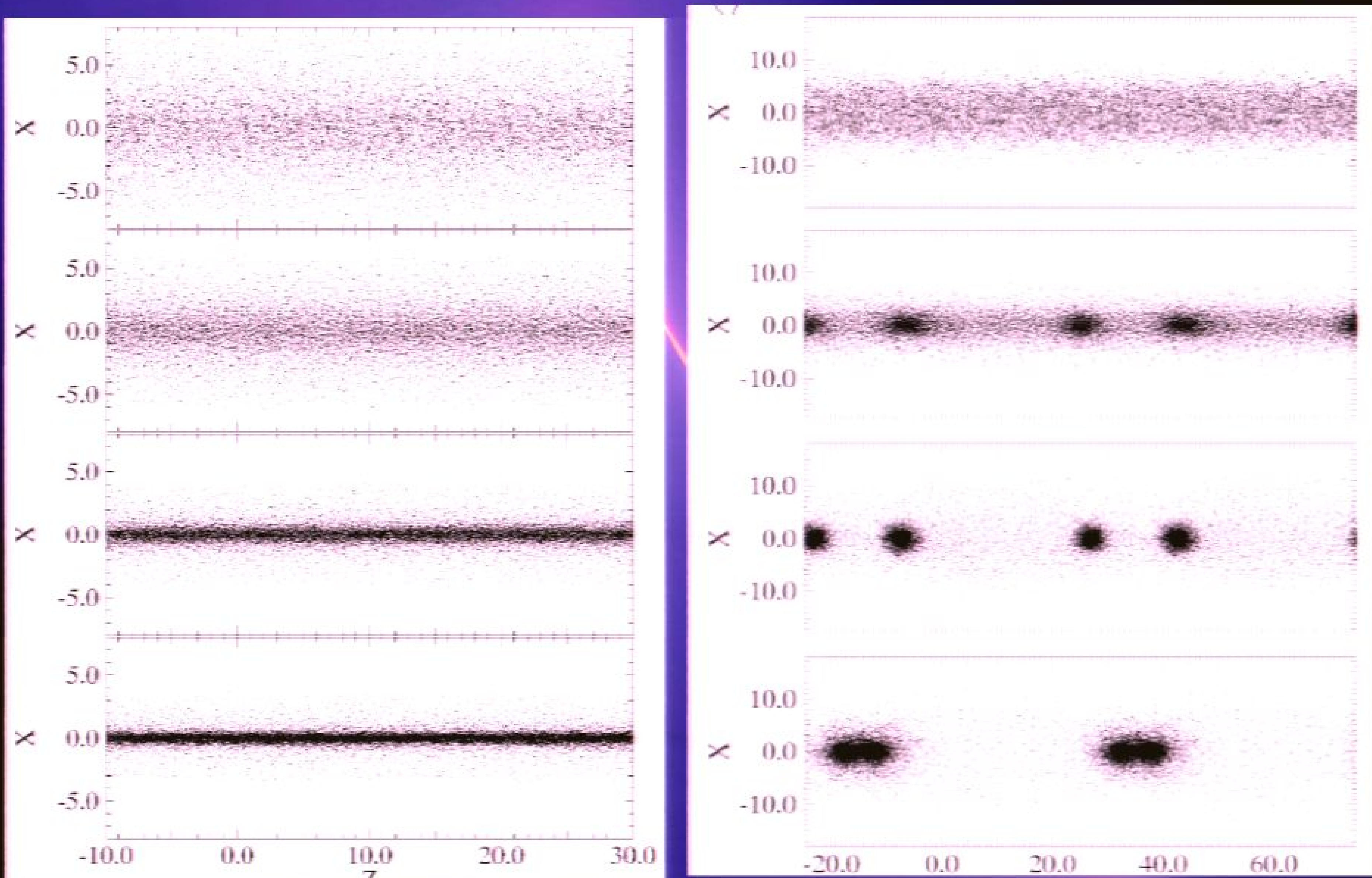
$$M_{line} \sim \frac{2c_s^2}{G}$$

- When the line mass the filament greatly exceeds the value for equilibrium, perturbations do not grow much. The entire filament collapse toward the axis--as long as the EOS remains isothermal

Larson 1985; Inutsuka & Miyama 1998

Iso-thermal collapse

Non-Iso-thermal collapse



Inutsuka & Miyama 1998

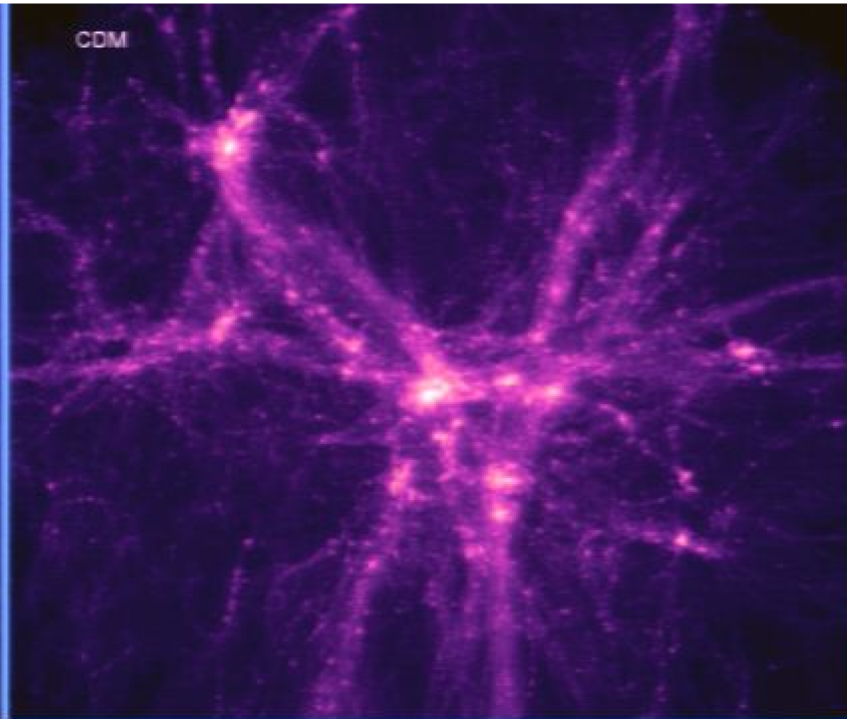
Application to a primordial filament 1.

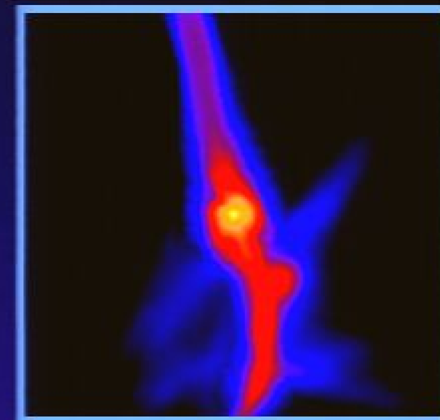
- Two density scales where primordial gas collapse may slow down.
- 1) n_h~10^4 cc where LTE level population are achieved. Fragmentation mass scale ~100 solar masses.
- 2) n_h>10^12 cc where gas become optical to H2 lines. Fragmentation mass scale <= 1-2 solar masses.

Application to a primordial filament 2.

- The filament is very uniform on large scales.
- There are powers no small scales in WDM.
- Seeds to trigger thermal - gravity has to transfer larger scale power (induced by tidal field) to small scales--implies fragmentation at very high density
- A range of mass of stars formed in a huge burst.

Summary





Conclusion

- The first stars were formed in filaments in WDM rather than in dark halos as occurred in CDM.
- The cold and dense filaments formed in WDM are very unstable, its fragmentation will possible lead to formation of a range mass of stars, including sub-solar mass, but also much more massive stars built through mergers and accretion. And thus the IMF of first stars in WDM will be likely very different from the CDM case.
- Whether or not existing low mass metal free stars maybe used to constrain the nature of dark matter.

Conclusion: CDM vs WDM

CDM:

- massive, short-lived stars

WDM:

- both low and high-mass stars
- low-mass stars may exist today
- origin of peculiar abundances in MW stars (This indeed explains existing two HMP stars better !).
- collapsing filament seed for super-massive black hole

Question: observability?

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Implications

- For WDM with larger free streaming scale (T_filament > 10^4 K), dwarf galaxies were likely formed via fragmentation of filaments. What we expect on properties of dwarf galaxies if DM is warm?

Implications

- Various constraints on Warm dark matter particles should be revisited! For example, re-ionization, lya forest etc…

No need to have dark halo to form stars and galaxies. Such star/galaxy formation mode have not yet been considered previously! More theoretical works are needed.

- Thank you!