Simulating AGN feedback in Clusters – the effect of Cluster Dynamics

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The Physics of the Intracluster Medium

University of Michigan, 8/24/2010

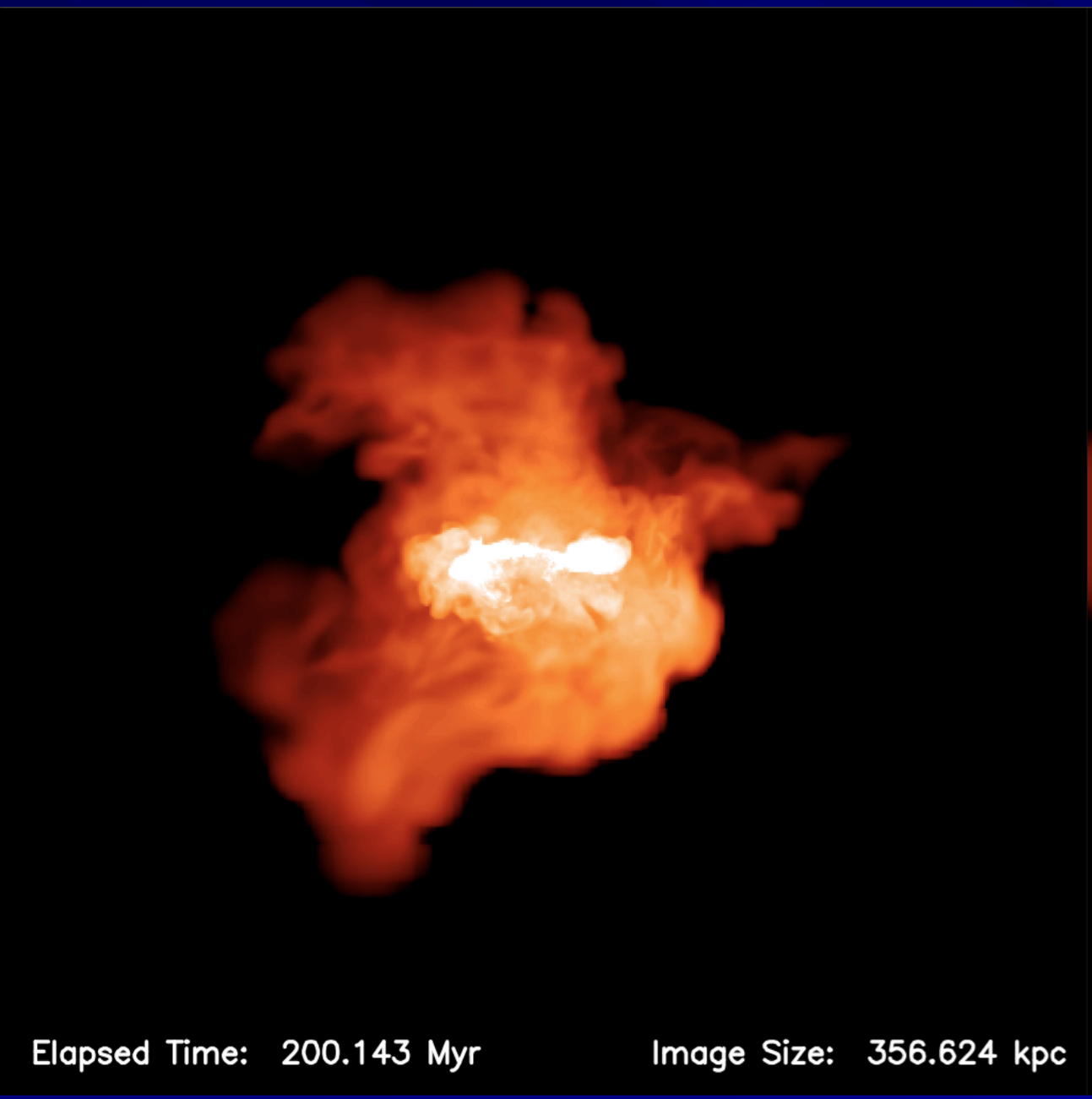
Outline

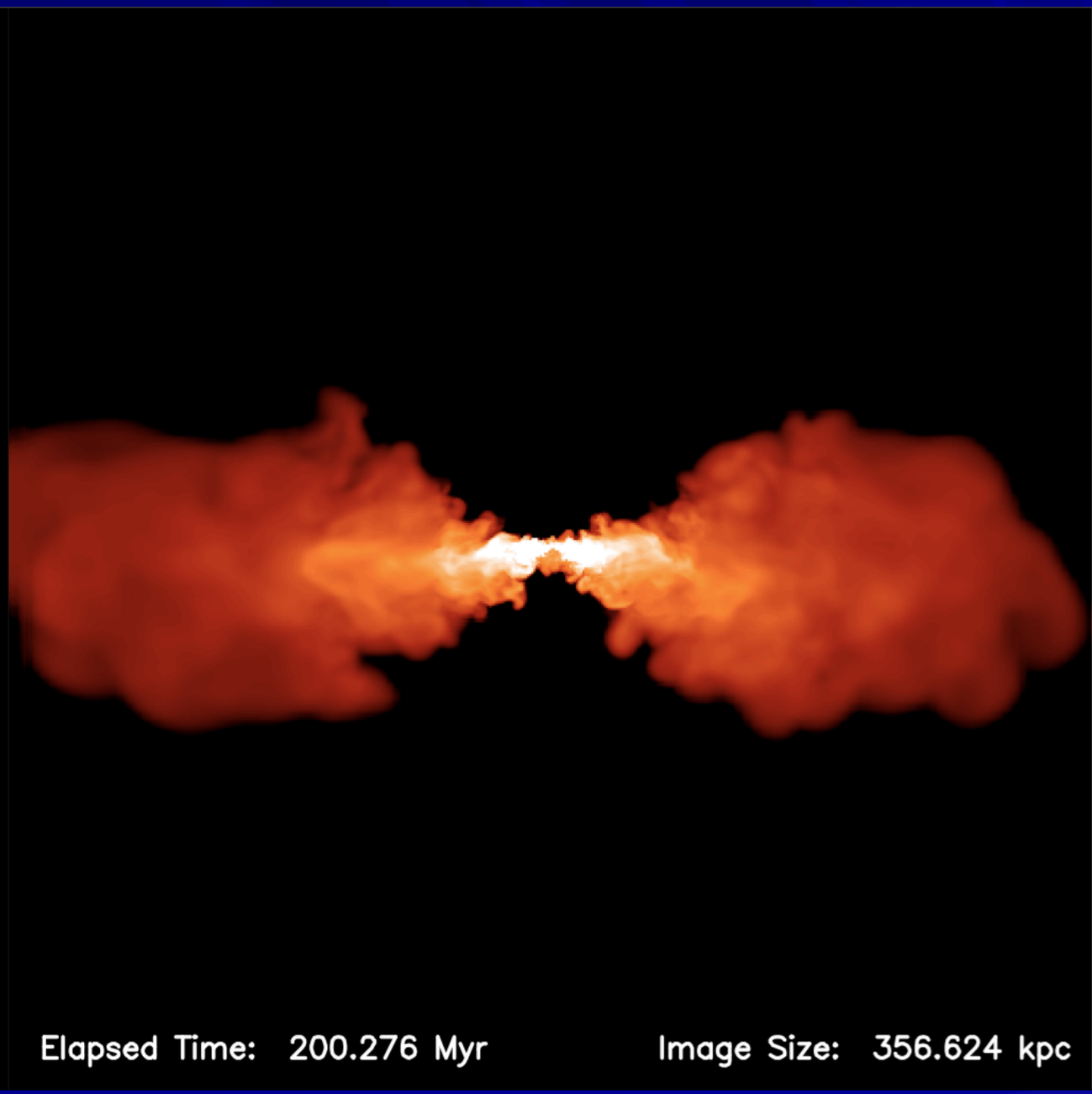
- Setups
- Comparison of Hydrostatic vs. Dynamics clusters
- Results
  - Multiple Bubbles
  - AGN Sphere of Influence
  - Jet Break-off Timescale
- Conclusions

Simulation Setup

- Random walk of jet axis by 20° to simulate dentist drill effect
- 200 Myr simulation
- Dynamic S2 cluster -or-
  - Stationary cluster with same density profile, initially hydrostatic
- Energy of 10^{44}, 10^{45} and 10^{46} erg/s
- AGN active for 30, 90 of 200 Myr

“Realistic” vs. Hydrostatic





Dynamic Cluster Radio

QuickTime™ and a
PNG decompressor
are needed to see this picture.

Dynamic Cluster X-ray

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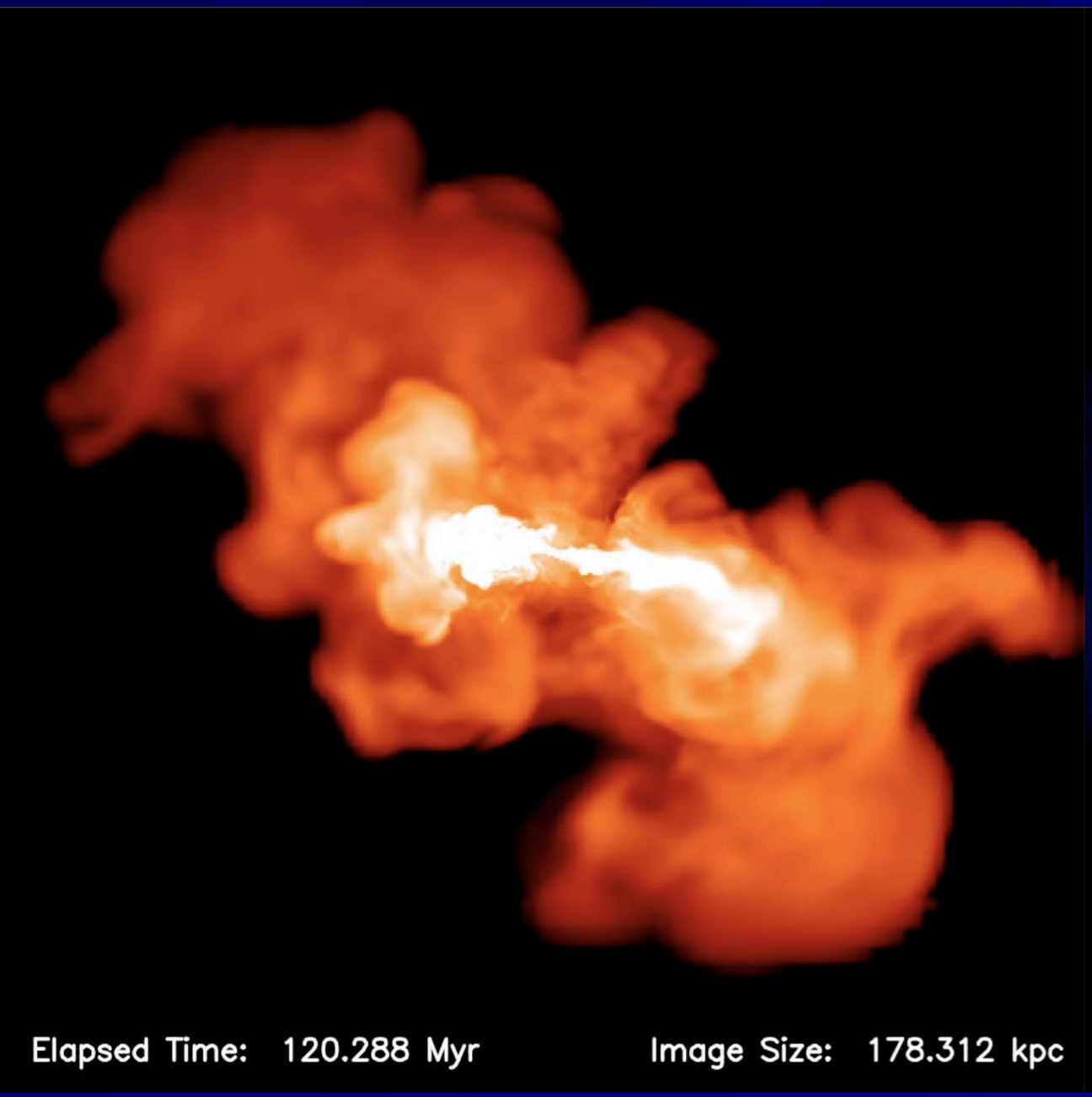
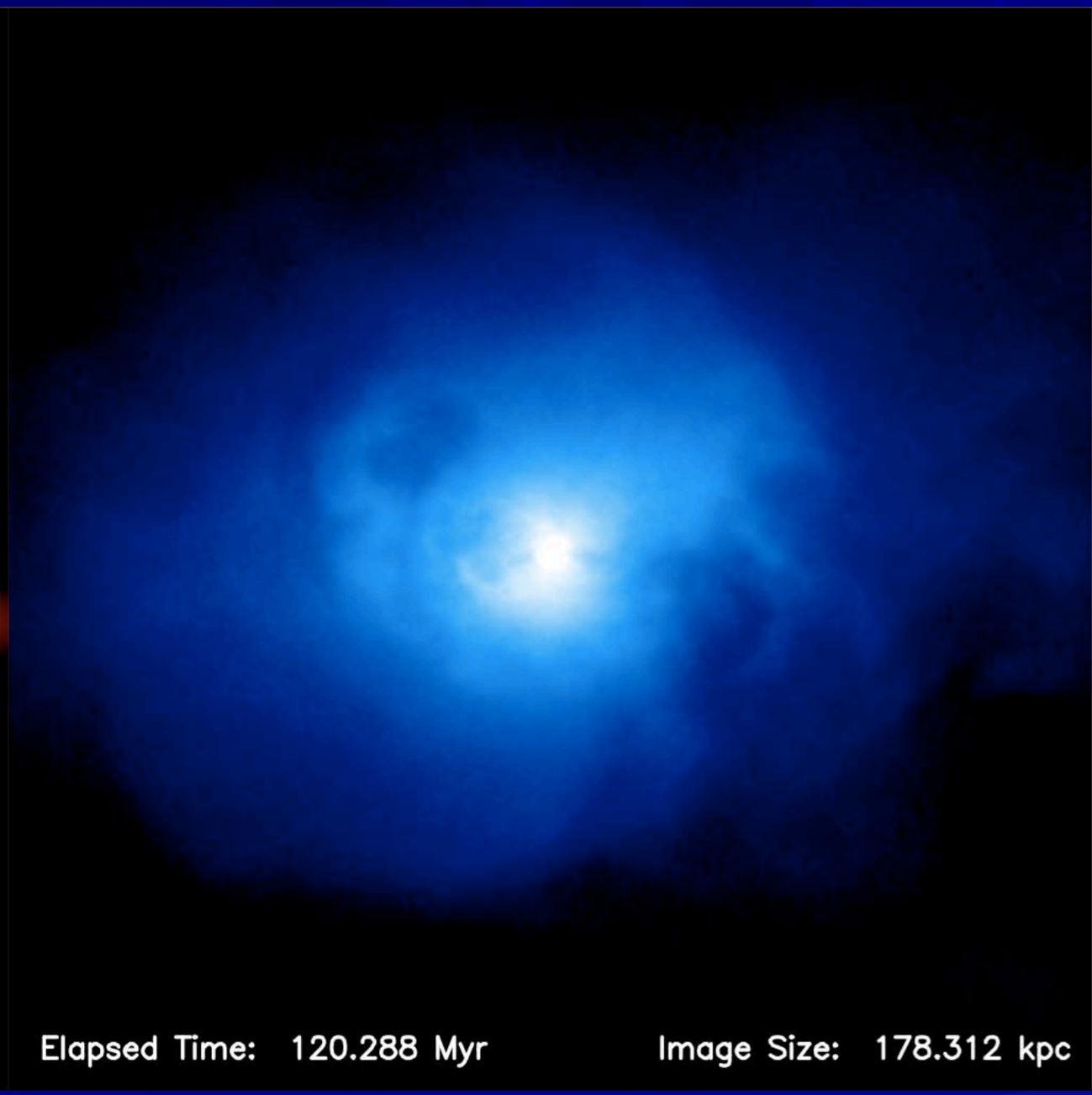
Radio and X-ray





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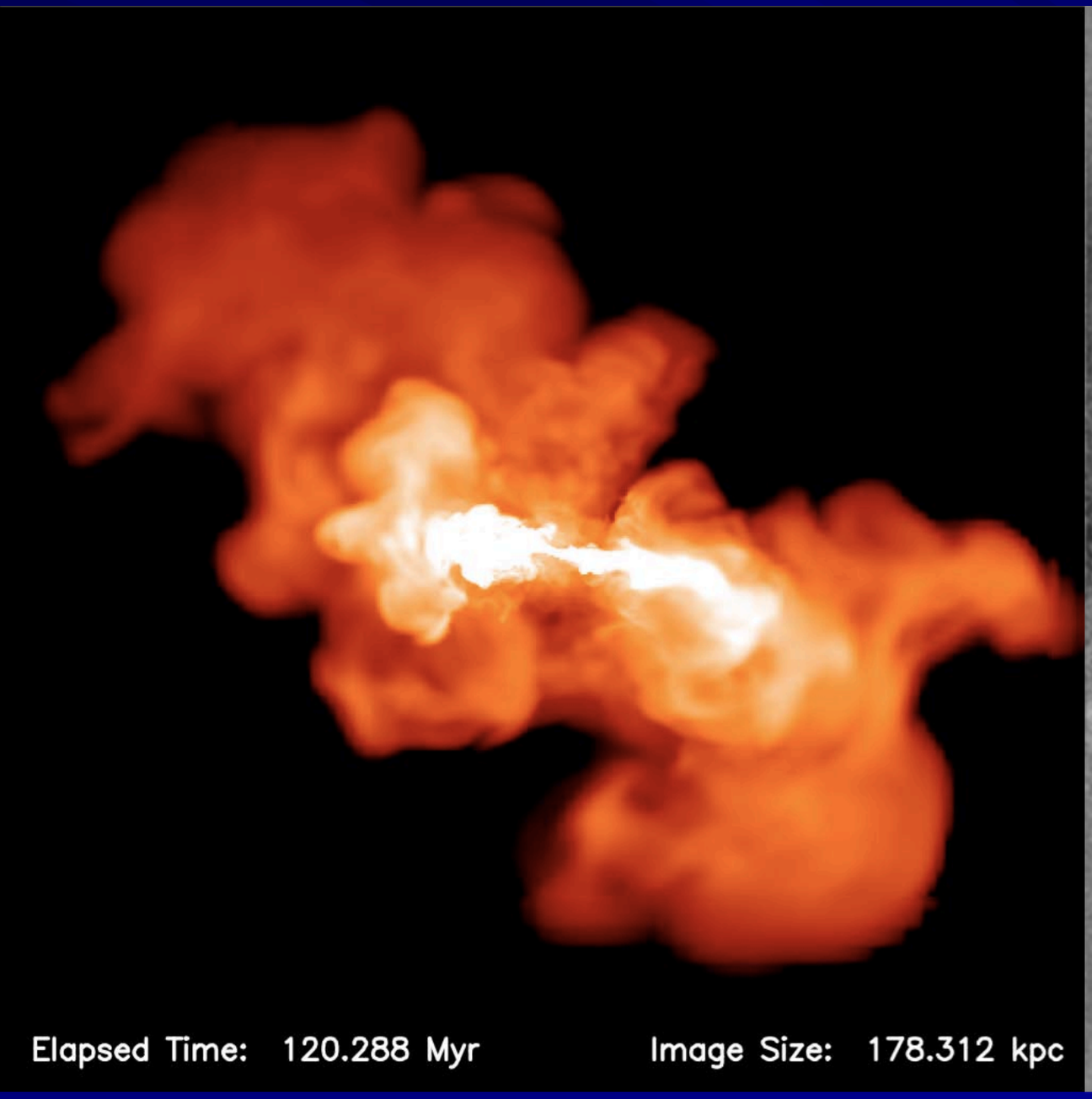
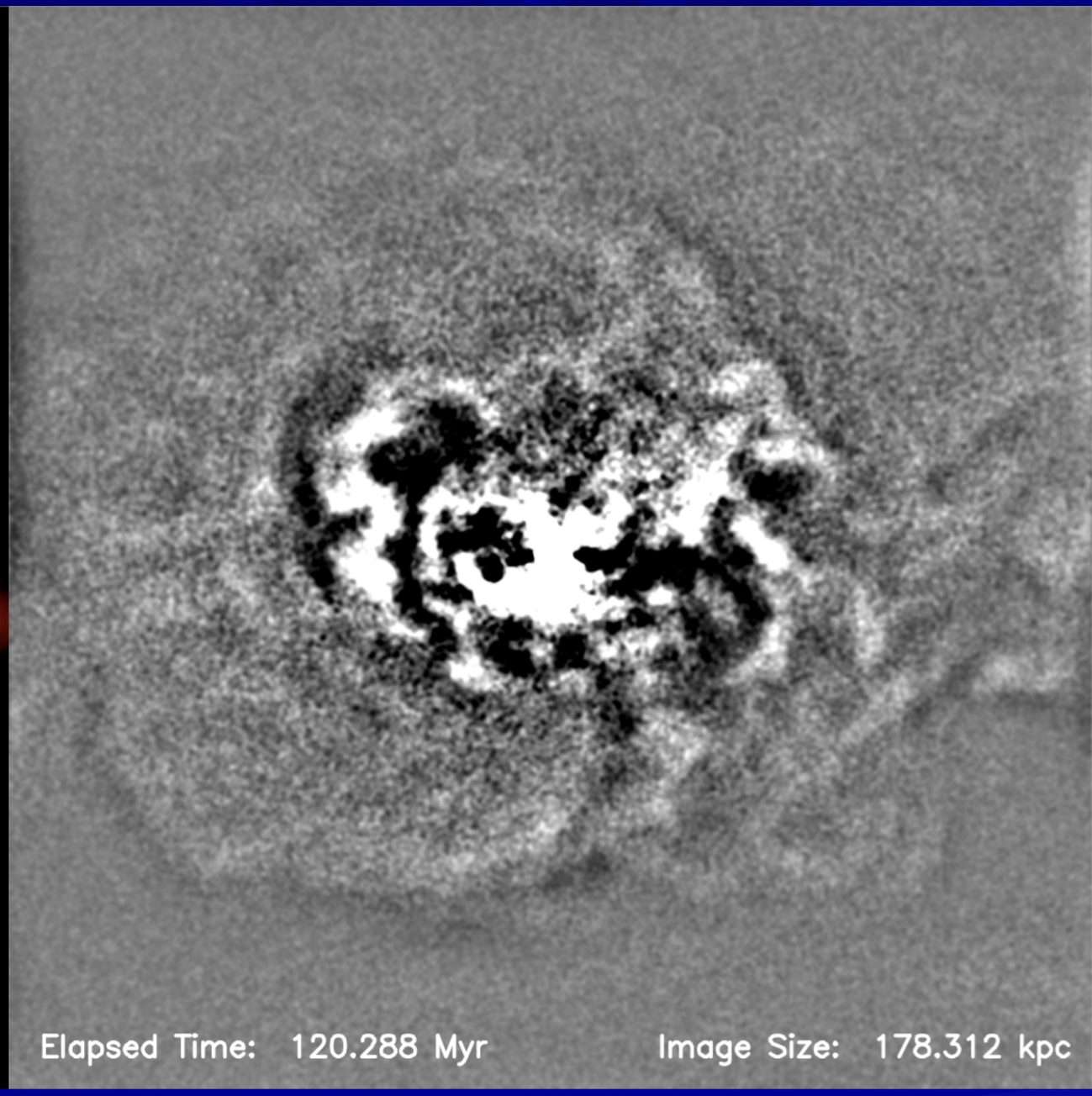
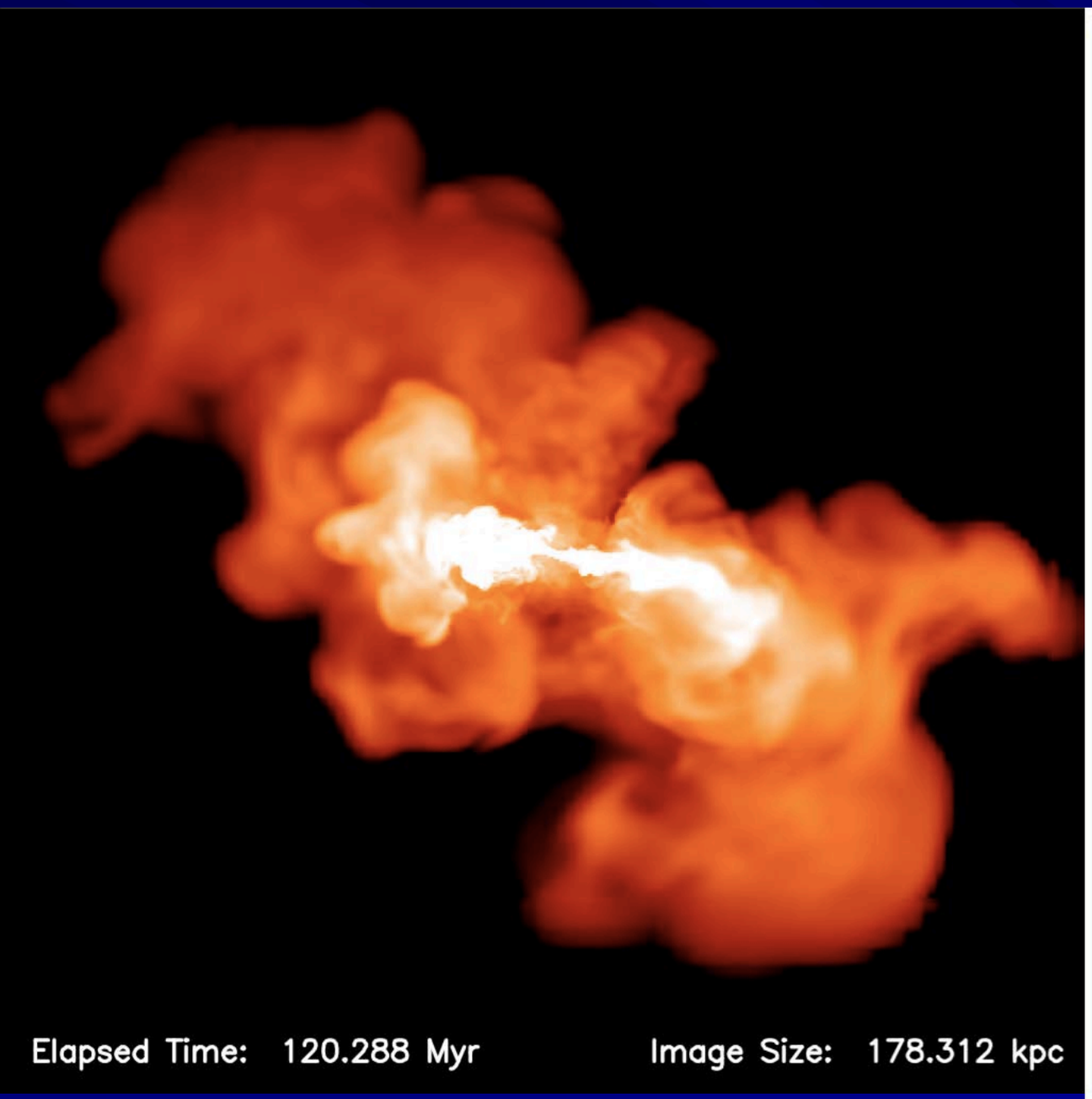
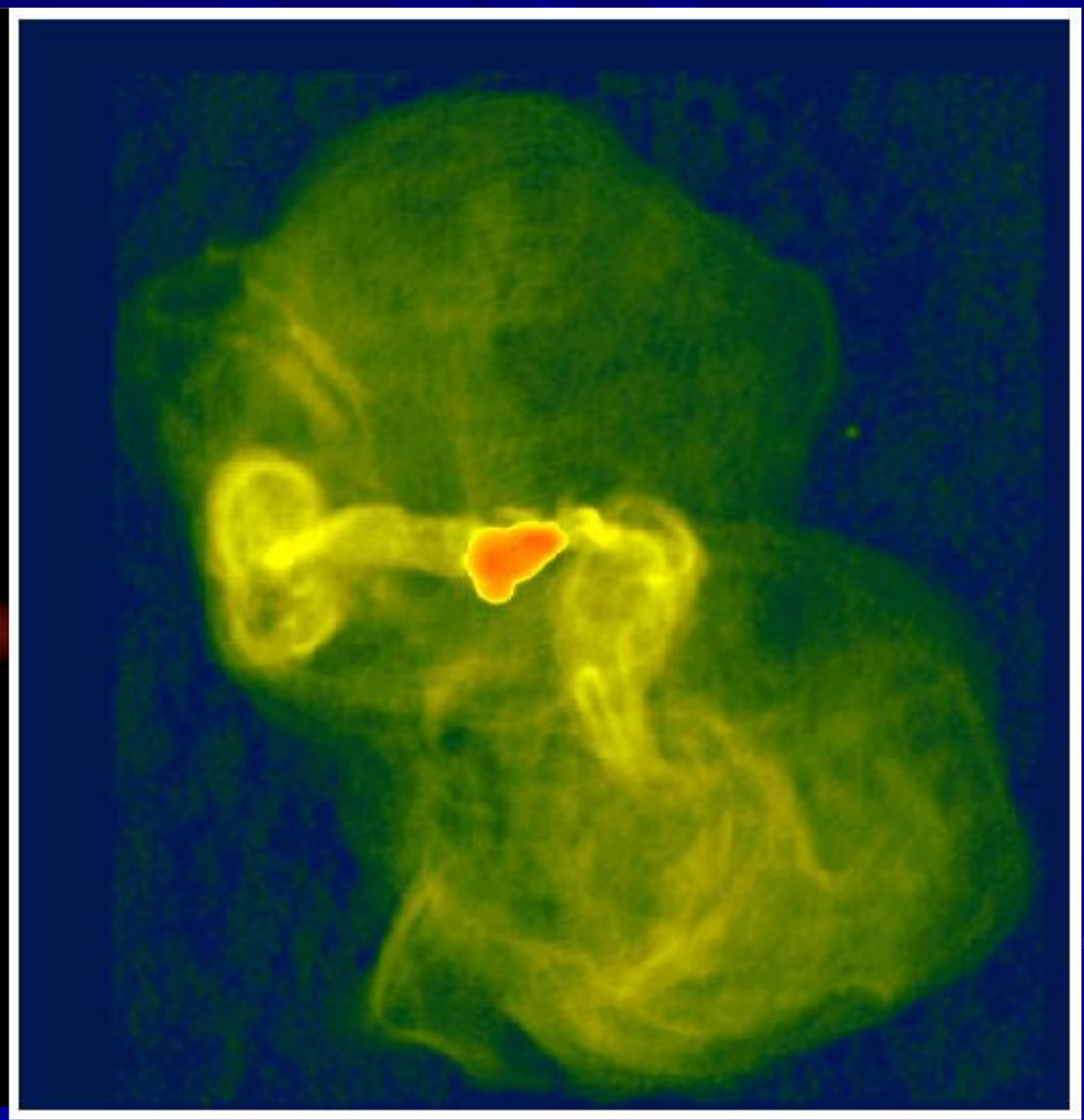




Radio Comparison

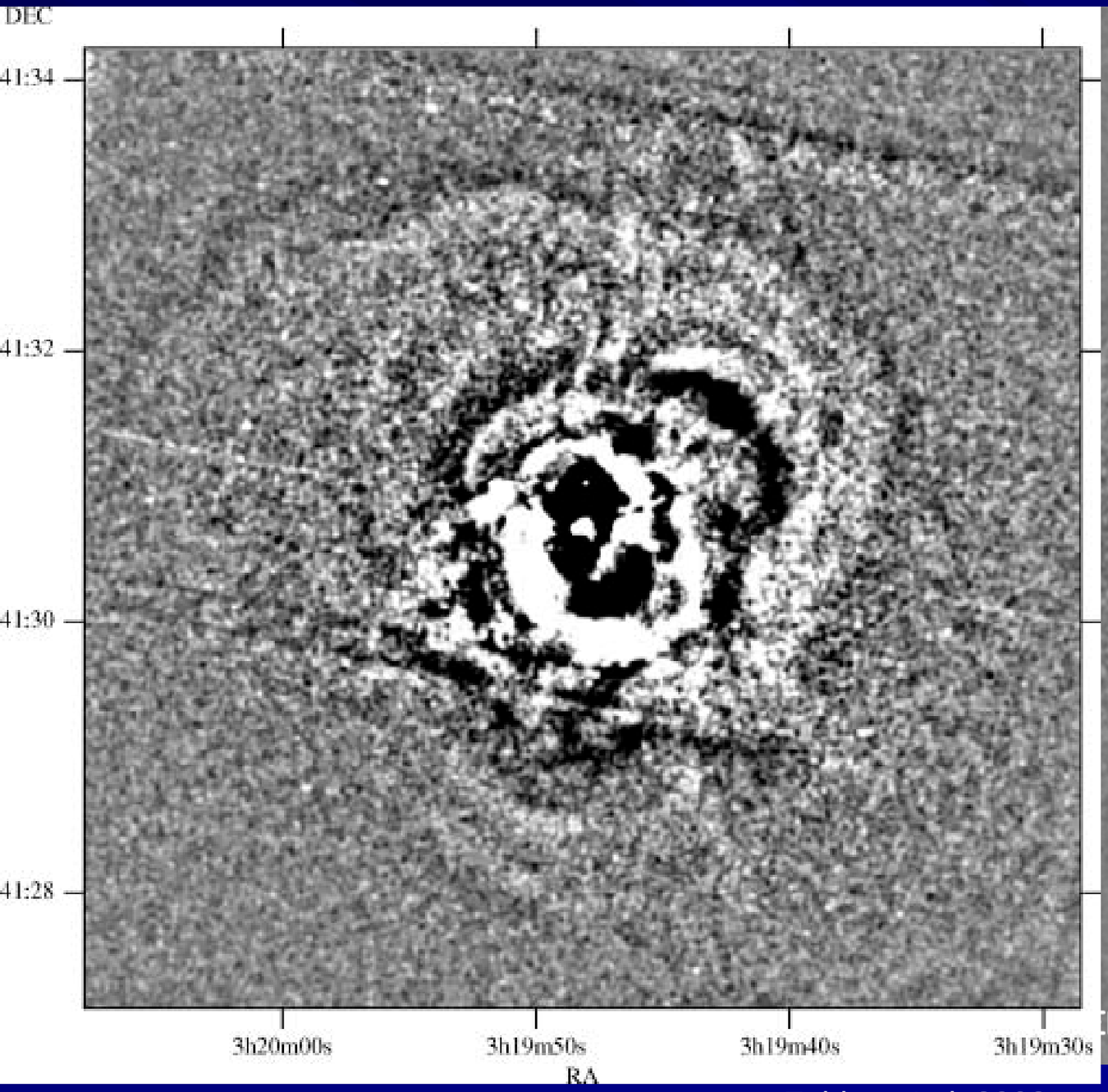


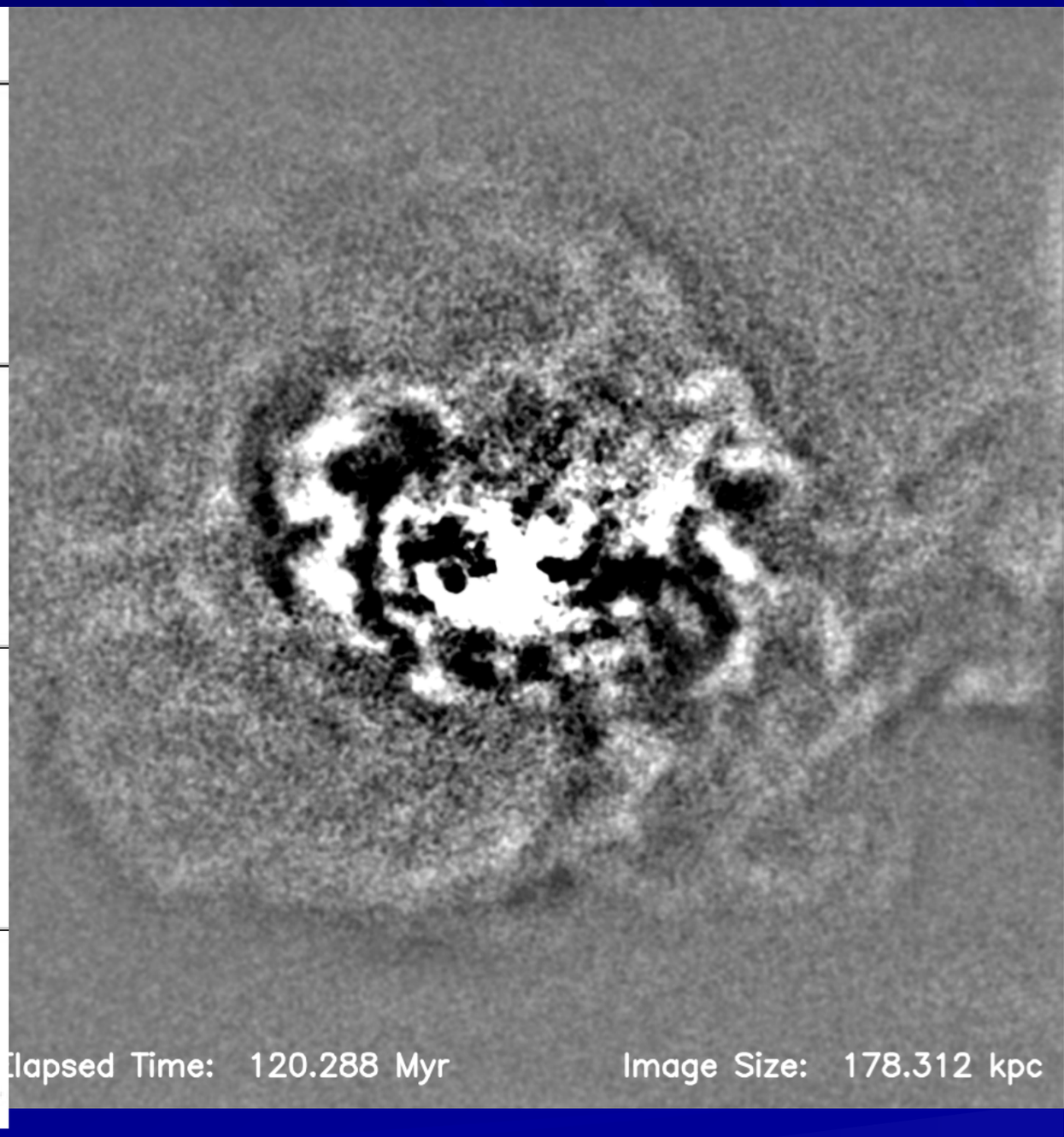


M87, 61 kpc

Owen et al. 2000

X-ray Comparison

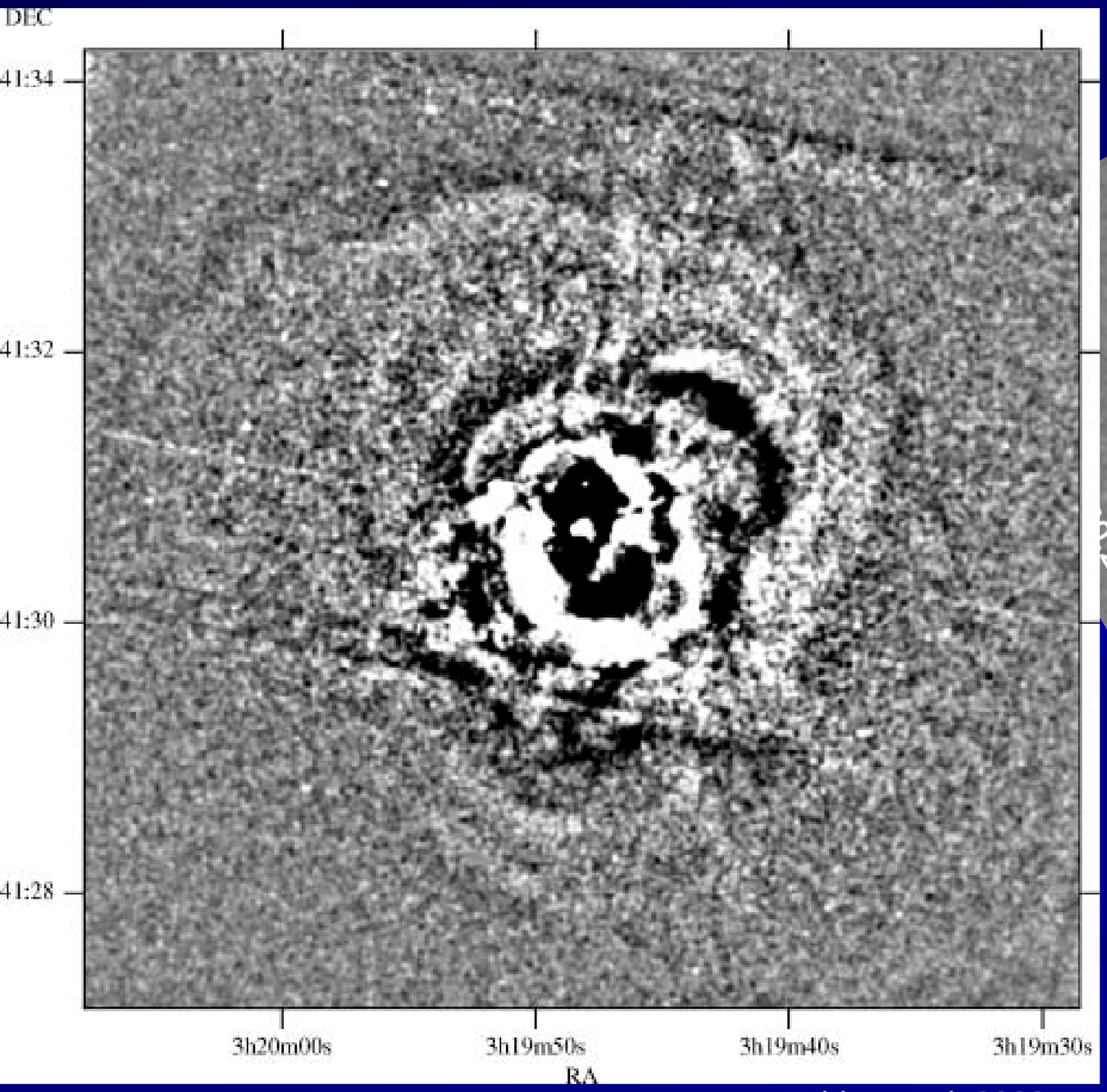


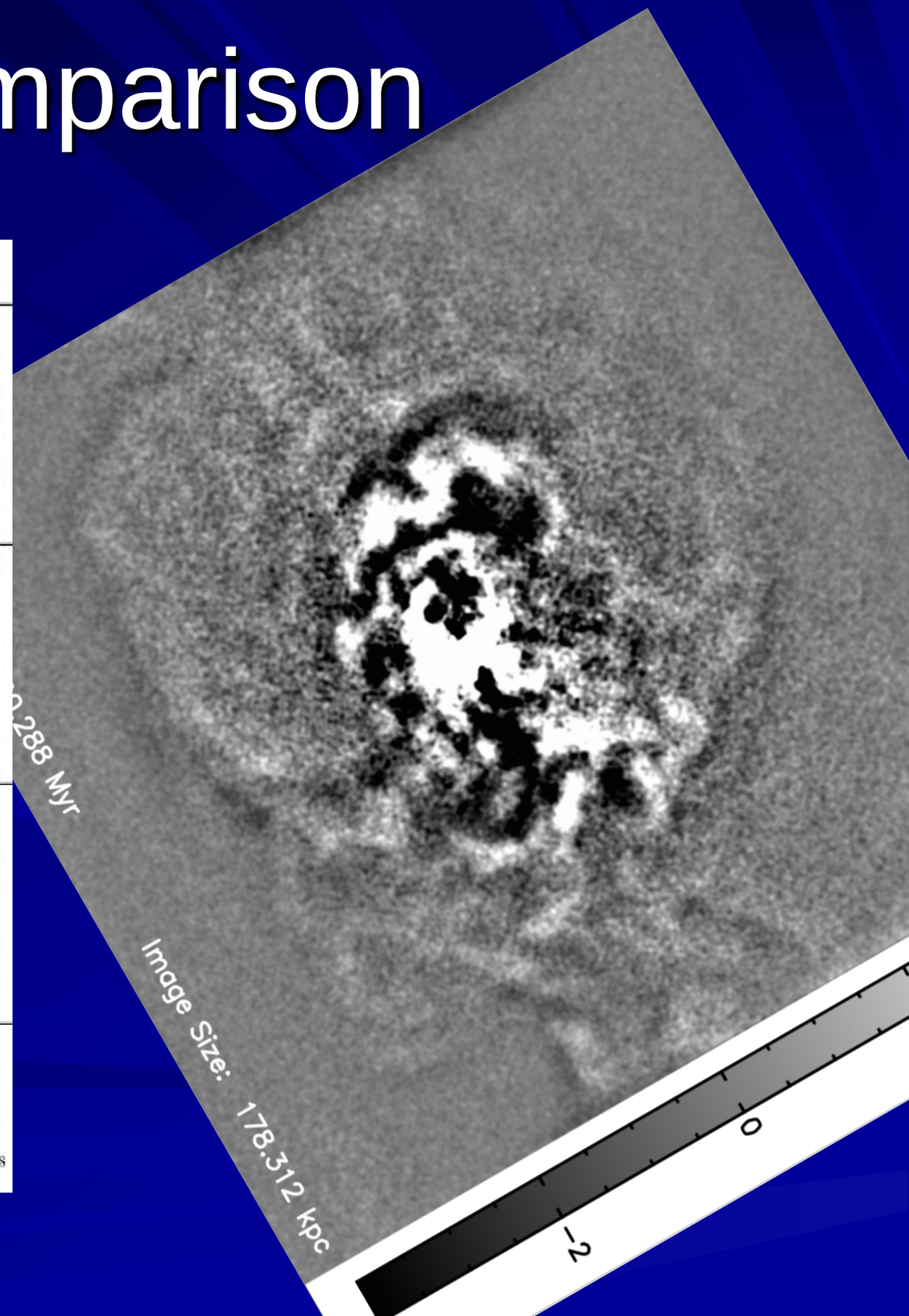


Fabian et al. 2003

Perseus, 131 kpc

X-ray Comparison





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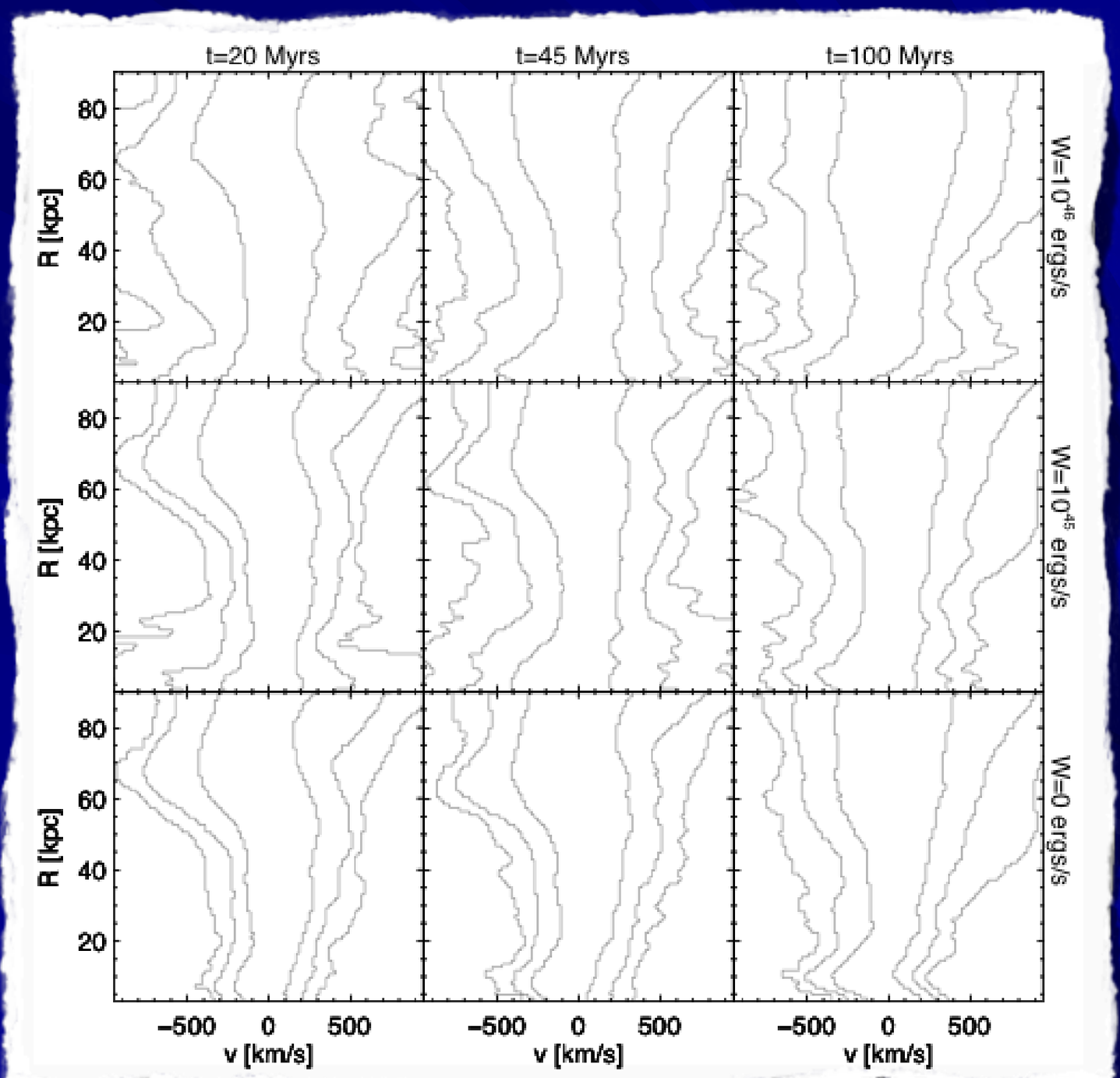
Perseus, 131 kpc

Velocity Dispersion

- 1σ, 2σ and 3σ contours
- Jets increase velocity dispersion in cluster center
- Detectable with ASTRO-H, IXO



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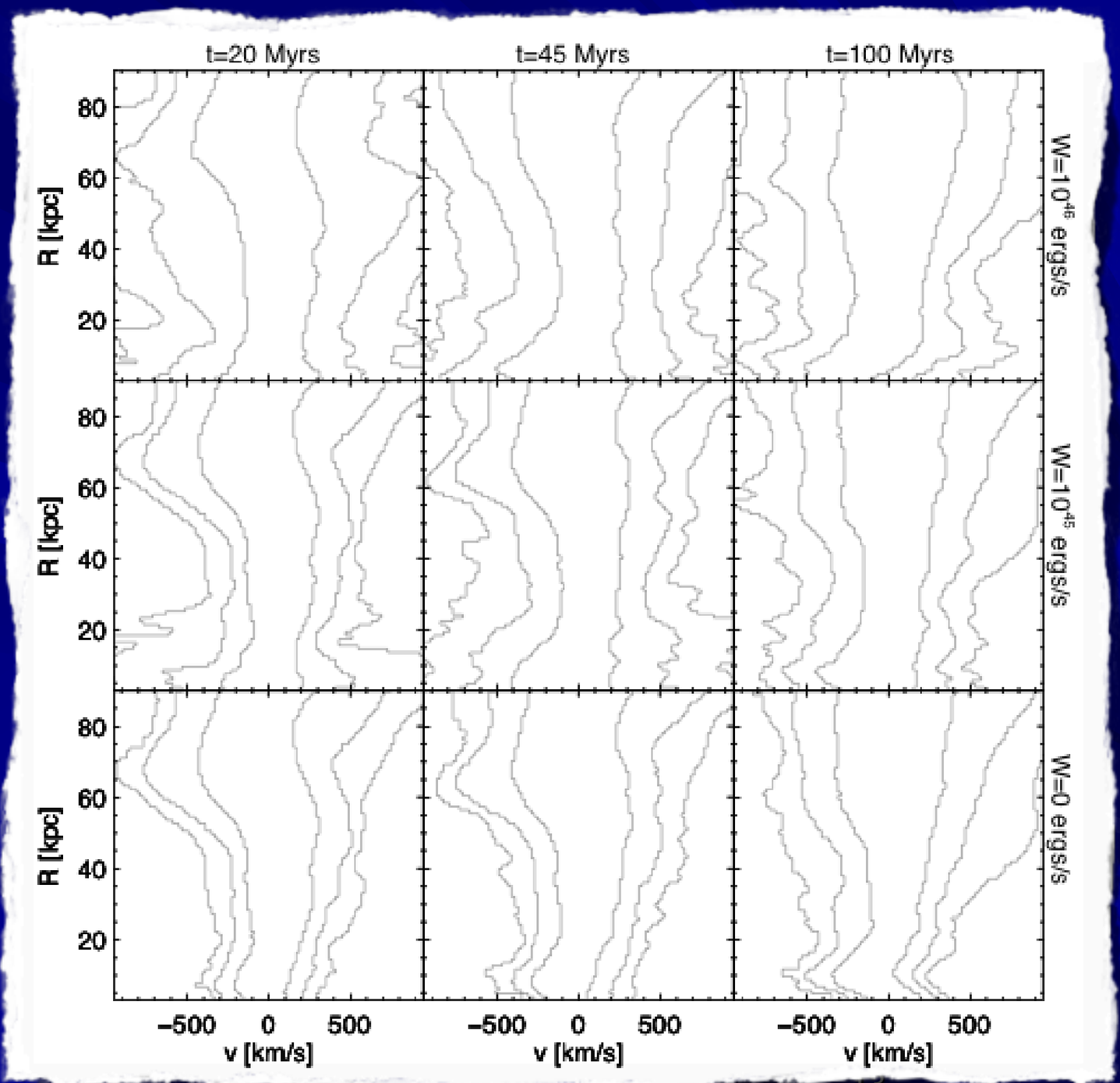
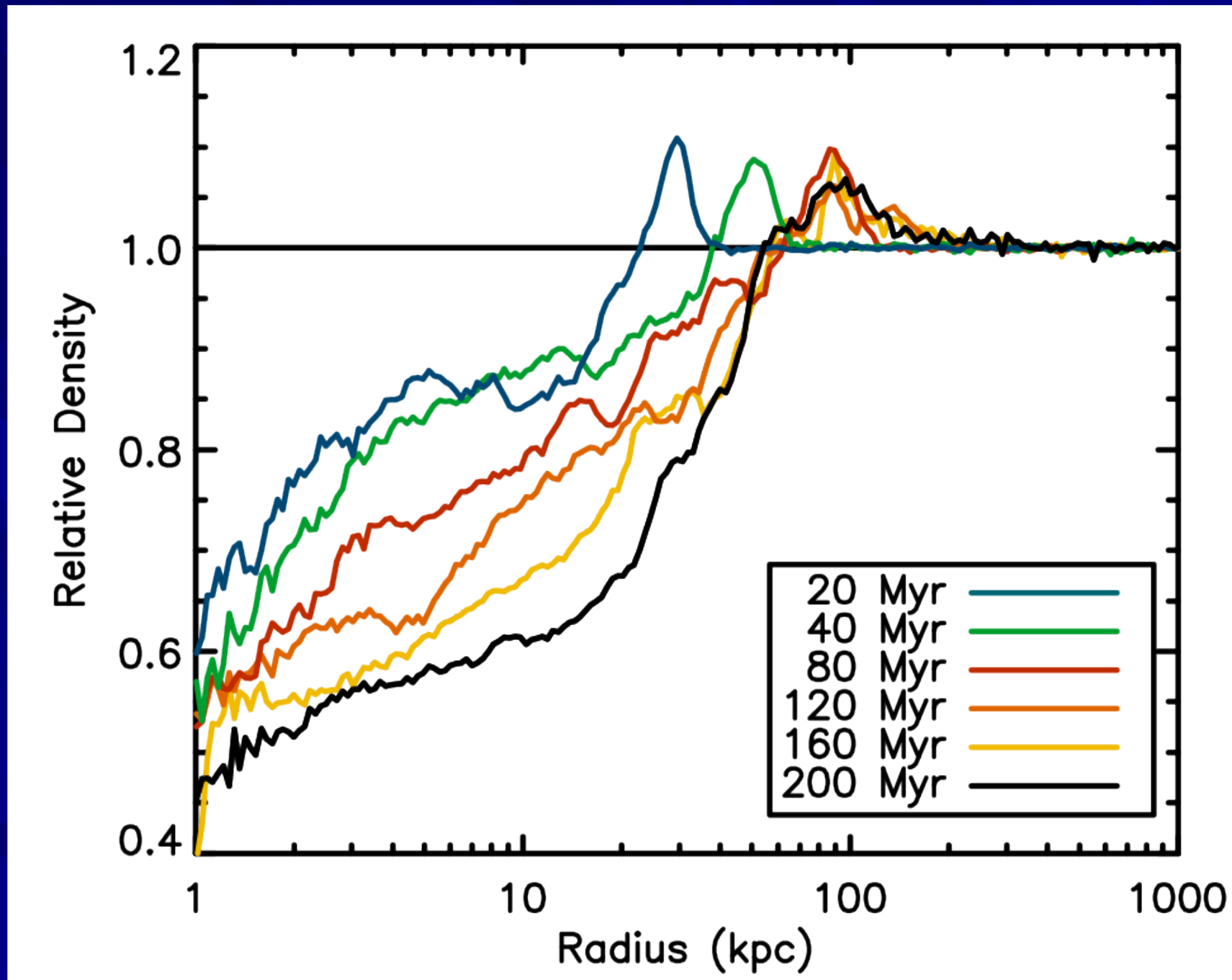
- Detectable with ASTRO-H, IXO
- Check back in 2020

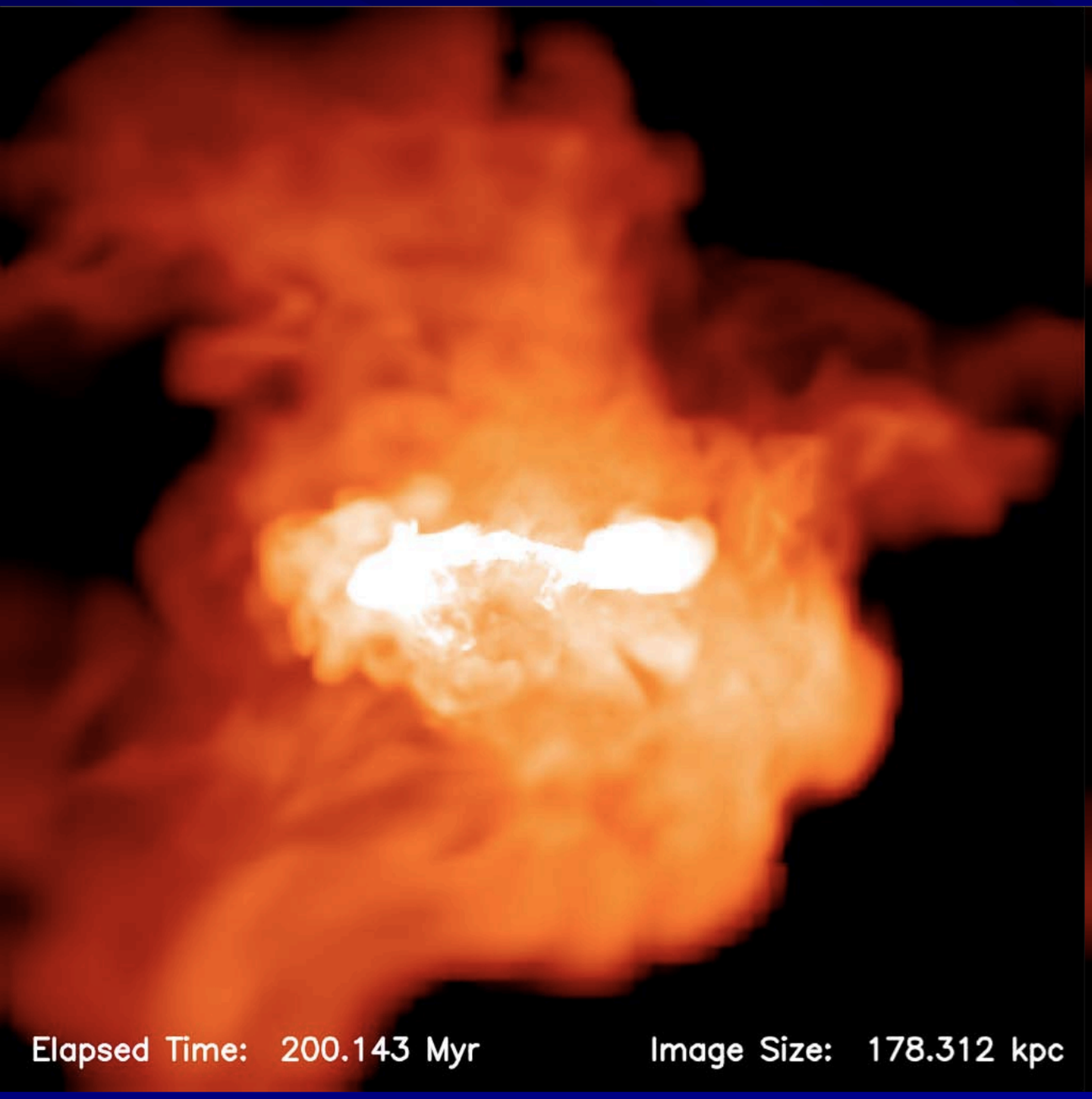


Time Evolution

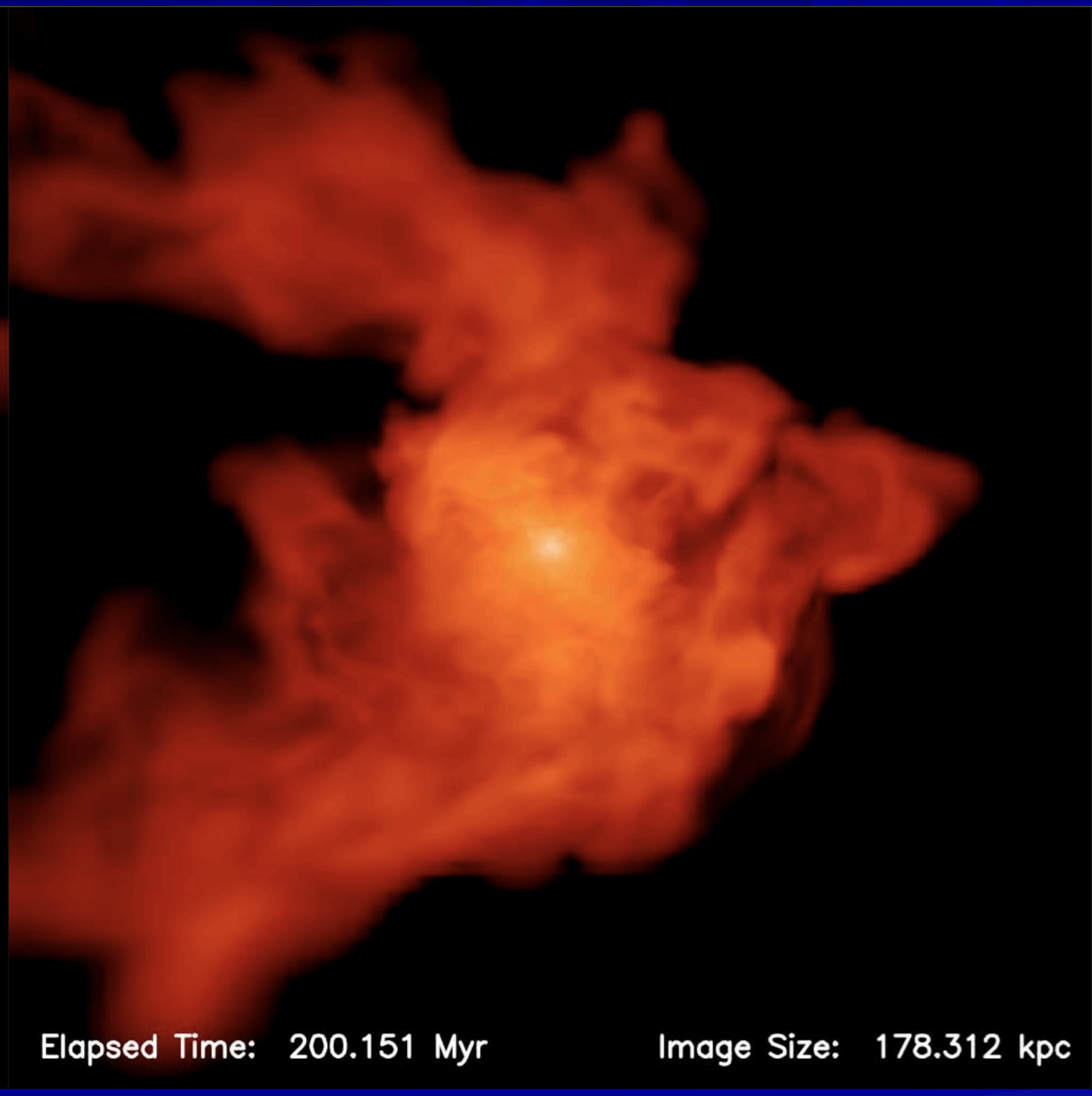
- 200 Myr continuous activity
- Excavated region reaches terminal size



AGN Duration



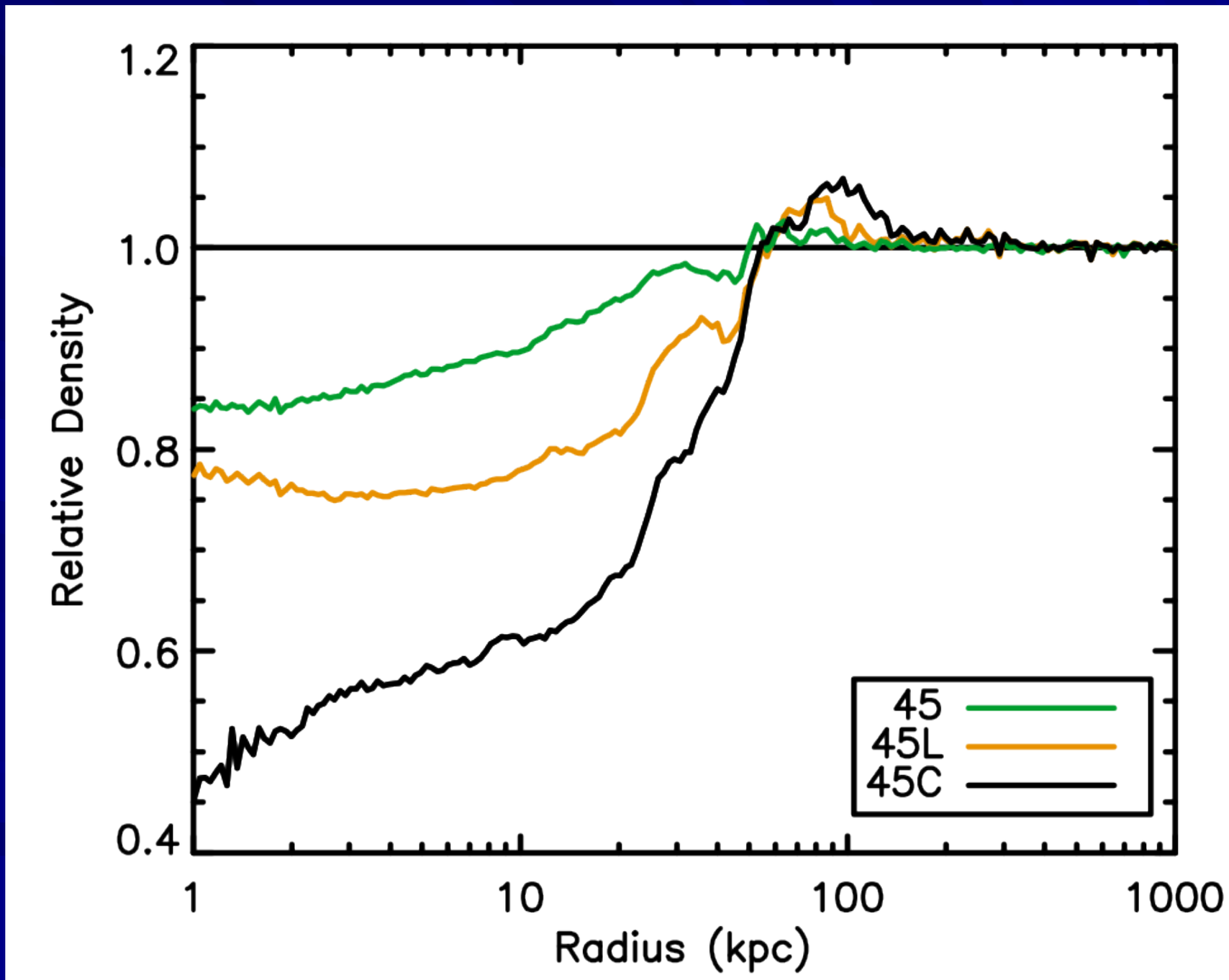
200 Myr Active



30 Myr Active, 170 Myr inactive

AGN Duration

- 30, 90 and 200 Myr of activity
- Longer duration removes more material
- Does not increase radius



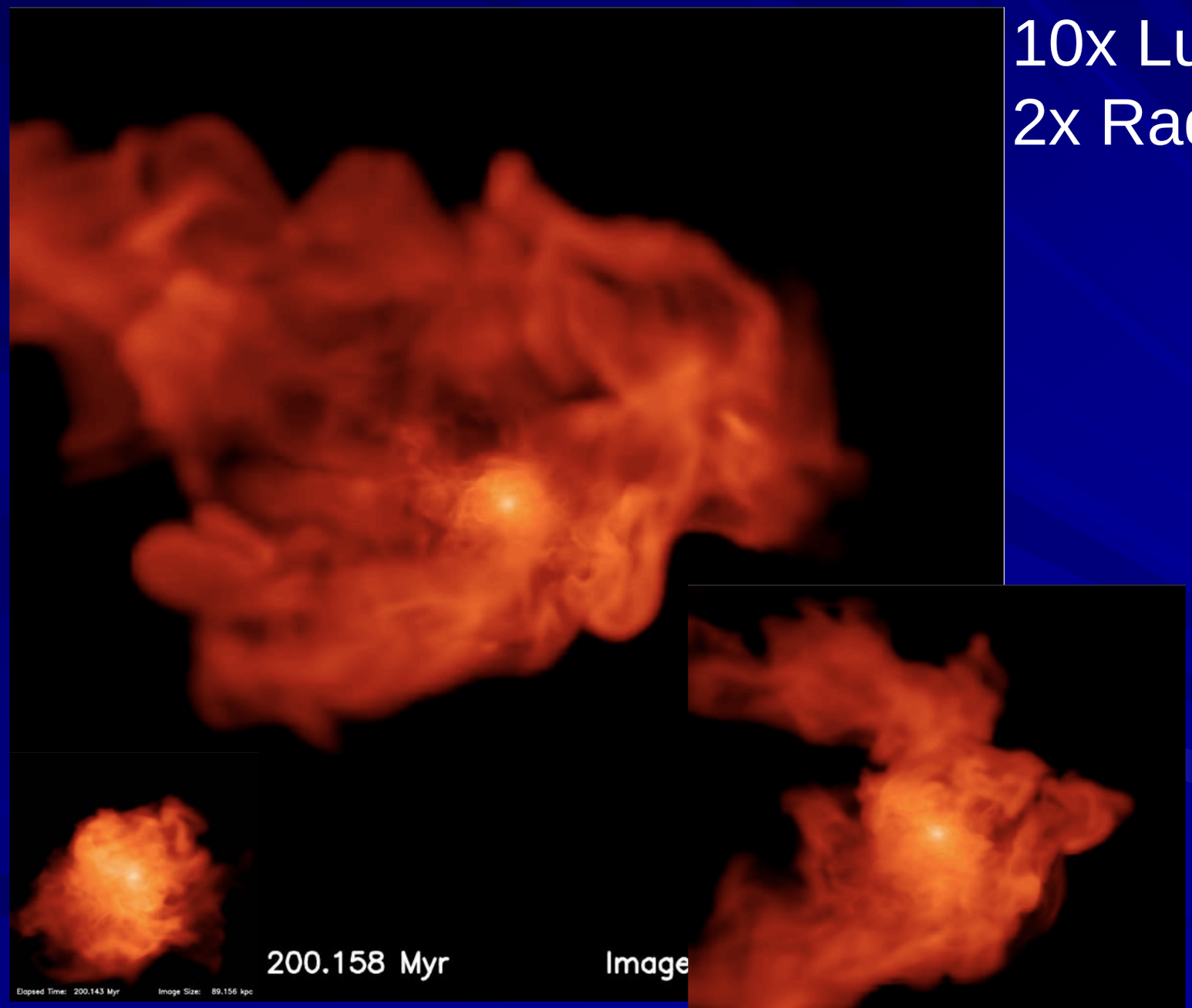
What's going on?

- Initial turn on of AGN send out shock wave, expanding cavity
- As it expands cavity pressure drops, but pressure at cluster center remains high
- Eventually, base of jet pinches off, bubble disconnected from jet
- New bubble forms behind first, expands on it's own, advected away by cluster motion
- Characteristic time scale about 20 Myr

AGN Luminosity

10^{44} – 10^{46} erg/s

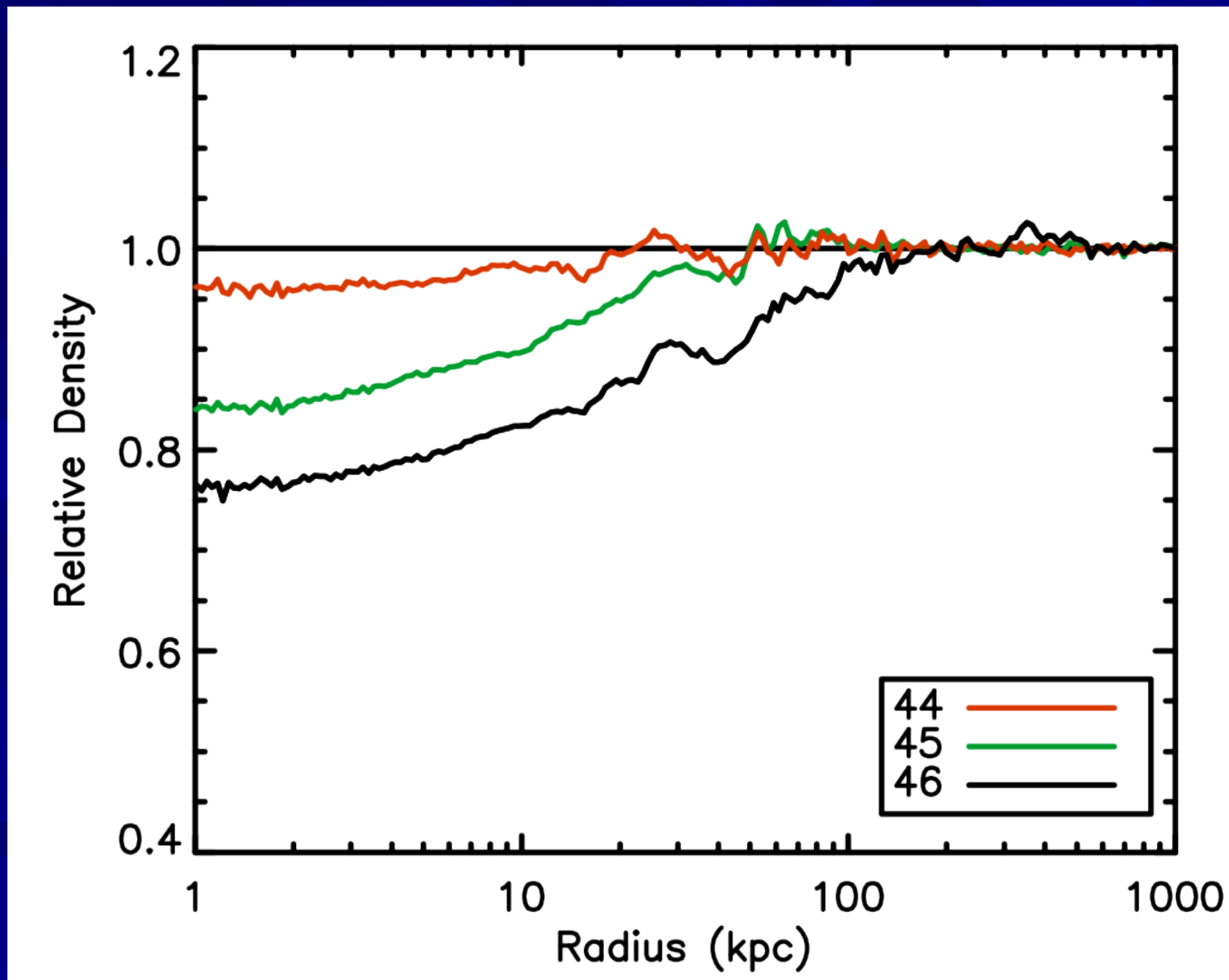
Active 30 Myr inactive 170 Myr



10x Luminosity ~ 2x Radius

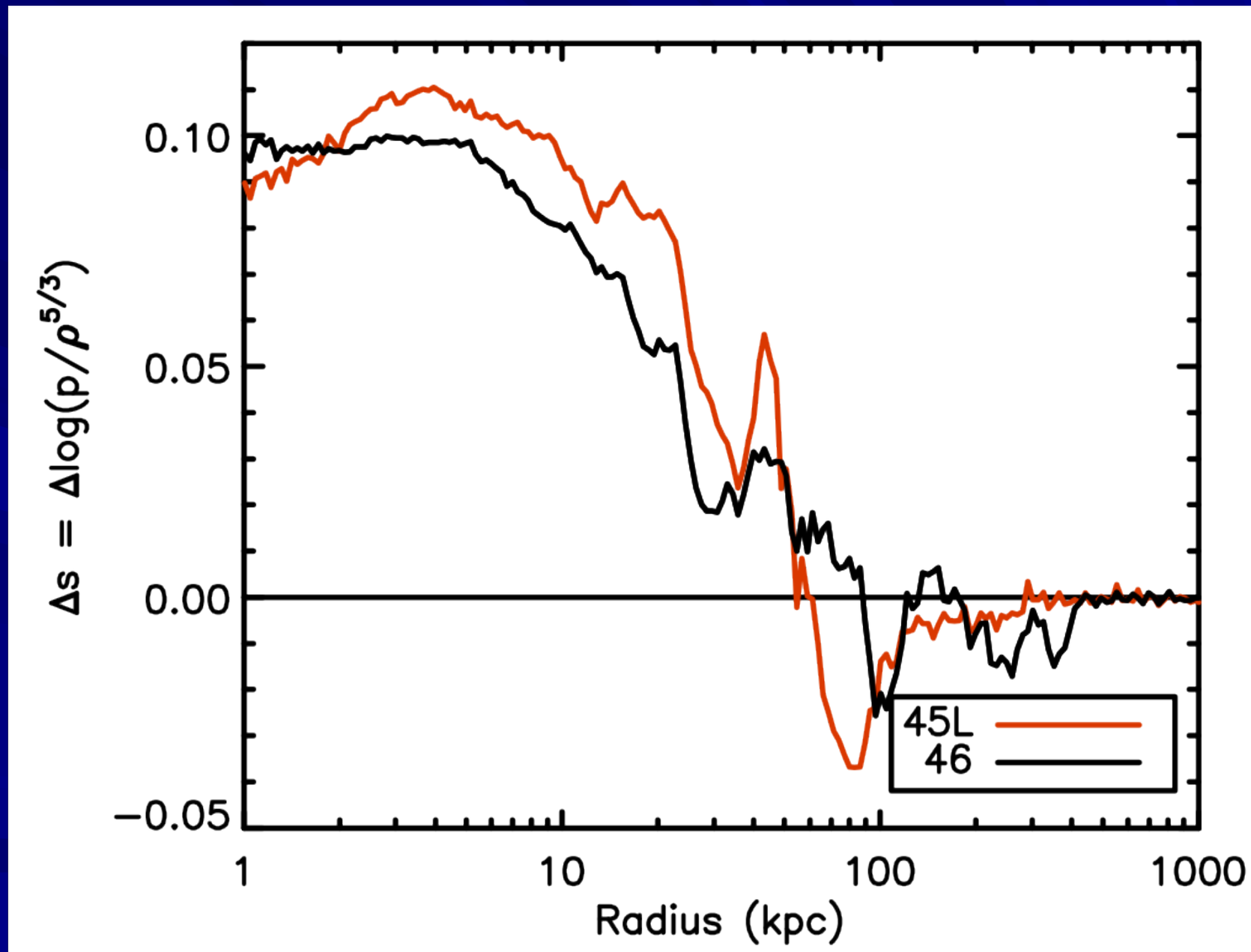
AGN Luminosity

- 10^{44} - 10^{46} erg/s
- High luminosity removes more material
- Increases radius as ~$L^{1/3}$



AGN Efficiency

- 10^{45} for 90 Myr vs. 10^{46} for 30 Myr
- Same entropy increase in core
- Smaller radius of increase

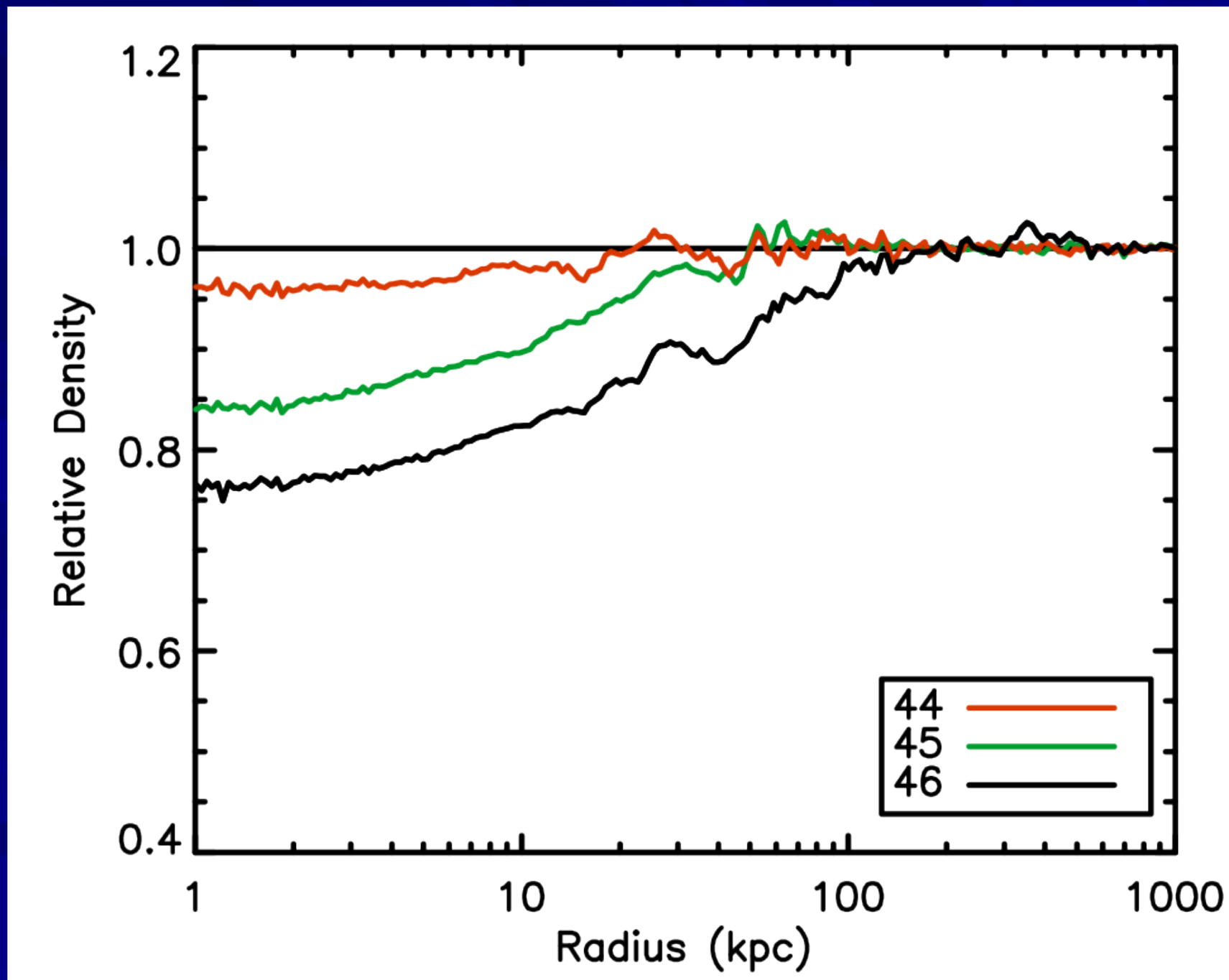


Conclusions

- Cluster environment strongly effects AGN evolution
- Multiple bubbles can be created from continuous AGN
  - Range of AGN influence set by first generation of bubble formation
  - Longer duration AGN does not increase radius of influence
- Radius of influence does increase with luminosity as $R \sim L^{1/3}$
  - Lower luminosity more efficient at heating cluster center

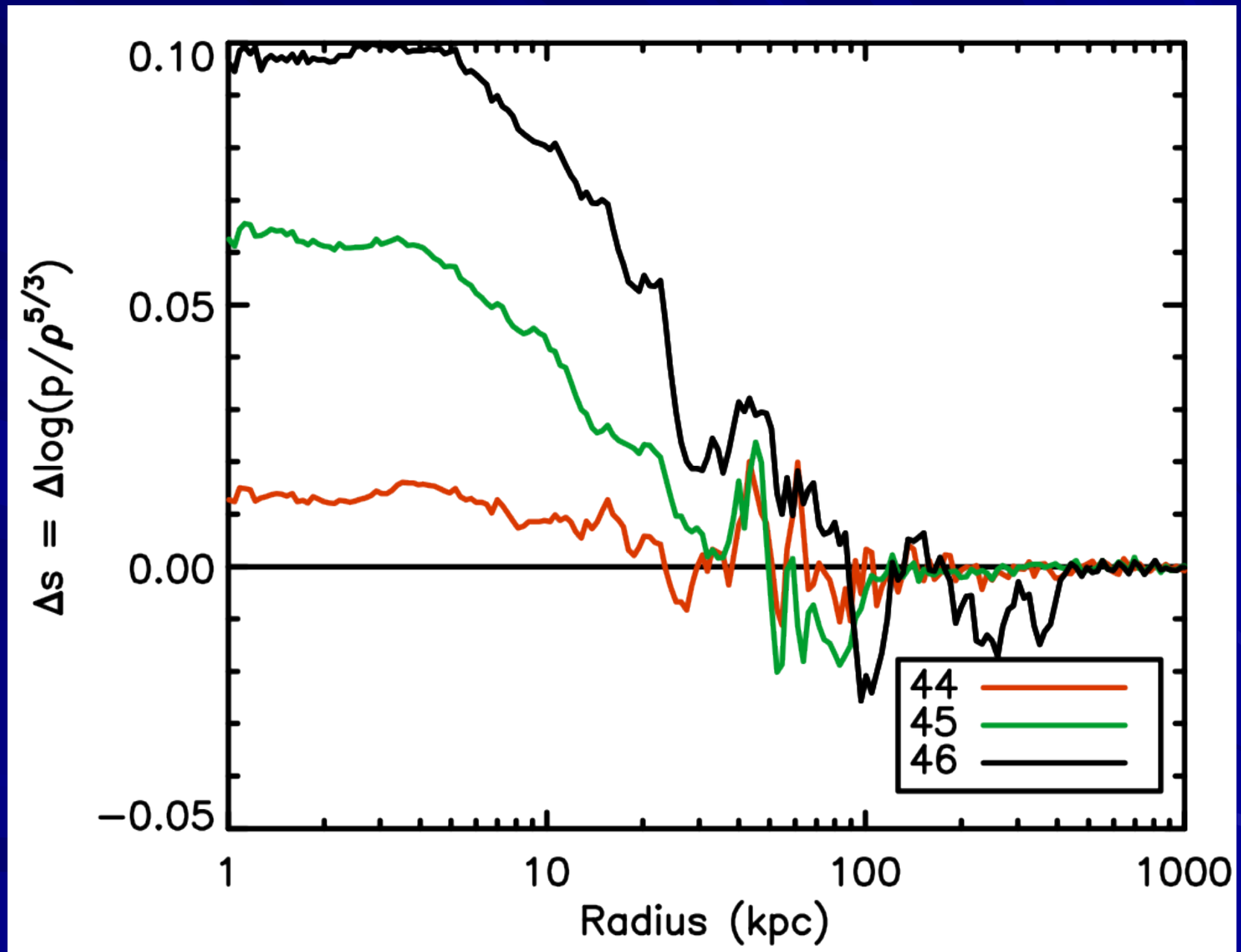
AGN Luminosity

- 10^{44} - 10^{46} erg/s
- High luminosity removes more material
- Increases radius ~2-2.5x per 10x power



AGN Luminosity

- $10^{44, 45, 46}$ erg s^{-1}
- High luminosity increases entropy more



Summary

- Cluster motion distributes AGN energy across wide angle - That's Good
- Radius of AGN impact scales as $R \sim L^{1/3}$
  - –Low power AGN more efficient – That's Good
  - –Heating depends on how energy is delivered – That's Bad
- Multiple bubbles can be made from one period of AGN activity
  - –Looks like observations – That's Good
  - –Doesn't tell you about duty cycle – That's Bad

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What does this mean for Feedback?

- AGN can provide heating in cluster center
- If outer cluster needs to be heated, need either very powerful AGN or some other heat source

- Cluster dynamical motion strongly effects AGN evolution

Cluster Properties

- Big, ~10^{15} solar masses
- Lots of hot, X-ray emitting gas
- Hot gas pressure supported
- Cooling time in the center is much less than the age of the universe
- Gas in center should cool with gas from farther out falling in to replace it – “Cooling flow”

Cluster Properties

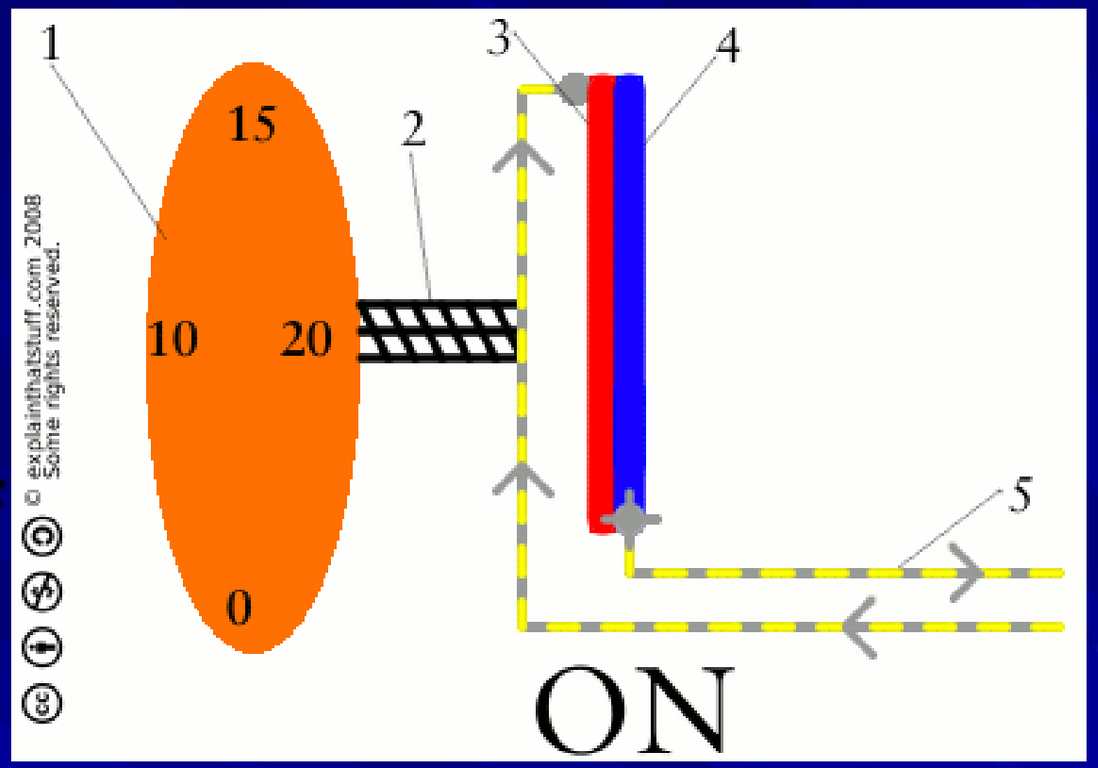
- Cooling gas should collect in center
- Either:
  - Lots of cold gas in cluster
  - Lots of star formation in central galaxy
- But, this isn't found.
  - Central galaxies are giant elliptical (red) galaxies
  - Not much gas below about 2 keV
- Need feedback to regulate this

Feedback

- What does feedback mean to me?
- Need a heat source
- Powerful enough to balance cooling
- Knows how much cooling is going on and adjust its self
- Fairly stable on long time scales

Example: Thermostat

- Metal contracts, triggers a switch
- Heat source turns on, gets warm
- Metal expands, turns heat off
- Room cools, repeat
- Heater needs to be powerful enough, but not too powerful



Feedback Candidates

- Star Formation – Probably not
- Gravitational Heating
- Dynamical friction / sloshing
- Cosmic rays
- Conduction
- AGN Jets – at least the exist
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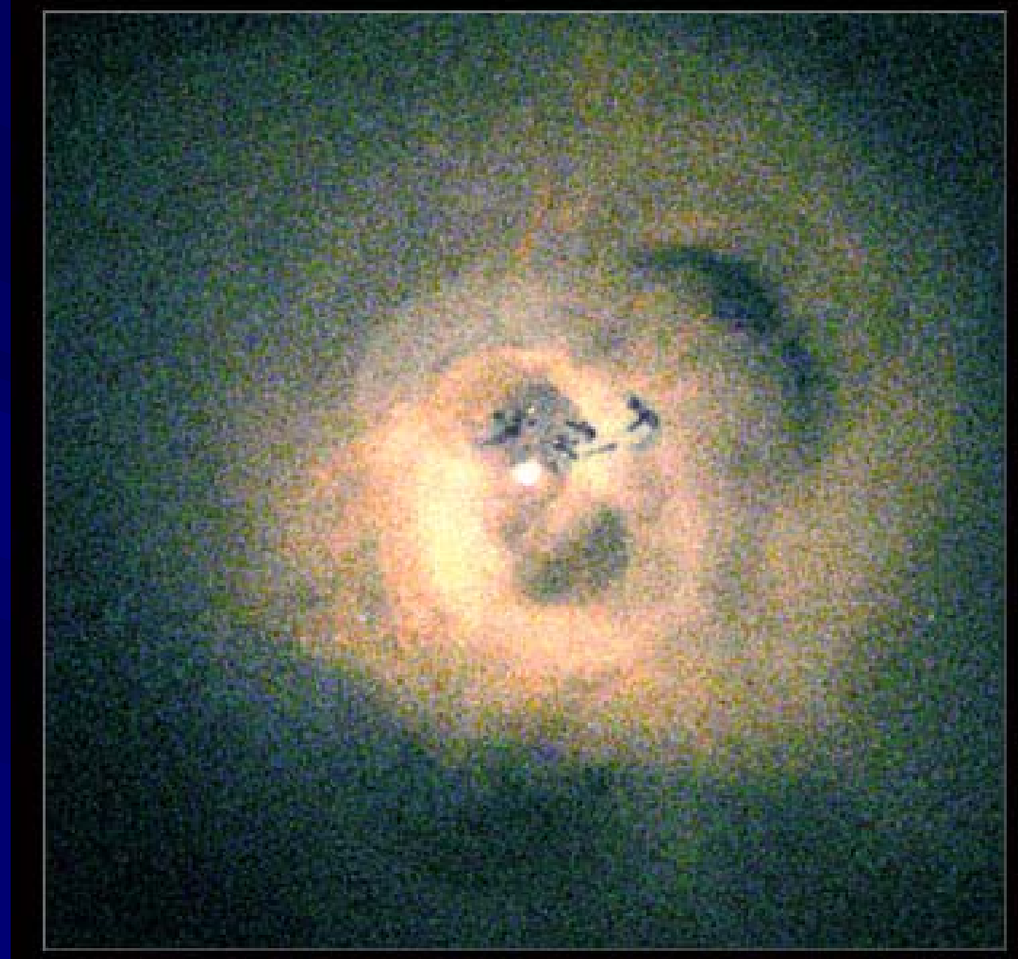
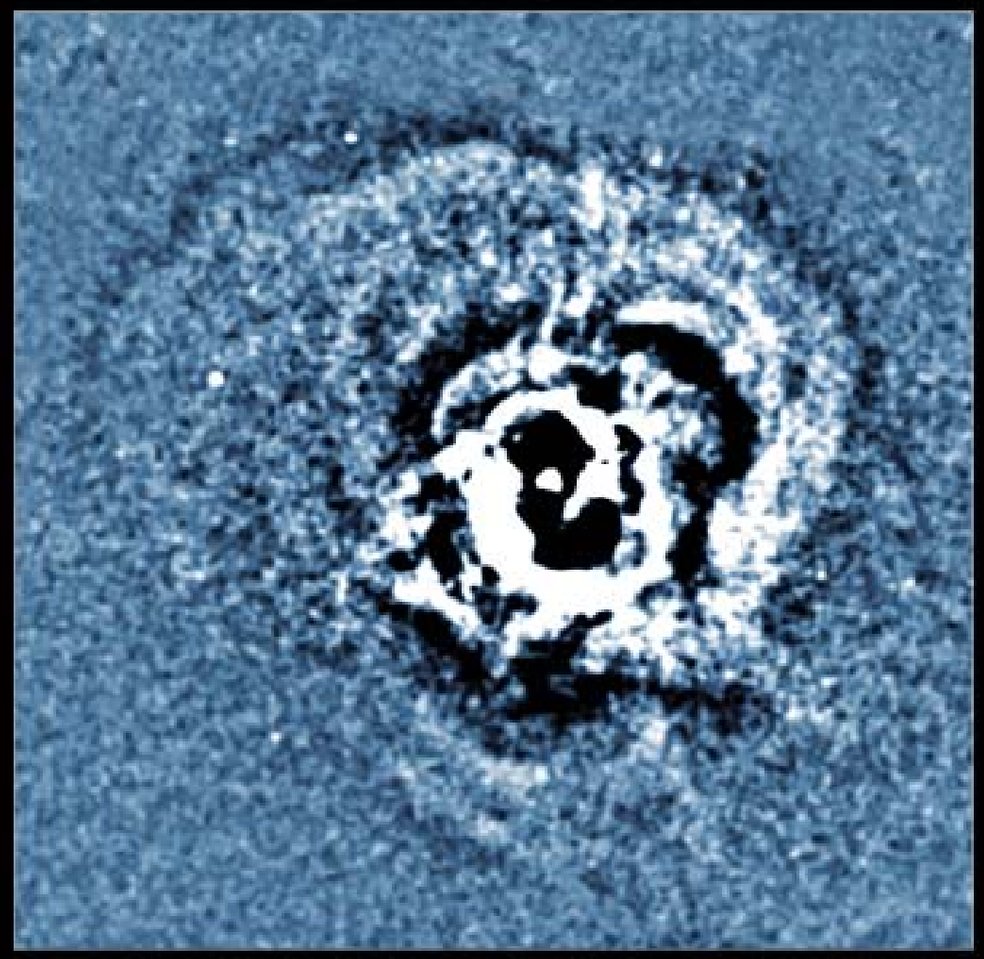
  - –Cool gas accretes onto super massive BH
  - –Accretion powers jet outflows
  - –Jets heat cluster gas, stop accretion

Cluster Observations



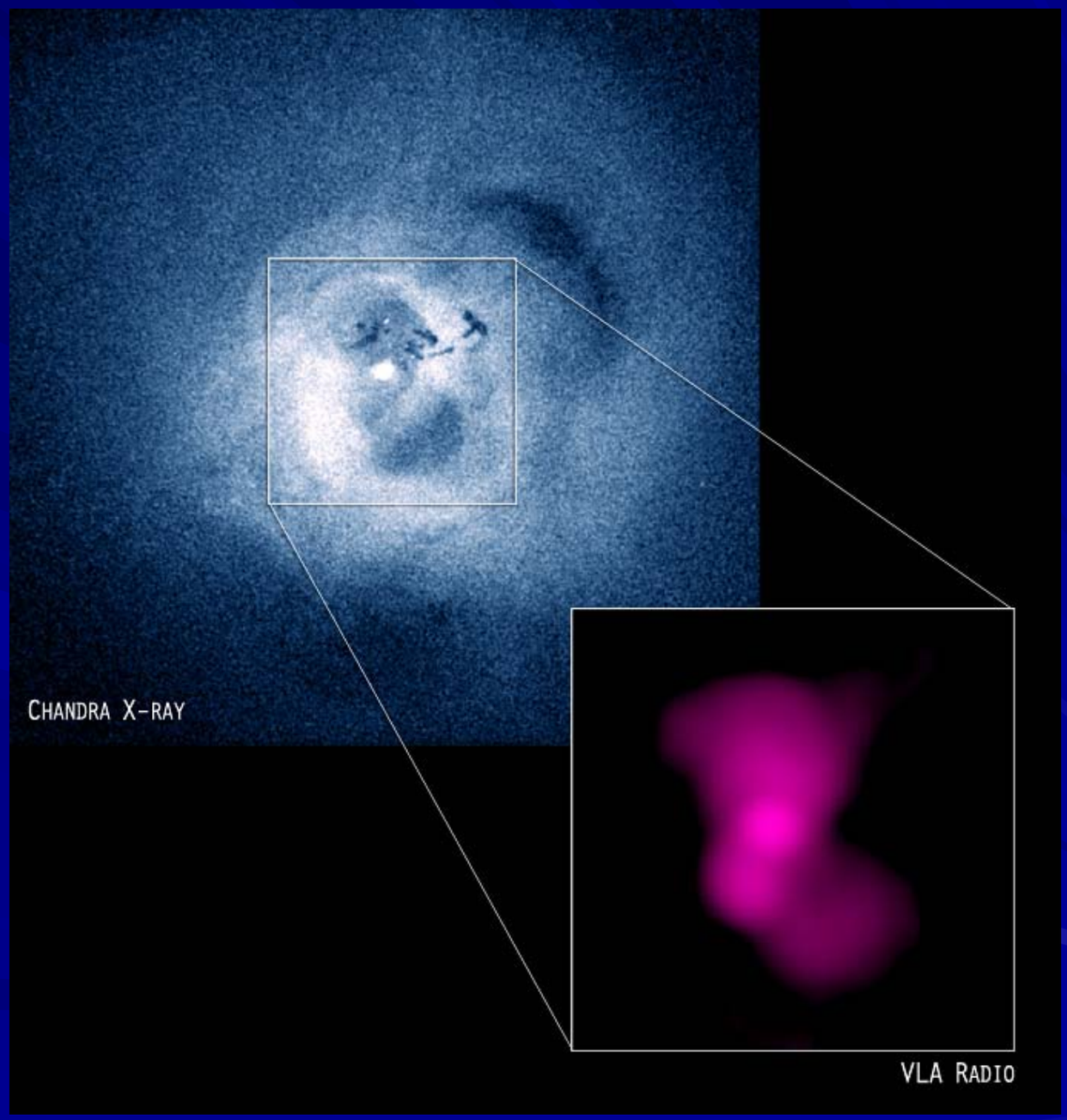


Fabian et al. 2003

- Perseus Cluster X-ray Image
- Multiple X-ray cavities
- “Sound waves” extending out from cluster center

Cluster Observations

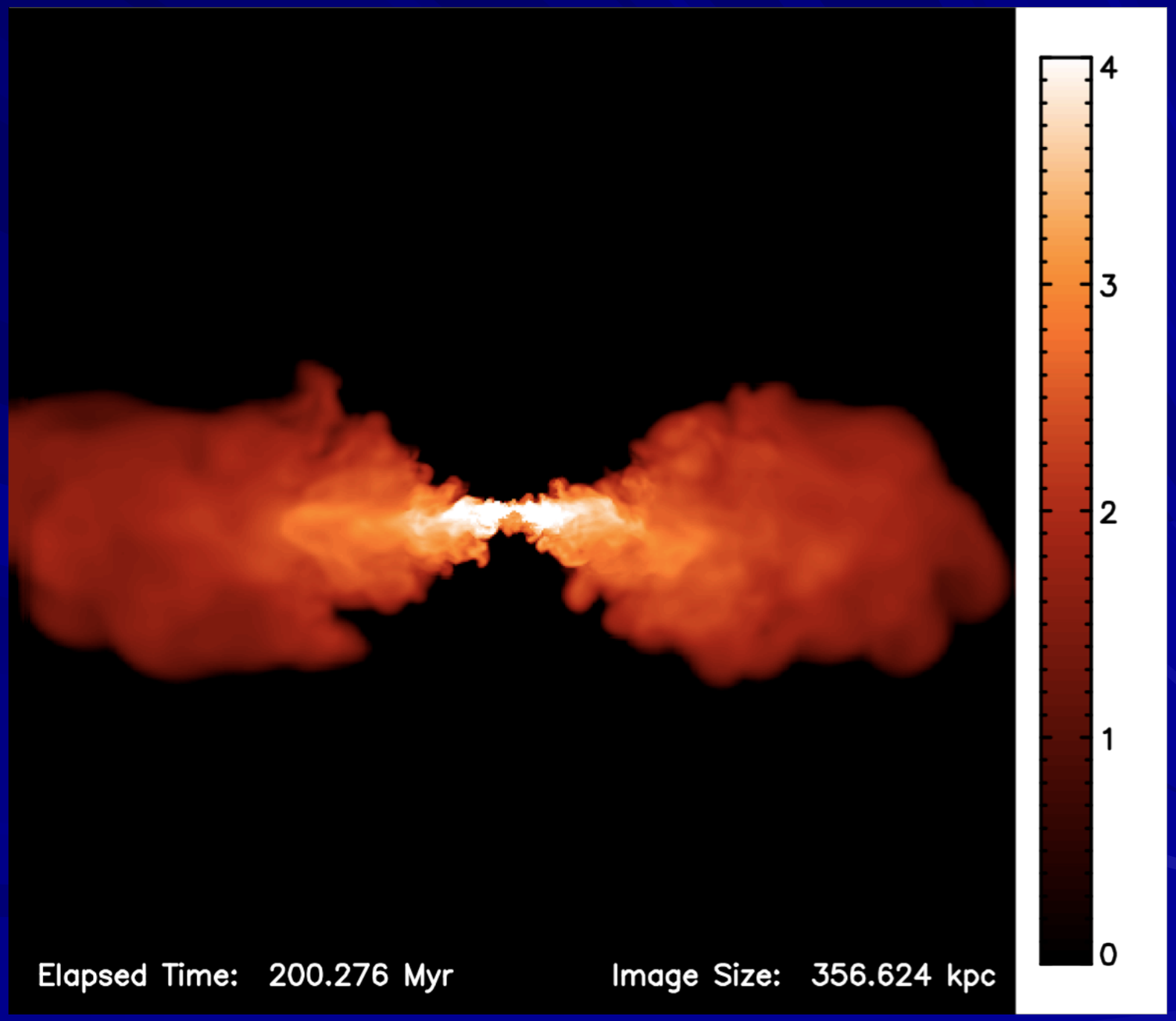
- Inner cavities filled with radio emission



Cluster Observations

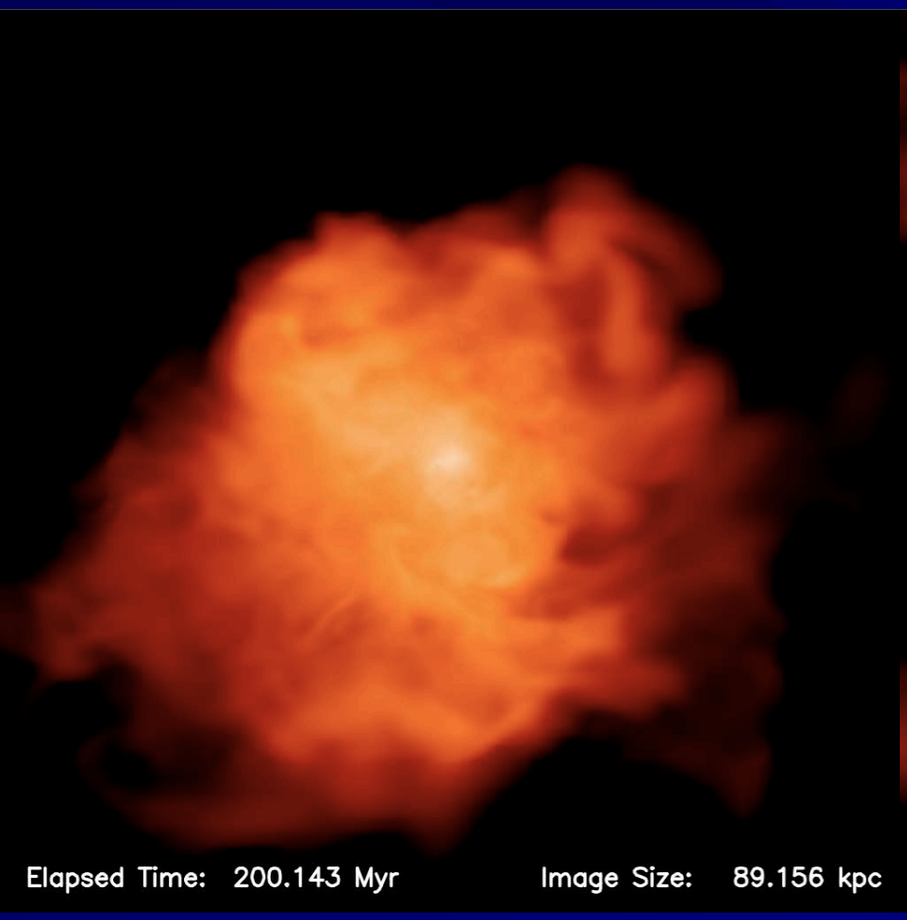
Hydrostatic Cluster

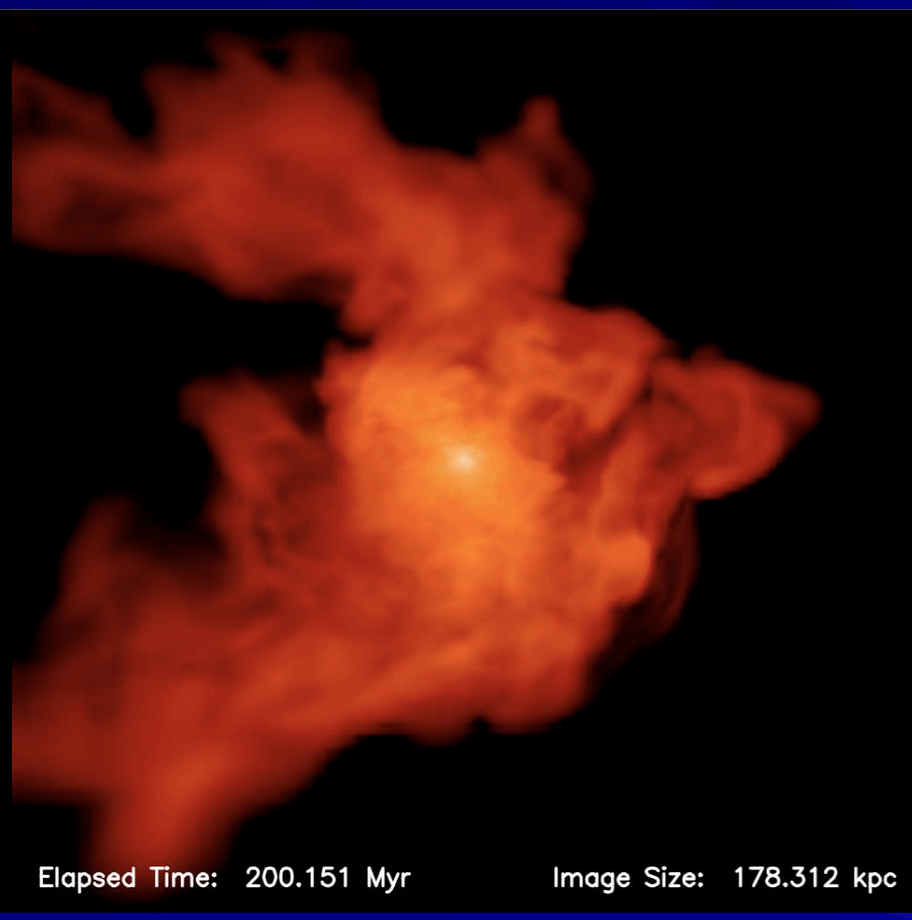
- Inflate two big cavities
- Stay in jet direction

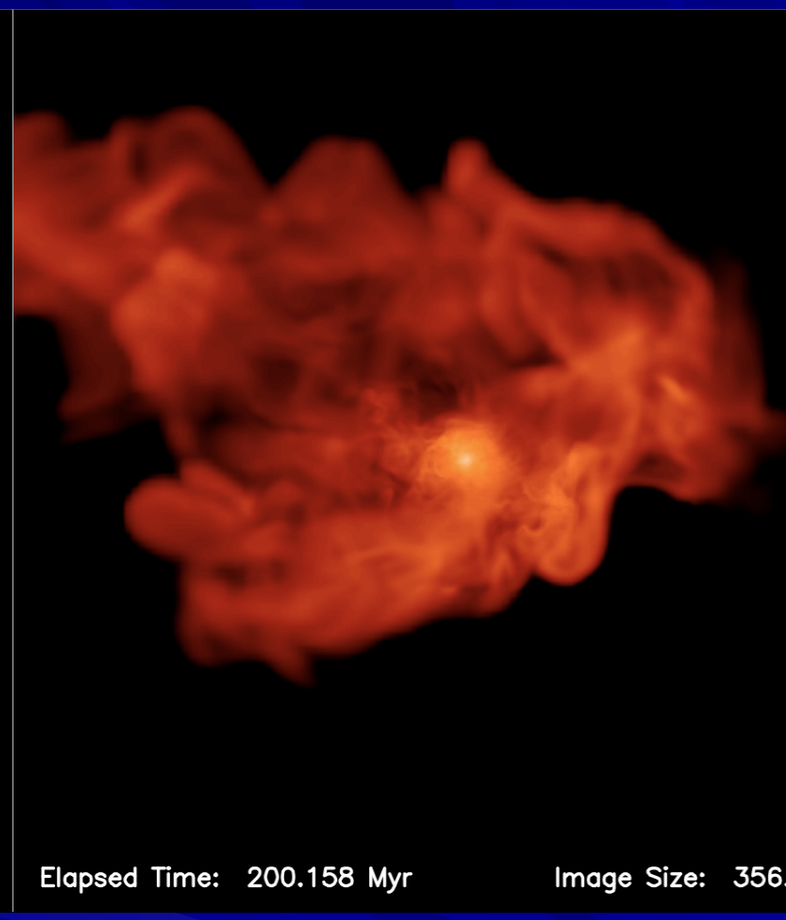


~12 Generation of Bubbles

AGN Luminosity







10^{44} erg/s, 90 kpc

10^{45} erg/s, 180 kpc

10^{46} erg/s, 360 kpc

- Active 30 Myr, inactive 170 Myr

Dynamic Cluster X-ray