AGN Heating of Cooling Flow Clusters: The Failure of Simple Hydrodynamical Models

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Background

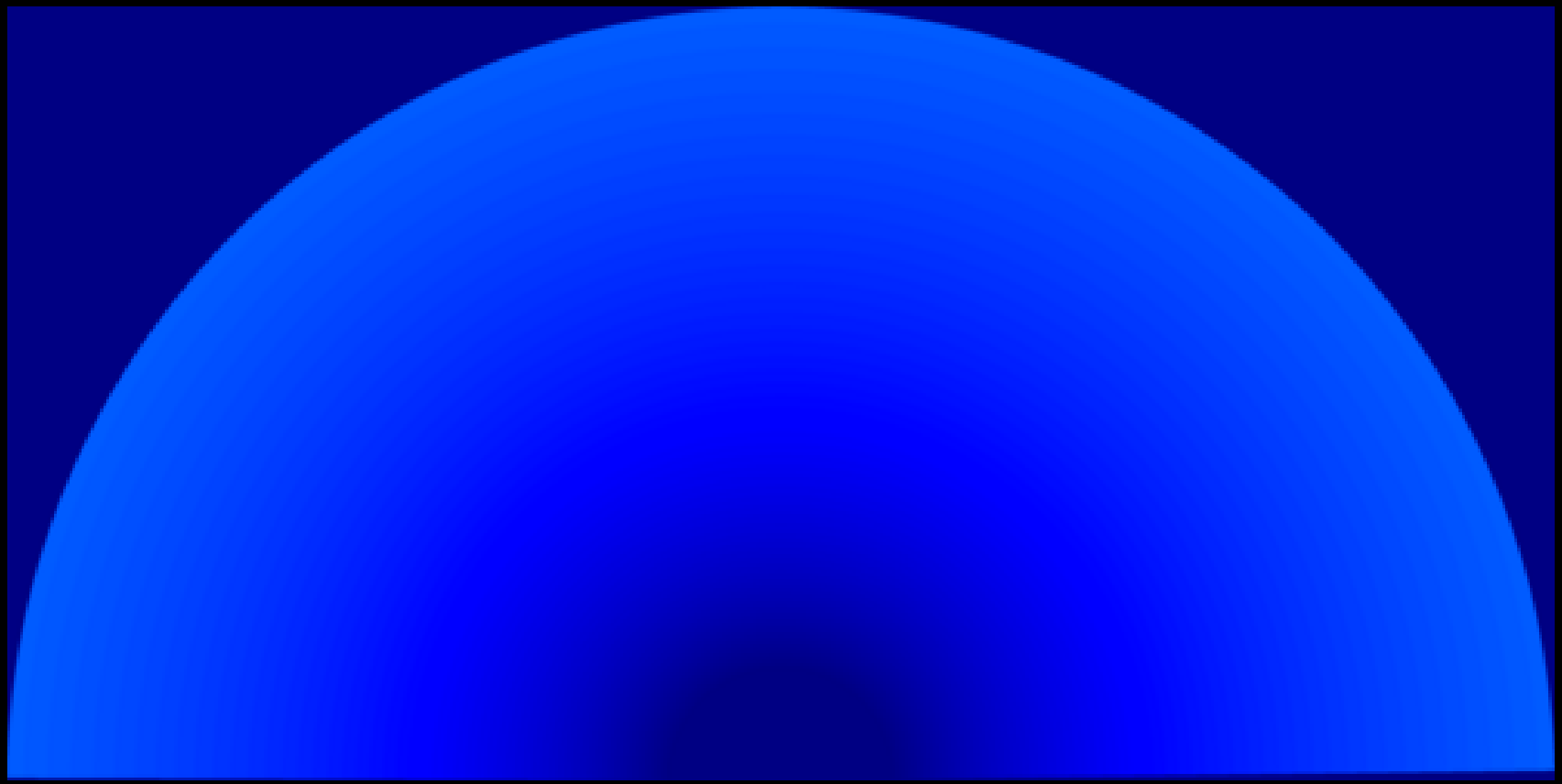
- The Intracluster Medium (ICM) in rich relaxed clusters is cooling, with central cooling times shorter than the age of the cluster.
- Massive galaxies in cluster centers are not still forming.
- No reservoirs of cold gas in central regions.
- Classic cooling flow problem.

Model

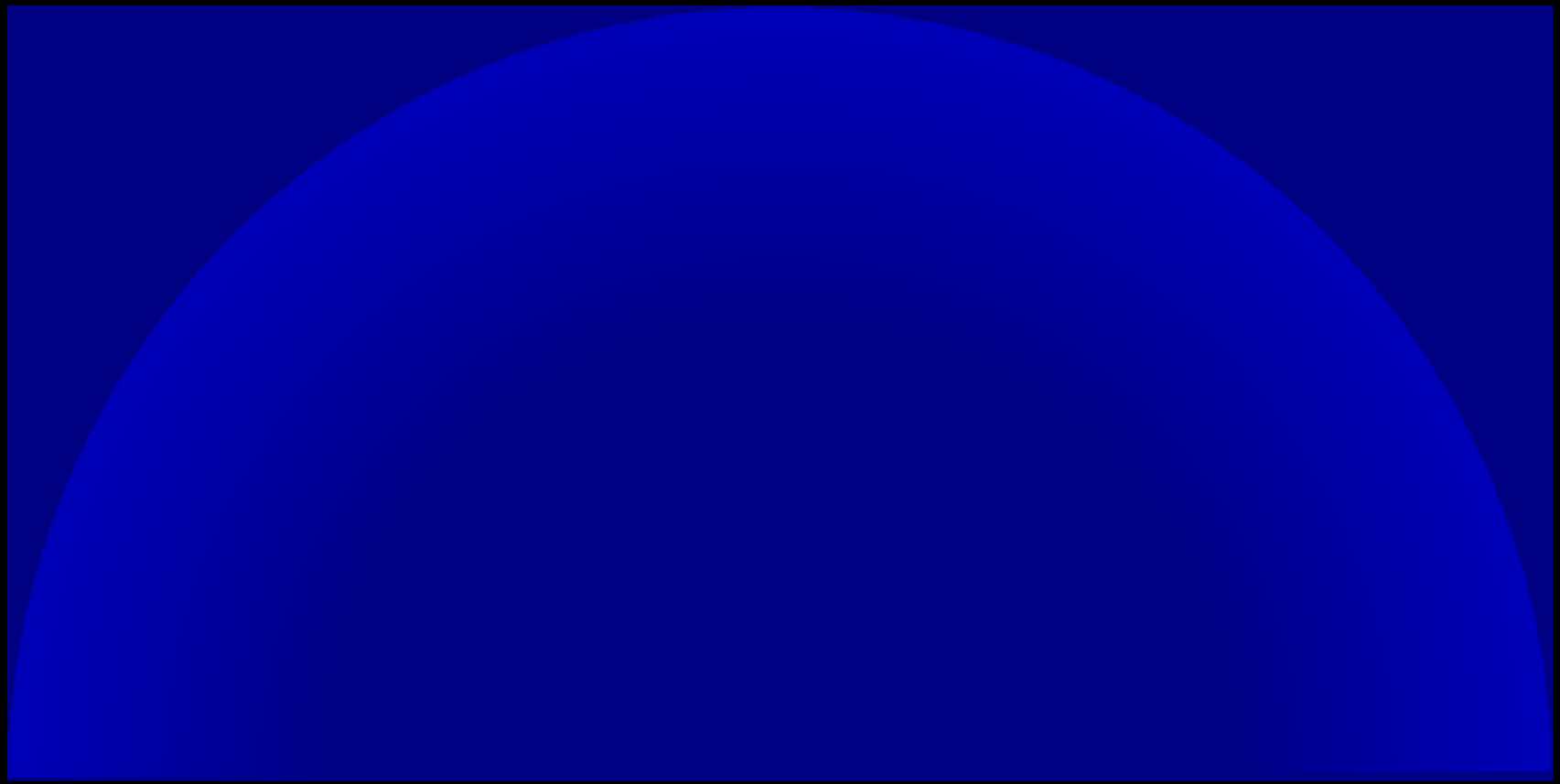
- Can AGN solve this?
  - They have approximately enough energy to offset cooling.
- High resolution 3D models with modified ZEUS-MP V1[1].
- Pure hydro with optically thin radiative cooling.
- Light, (usually) supersonic jet injected in center.
- Different prescriptions for feedback:
  - Pure Cooling
  - Single Jet
  - Instantaneous Feedback
  - Delayed Feedback

[1] www.astro.umd.edu/~vernaleo/zeusmp.html

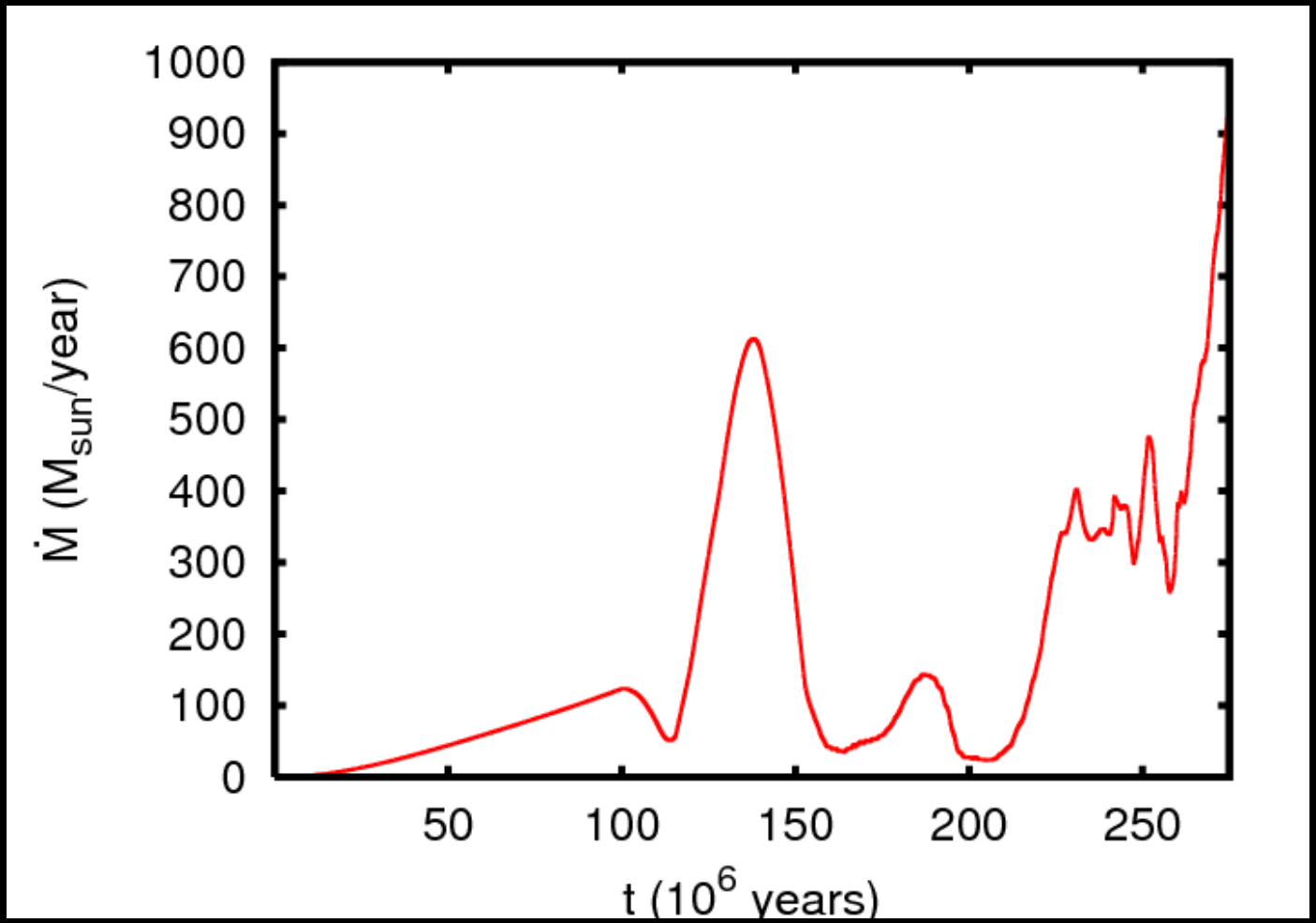
Single Jet Burst – Entropy



Delayed Feedback – Entropy (central regions)



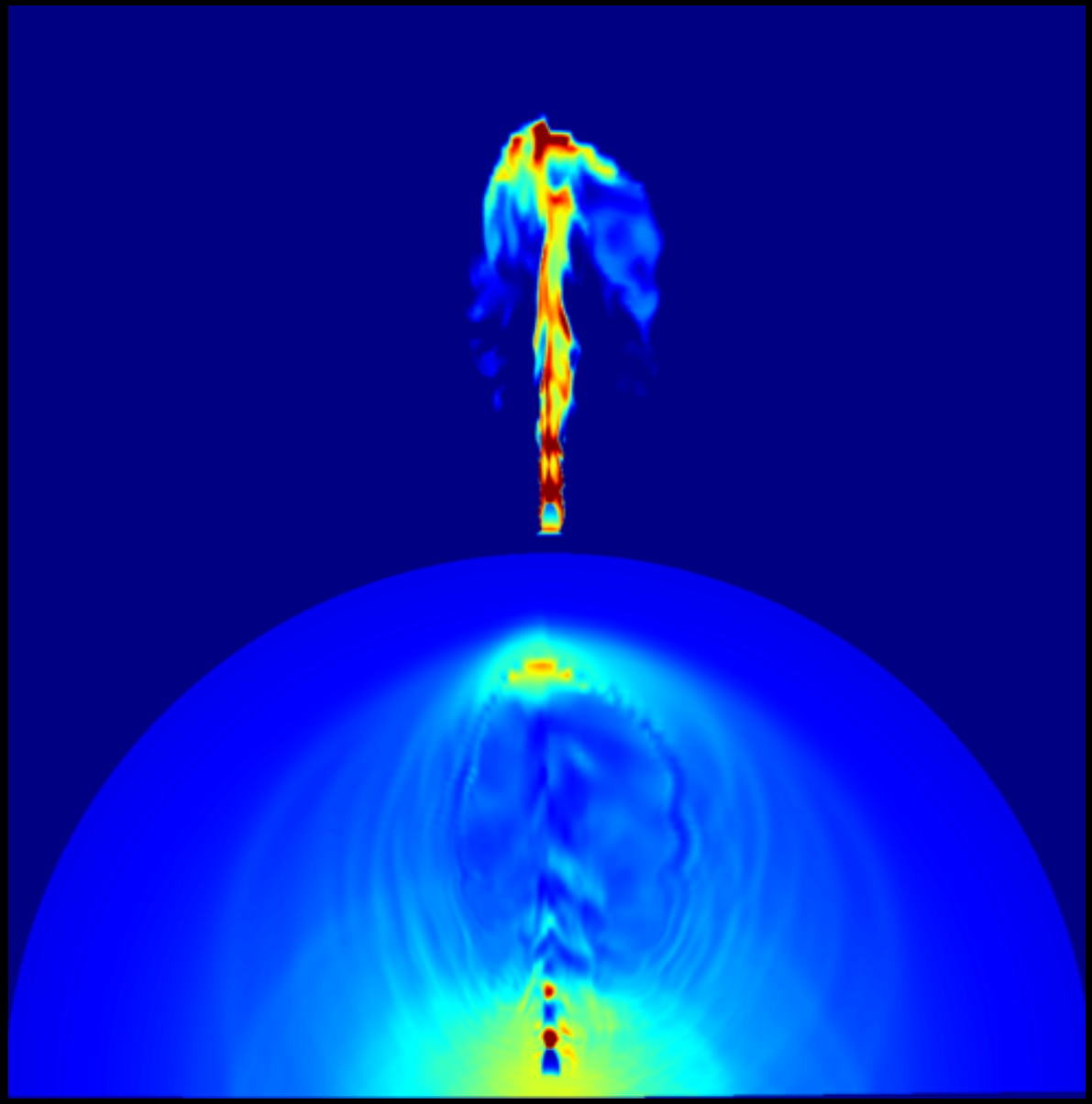
Delayed Feedback – Mass accretion on inner boundary



Failure of Simple Models

- In all cases, regardless of η, we can only delay catastrophic cooling (on the order of a few times 50 Myrs at most).
- Energy is not spatially distributed properly to prevent cooling.

Channels and Deposition



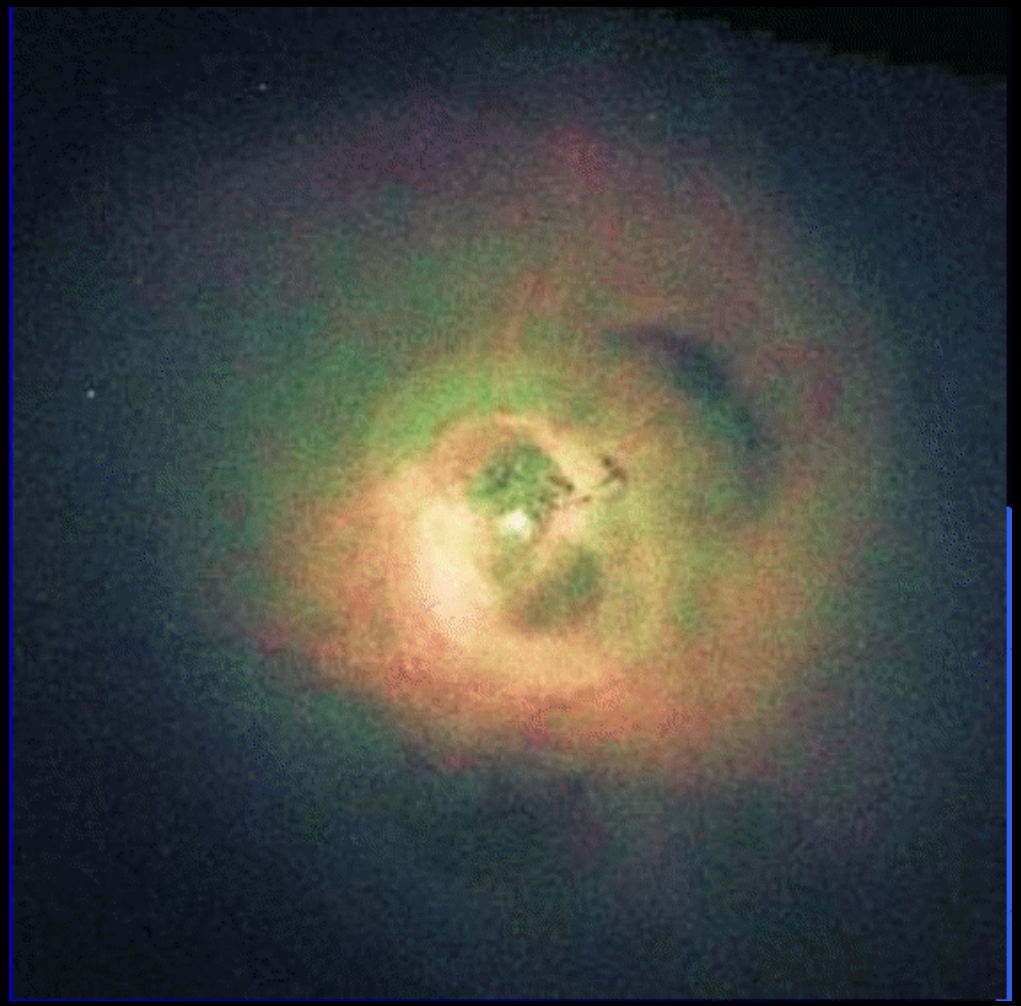
Possible Solution

- Simple jet model may not properly capture jet dynamics
- Background ICM motions and turbulence
- Additional physics
  - Thermal Conduction
  - Viscosity
  - Magnetic Fields
- Cosmic Rays
- Dynamical Friction
- Precessing Jets

Conclusion

We have done high resolution, three dimensional hydrodynamical simulations of jets in a cooling flow cluster. We find that when simple hydrodynamic models of jets are used, they do not offset cooling, even though they are energetically capable of doing so.

Core Region of Perseus Cluster



Perseus cluster: Chandra X-ray Observatory (Fabian et al. 2003).

Cooling

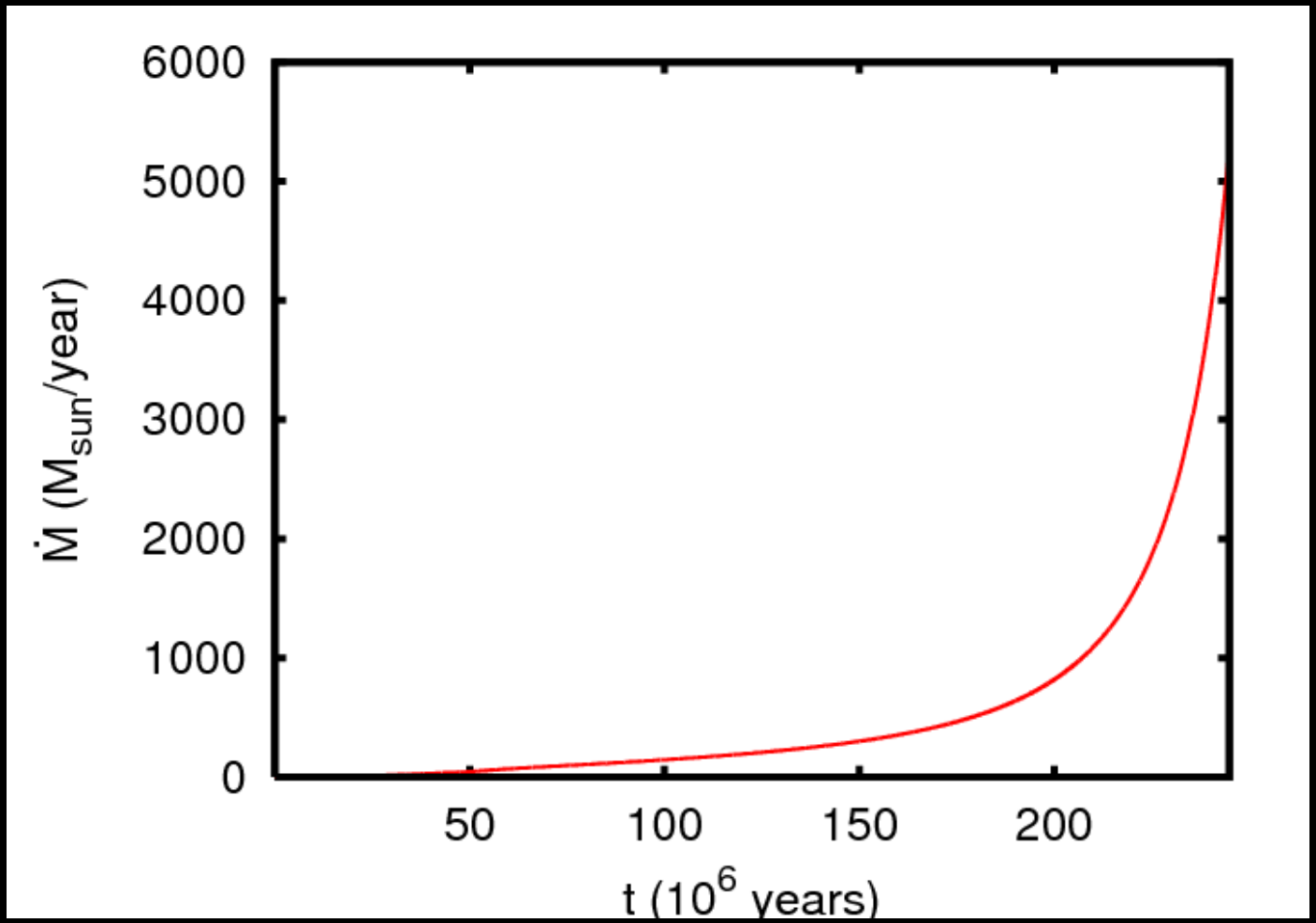
Thermal bremsstrahlung for cluster gas:

$$\Lambda = [C_1 (k_B T)^{\alpha} + C_2 (k_B T)^{\beta} + C_3] 0.704 \, (\frac{\rho}{m_p})^2 \times 10^{-22} \text{ ergs cm}^{-3} s^{-1}$$

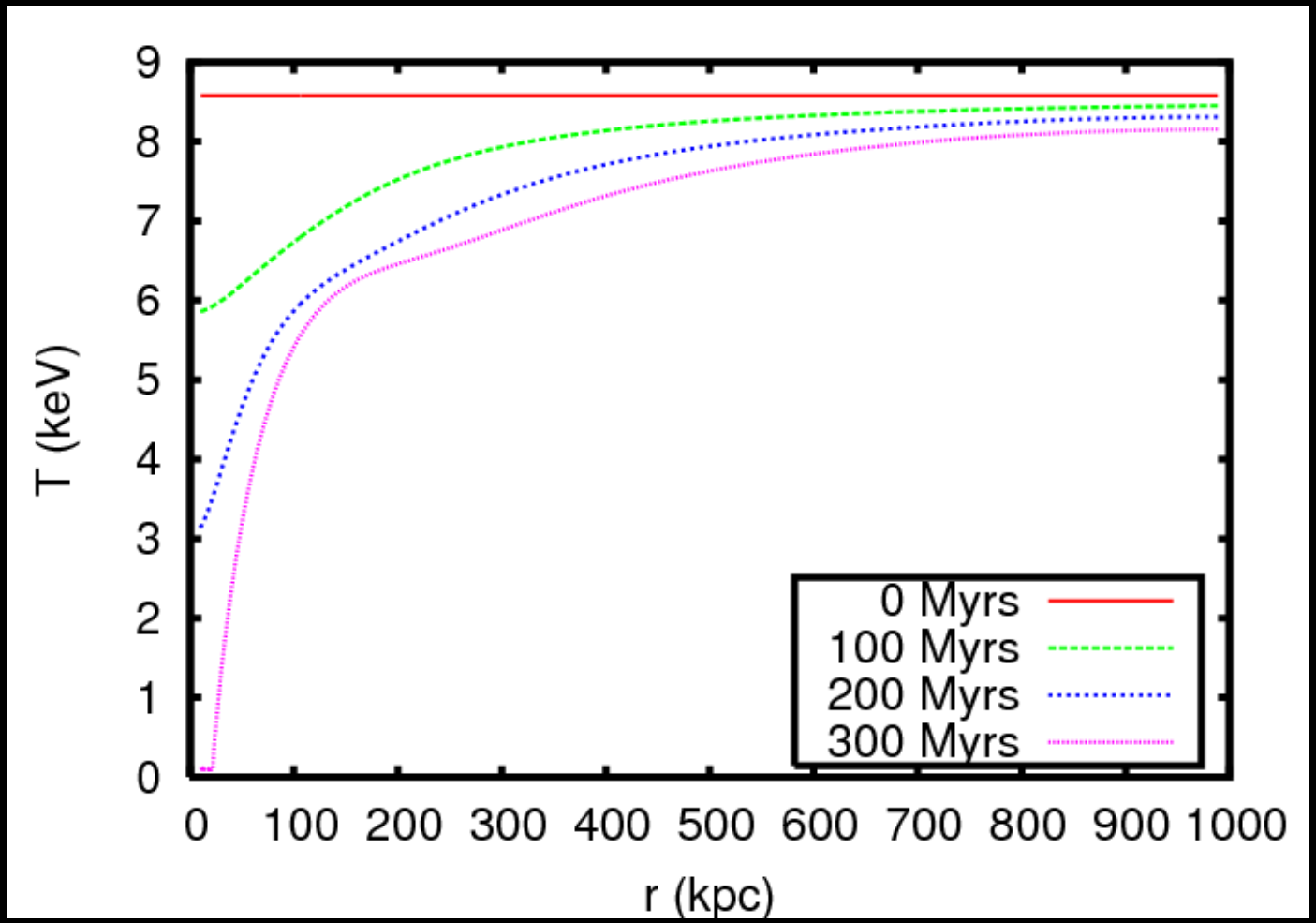
with $C_1 = 8.6 \times 10^{-3}$, $C_2 = 5.8 \times 10^{-2}$, $C_3 = 6.4 \times 10^{-2}$, $\alpha = -1.7$, and $\beta = 0.5$.

This is the same cooling function as Ruszkowski and Begelman 2002.

Pure Cooling – Mass accretion on inner boundary



Radial Temperature Dependence



Single Jet Burst – Mass accretion on inner boundary