

# Dynamics of AGN bubbles and cosmic rays in cool core clusters

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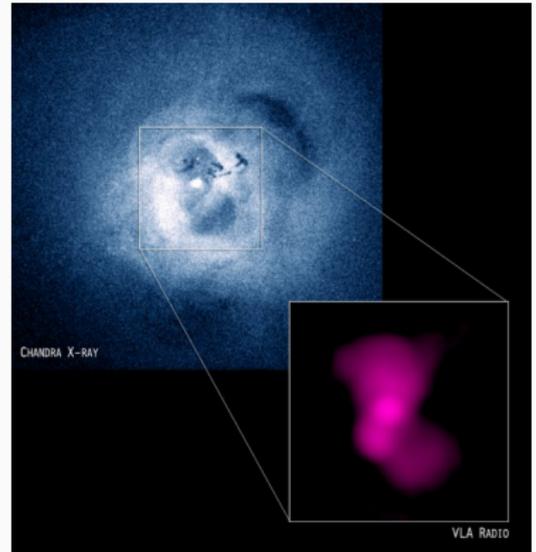
Kristian Ehlert, Christoph Pfrommer (AIP, Potsdam)

Rainer Weinberger, Rüdiger Pakmor (HITS, Heidelberg)

March 7, 2018

# Heating in cool-core clusters

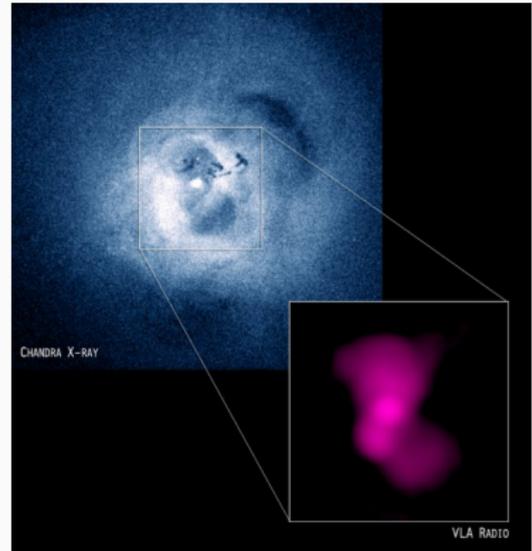
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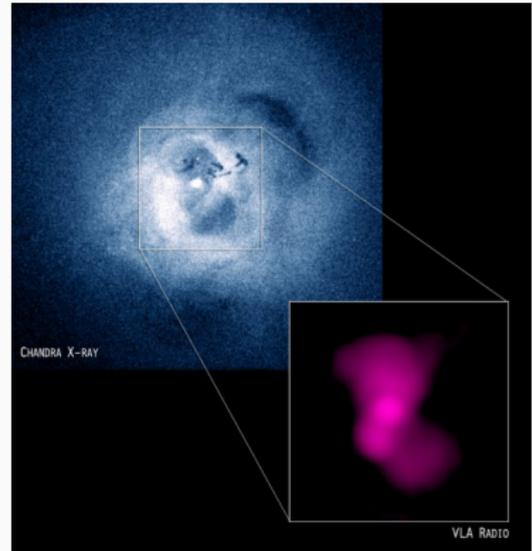
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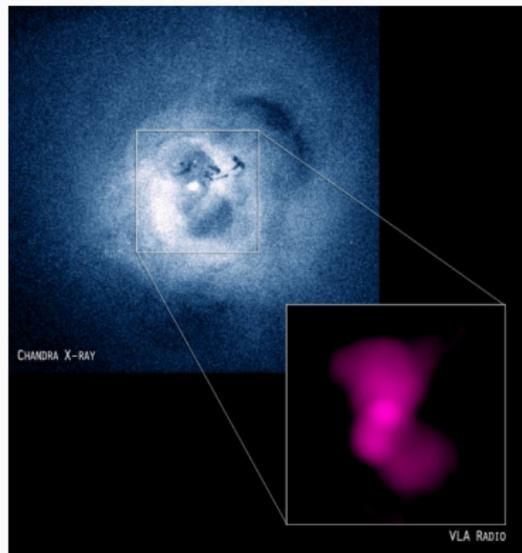
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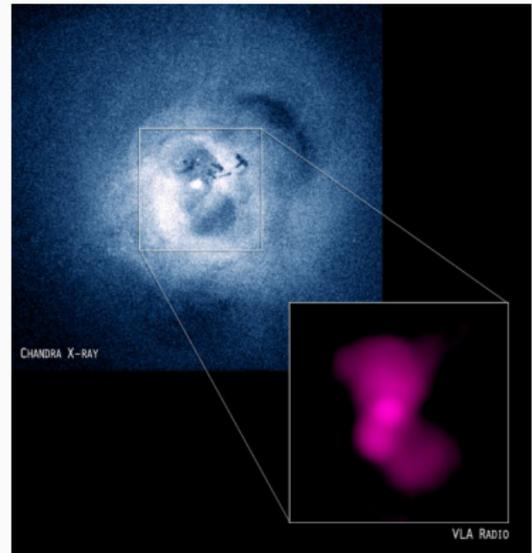
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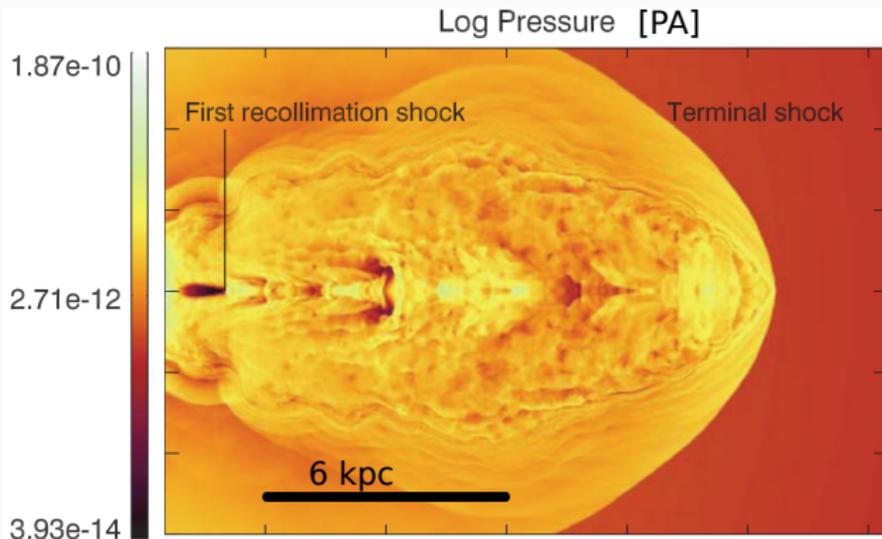
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- **jet accelerates CRs**  $\Rightarrow$  release from bubbles provides source of heat



# Evidence for CR acceleration in AGN shocks

- linked to **hotspots** observationally
- simulations: collision of **internal shocks**

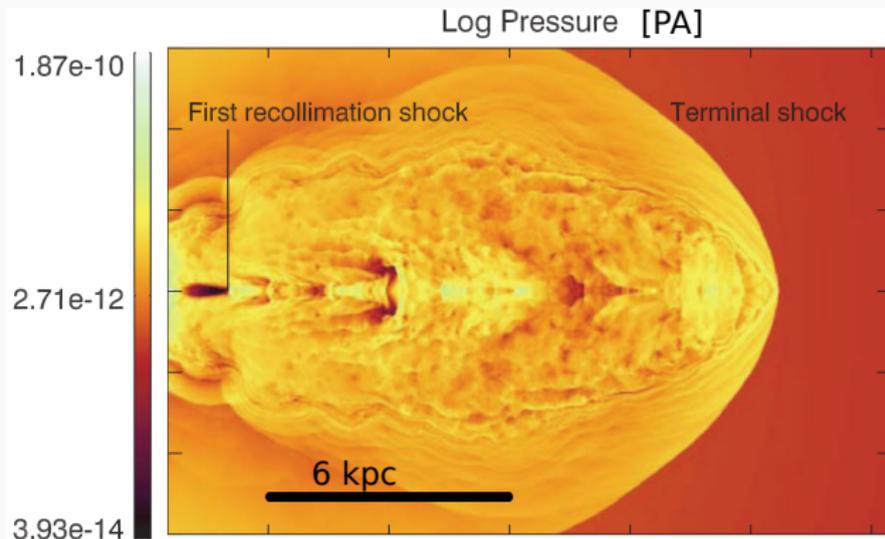


Relativistic jet simulation (Perucho and Martí, 2007)

- **missing pressure in lobes**; at most 5 – 10% of pressure due to magnetic field & electrons

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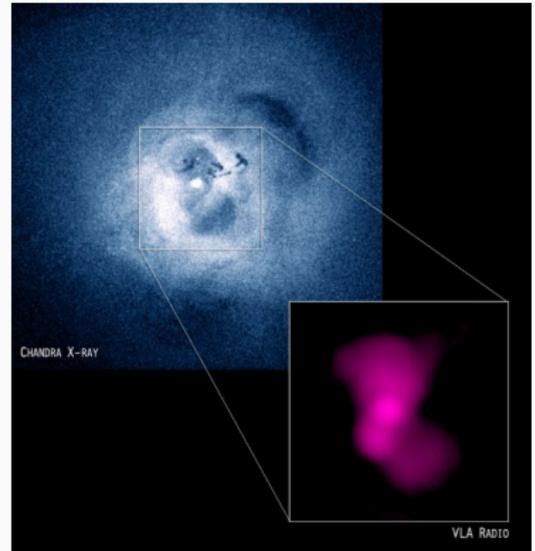
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→ significant CR proton population!

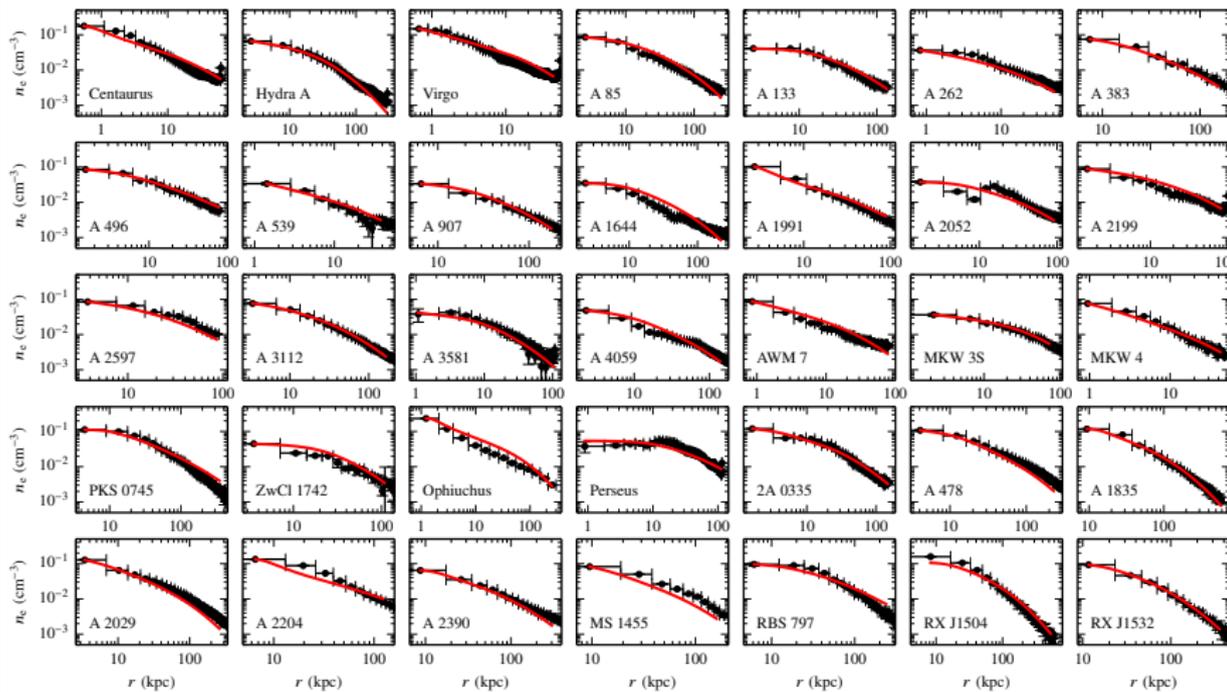
# CR-heating steady-state models

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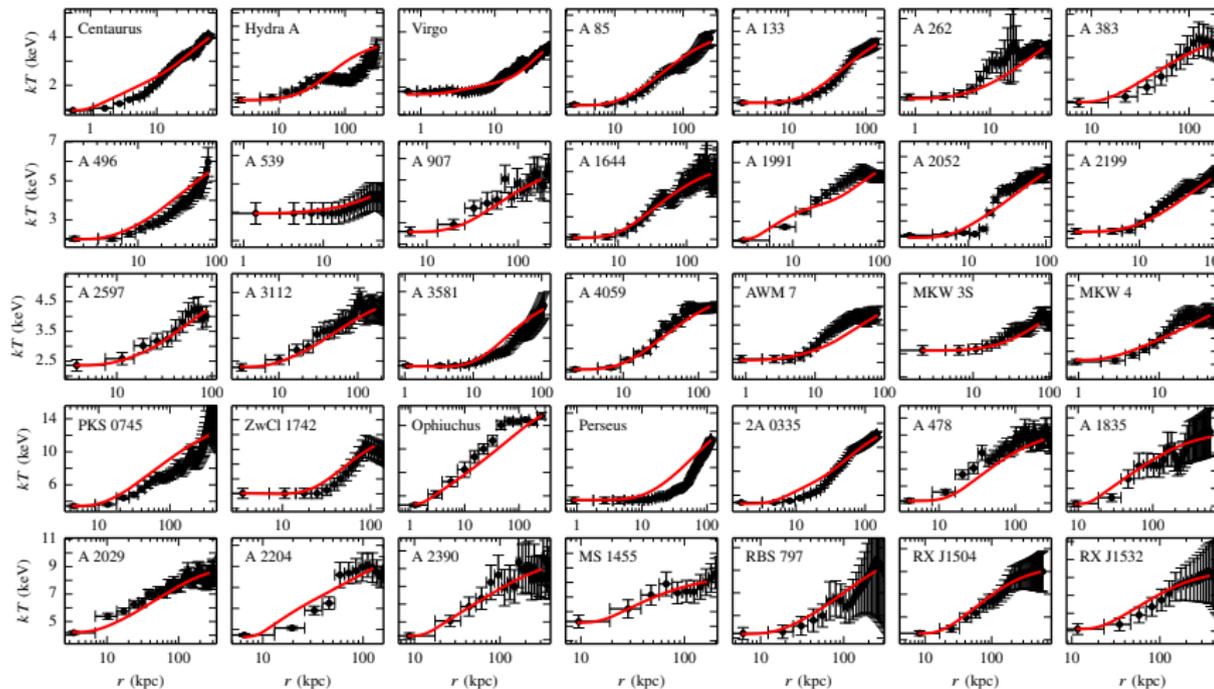
- Jacob and Pfrommer (2017a,b): study large sample of 40 cool-core clusters
- spherically symmetric steady-state solutions where cosmic ray heating balances cooling



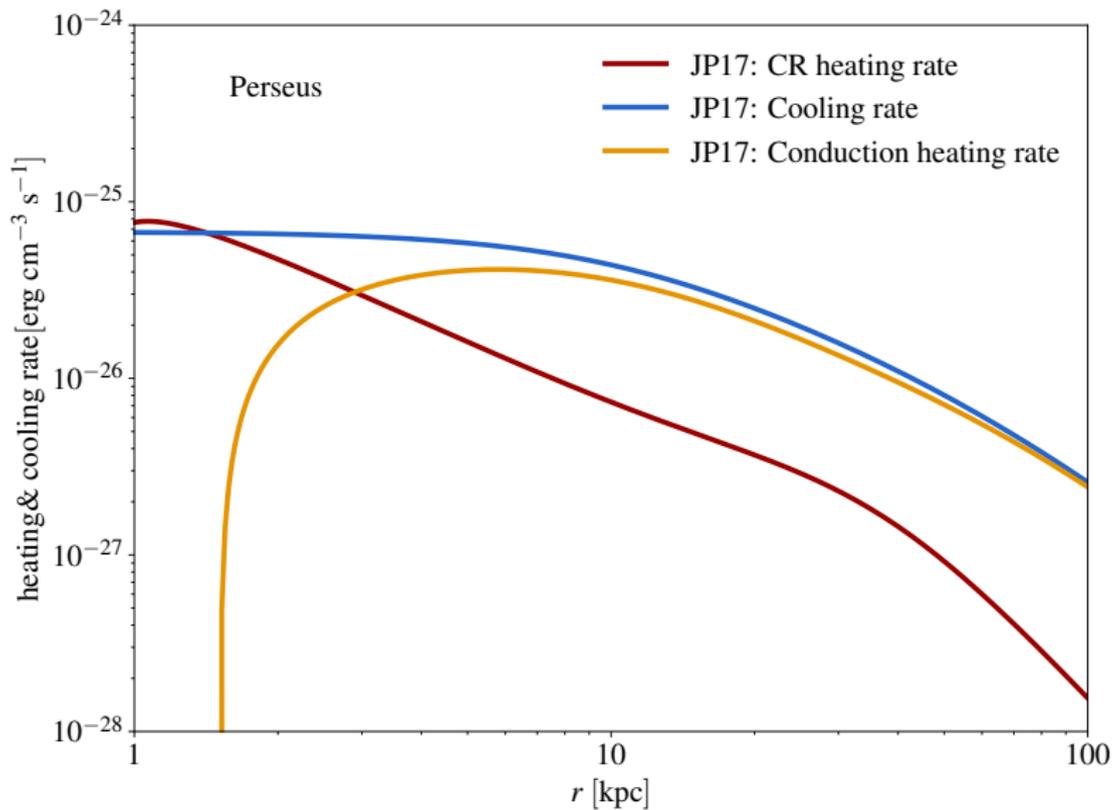
# Density profiles: Model & observations



# Temperature profiles: Model & observations



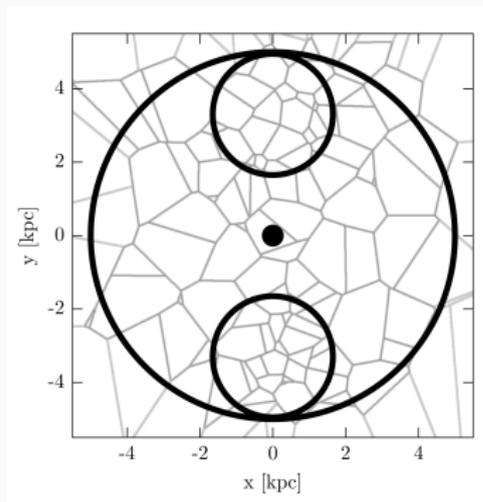
# Heating and cooling rates: Perseus



# Outline of talk

- real-life not steady state and 2D
- use 3D simulations
- focus on:
  - CR heating
  - magnetic field structure
  - parameter study of jet energy, luminosity, life time

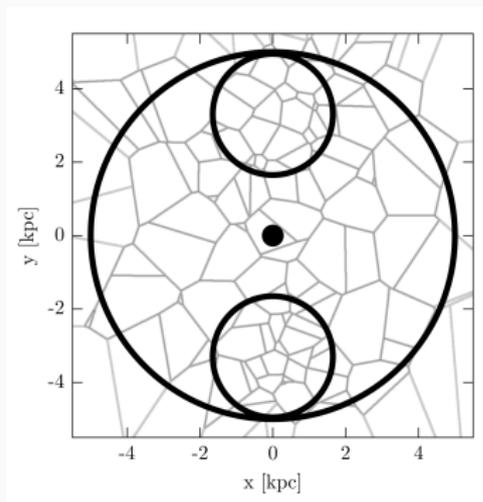
# MHD jet simulations



- MHD moving-mesh code AREPO
- NFW cluster potential

AREPO: Jet injection region  
(Weinberger et al., 2017)

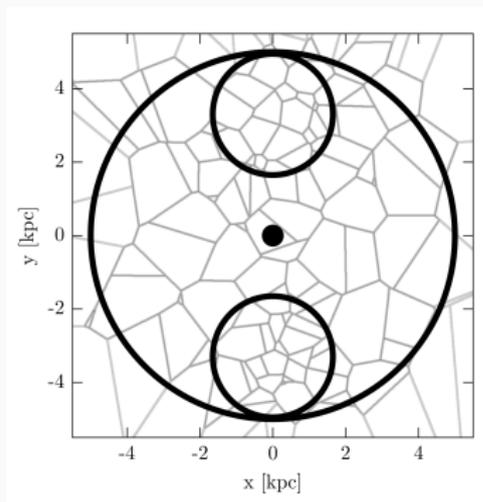
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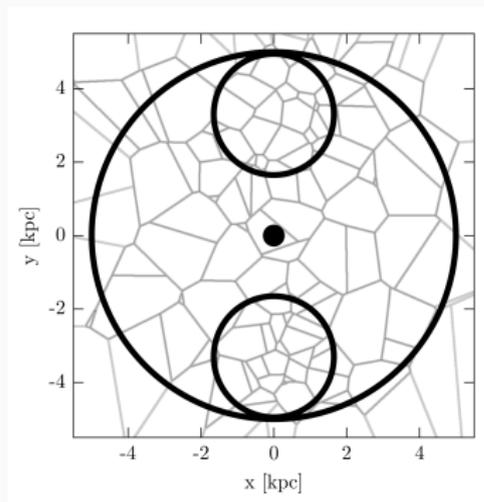
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- Subgrid CR shock acceleration:  
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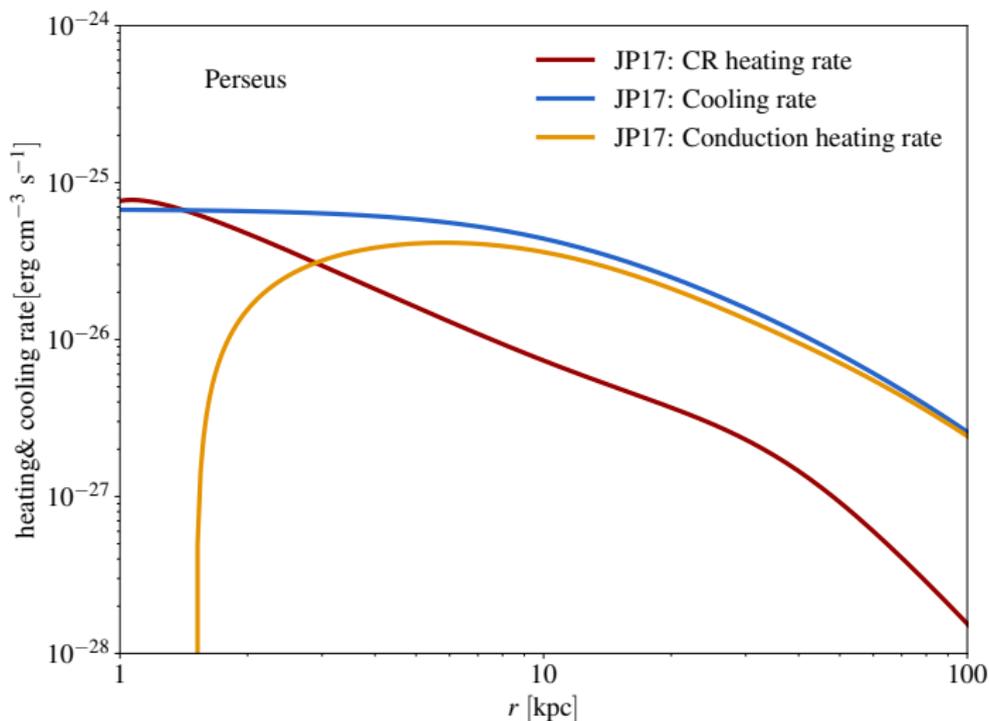


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- Subgrid CR shock acceleration:  
 $E_{\text{kin}} \rightarrow E_{\text{cr}}$
- CR diffusion & Alfvén cooling

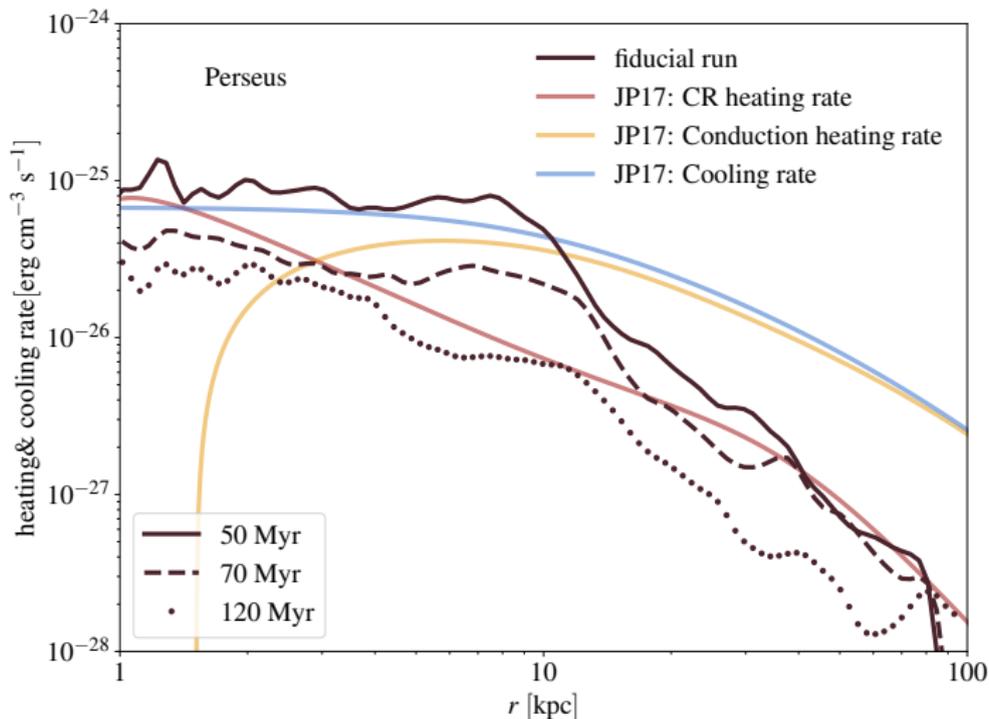
# Bubble dynamics

# Heating and cooling rates: Steady-state model



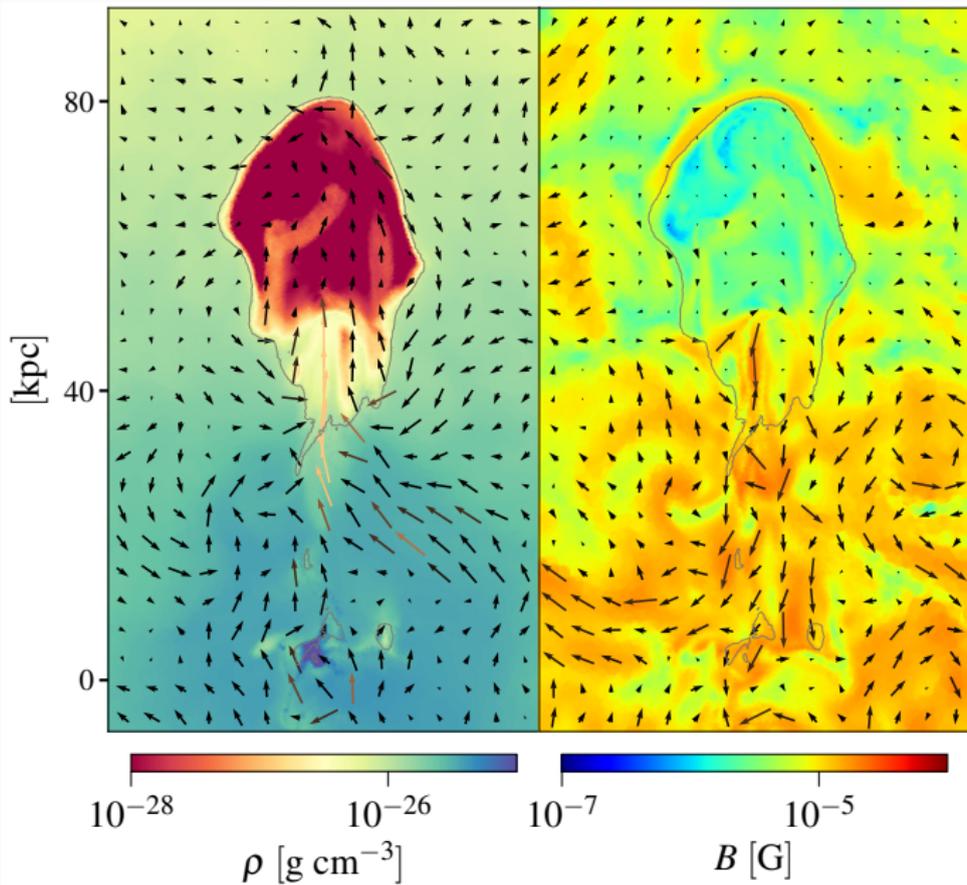
CR-heating in Perseus (Jacob and Pfrommer, 2017a)

# Heating and cooling rates: Simulation



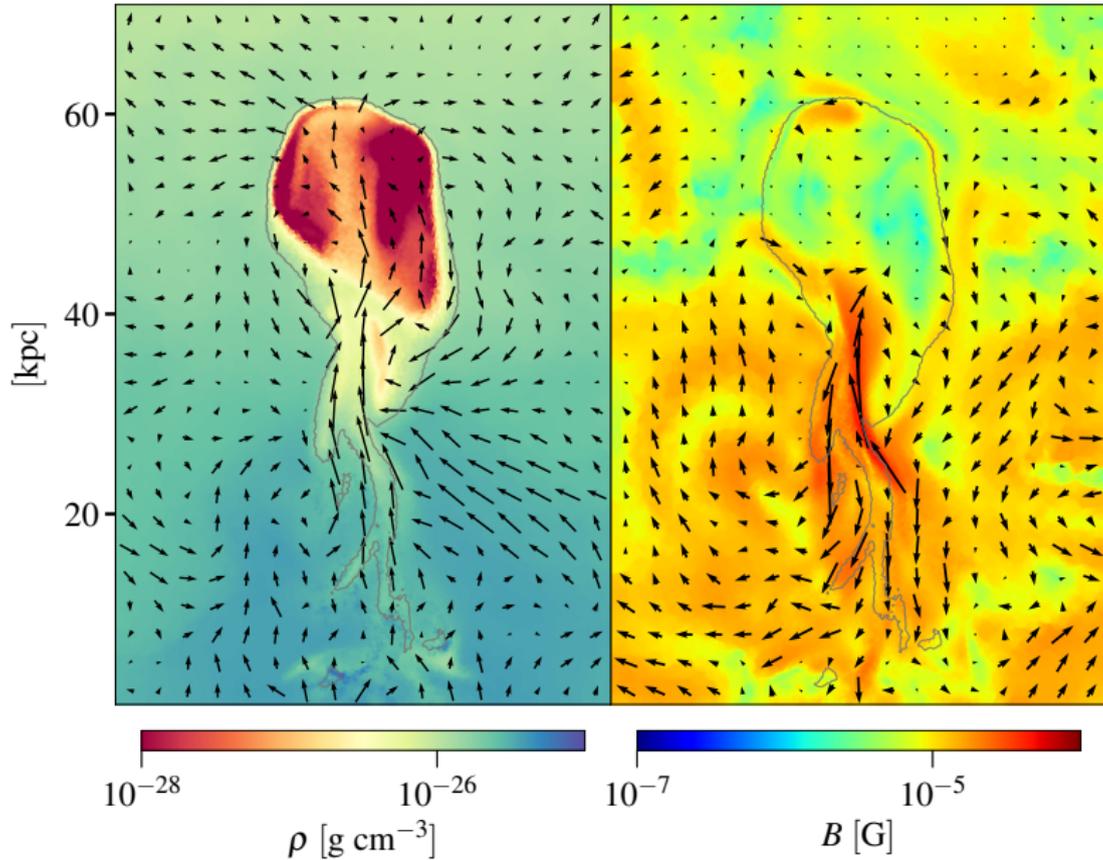
steady-state model & simulation

# Magnetic draping

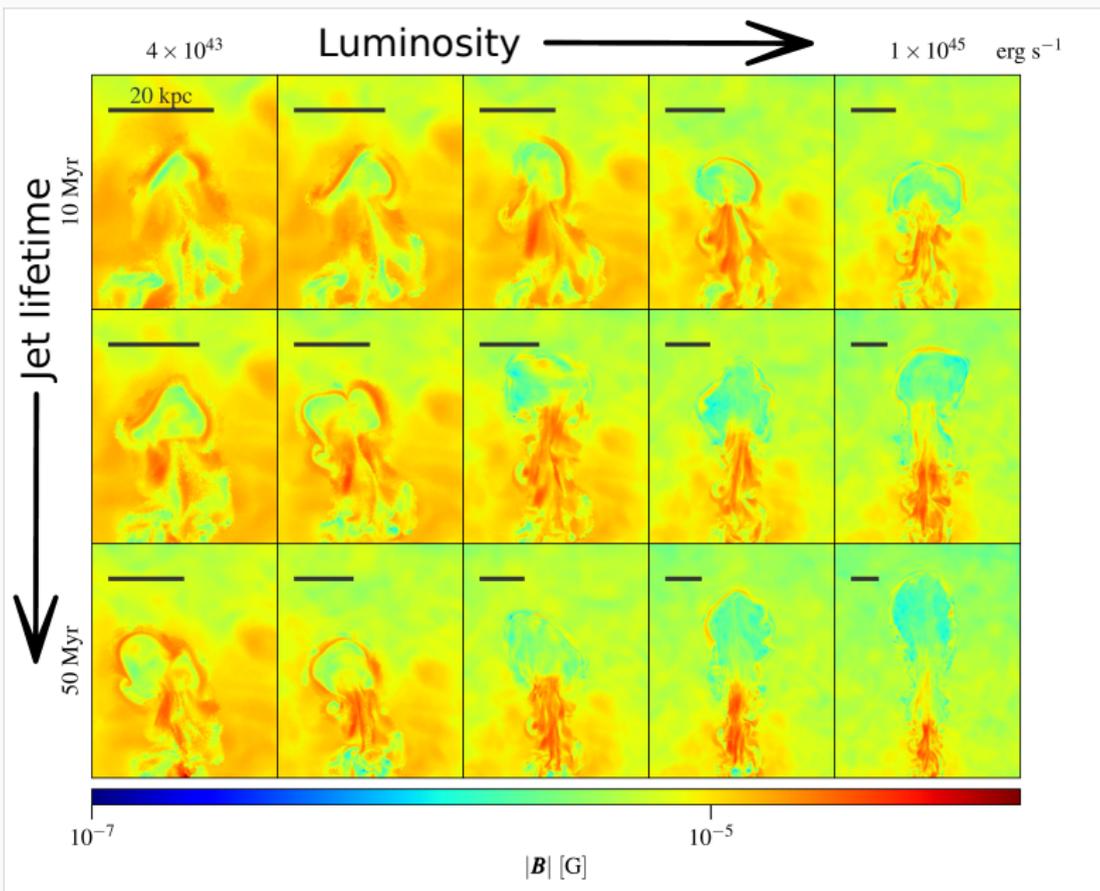


## Draping by Dursi and Pfrommer (2008)

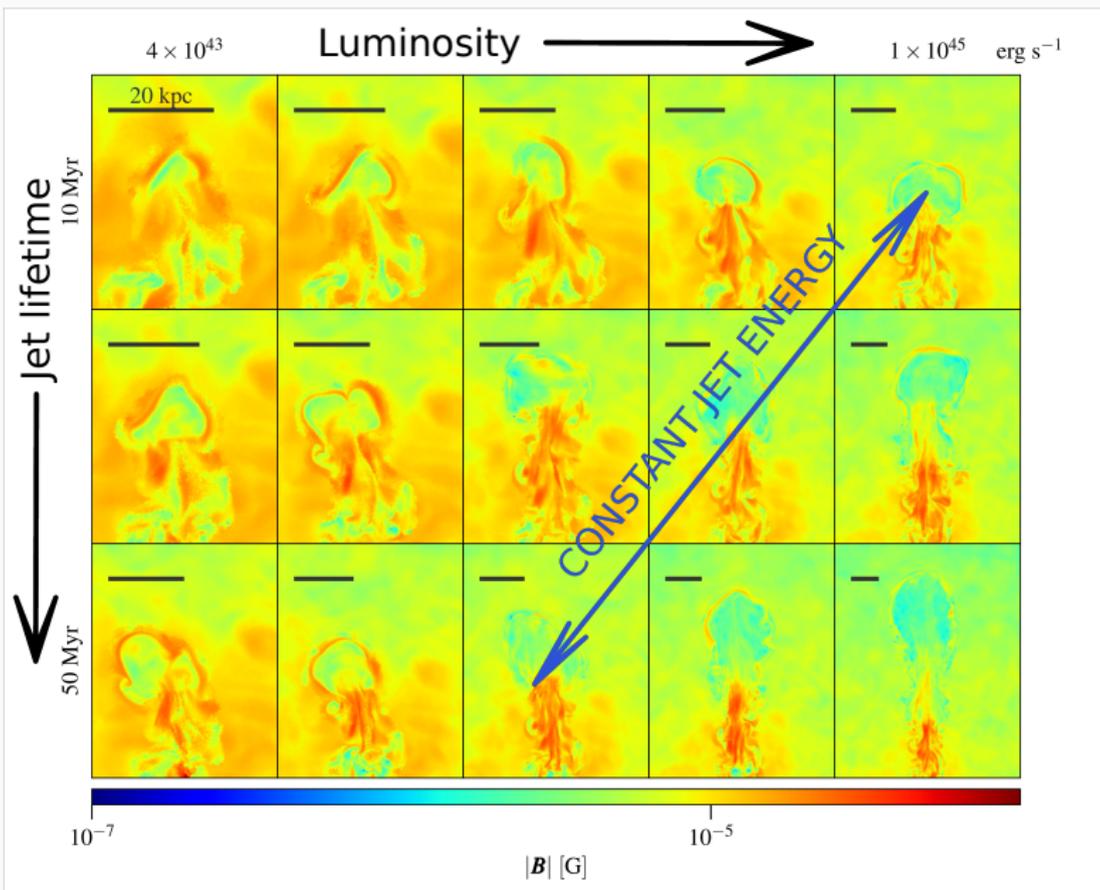
# Magnetic enhancement in the wake



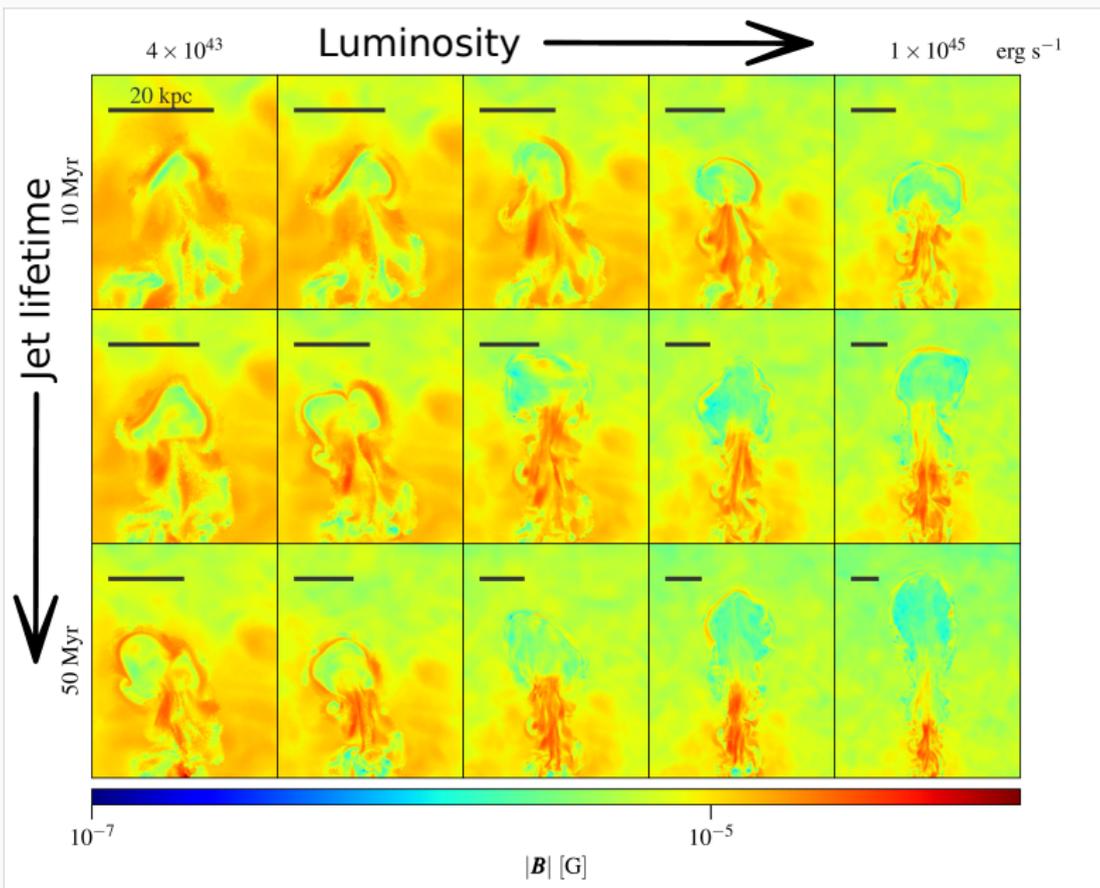
# Magnetic field structure



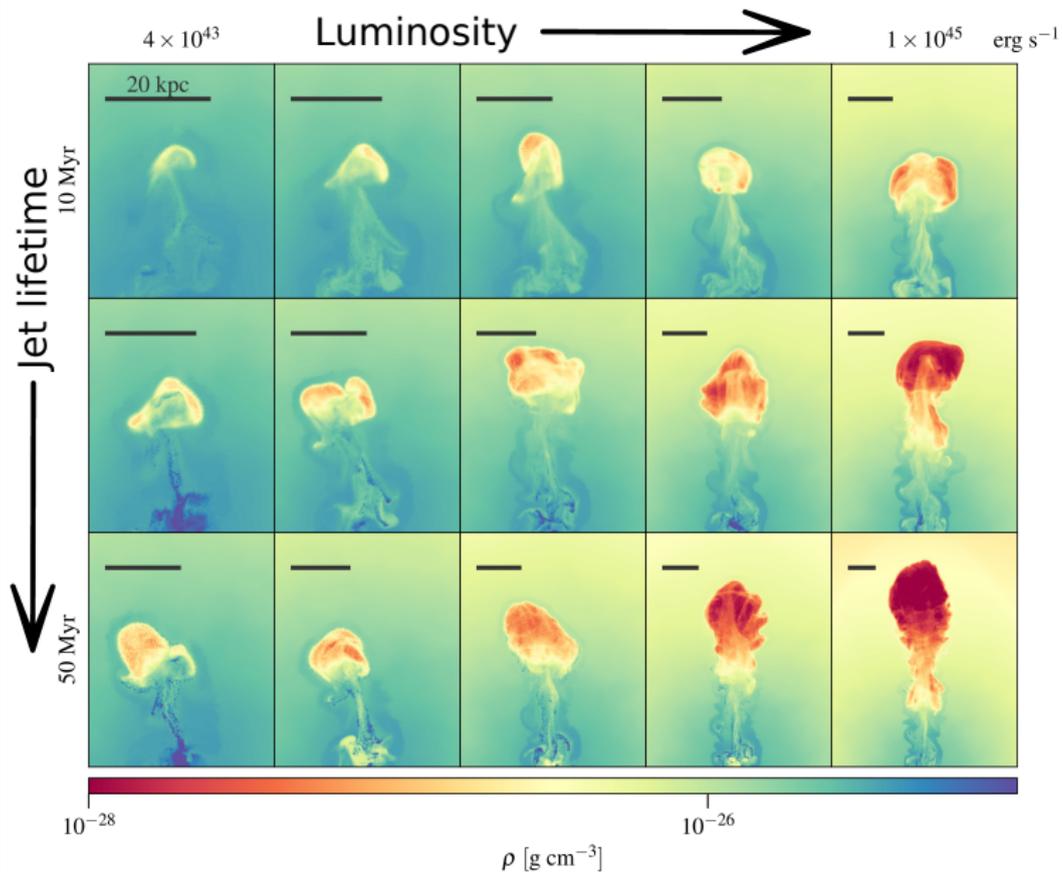
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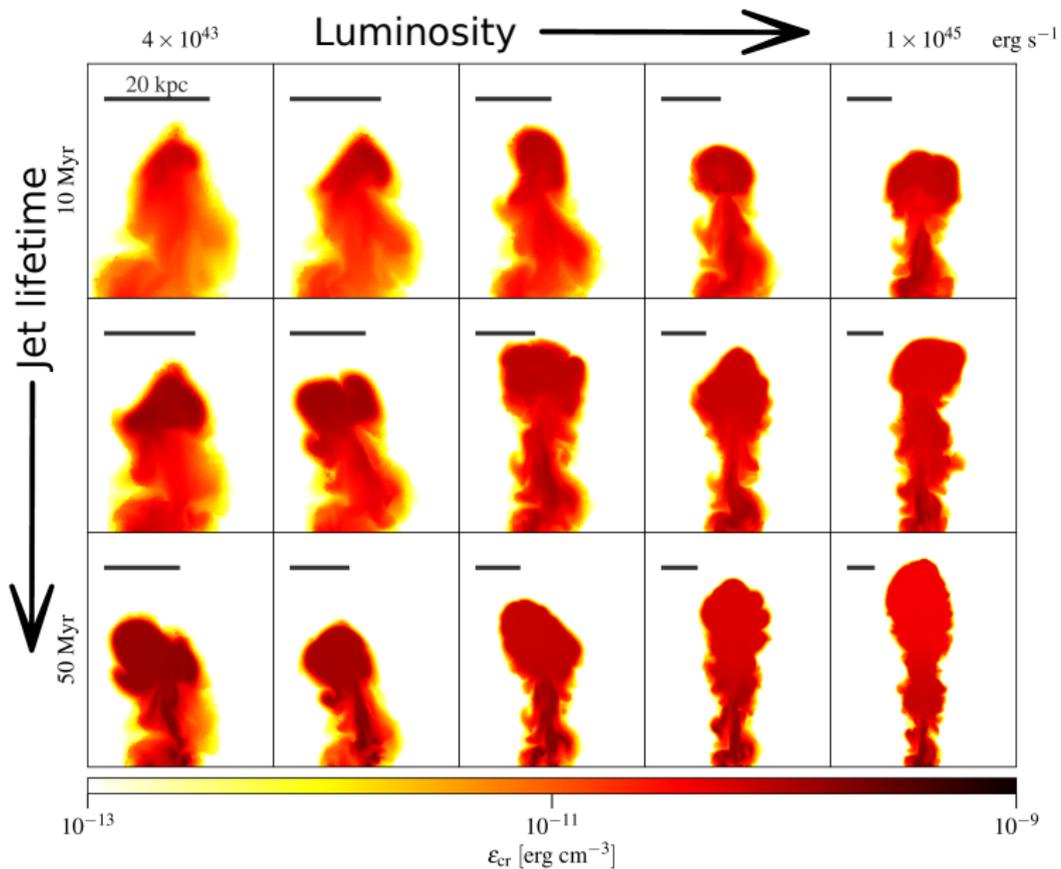
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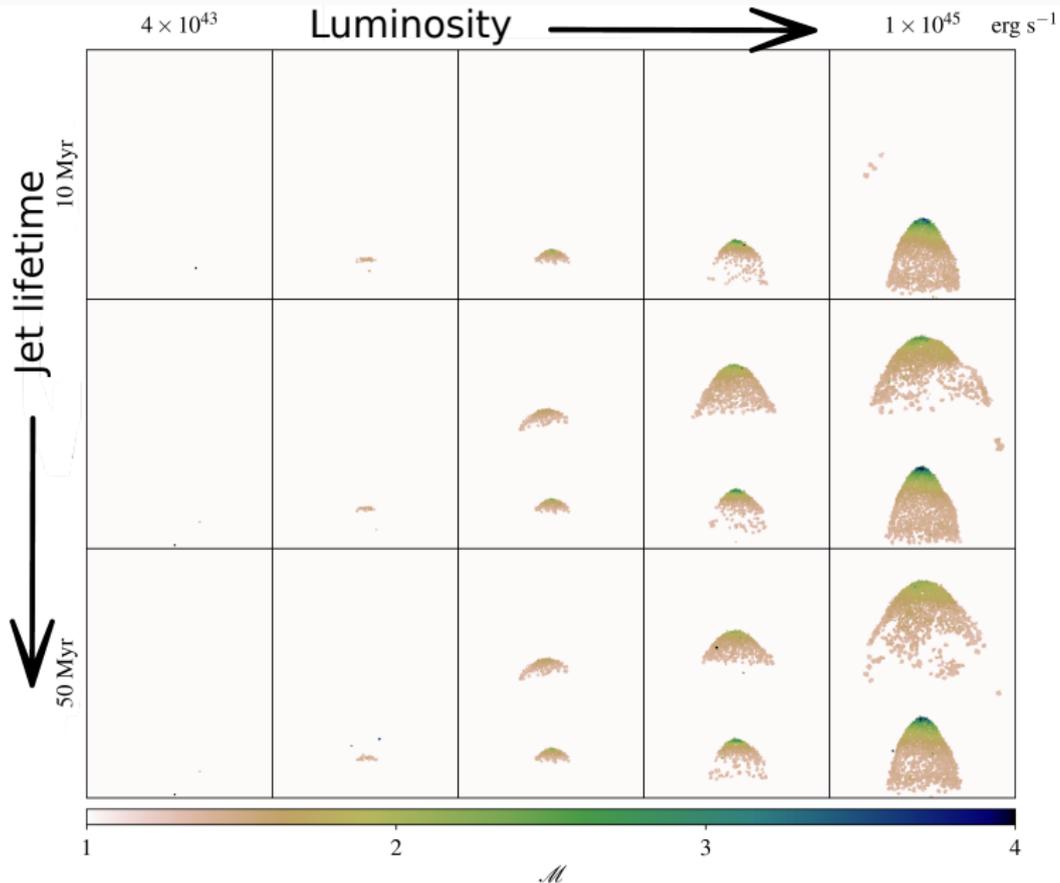
# Jet morphology



# CR distribution



# Jet Mach numbers



## Summary

- CR heating balances cooling in cluster centers
- Magnetic draping confines CRs and stabilizes bubbles
- Magnetic field in wake allows CRs to escape
- Simulated FRI & FRII jets in agreement with observations

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## Outlook

- simulations with cooling and accretion → self-regulated evolution?
- cosmological simulations for more realistic environment

## References

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Dursi, L.J. and Pfrommer, C.: 2008, *ApJ* **677(2)**, 993

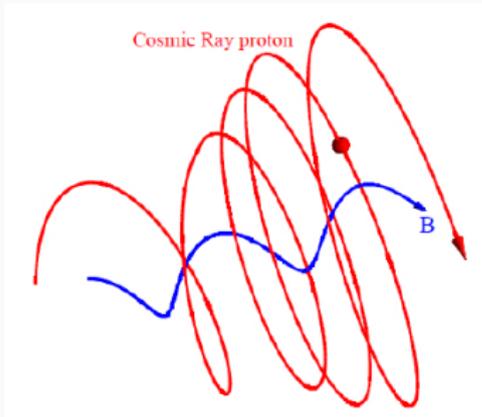
Jacob, S. and Pfrommer, C.: 2017a, *MNRAS* **467(2)**, 1449

Jacob, S. and Pfrommer, C.: 2017b, *MNRAS* **467(2)**, 1478

Perucho, M. and Martí, J.M.: 2007, *MNRAS* **382(2)**, 526

Weinberger, R. et al: 2017, *MNRAS* **470(4)**, 4530

# Streaming cosmic rays



Scattered CR proton on  
magnetic field perturbations

- streaming instability
- CRs self-confined via scattering on CR-generated Alfvén waves:

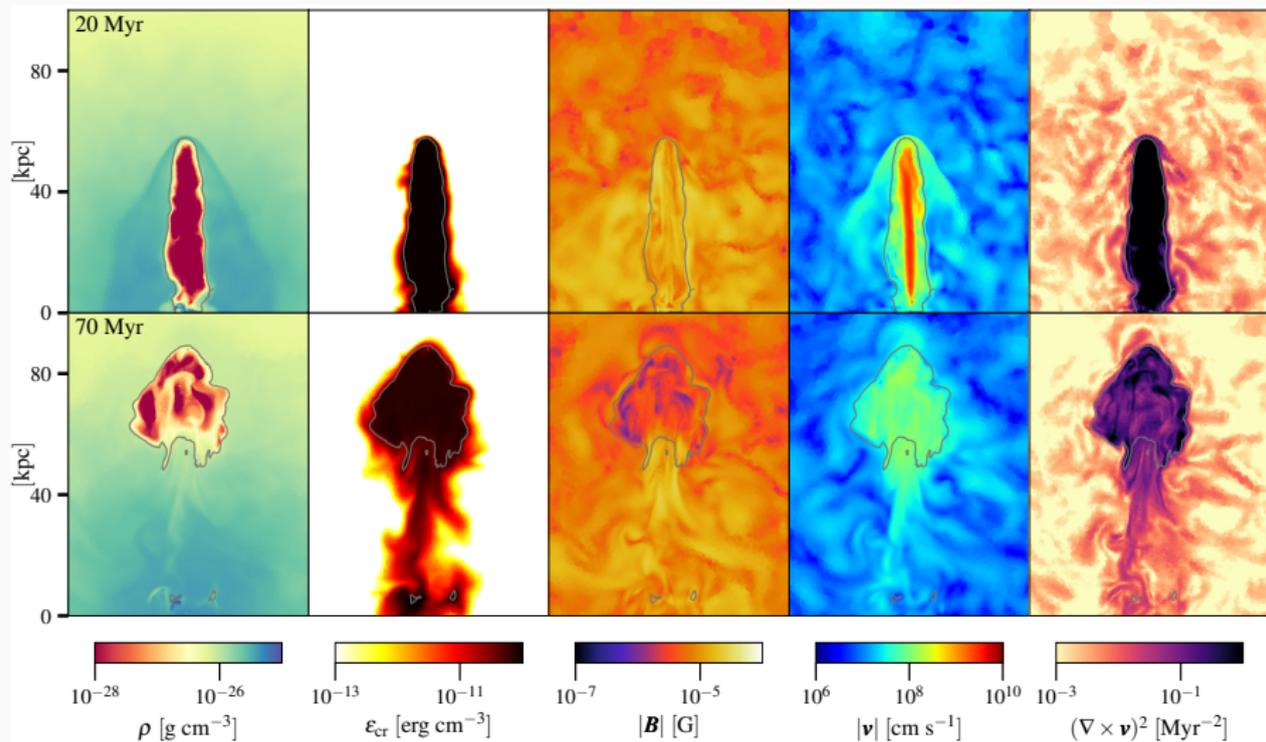
$$\mathbf{v}_{\text{st}} \approx -\mathbf{v}_A \frac{\mathbf{b} \cdot \nabla P_{\text{cr}}}{|\mathbf{b} \cdot \nabla P_{\text{cr}}|}$$

- transfer of CR to thermal energy via Alfvén wave damping:

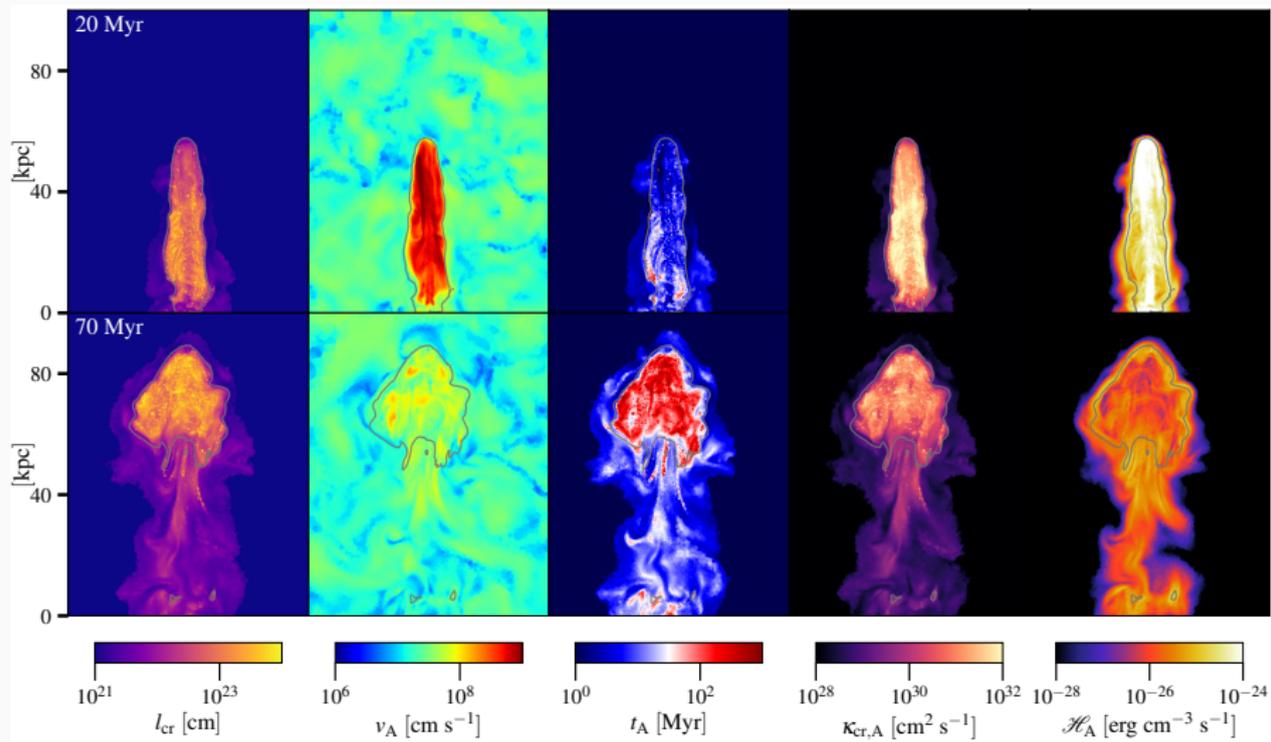
$$\mathcal{H}_{\text{cr}} = |\mathbf{v}_A \cdot \nabla P_{\text{cr}}|$$

- CRs viable heating mechanism in CC clusters
- expected radio and  $\gamma$ -ray emission consistent for CC clusters in feedback loop
- Limitations:
  - steady-state
  - isotropy
  - injection function for CRs

# Bubble evolution



# Bubble CRs



# Jet morphology

