

Title: Weak interaction Physics in Large-Scale Core-Collapse

Date: Jun 21, 2011 09:30 AM

URL: <http://pirsa.org/11060020>

Abstract:

## CHIMERA Collaboration

- ❑ Steve Bruenn, Pedro Marronetti (Florida Atlantic University)
- ❑ John Blondin (NC State University)
- ❑ Anthony Mezzacappa, Eirik Endeve, Raph Hix, Eric Lentz, Suzanne Parete-Koon (ORNL/UTK)
- ❑ Konstantin Yakunin (FAU), Reuben Budjiara, Austin Chertkow (UTK)

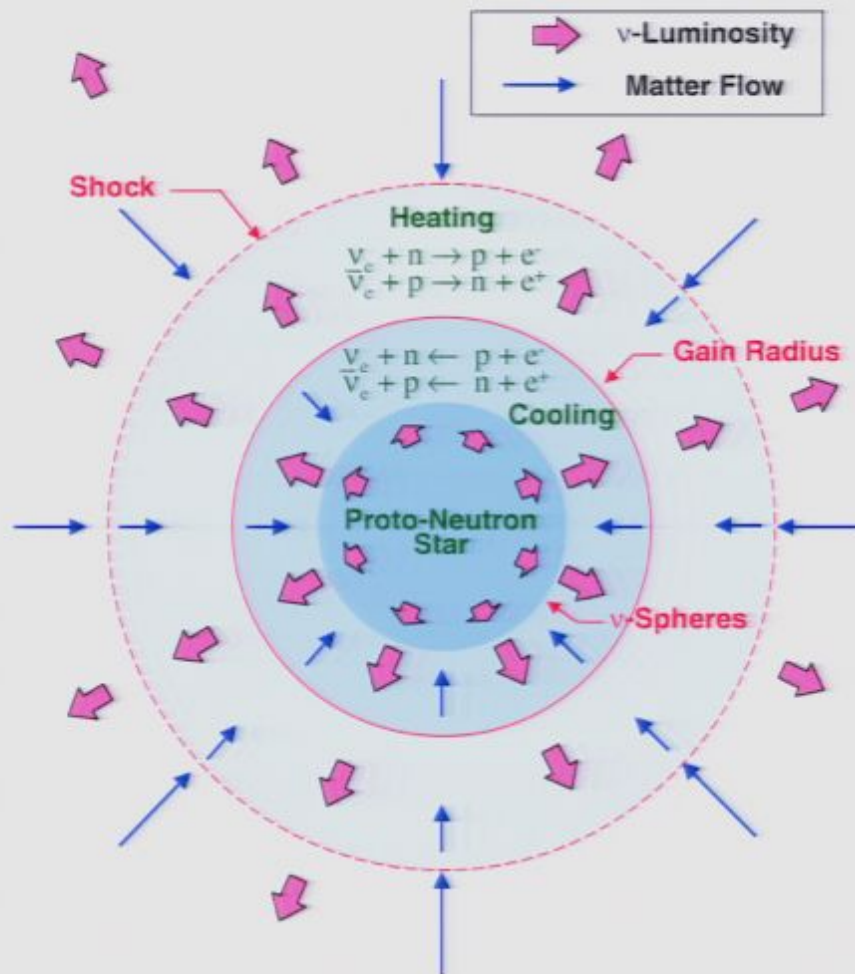
## AGILE-Boltztran

- ❑ M. Liebendörfer, A. Mezzacappa
- ❑ E. Lentz
- ❑ T. Fischer and others in Basel



# How is the supernova shock revived?

## Known, Potentially Important Ingredients

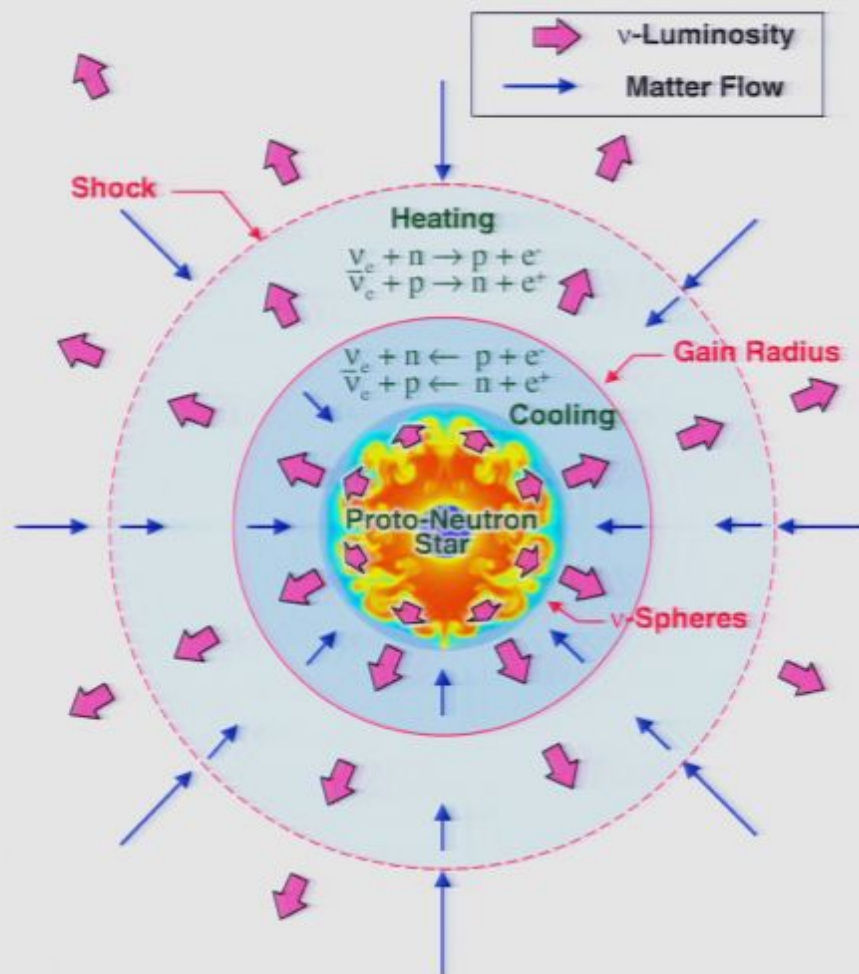


- Gravity
- Neutrino Heating
- Convection
- **Shock Instability (SASI)**
- Nuclear Burning
- Rotation
- Magnetic Fields

*Need 3D models with all of the above, treated with sufficient realism.*

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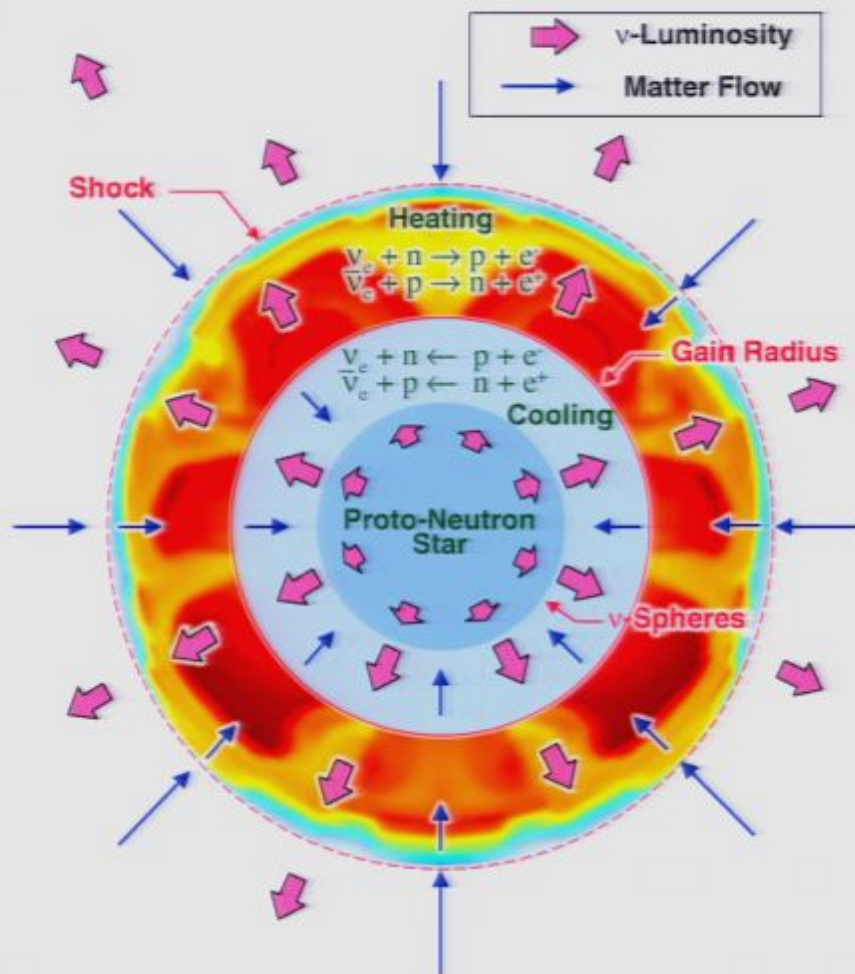


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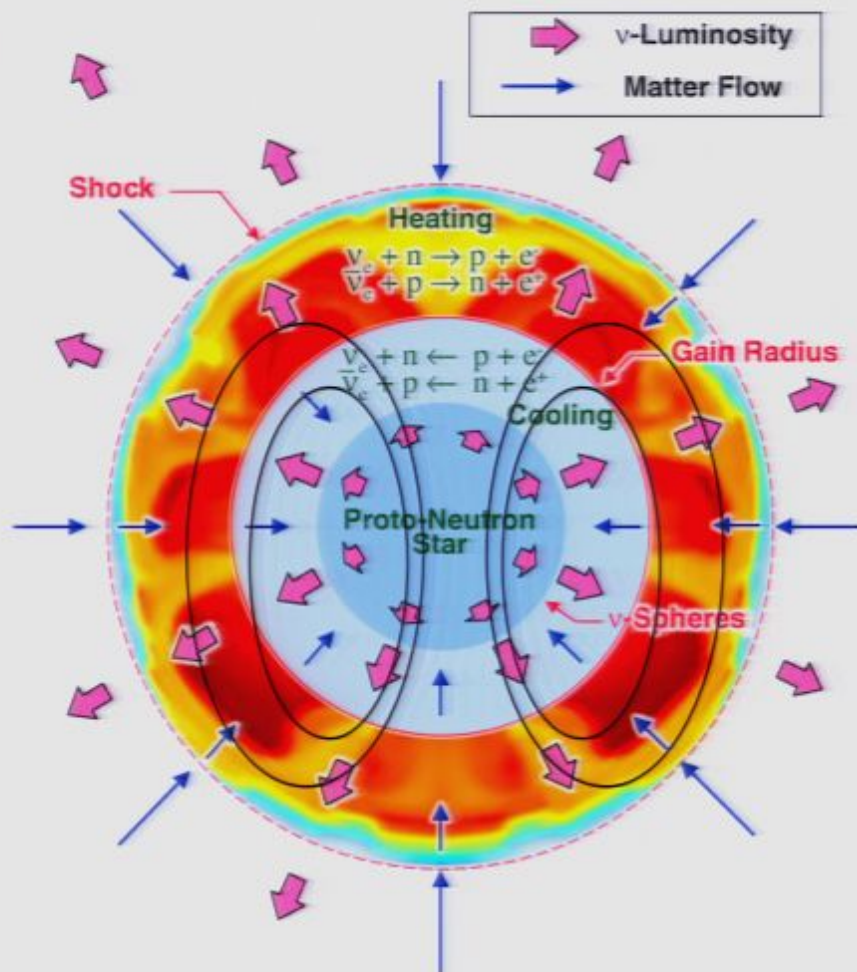


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# CHIMERA

- ❑ “RbR-Plus” MGFLD Neutrino Transport
  - ◆  $O(v/c)$ , GR time dilation and redshift, GR aberration (in flux limiter)
- ❑ 2D PPM Hydrodynamics
  - ◆ GR time dilation, effective gravitational potential,
  - ◆ adaptive radial grid
- ❑ Lattimer-Swesty EOS
- ❑ Nuclear (Alpha) Network
  - ◆ 14 alpha nuclei between helium and zinc
- ❑ 2D Effective Gravitational Potential
  - ◆ Marek et al. *A&A*, 445, 273 (2006)
- ❑ Neutrino Emissivities/Opacities
  - ◆ “Standard” + Elastic Scattering on Nucleons + Nucleon–Nucleon Bremsstrahlung



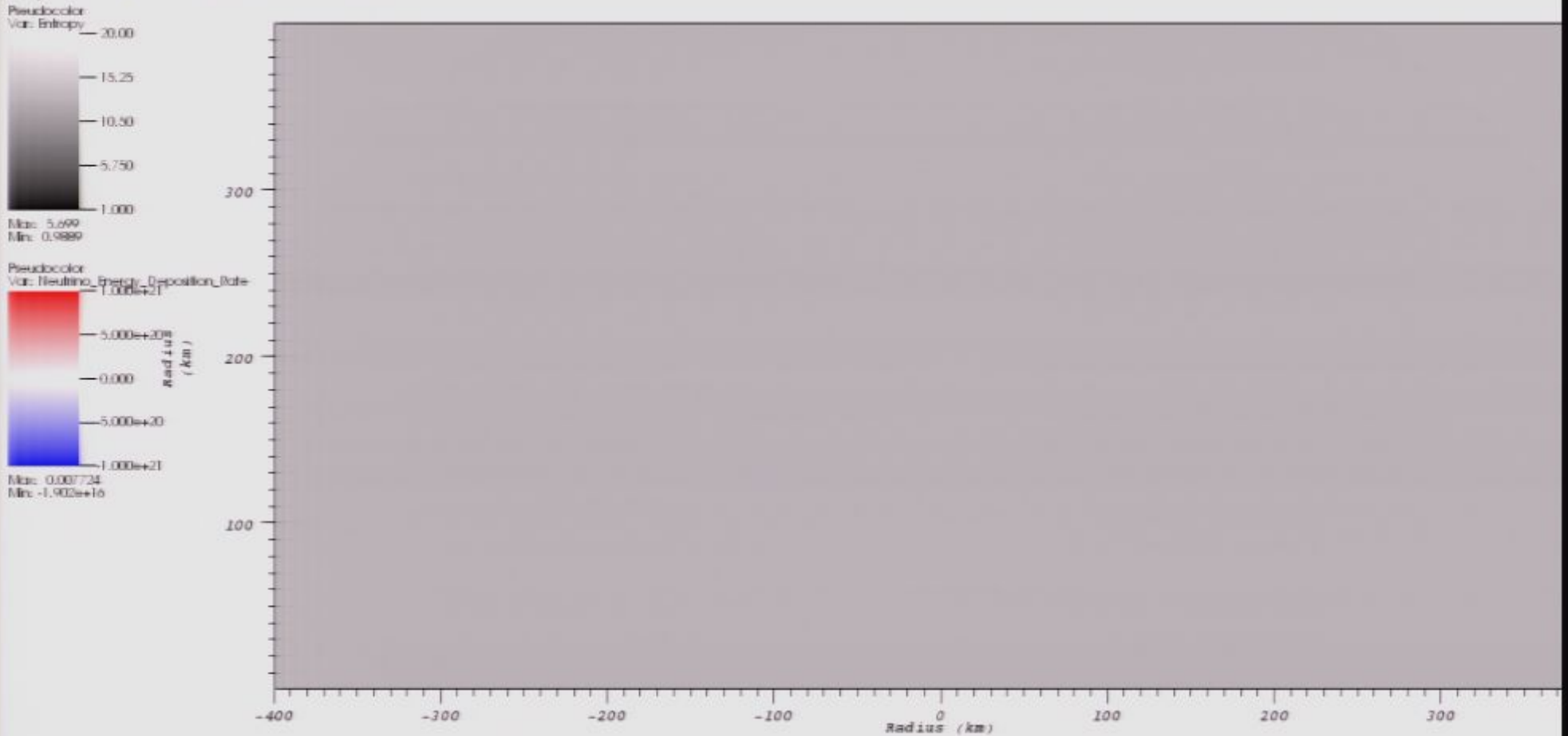
cf. Buras et al. *A&A*, **447**, 1049 (2003)

# 2D simulations

DB: 00021.silo

Cycle: 21

Time: 0.105065





# 2D simulations

DB: 00052.silo

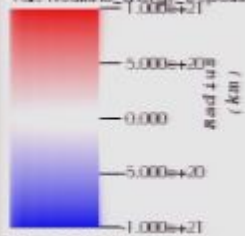
Cycle: 52 Time: 0.260004

Pseudocolor  
Var: Entropy

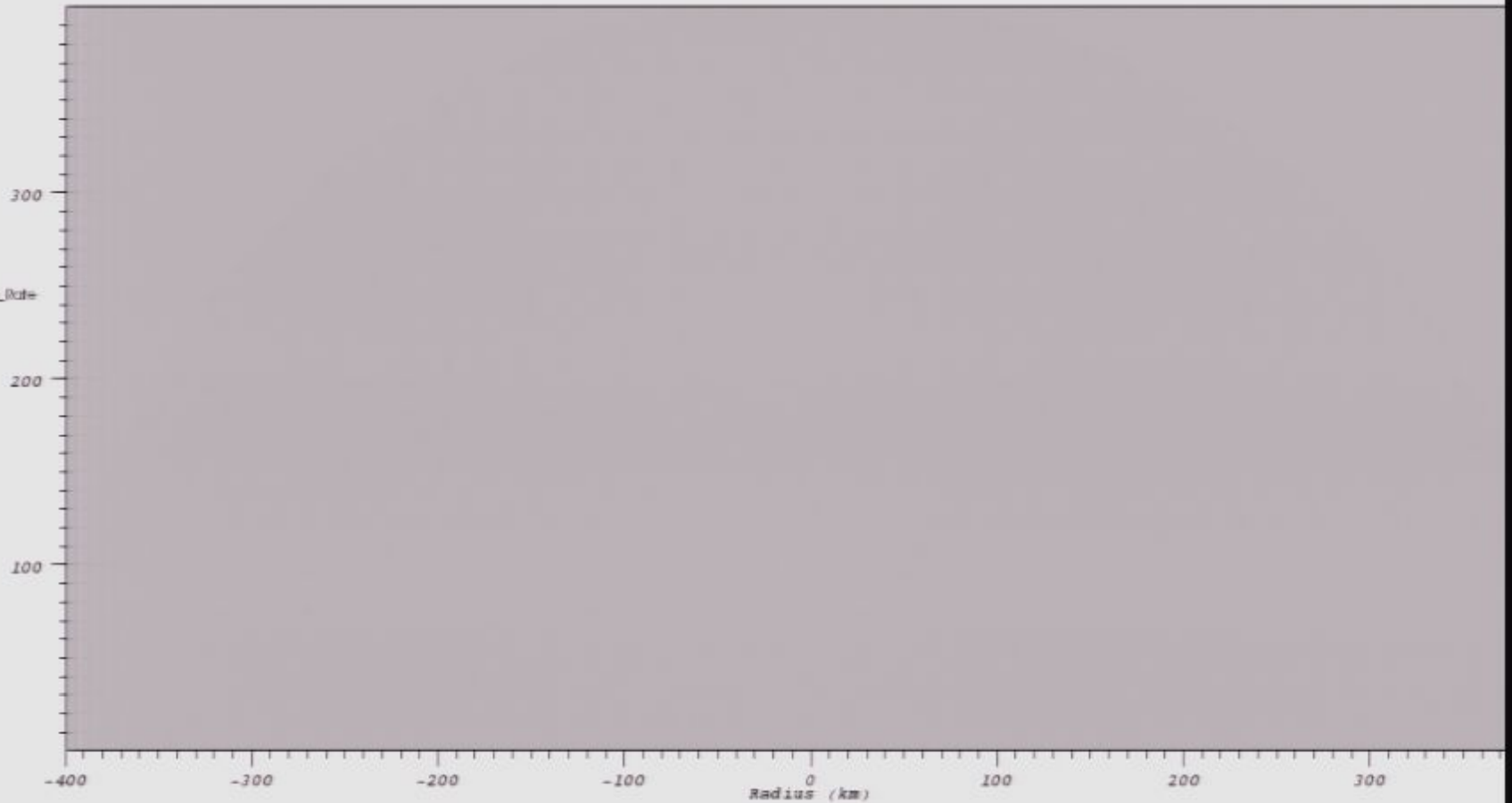


Max: 5.721  
Min: 0.9920

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



Max: 0.01120  
Min: -8.341e+16

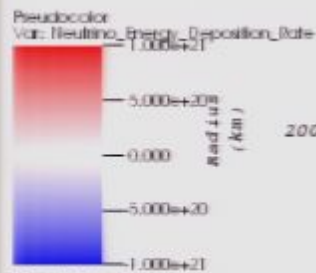


# 2D simulations

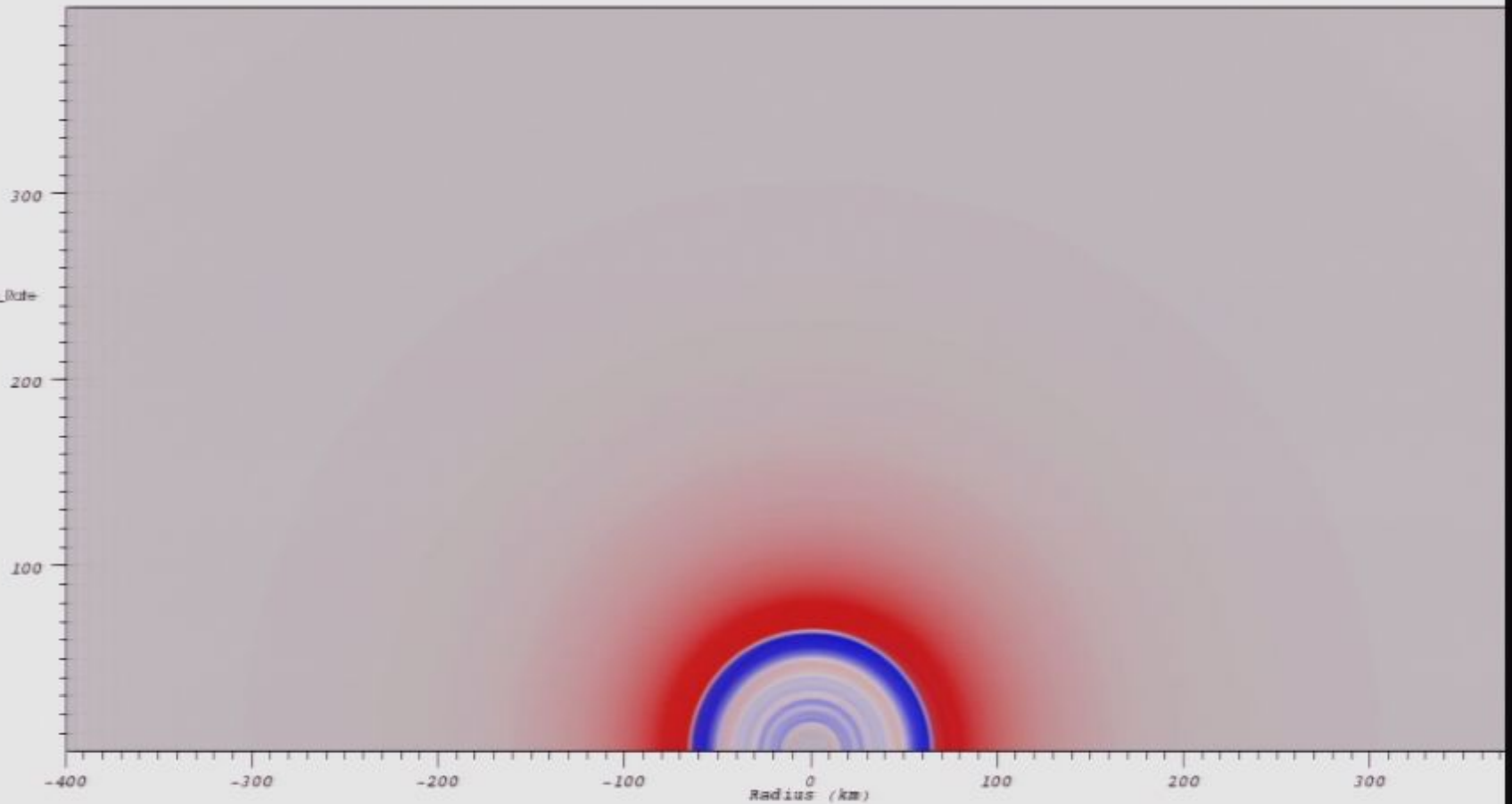
DB: 00115.silo  
Cycle: 115 Time:0.448411



Max: 5.854  
Min: 1.364



Max: 1.873e+21  
Min: -5.227e+21



# 2D simulations

DB: 00131.silo

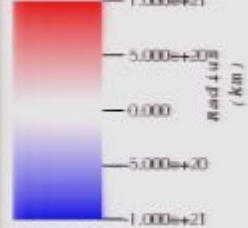
Cycle: 131 Time: 0.451611

Pseudocolor  
Var: Entropy

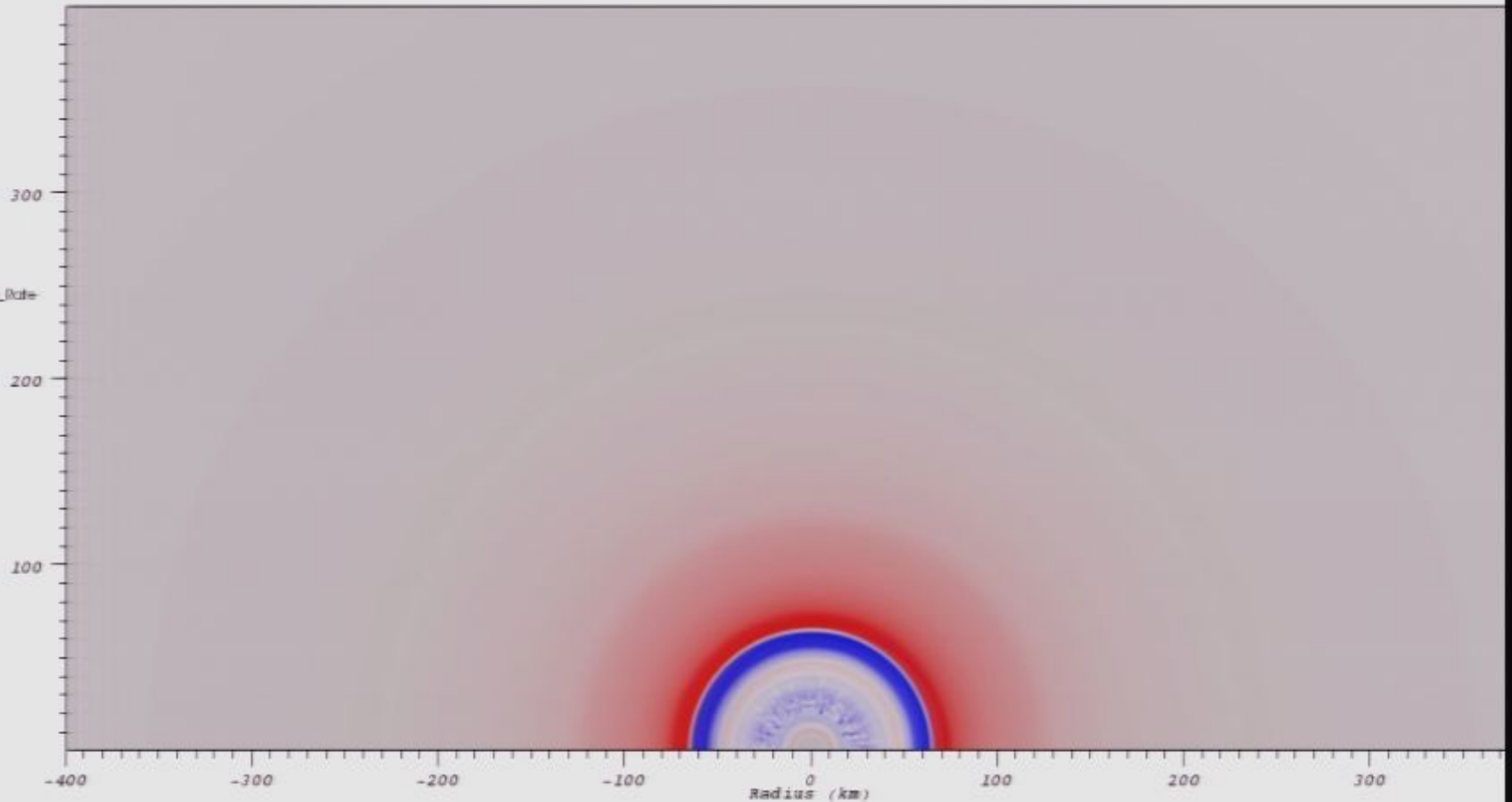


Max: 5.845  
Min: 1.269

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate

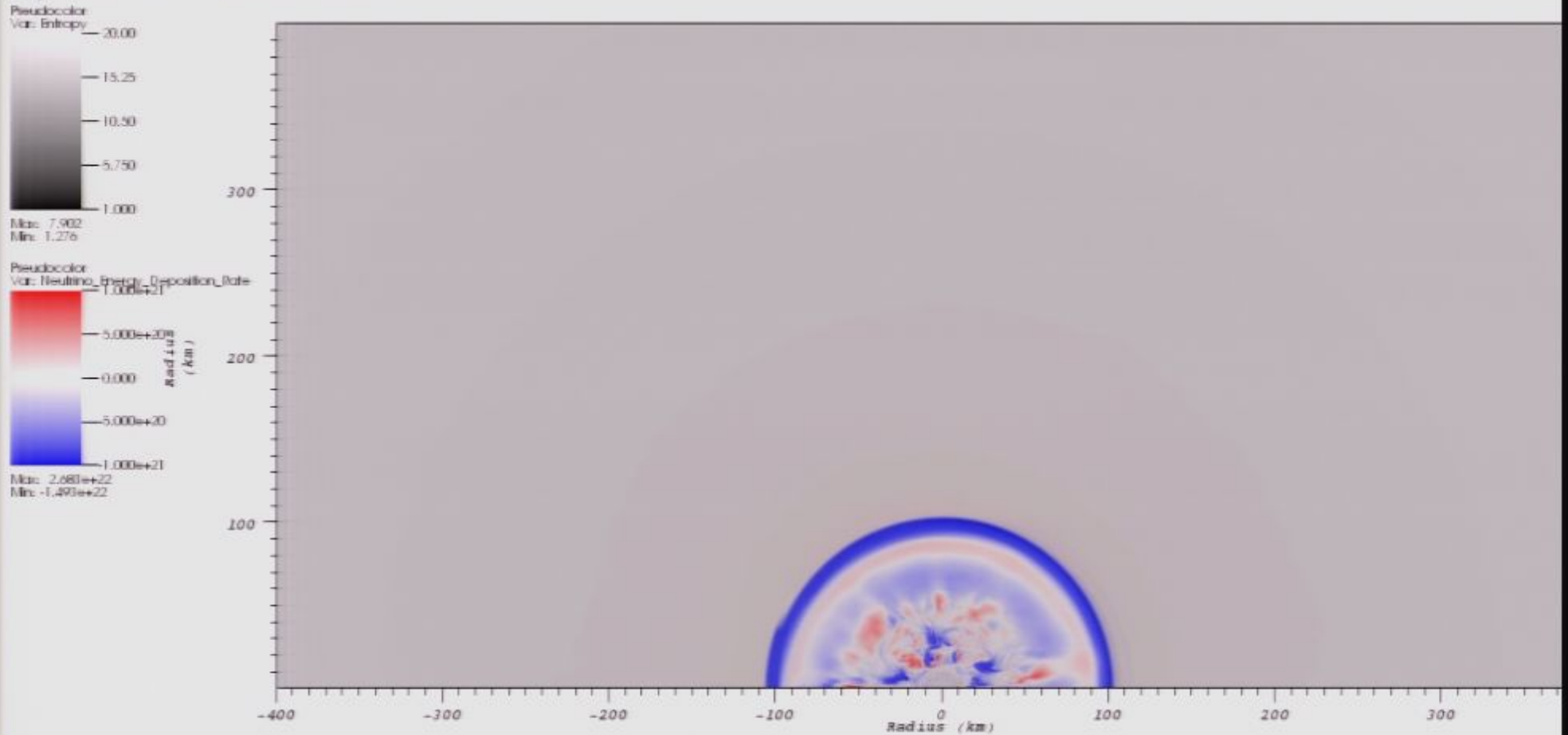


Max:  $2.907 \times 10^{21}$   
Min:  $-6.207 \times 10^{21}$



# 2D simulations

DB: 00173.silo  
Cycle: 173 Time: 0.460011



# 2D simulations

DB: 00213.silo

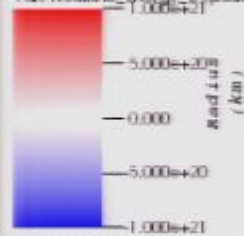
Cycle: 213 Time: 0.468011

Pseudocolor  
Var: Entropy

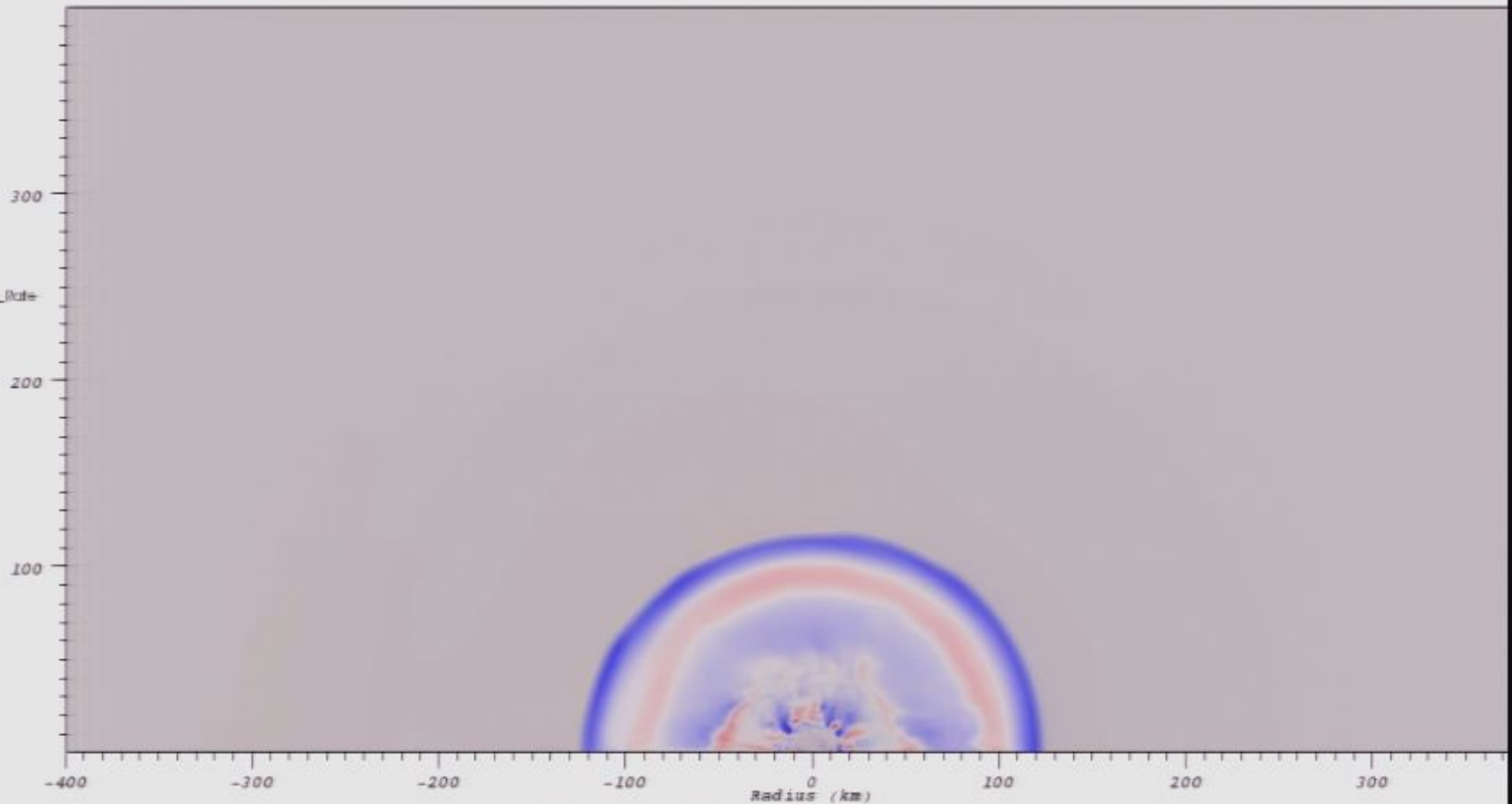


Max: 8.716  
Min: 1.274

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



Max:  $5.670 \times 10^{21}$   
Min:  $-2.812 \times 10^{21}$



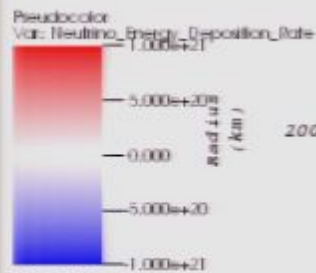
# 2D simulations

DB: 00229.silo

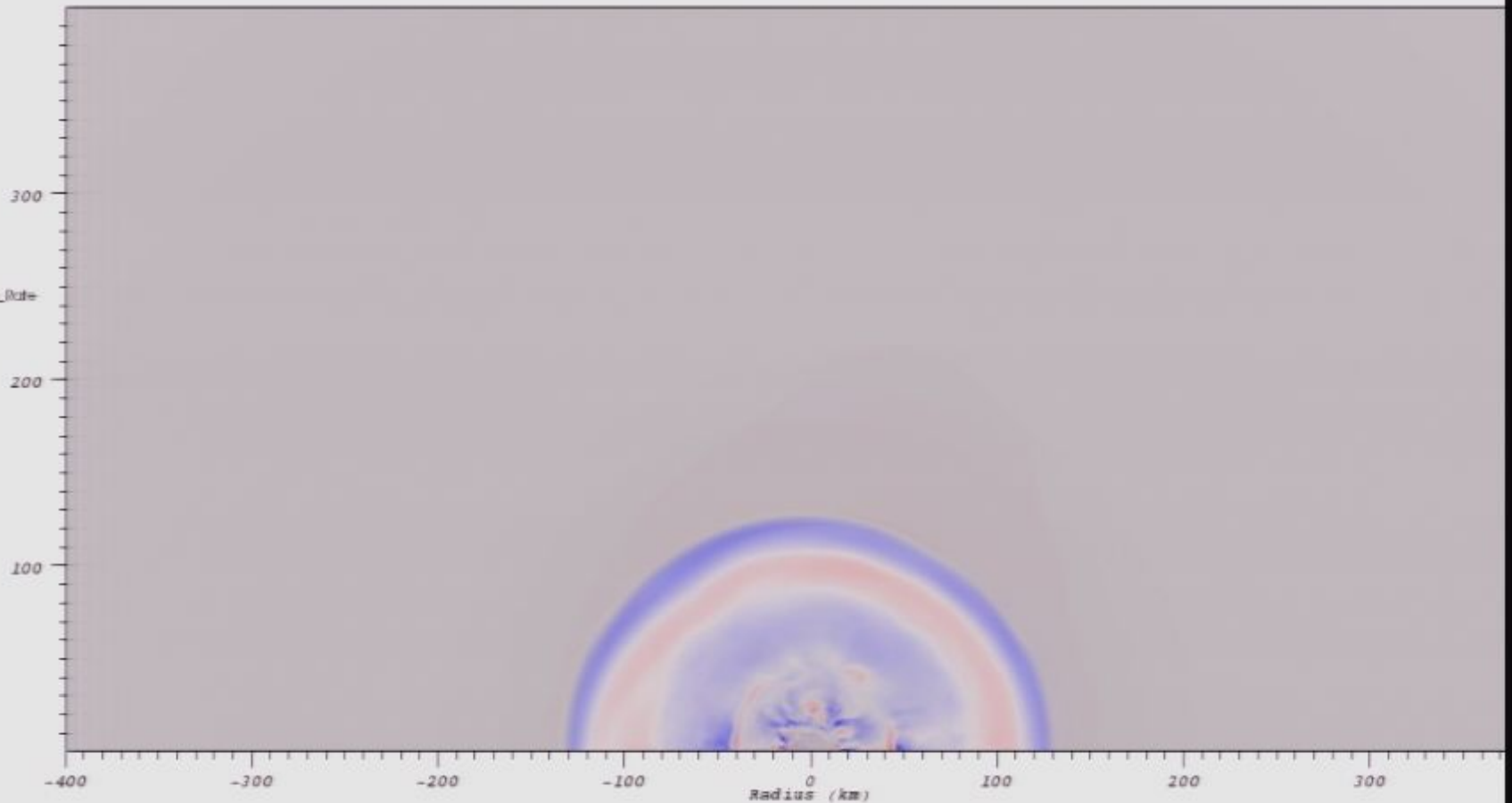
Cycle: 229 Time: 0.471211



Max: 8.629  
Min: 1.277



Max:  $3.191 \times 10^{21}$   
Min:  $-2.961 \times 10^{21}$



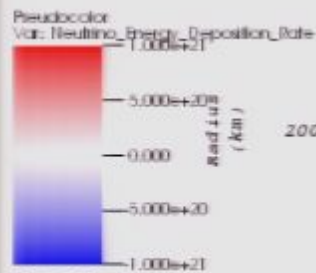
# 2D simulations

DB: 00245.silo

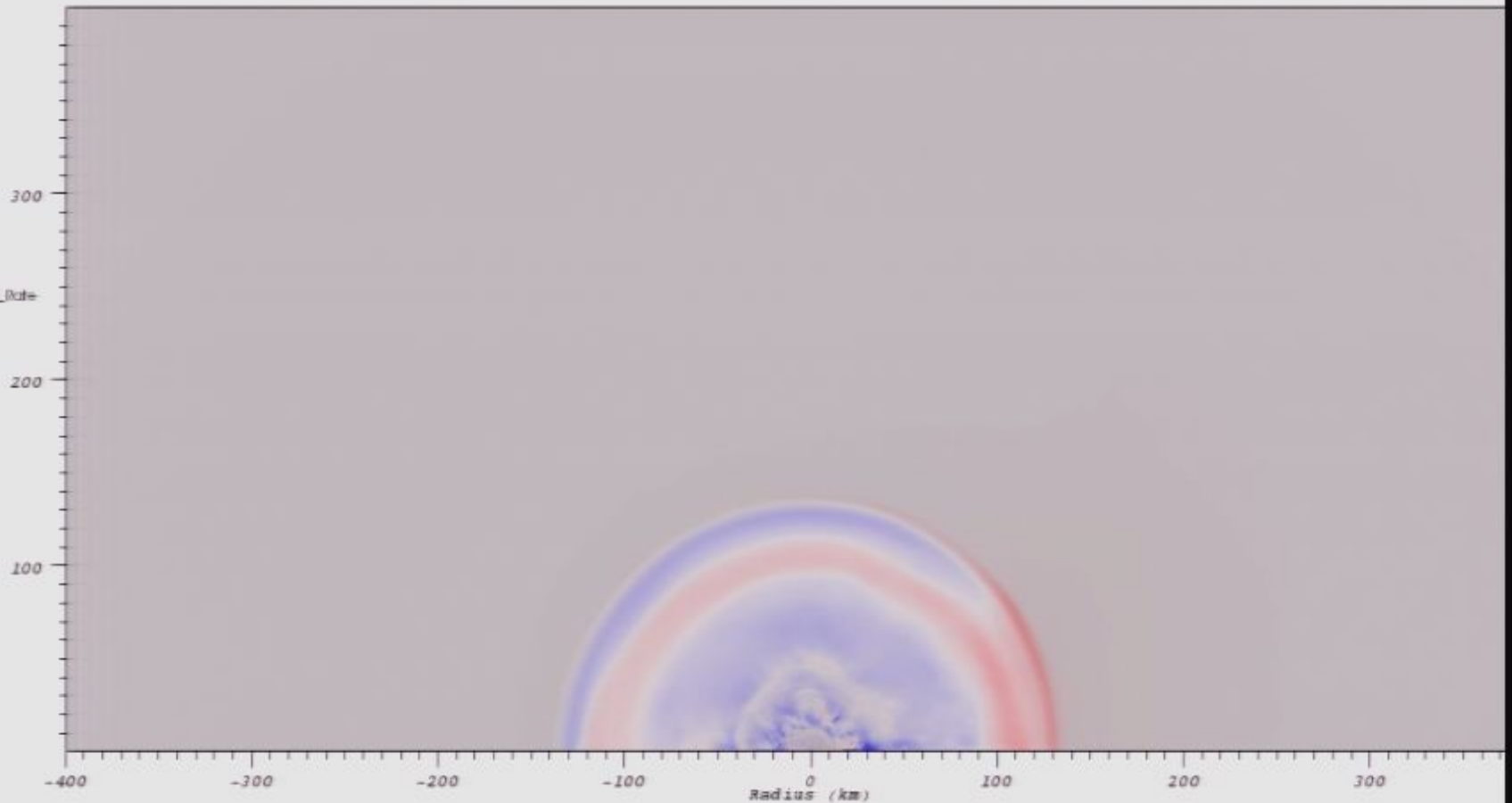
Cycle: 245 Time: 0.474412



Max: 8.732  
Min: 1.272



Max:  $2.826 \times 10^{21}$   
Min:  $-2.400 \times 10^{21}$



# 2D simulations

DB: 00260.silo

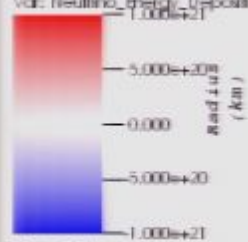
Cycle: 260 Time: 0.477411

Pseudocolor  
Var: Entropy

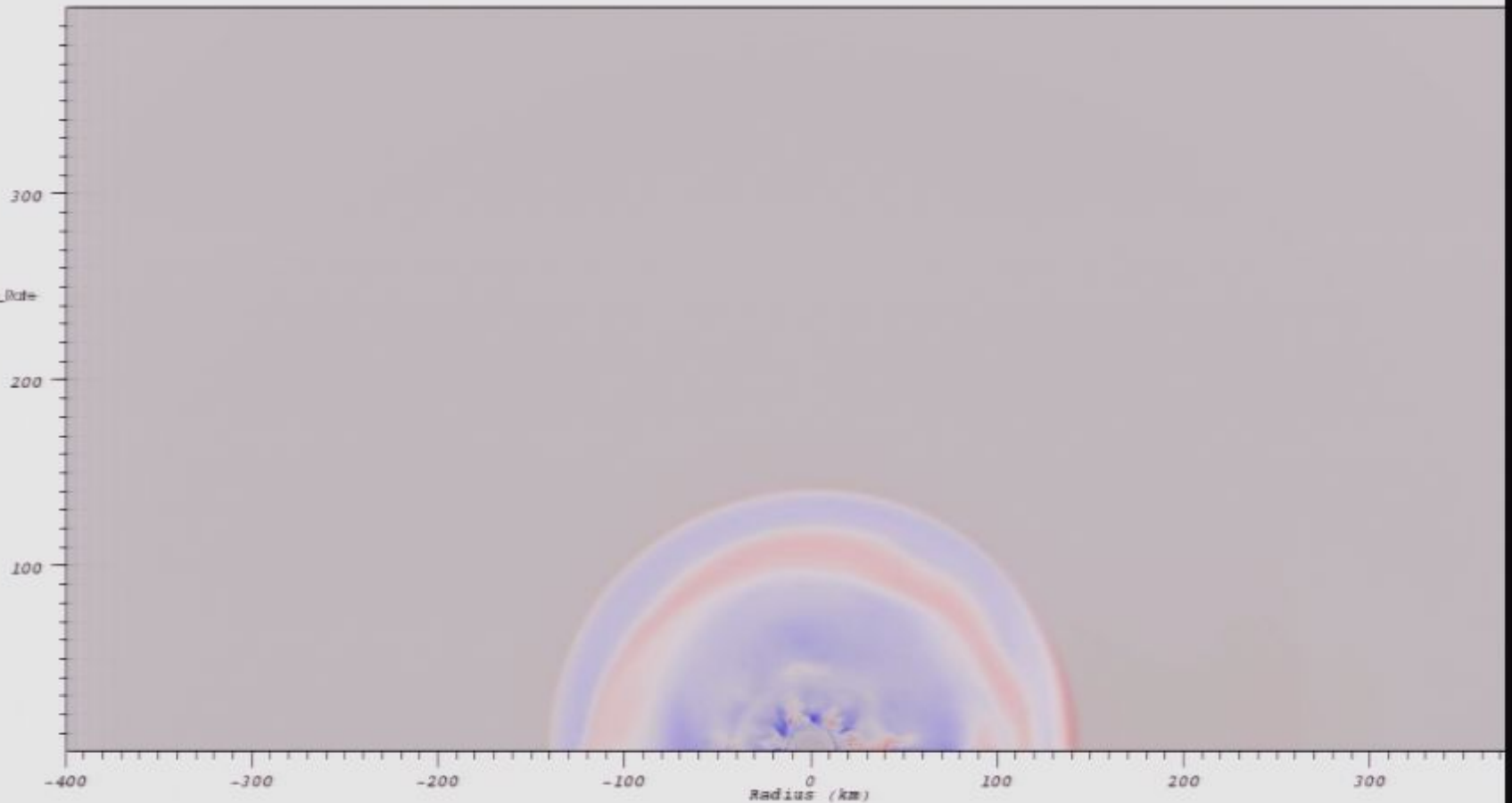


Max: 10.05  
Min: 1.271

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



Max:  $7.771 \times 10^{20}$   
Min:  $-1.306 \times 10^{21}$



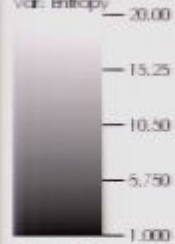


# 2D simulations

DB: 00276.silo

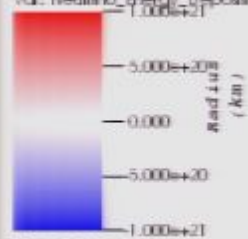
Cycle: 276 Time: 0.480611

Pseudocolor  
Var: Entropy

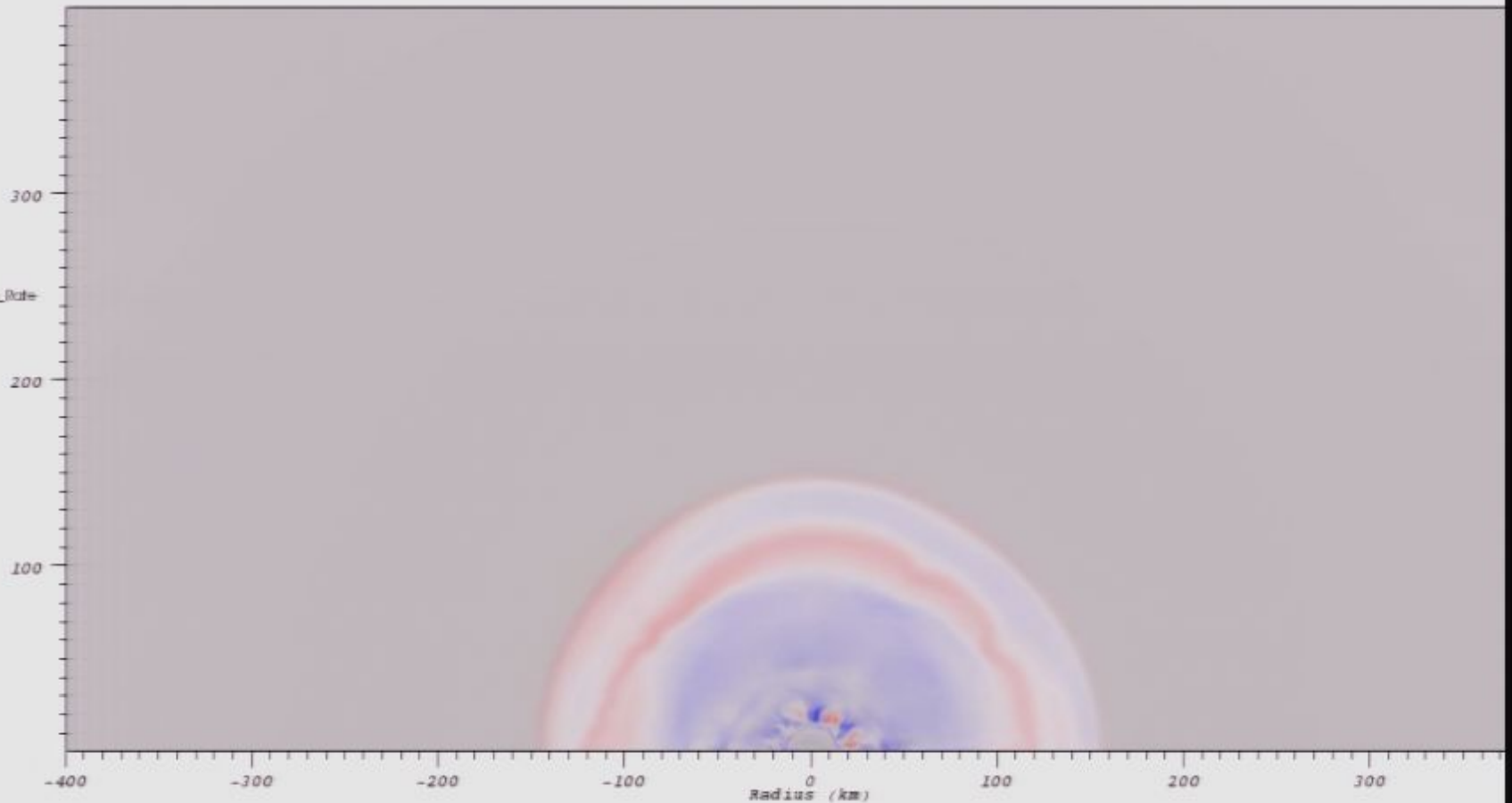


Max: 9.959  
Min: 1.270

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



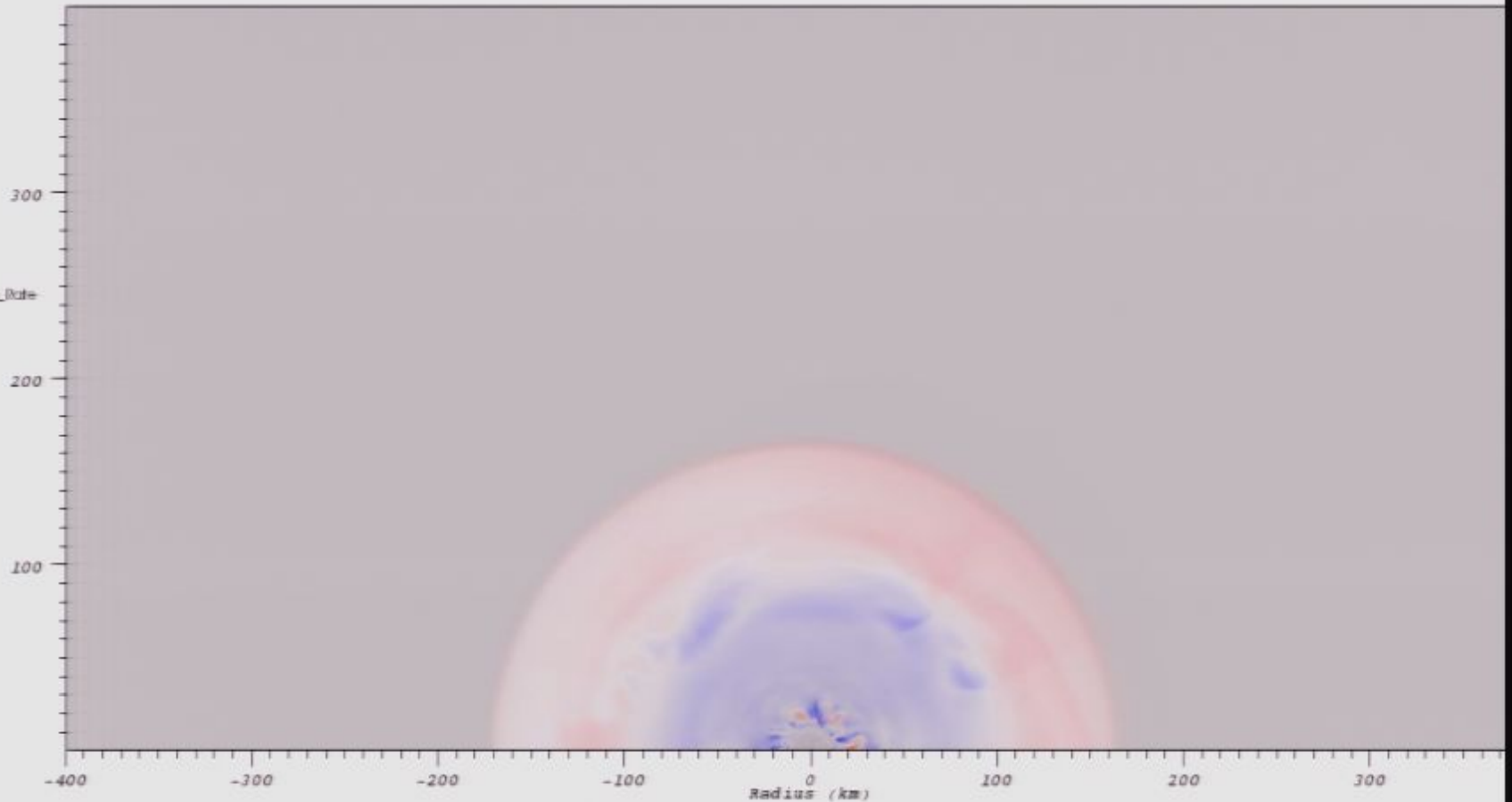
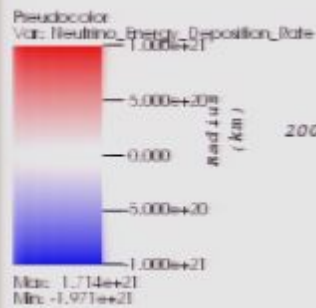
Max:  $7.287 \times 10^{20}$   
Min:  $-1.466 \times 10^{21}$



# 2D simulations

DB: 00323.silo

Cycle: 323 Time: 0.490011



# 2D simulations

DB: 00348.silo

Cycle: 348

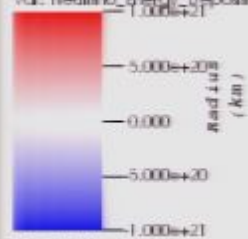
Time: 0.495011

Pseudocolor  
Var: Entropy

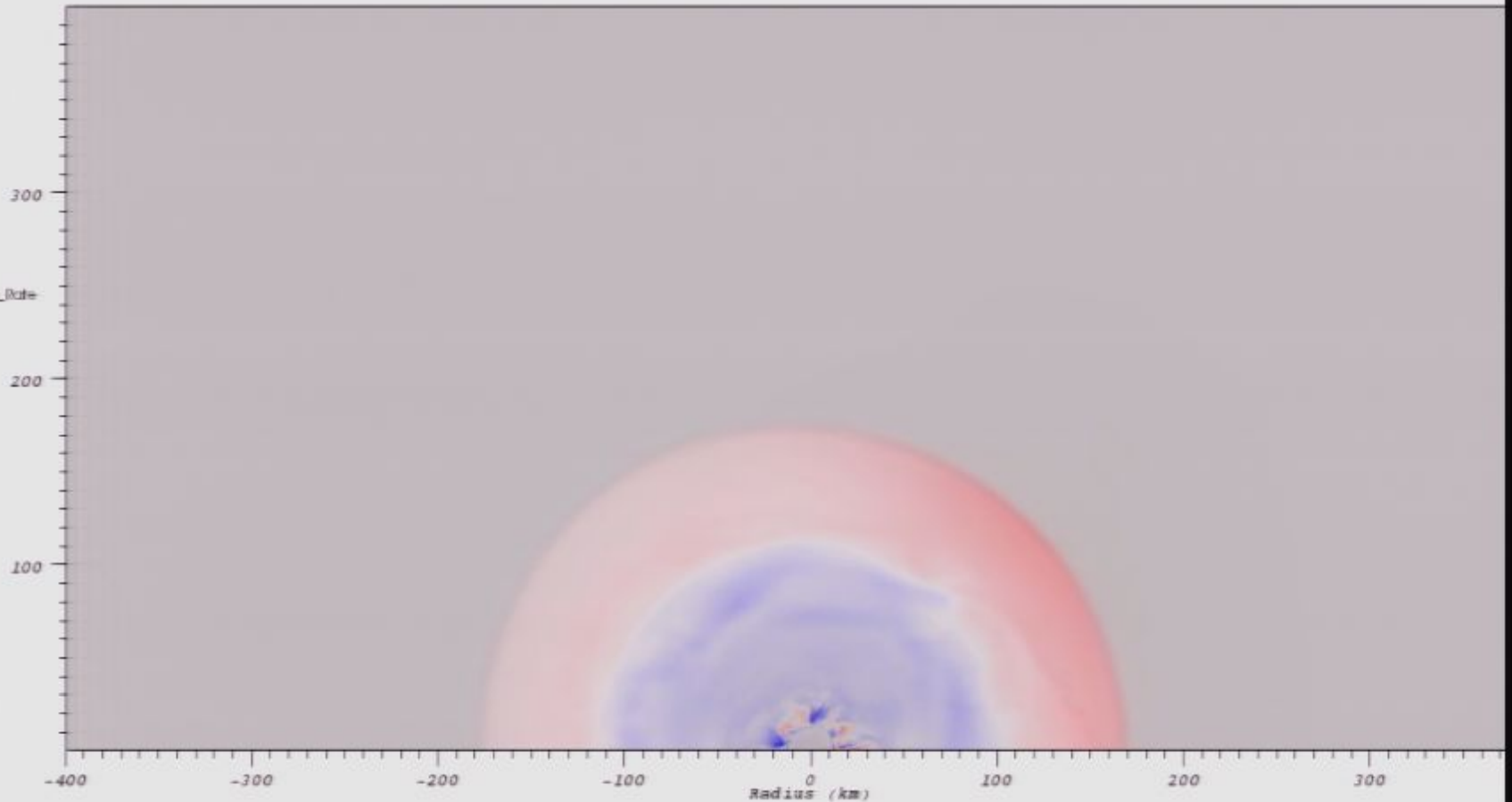


Max: 11.00  
Min: 1.270

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



Max:  $1.401 \times 10^{21}$   
Min:  $-3.193 \times 10^{21}$



# 2D simulations

DB: 00379.silo

Cycle: 379 Time: 0.501212

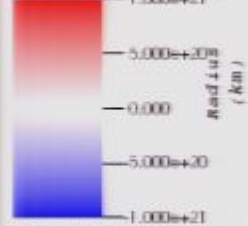
Pseudocolor  
Var: Entropy



Max: 11.84

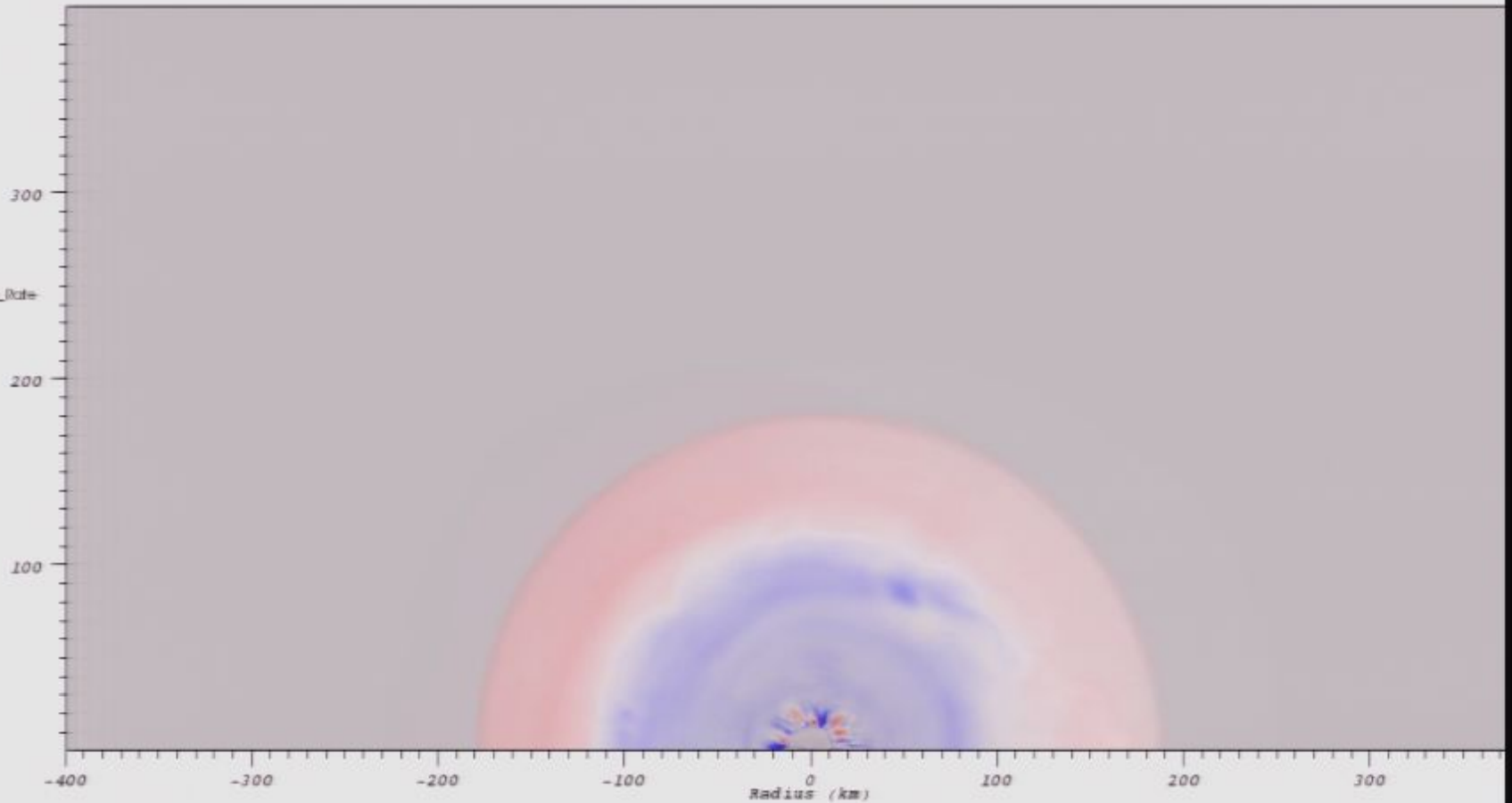
Min: 1.277

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



Max: 2.728e+21

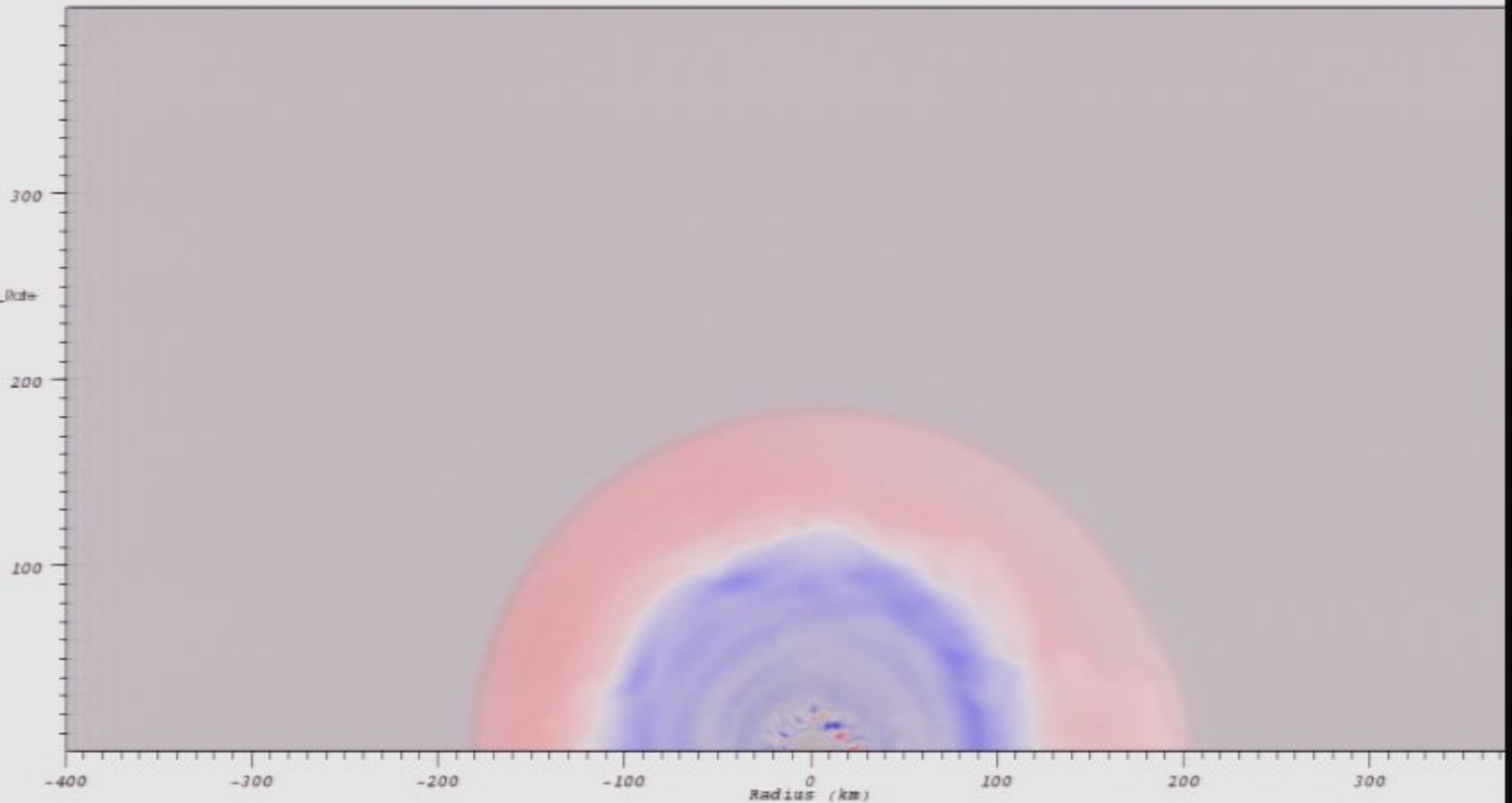
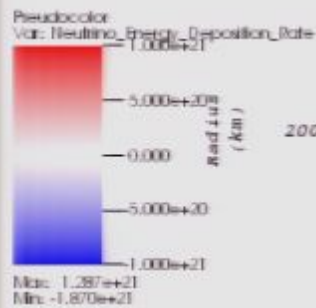
Min: -3.403e+21



# 2D simulations

DB: 00437.silo

Cycle: 437 Time: 0.512811



# 2D simulations

DB: 00477.silo

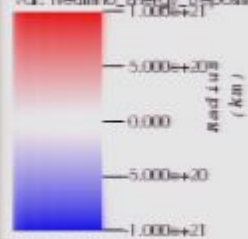
Cycle: 477 Time: 0.520811

Pseudocolor  
Var: Entropy

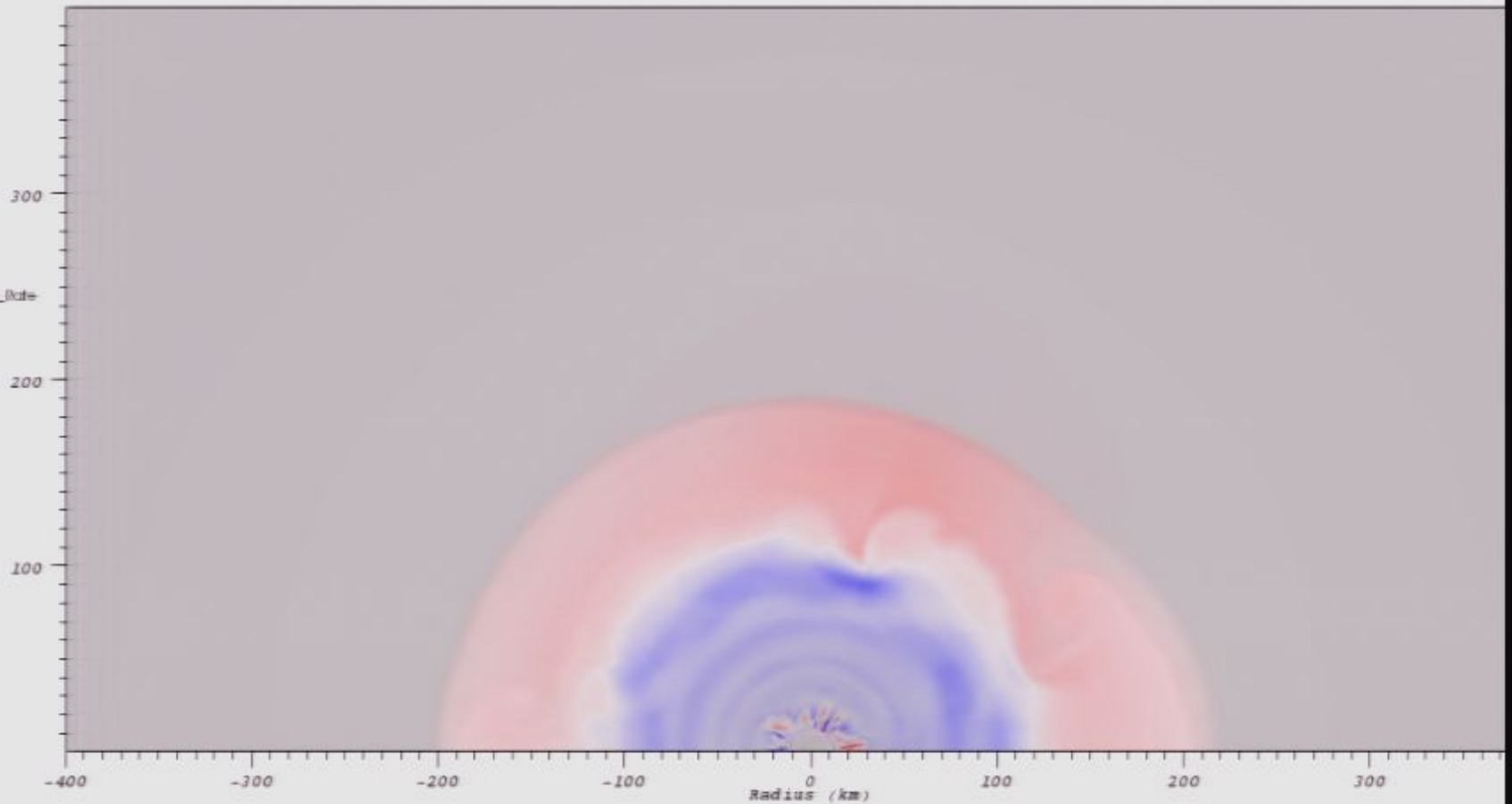


Max: 12.61  
Min: 1.275

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



Max:  $5.514 \times 10^{21}$   
Min:  $-5.510 \times 10^{21}$



# 2D simulations

DB: 00502.silo

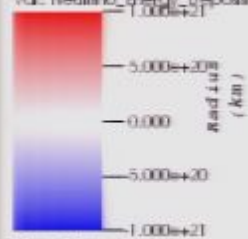
Cycle: 502 Time: 0.525812

Pseudocolor  
Var: Entropy

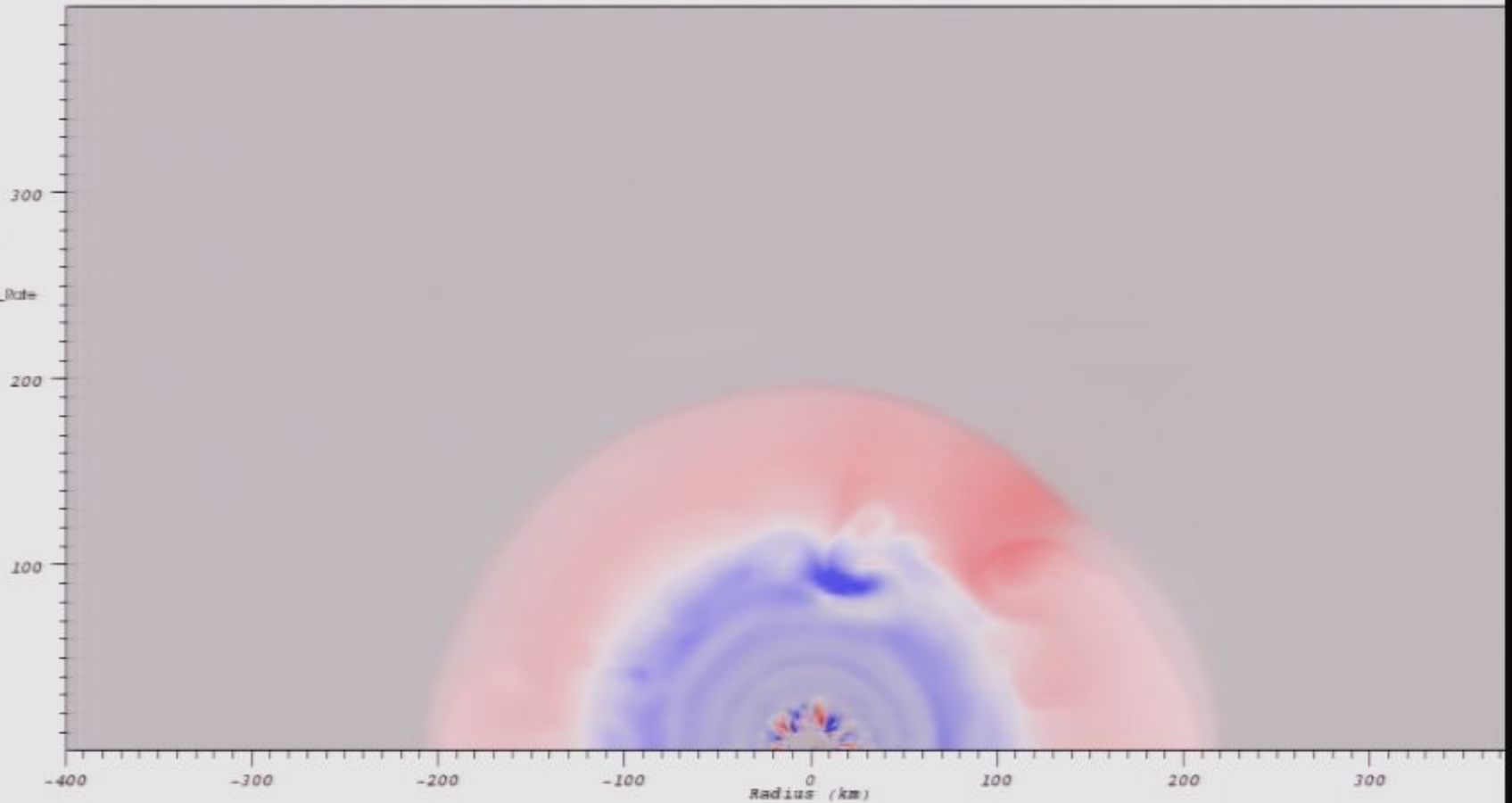


Max: 13.00  
Min: 1.274

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



Max:  $7.153 \times 10^{21}$   
Min:  $-5.005 \times 10^{21}$



# 2D simulations

DB: 00525.silo

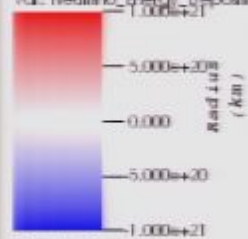
Cycle: 525 Time: 0.530412

Pseudocolor  
Var: Entropy

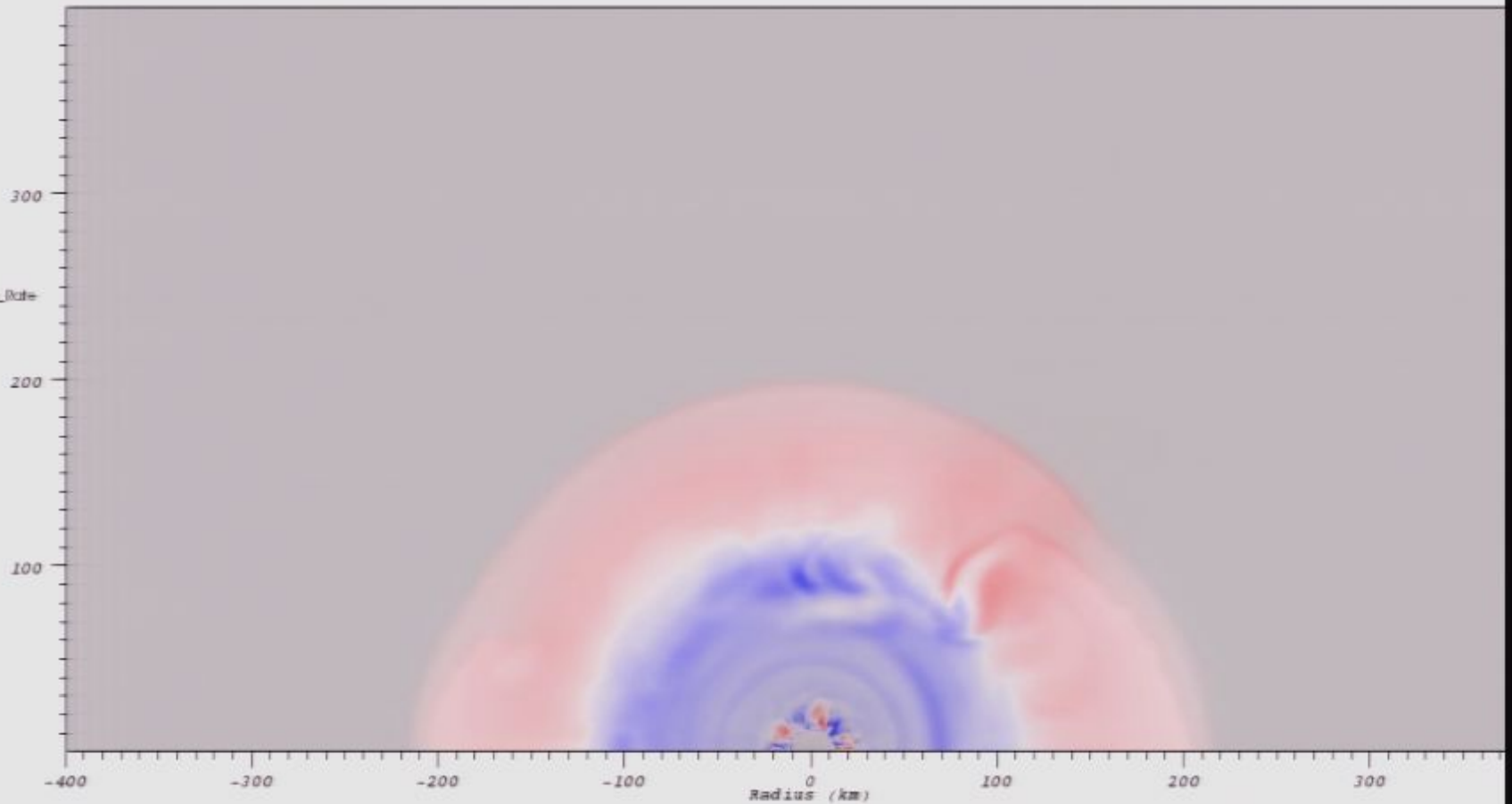


Max: 13.75  
Min: 1.273

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



Max:  $1.505 \times 10^{21}$   
Min:  $-1.996 \times 10^{21}$





# 2D simulations

DB: 00549.silo

Cycle: 549

Time: 0.535211

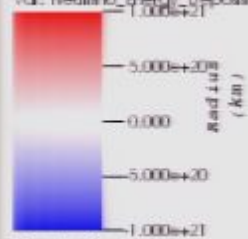
Pseudocolor  
Var: Entropy



Max: 13.94

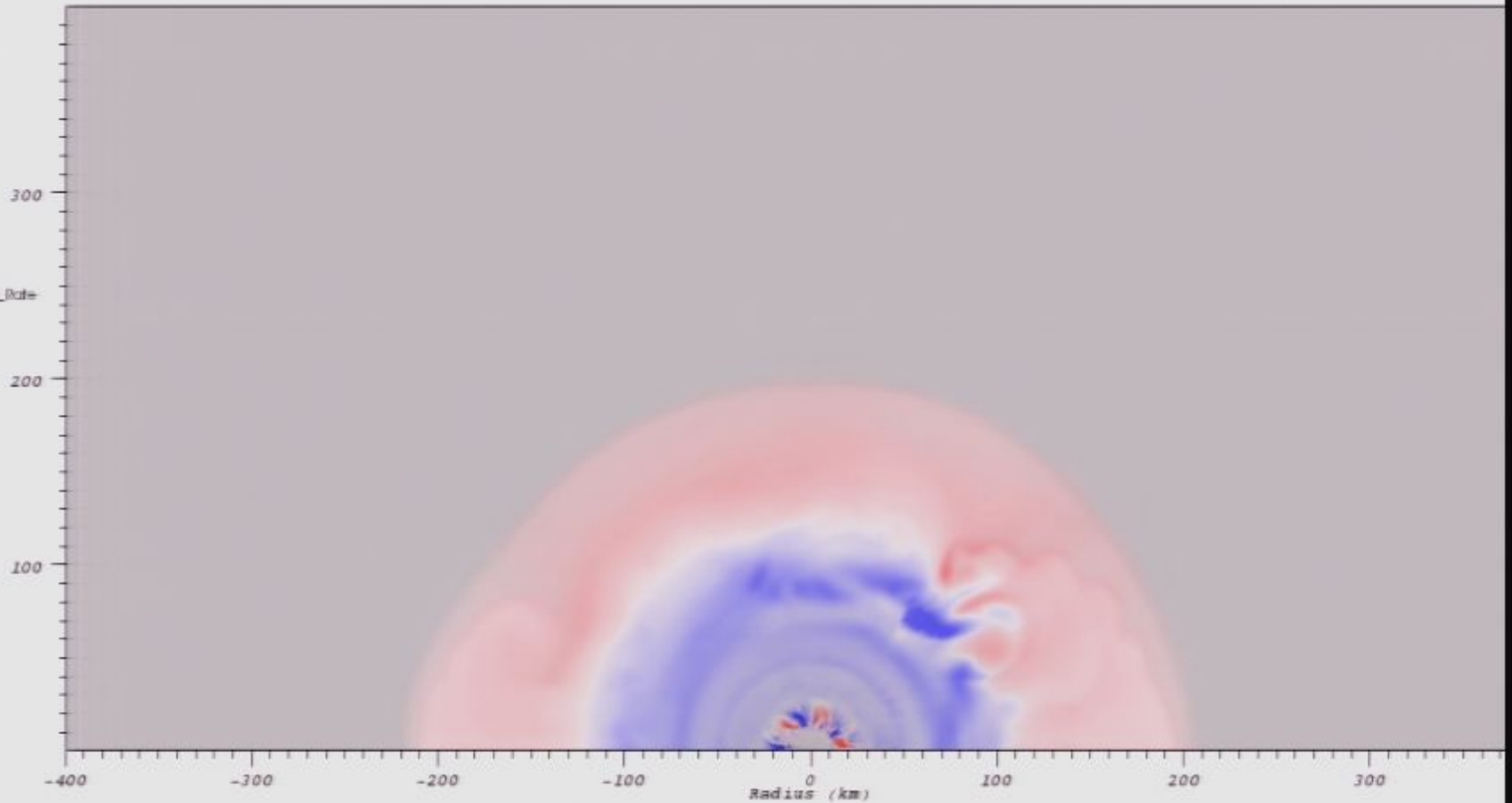
Min: 1.273

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



Max:  $1.644 \times 10^{21}$

Min:  $-4.282 \times 10^{21}$



# 2D simulations

DB: 00565.silo

Cycle: 565

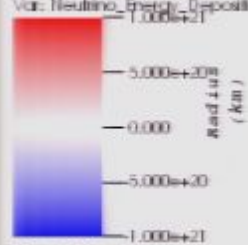
Time: 0.538411

Pseudocolor  
Var: Entropy

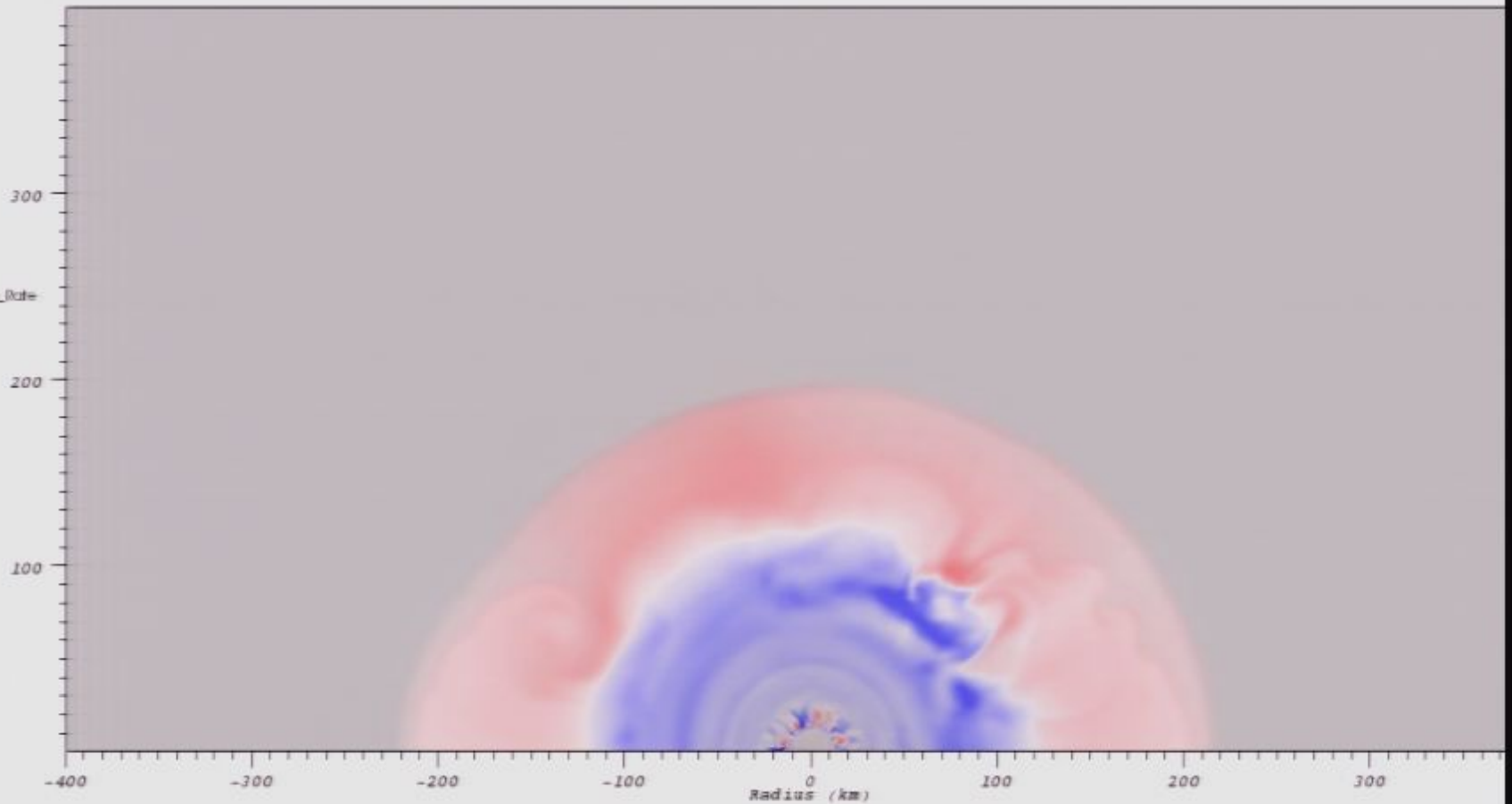


Max: 14.24  
Min: 1.273

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



Max:  $3.011 \times 10^{21}$   
Min:  $-3.595 \times 10^{21}$



# 2D simulations

DB: 00580.silo

Cycle: 580

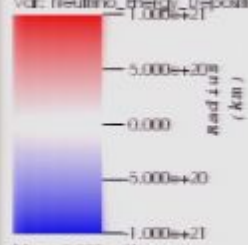
Time: 0.541411

Pseudocolor  
Var: Entropy

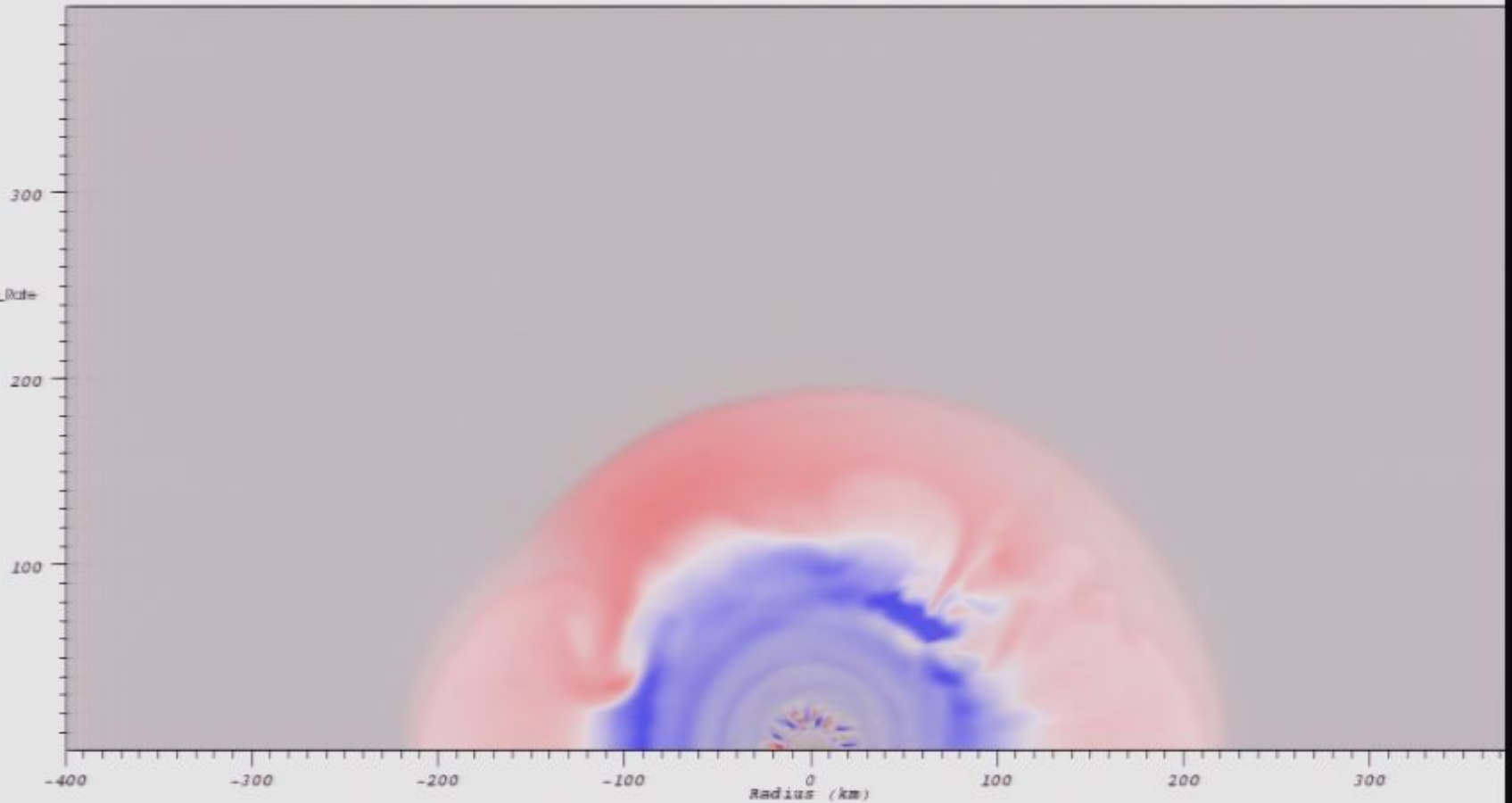


Max: 14.60  
Min: 1.273

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate

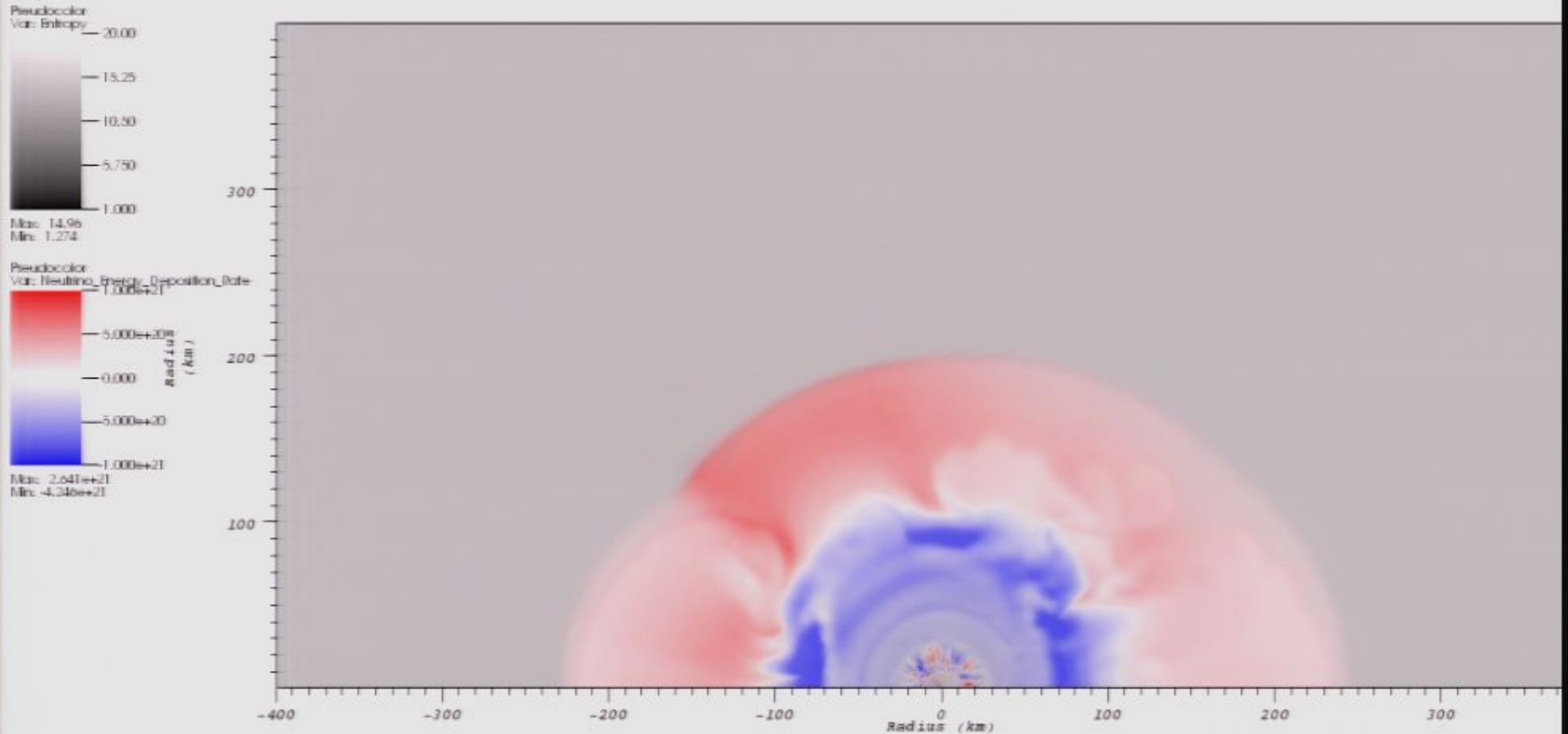


Max:  $2.277 \times 10^{21}$   
Min:  $-3.279 \times 10^{21}$



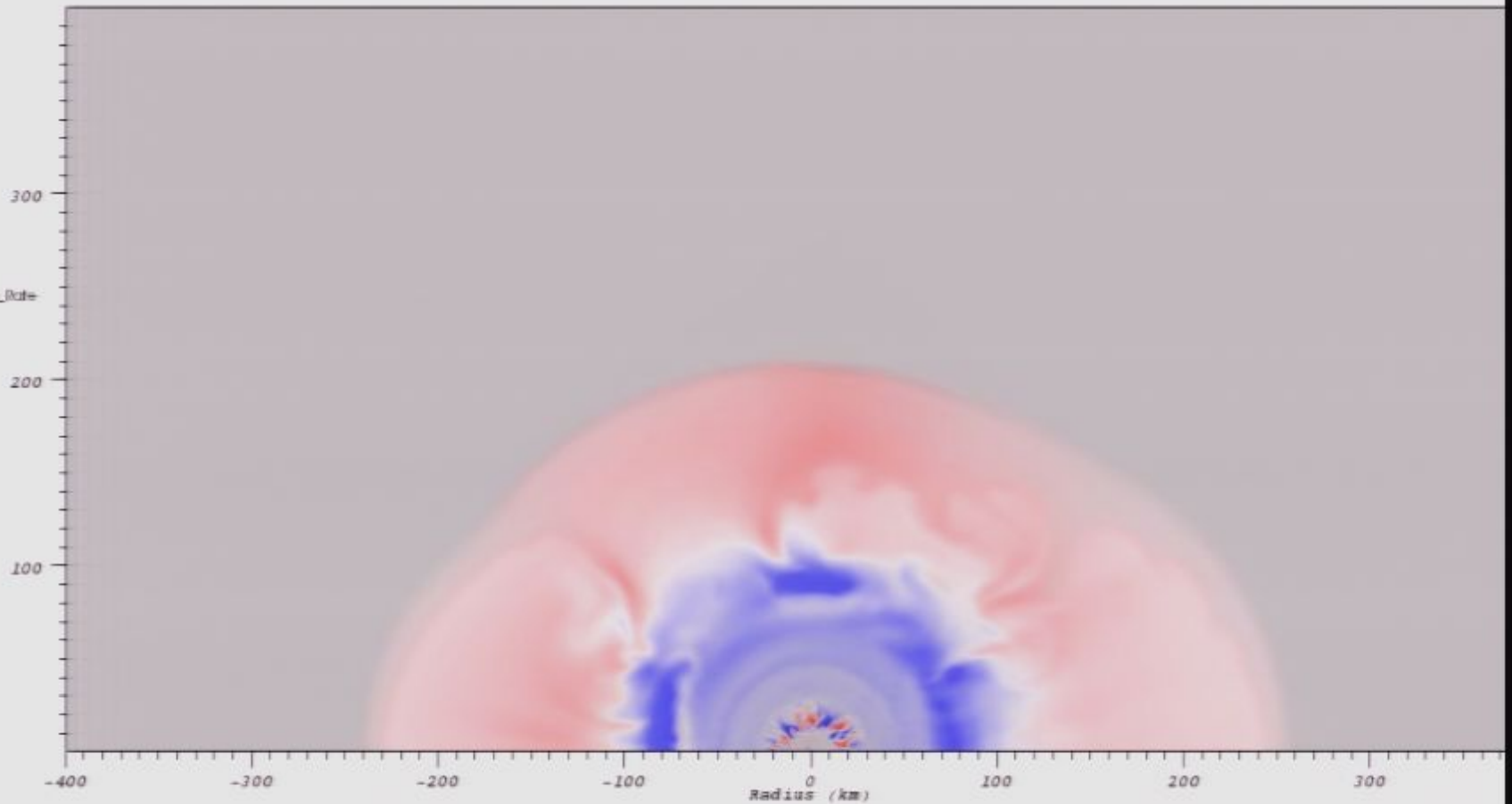
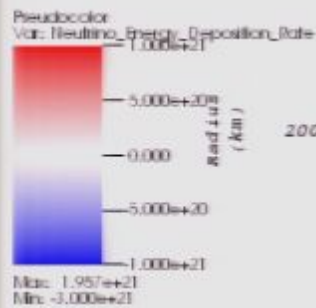
# 2D simulations

DB: 00612.silo  
Cycle: 612 Time: 0.547811



# 2D simulations

DB: 00628.silo  
Cycle: 628 Time: 0.551011



# 2D simulations

DB: 00643.silo

Cycle: 643

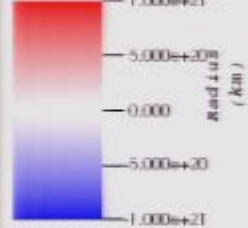
Time: 0.554011

Pseudocolor  
Var: Entropy

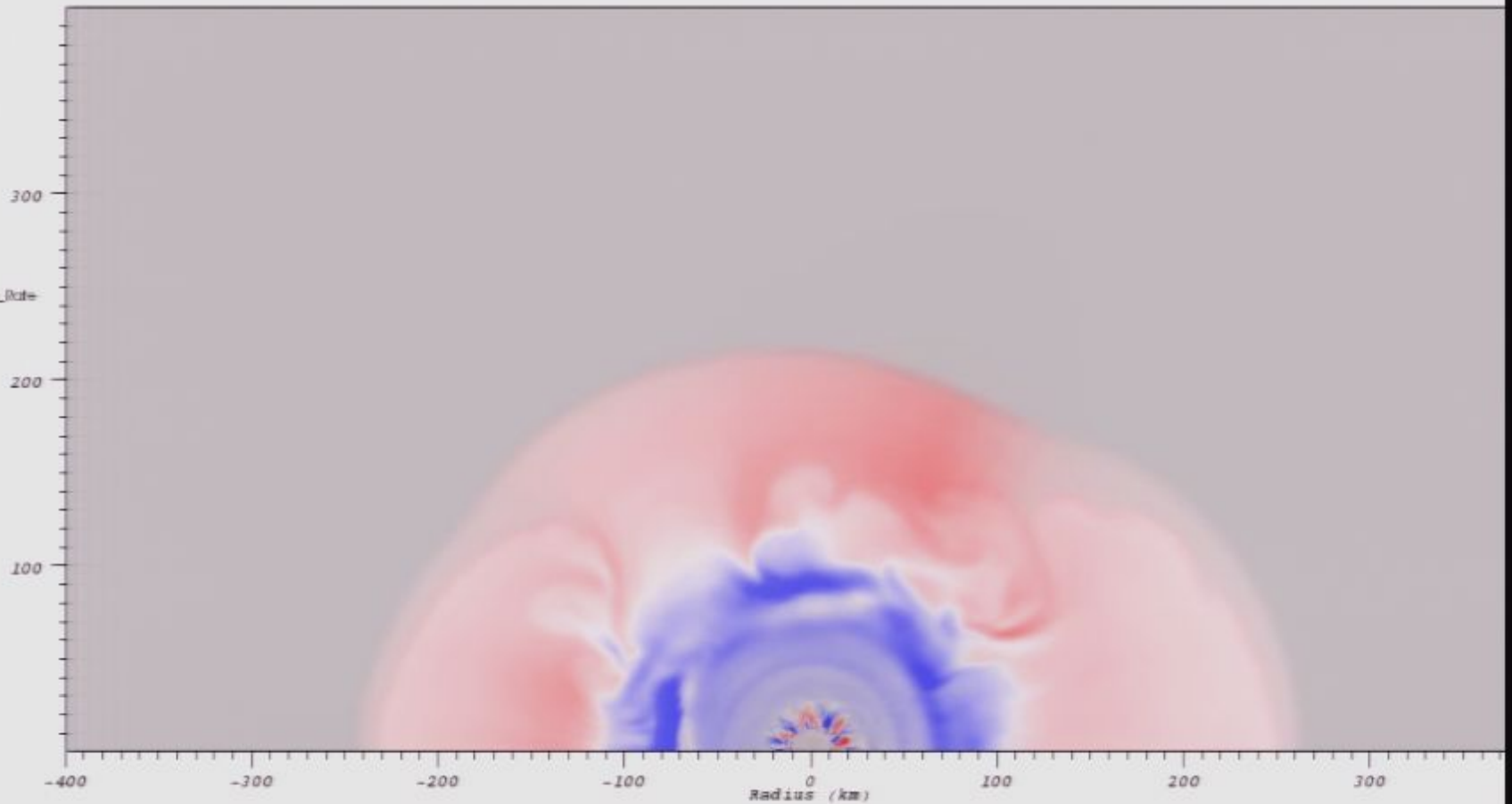


Max: 15.09  
Min: 1.277

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



Max:  $5.053 \times 10^{21}$   
Min:  $-3.953 \times 10^{21}$



# 2D simulations

DB: 00659.silo

Cycle: 659

Time: 0.557211

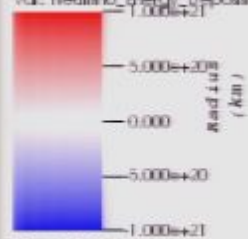
Pseudocolor  
Var: Entropy



Max: 15.25

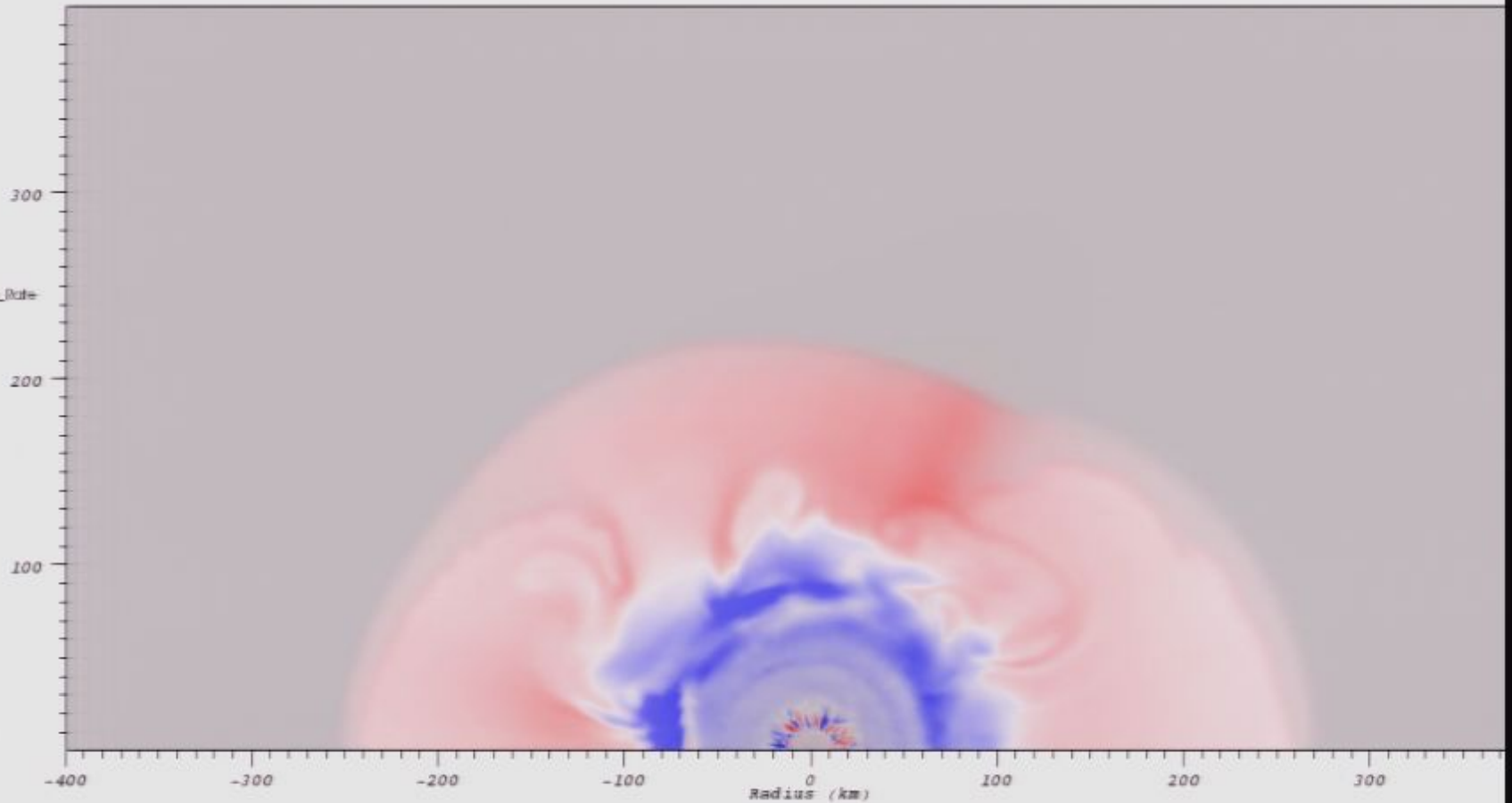
Min: 1.277

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



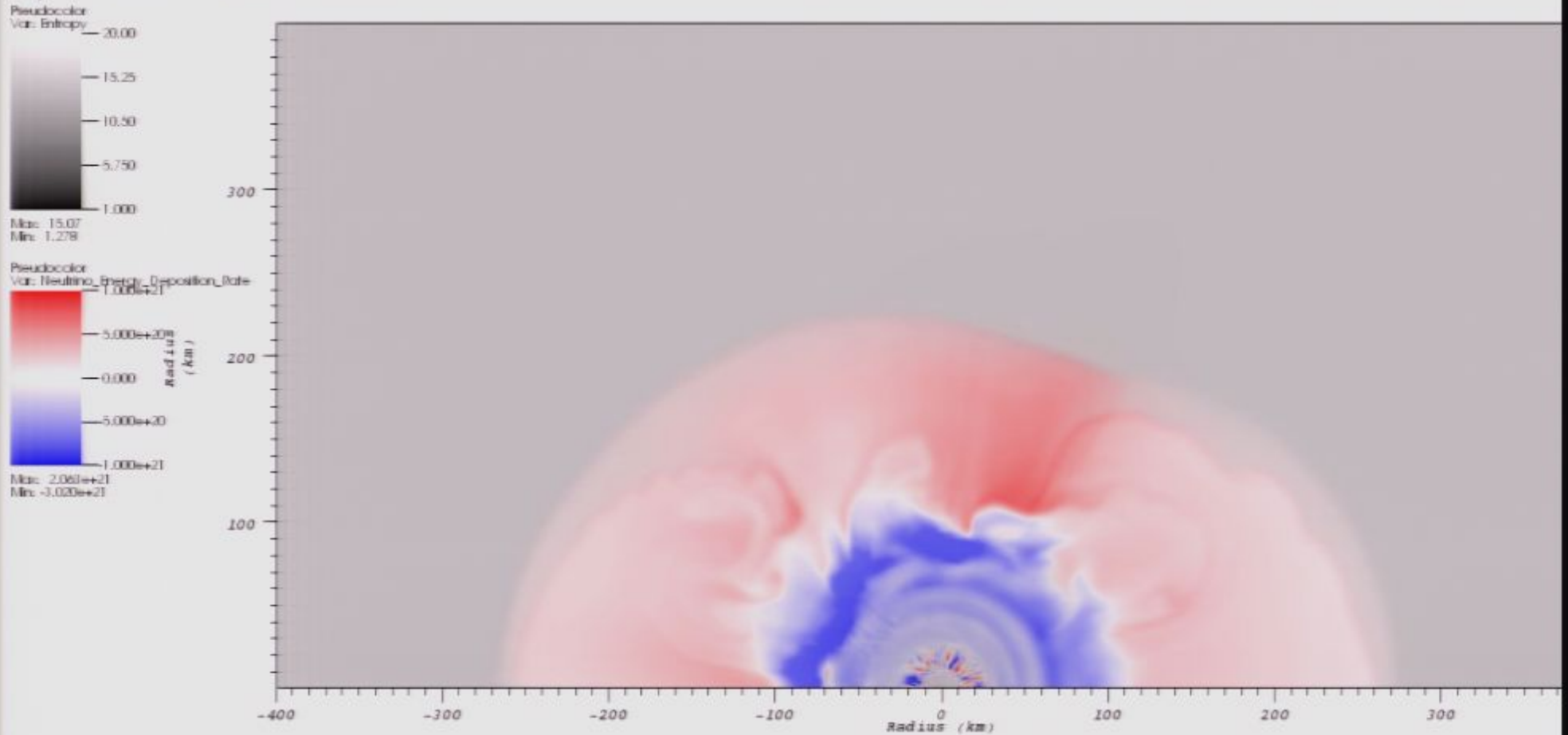
Max:  $3.908 \times 10^{21}$

Min:  $-3.881 \times 10^{21}$



# 2D simulations

DB: 00675.silo  
Cycle: 675 Time: 0.560411

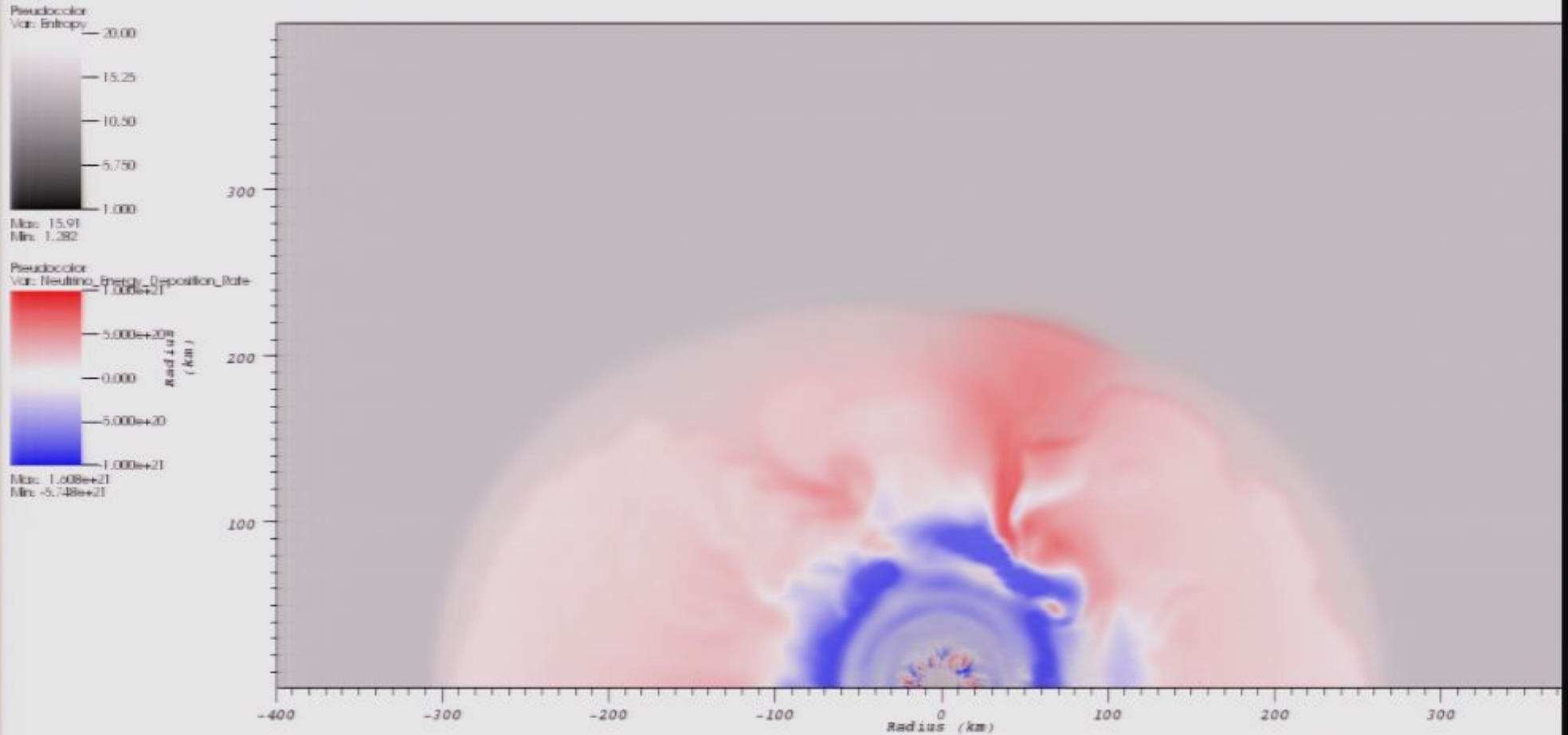




# 2D simulations

DB: 00710.silo

Cycle: 710 Time: 0.567411



# 2D simulations

DB: 00747.silo

Cycle: 747

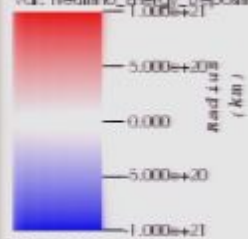
Time: 0.574811

Pseudocolor  
Var: Entropy

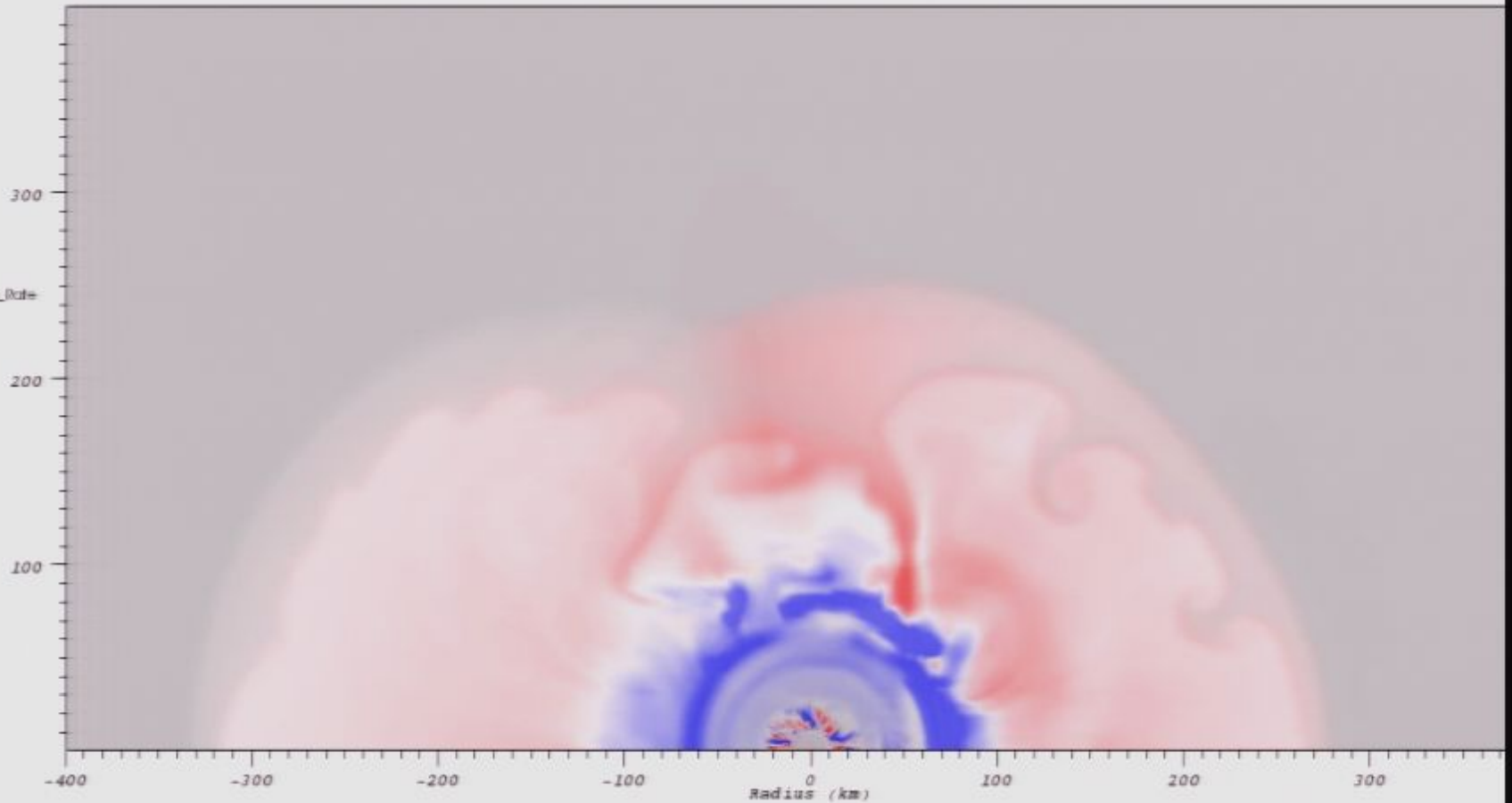


Max: 16.53  
Min: 1.285

Pseudocolor  
Var: Neutino\_Energy\_Deposition\_Rate



Max: 3.207e+21  
Min: -4.992e+21



# 2D simulations

DB: 00789.silo

Cycle: 789

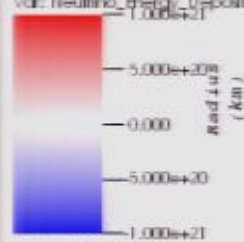
Time: 0.583211

Pseudocolor  
Var: Entropy

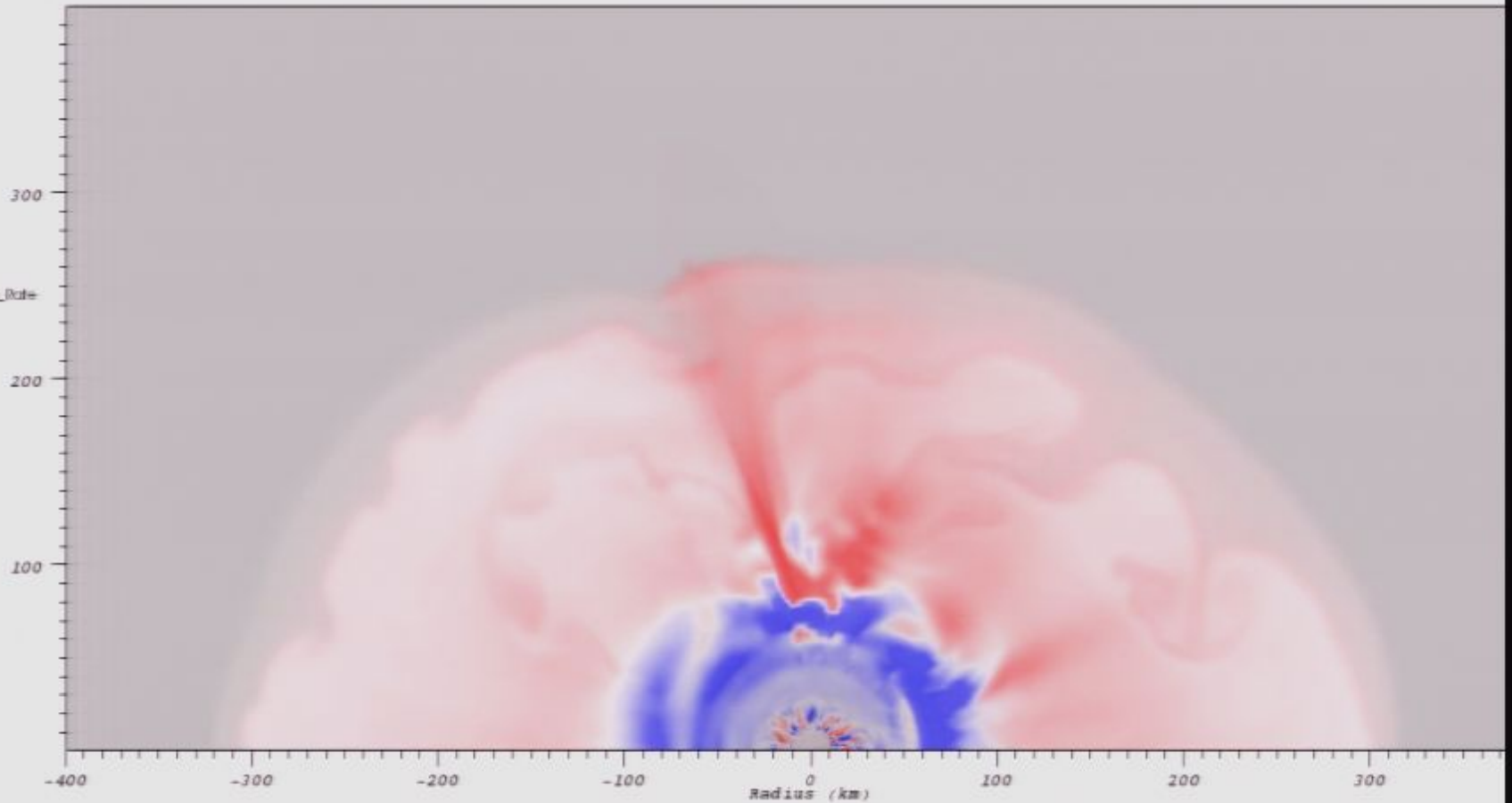


Max: 17.31  
Min: 1.285

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



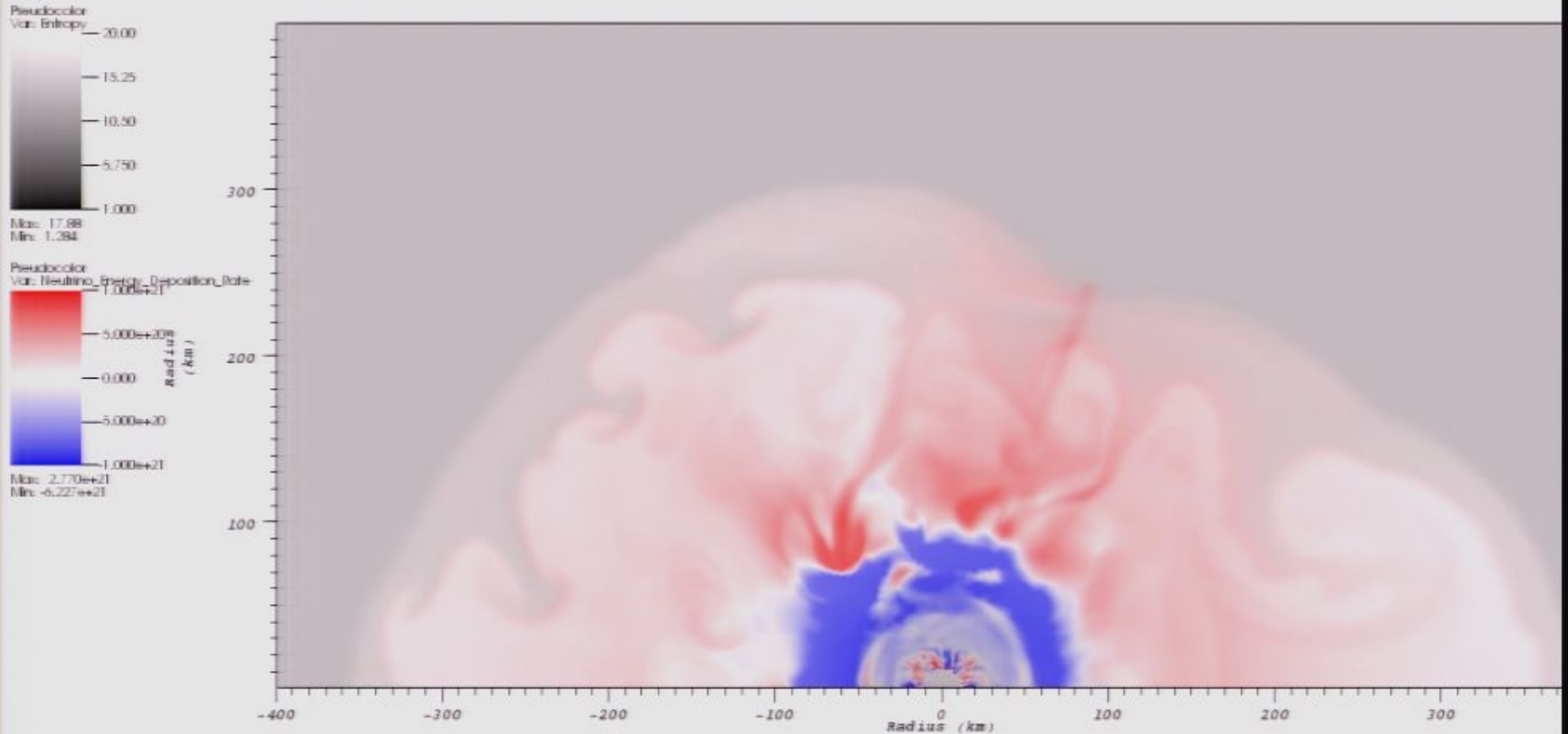
Max:  $7.198 \times 10^{21}$   
Min:  $-8.157 \times 10^{21}$



# 2D simulations

DB: 00829.silo

Cycle: 829 Time: 0.591211

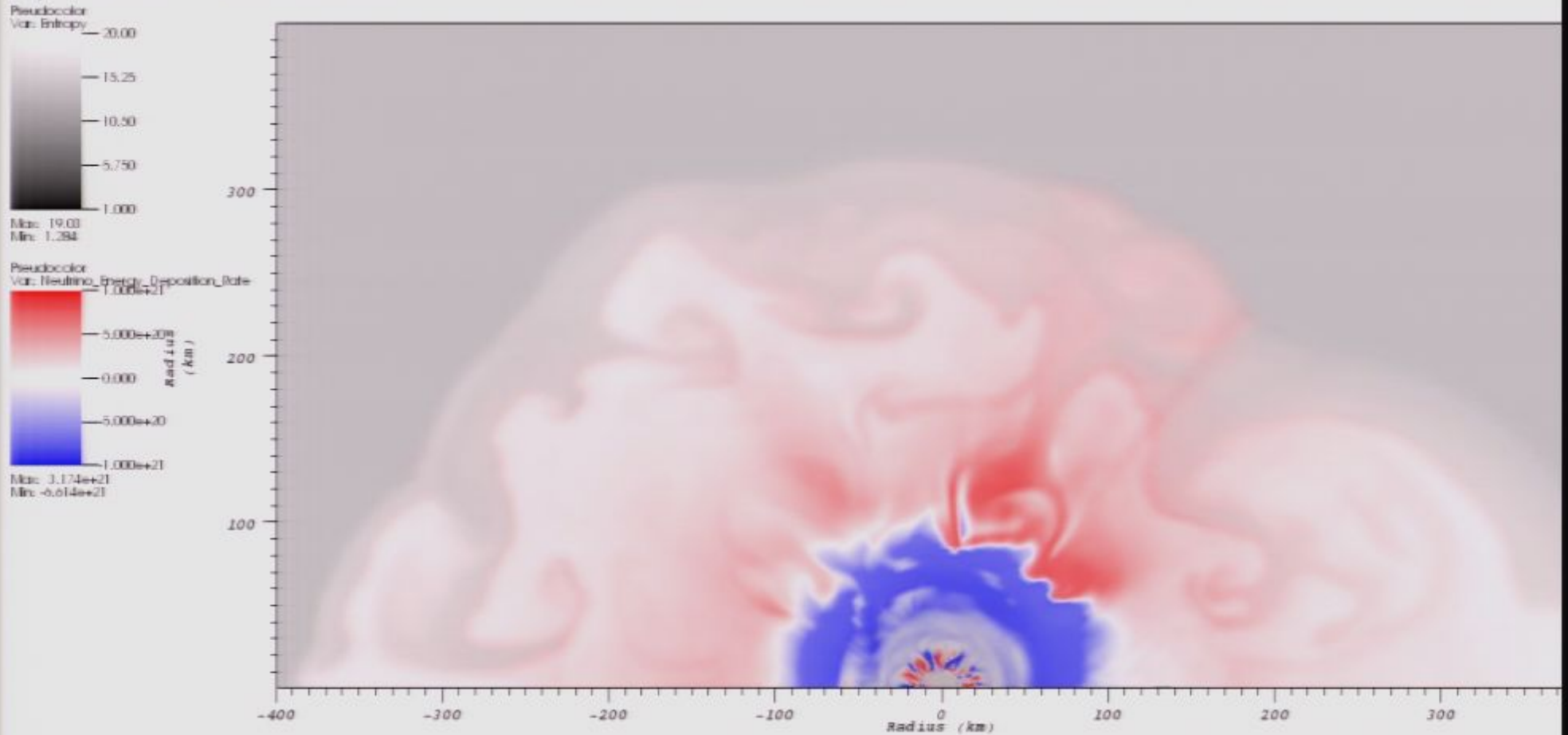


# 2D simulations

DB: 00866.silo

Cycle: 866

Time: 0.598611



# 2D simulations

DB: 00908.silo

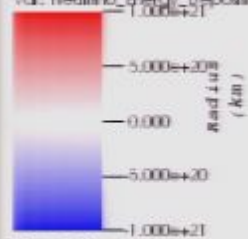
Cycle: 908 Time: 0.607012

Pseudocolor  
Var: Entropy

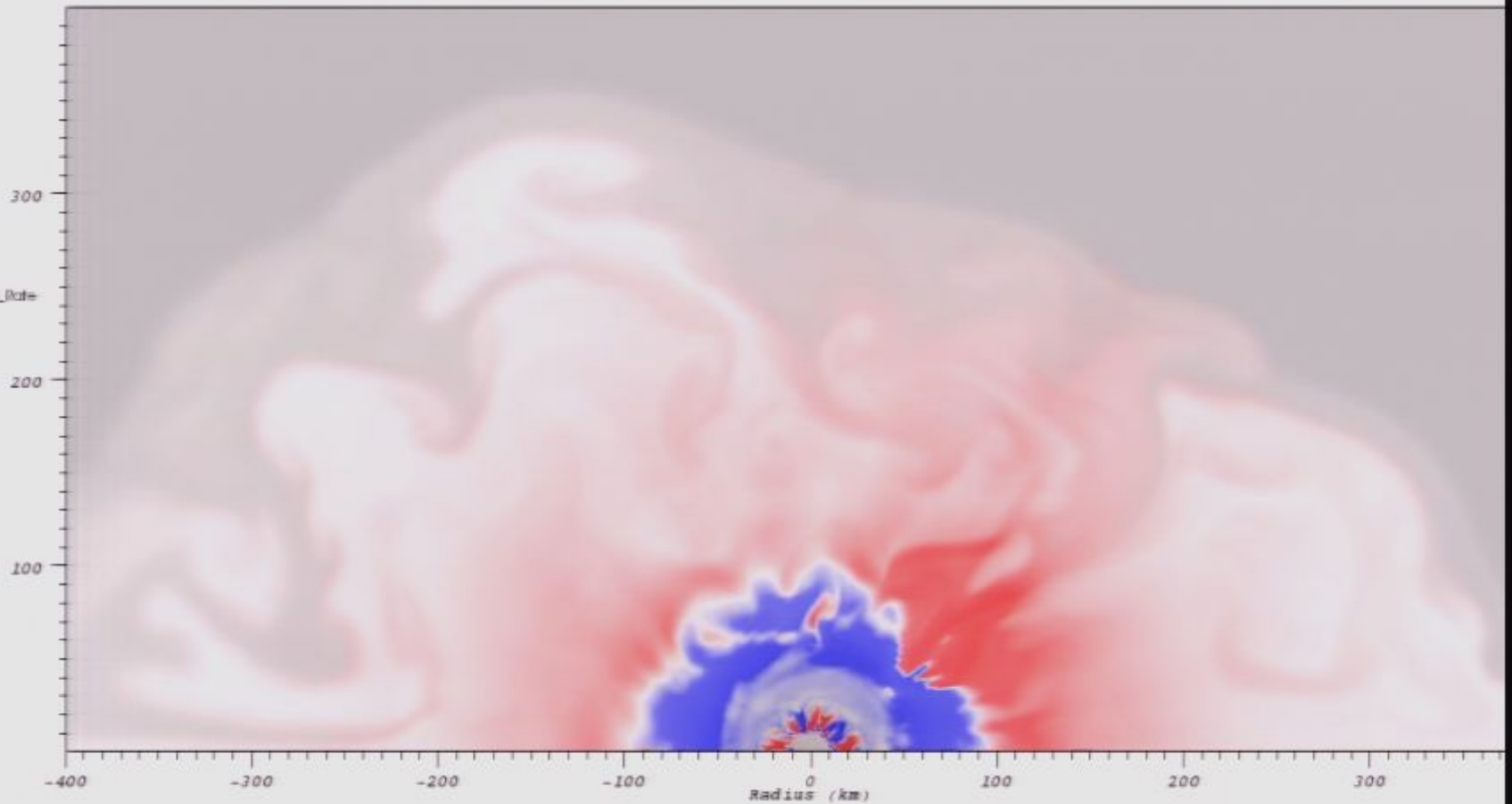


Max: 19.33  
Min: 1.282

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



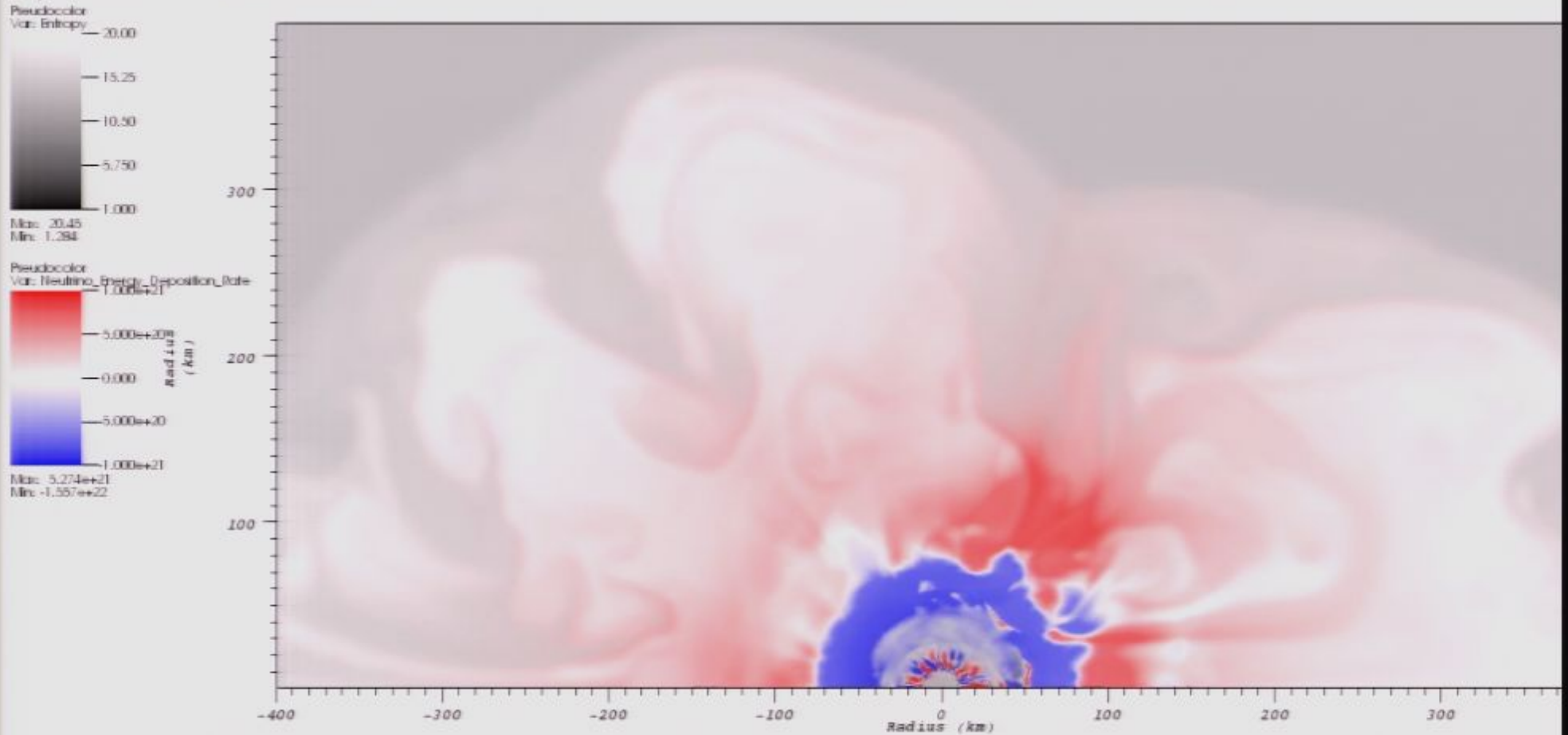
Max:  $7.723 \times 10^{21}$   
Min:  $-1.922 \times 10^{22}$



# 2D simulations

DB: 00948.silo

Cycle: 948 Time:0.615011

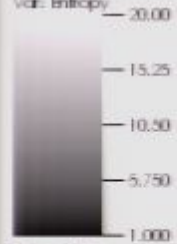


# 2D simulations

DB: 00988.silo

Cycle: 988 Time: 0.623011

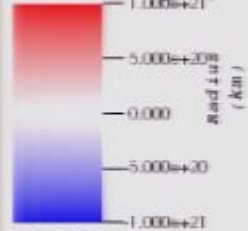
Pseudocolor  
Var: Entropy



Max: 20.04

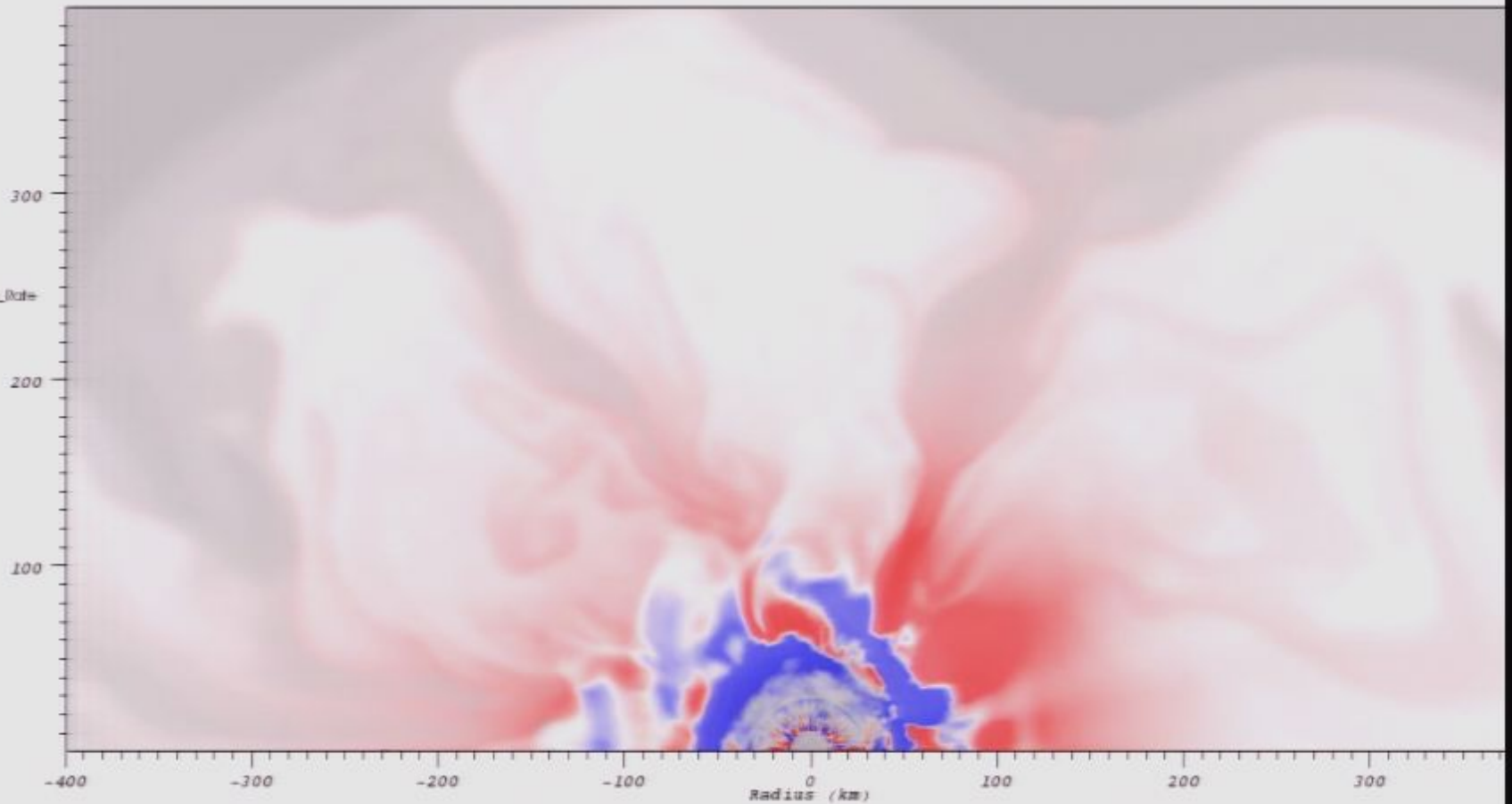
Min: 1.287

Pseudocolor  
Var: Neutrino\_Energy\_Deposition\_Rate



Max:  $9.372 \times 10^{21}$

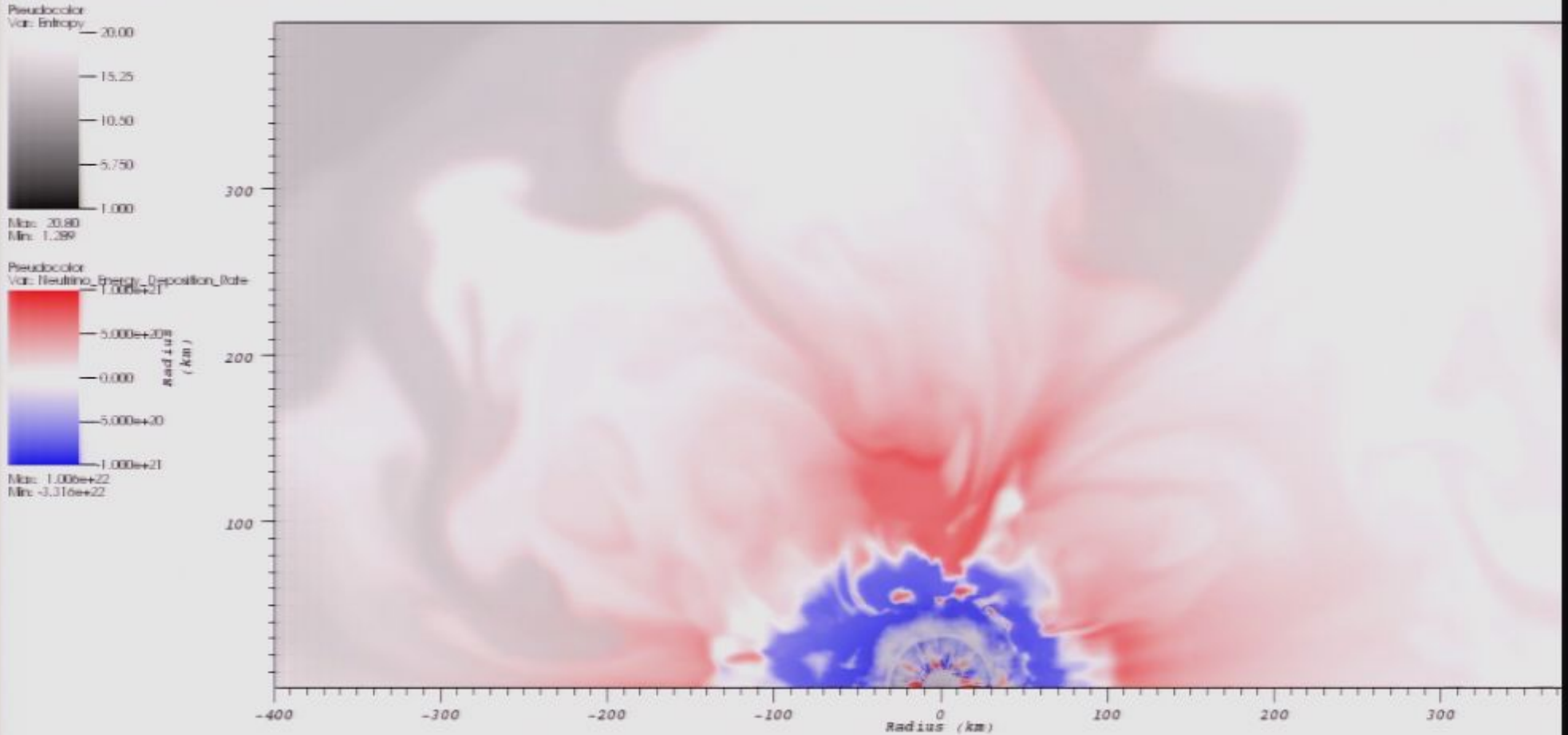
Min:  $-2.057 \times 10^{22}$





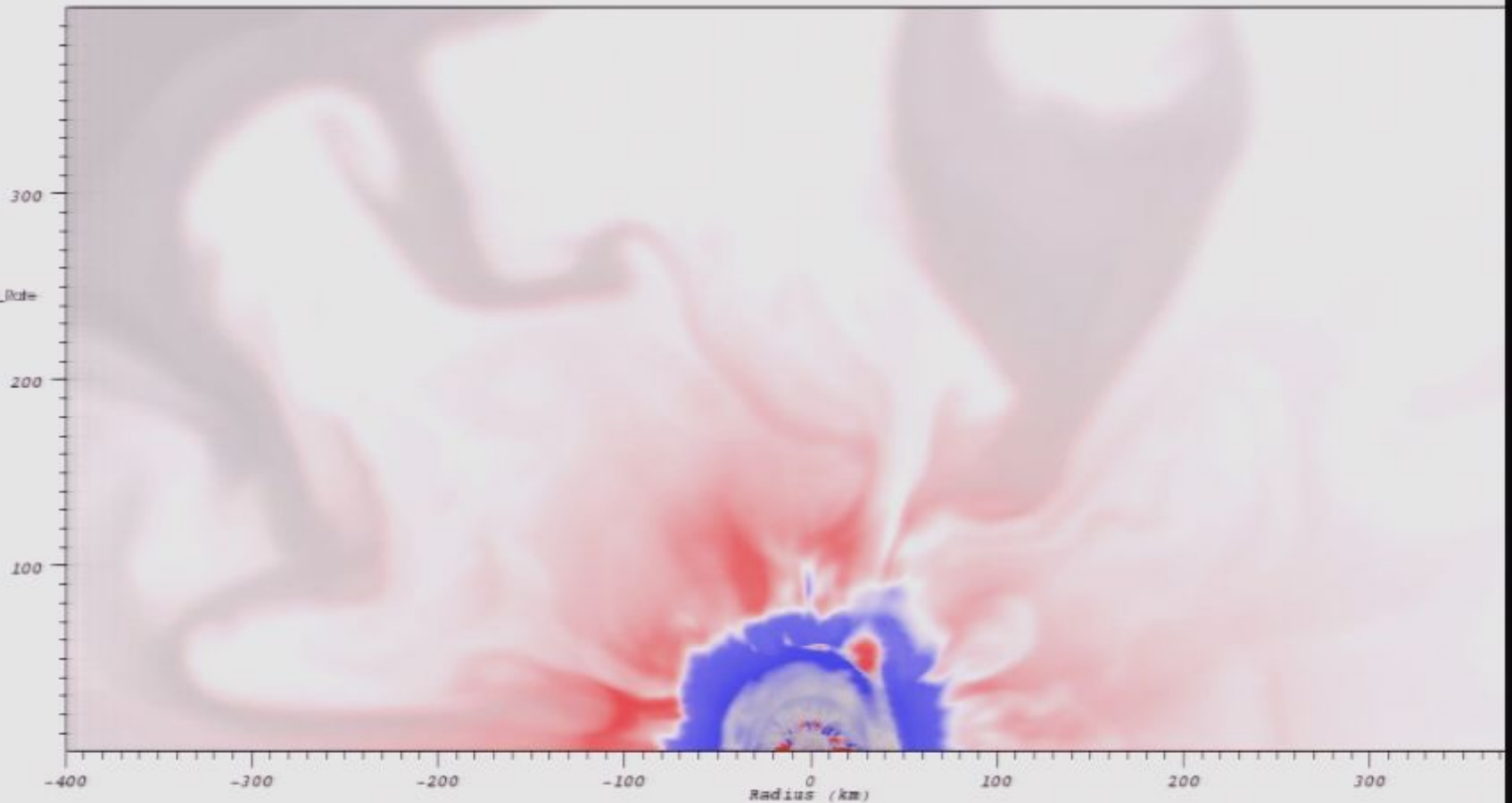
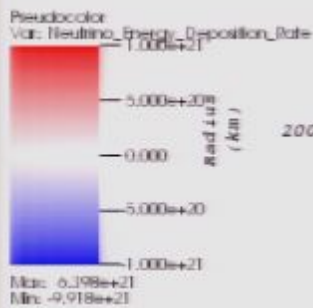
# 2D simulations

DB: 01030.silo  
Cycle: 1030 Time: 0.631411



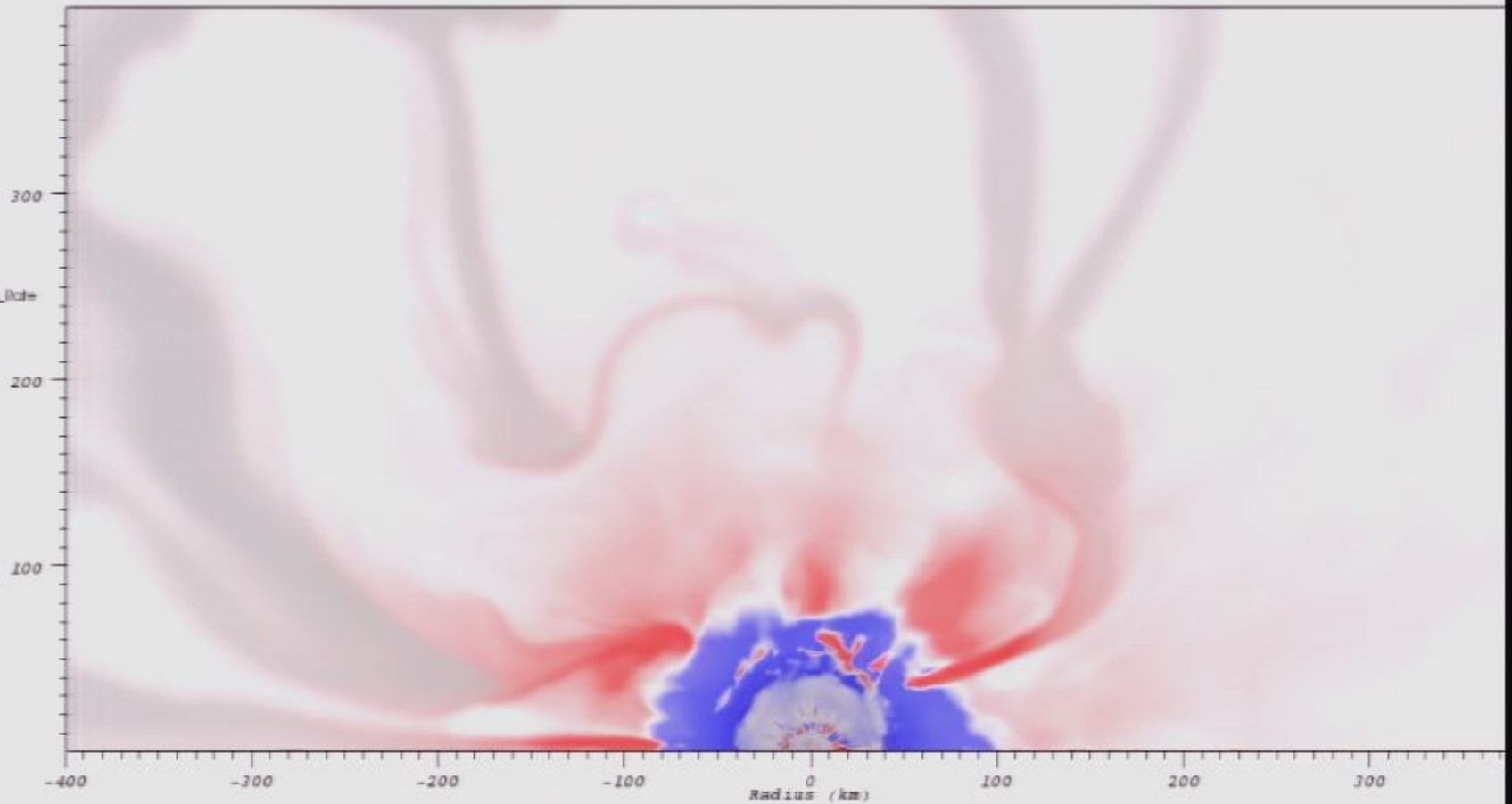
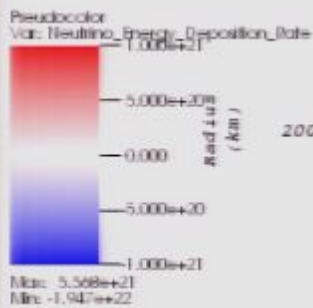
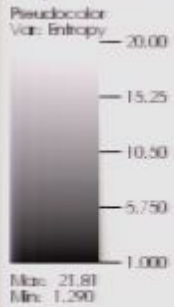
# 2D simulations

DB: 01067.silo  
Cycle: 1067 Time: 0.638811



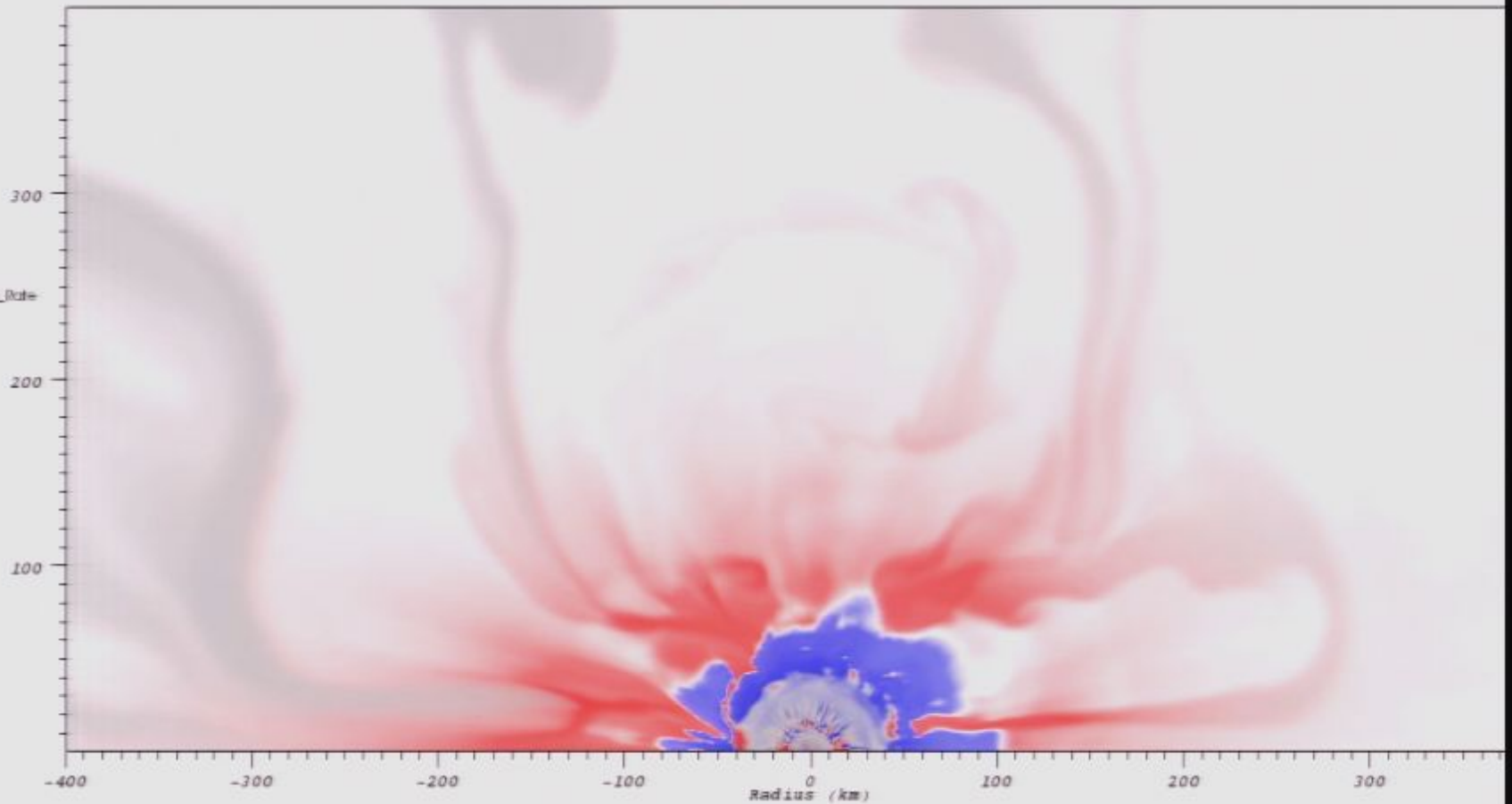
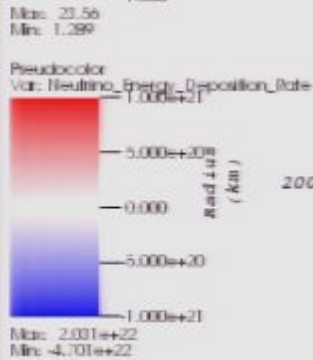
# 2D simulations

DB: 01109.silo  
Cycle: 1109 Time:0.647212



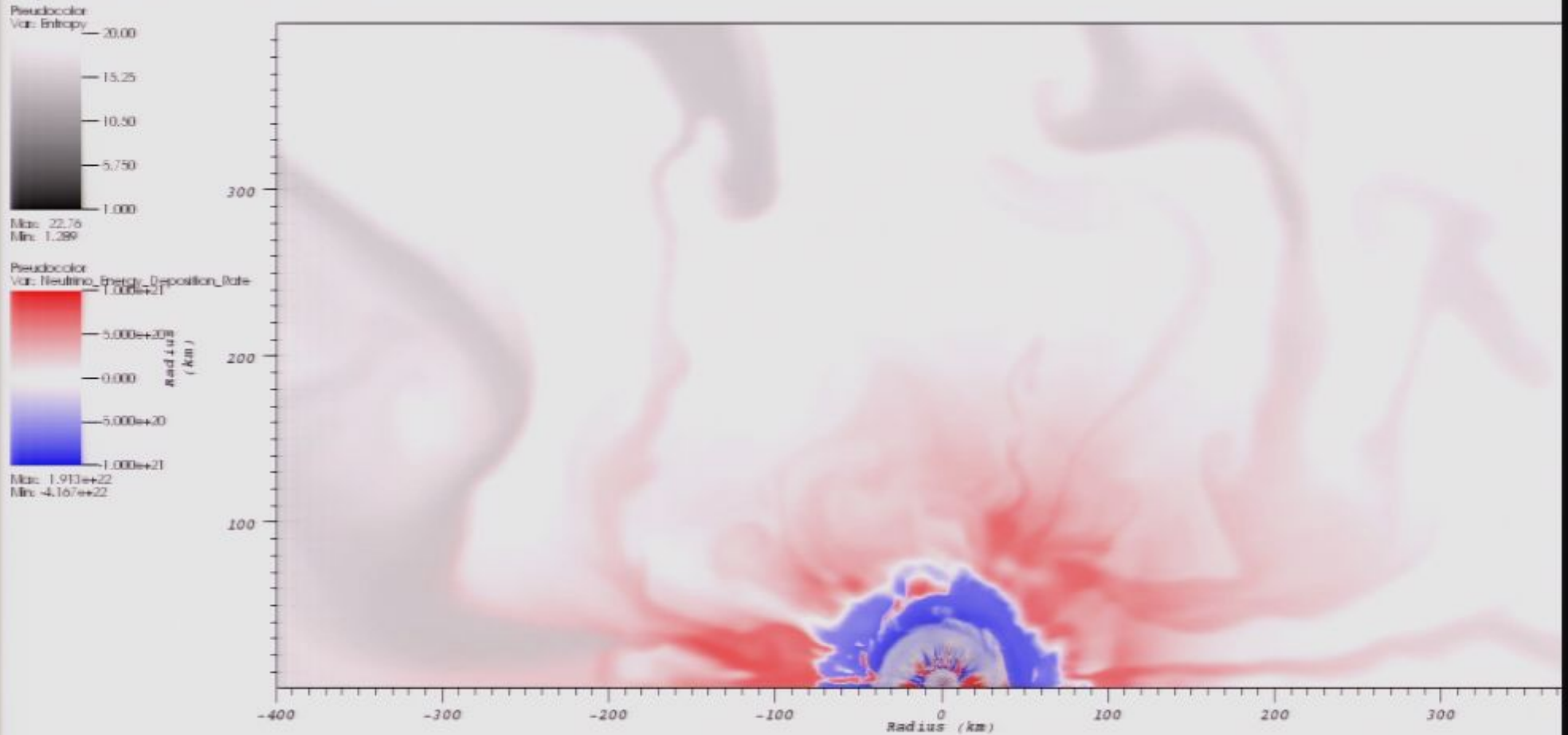
# 2D simulations

DB: 01149.silo  
Cycle: 1149 Time: 0.655211



# 2D simulations

DB: 01186.silo  
Cycle: 1186 Time:0.662611



# Important Neutrino Emissivities/Opacities

$$\star e^{-(+)} + p(n), A \leftrightarrow \nu_e (\bar{\nu}_e) + n(p), A'$$

Bruenn, *Ap.J. Suppl.* (1985)

- Nucleons treated as independent in nuclei
- No energy exchange in nucleonic scattering

Langanke et al. *PRL*, **90**, 241102 (2003)

- **Included correlations between nucleons in nuclei.**

$$e^+ + e^- \leftrightarrow \nu_{e,\mu,\tau} + \bar{\nu}_{e,\mu,\tau}$$

$$\star \nu + n, p, A \rightarrow \nu + n, p, A$$

Reddy, Prakash, and Lattimer, *PRD*, **58**, 013009 (1998)

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- (Small) **Energy is exchanged due to nucleon recoil**
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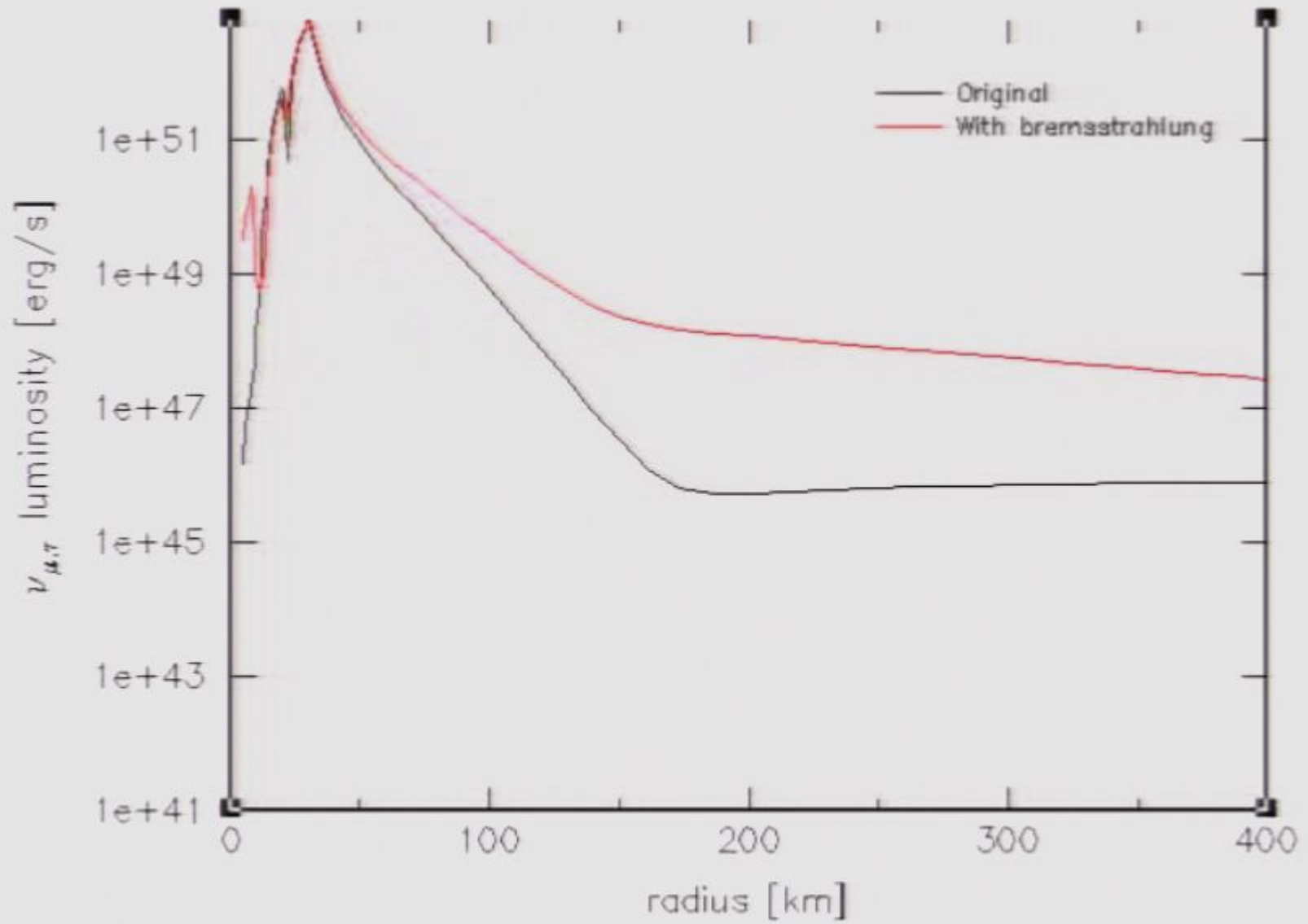
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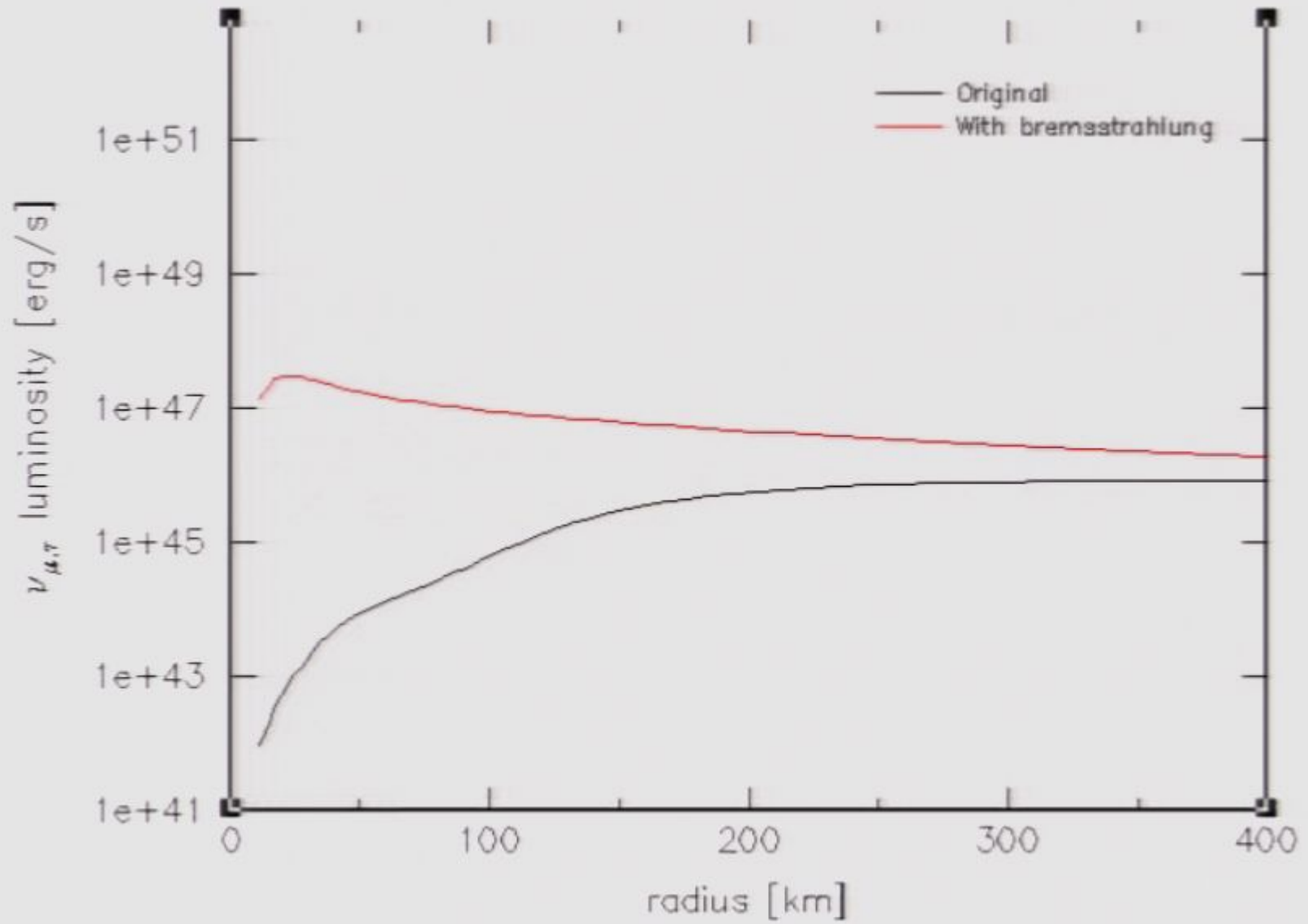
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# NN bremsstrahlung (AGILE-Boltztran)



onset of bounce -----> ~50 ms post-bounce

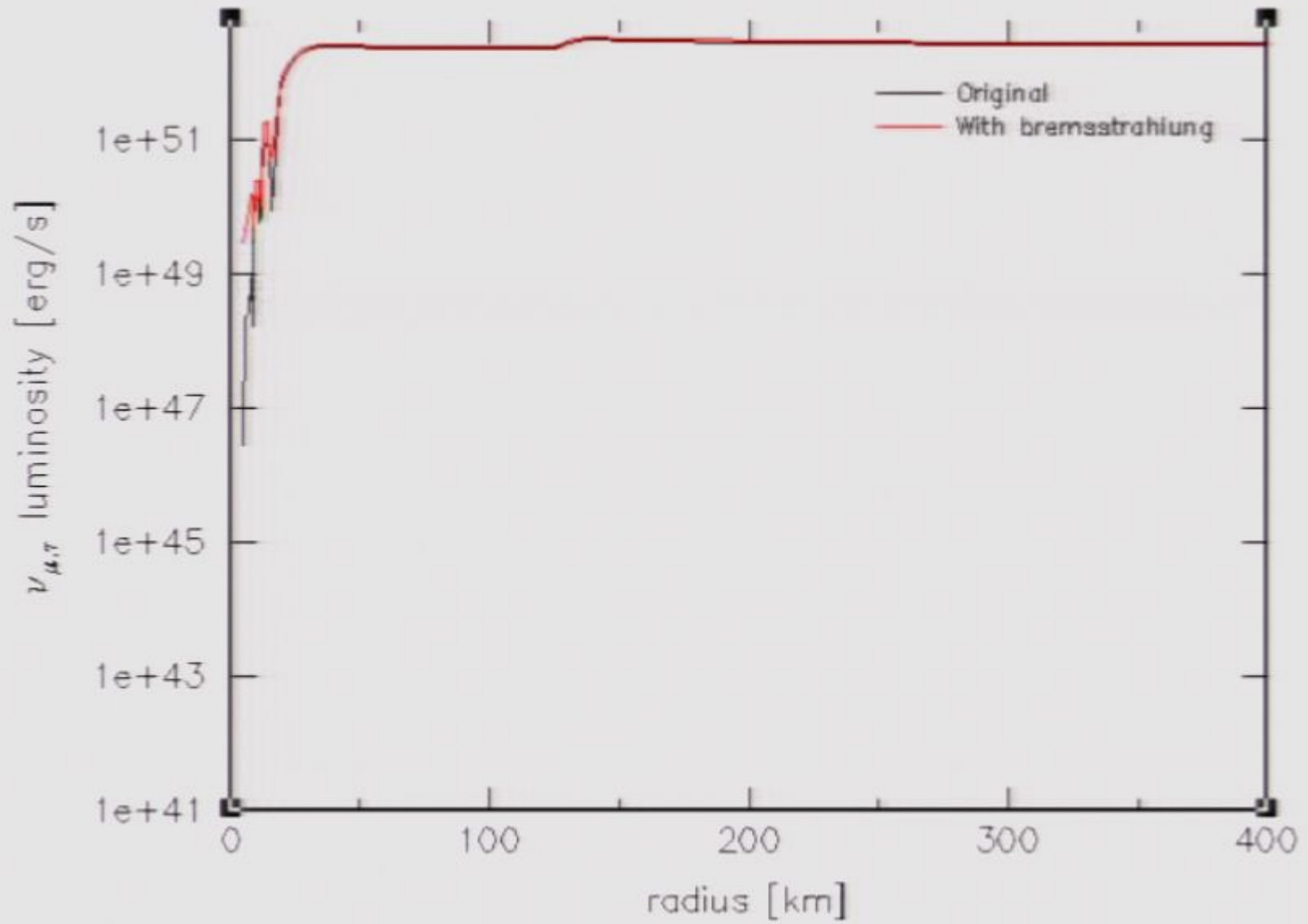
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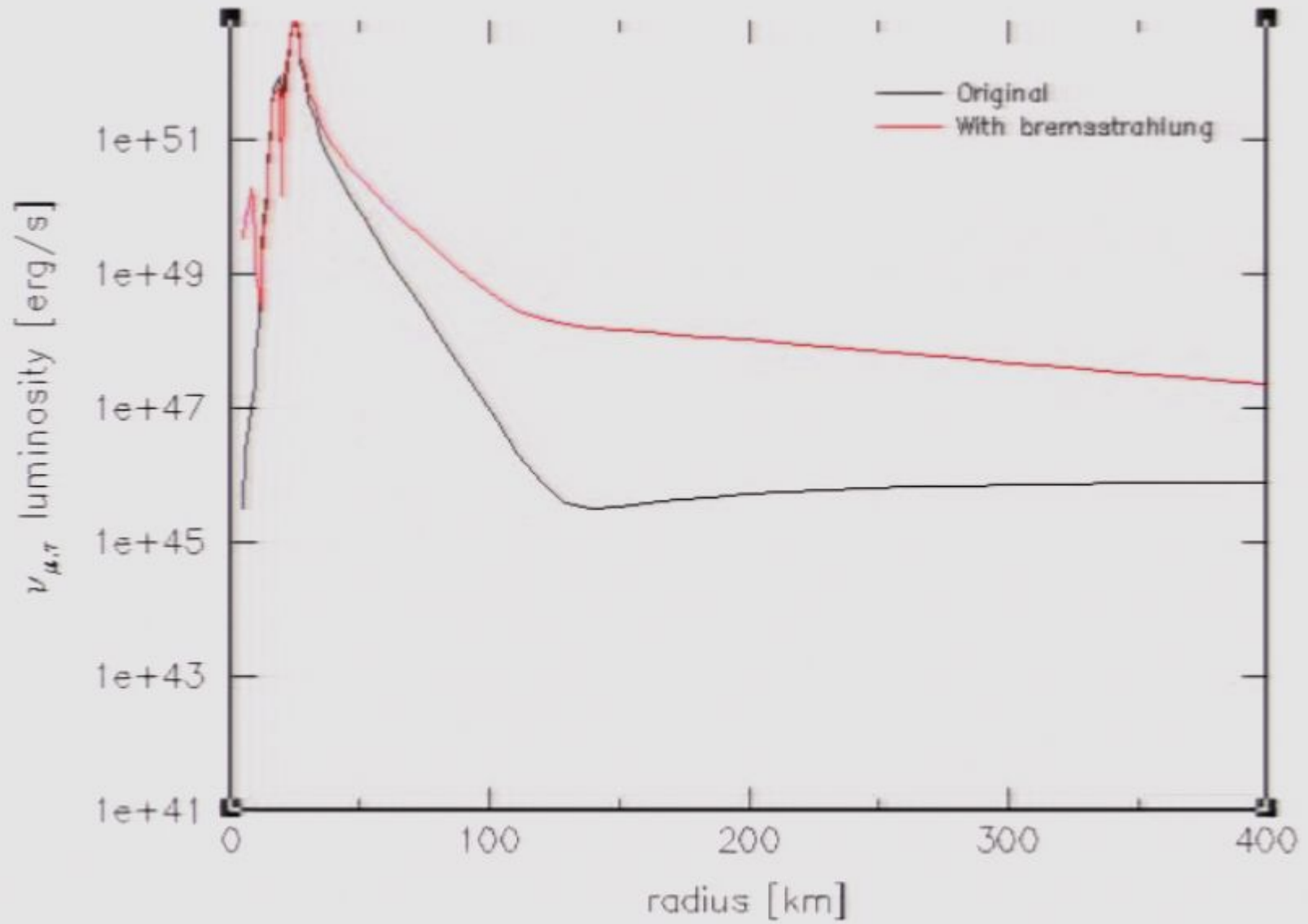


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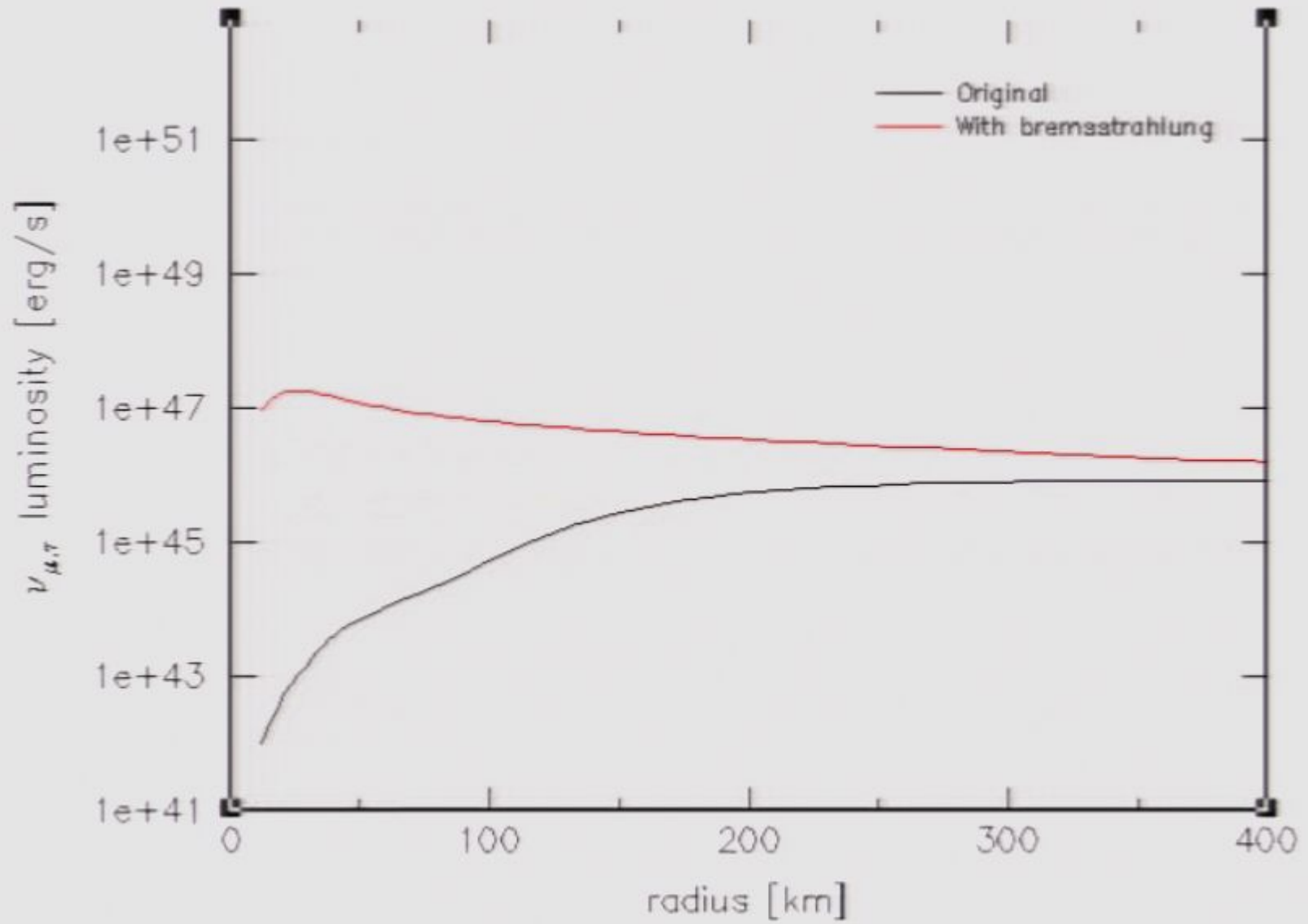
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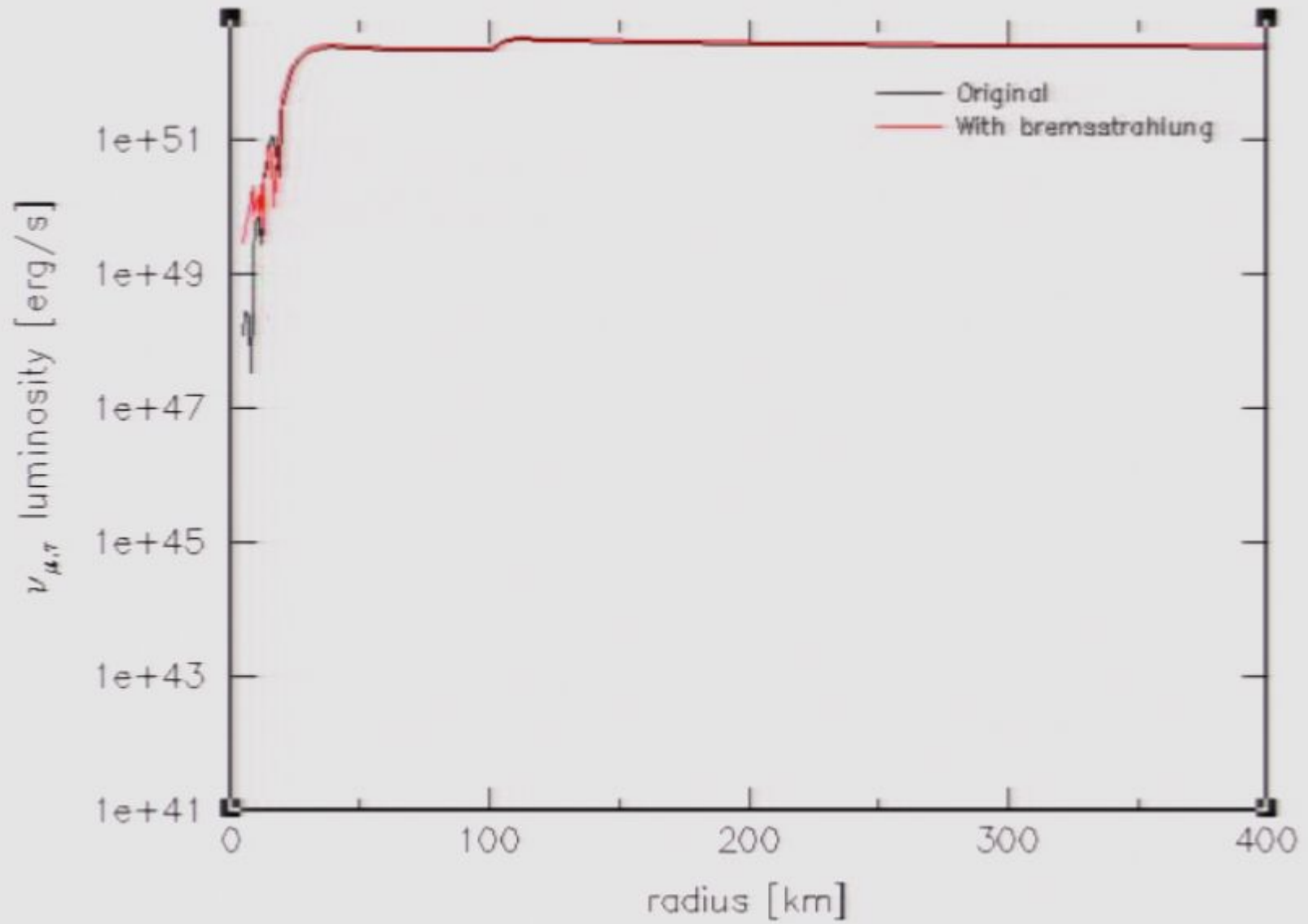
onset of bounce ----->  $\sim 50$  ms post-bounce

# NN bremsstrahlung (AGILE-Boltztran)

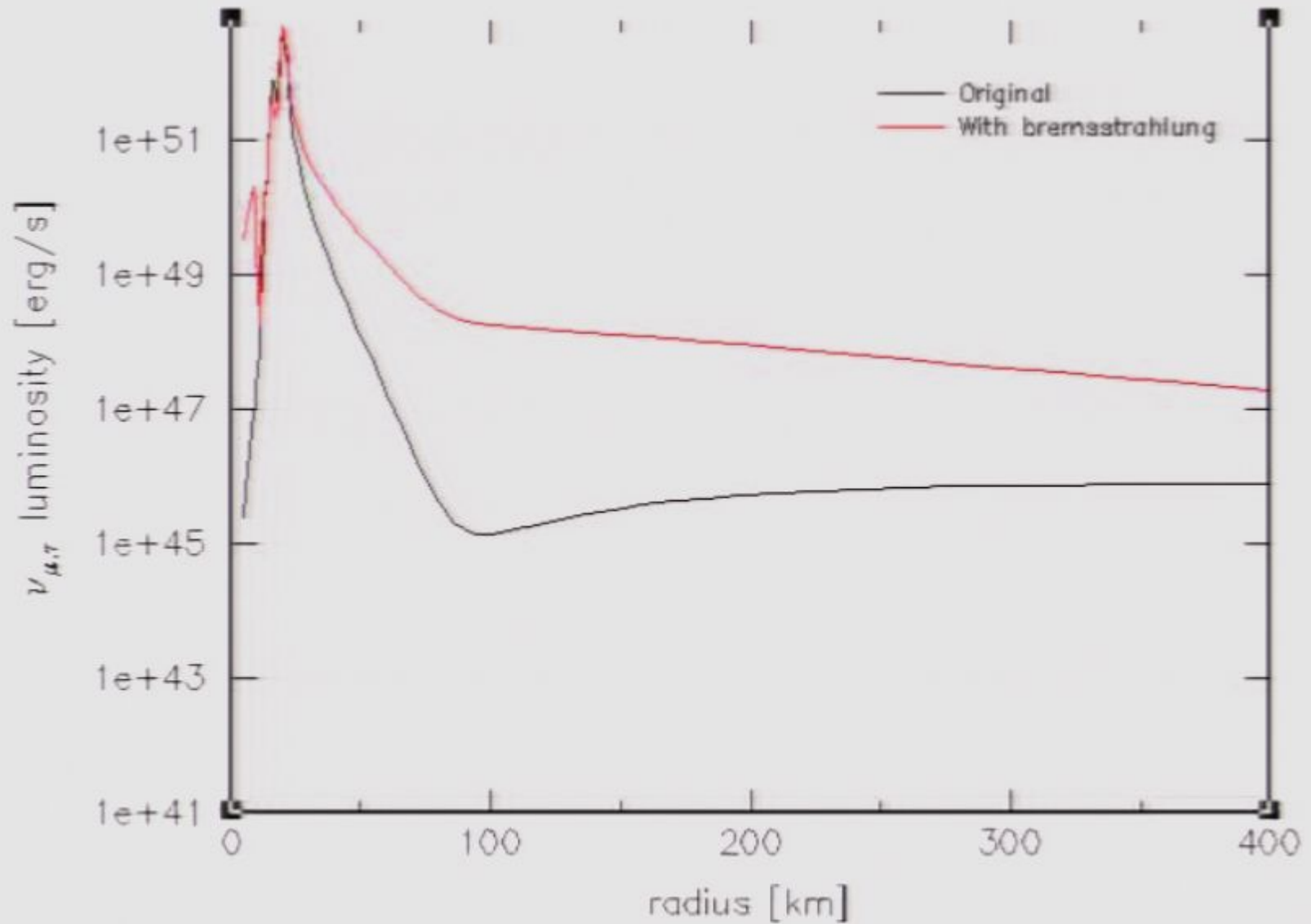


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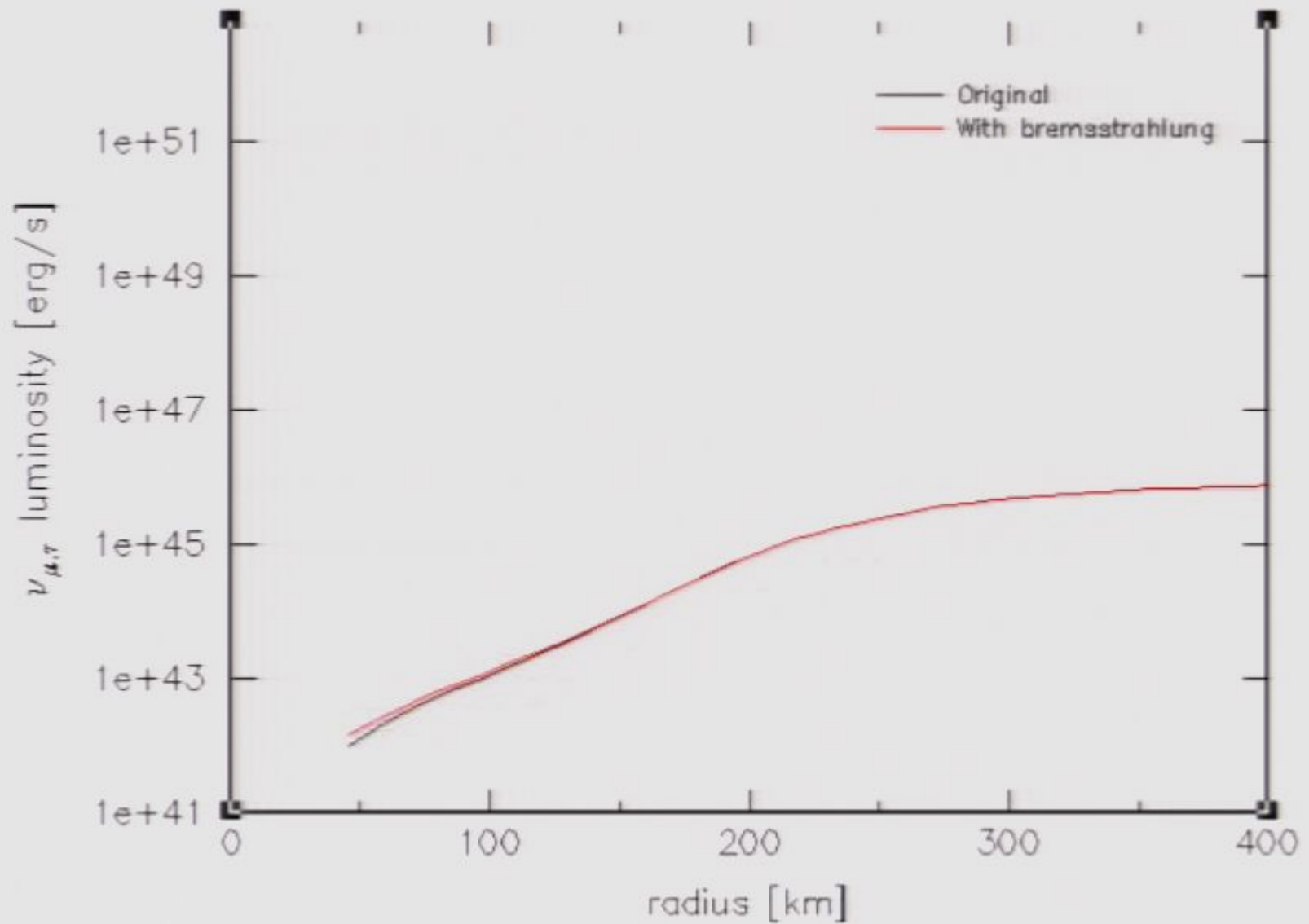
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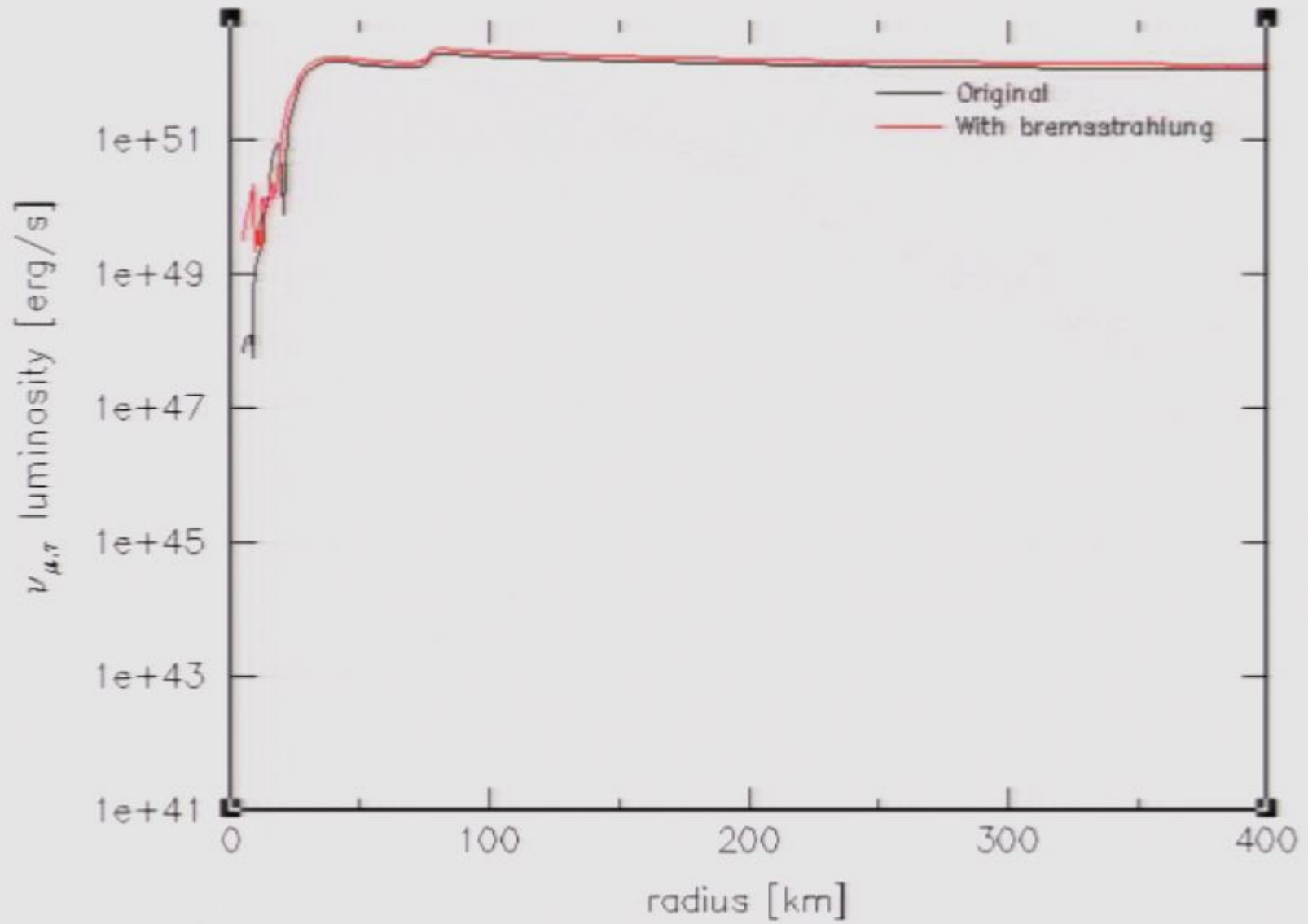


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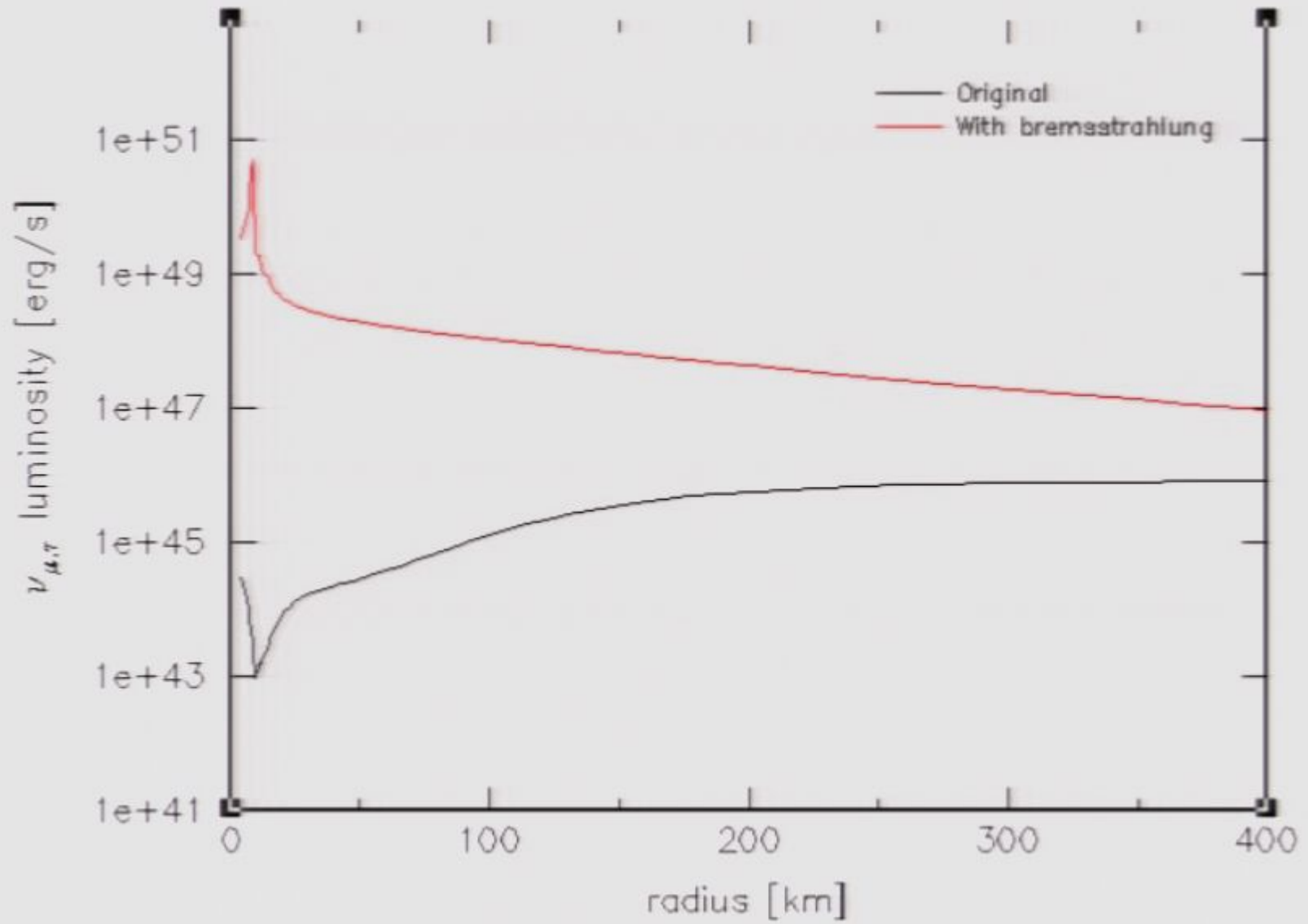


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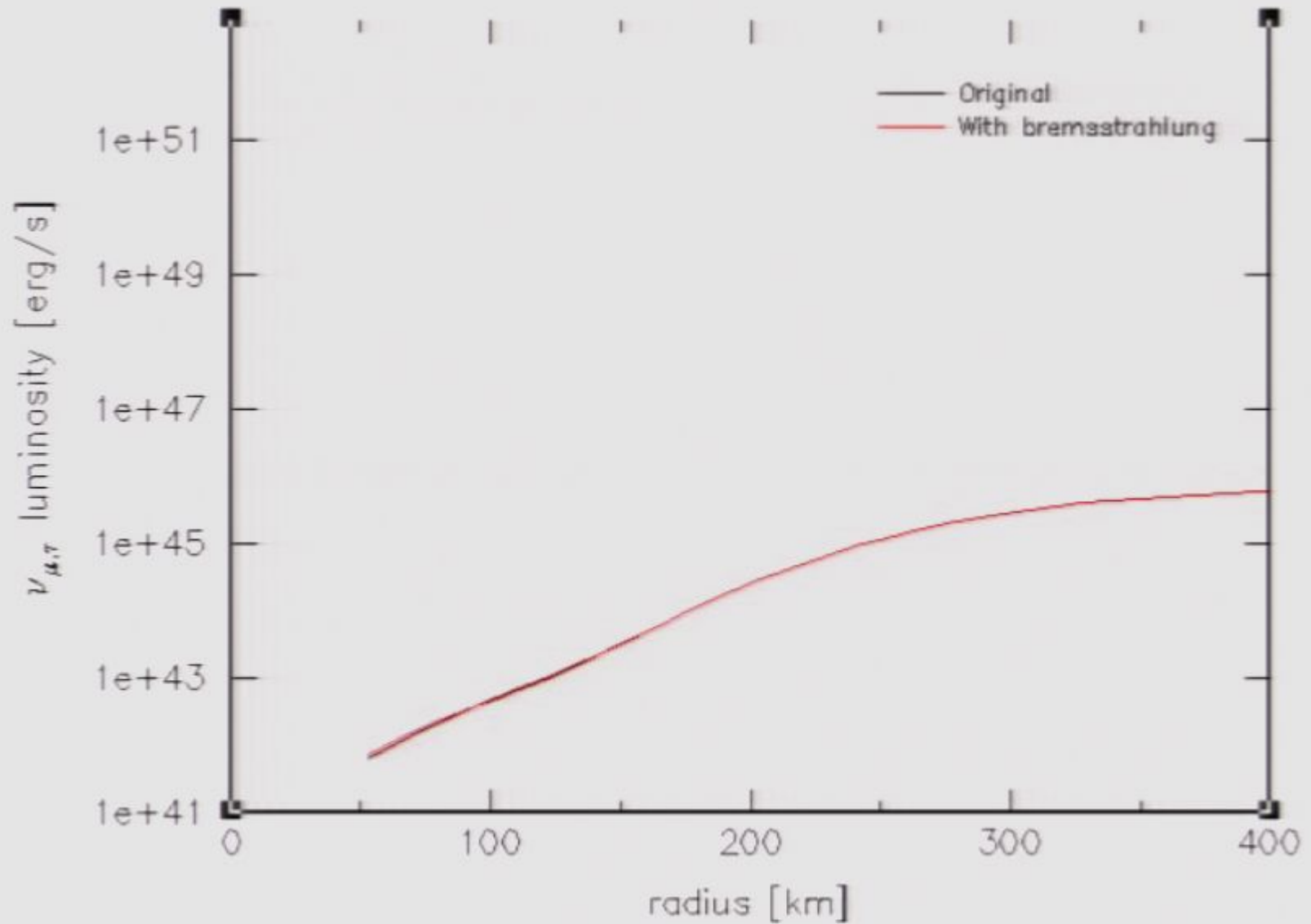
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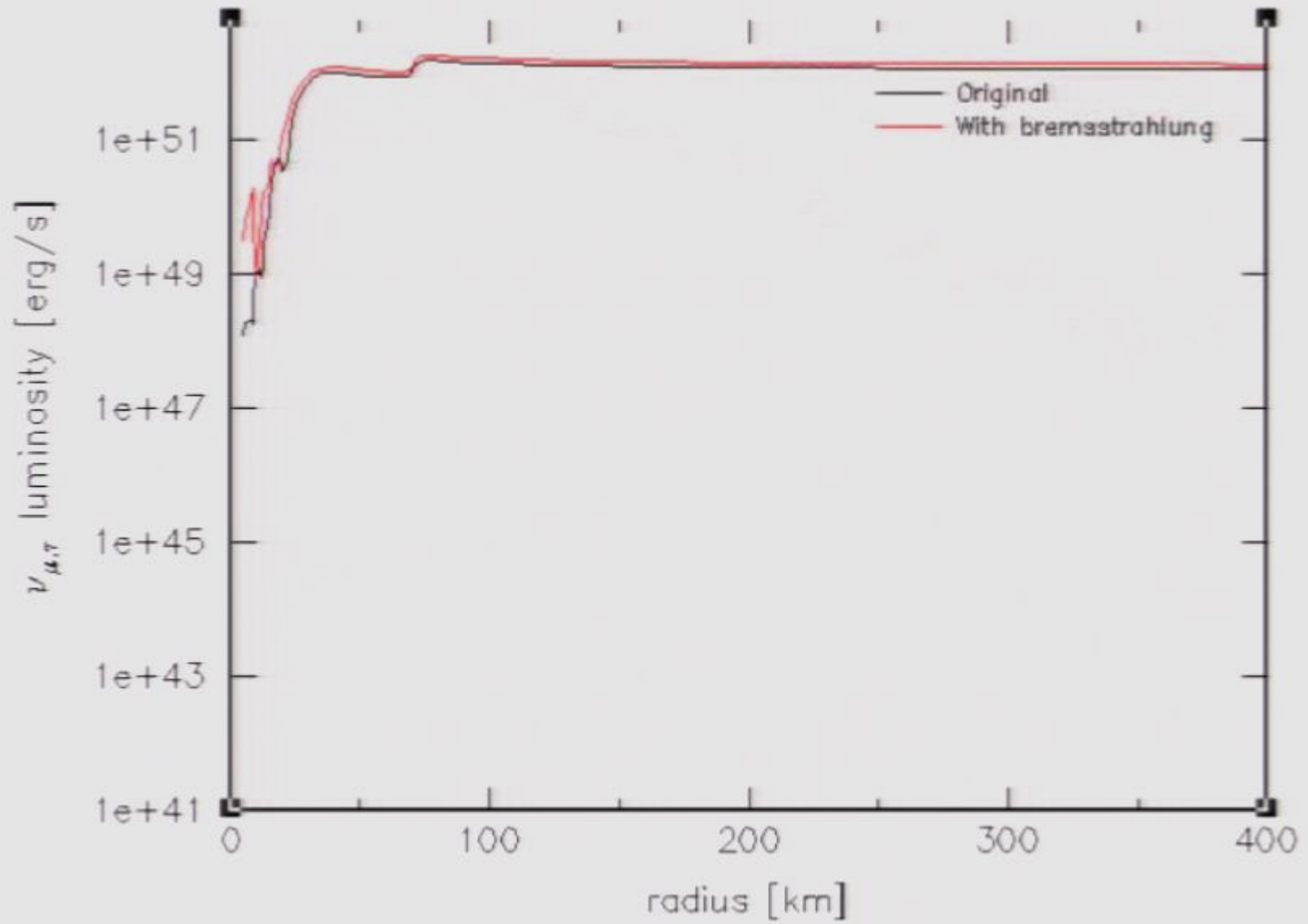
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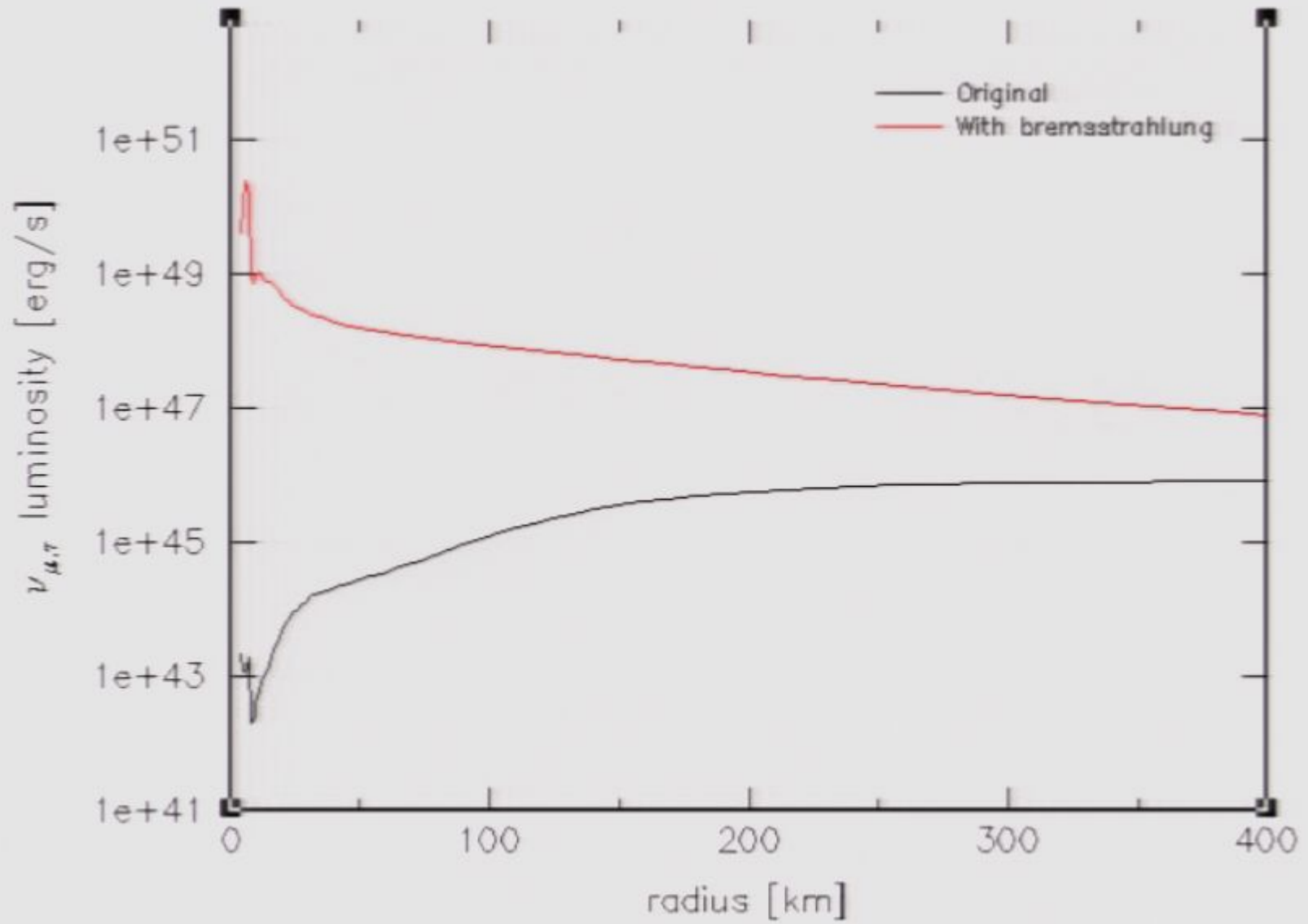


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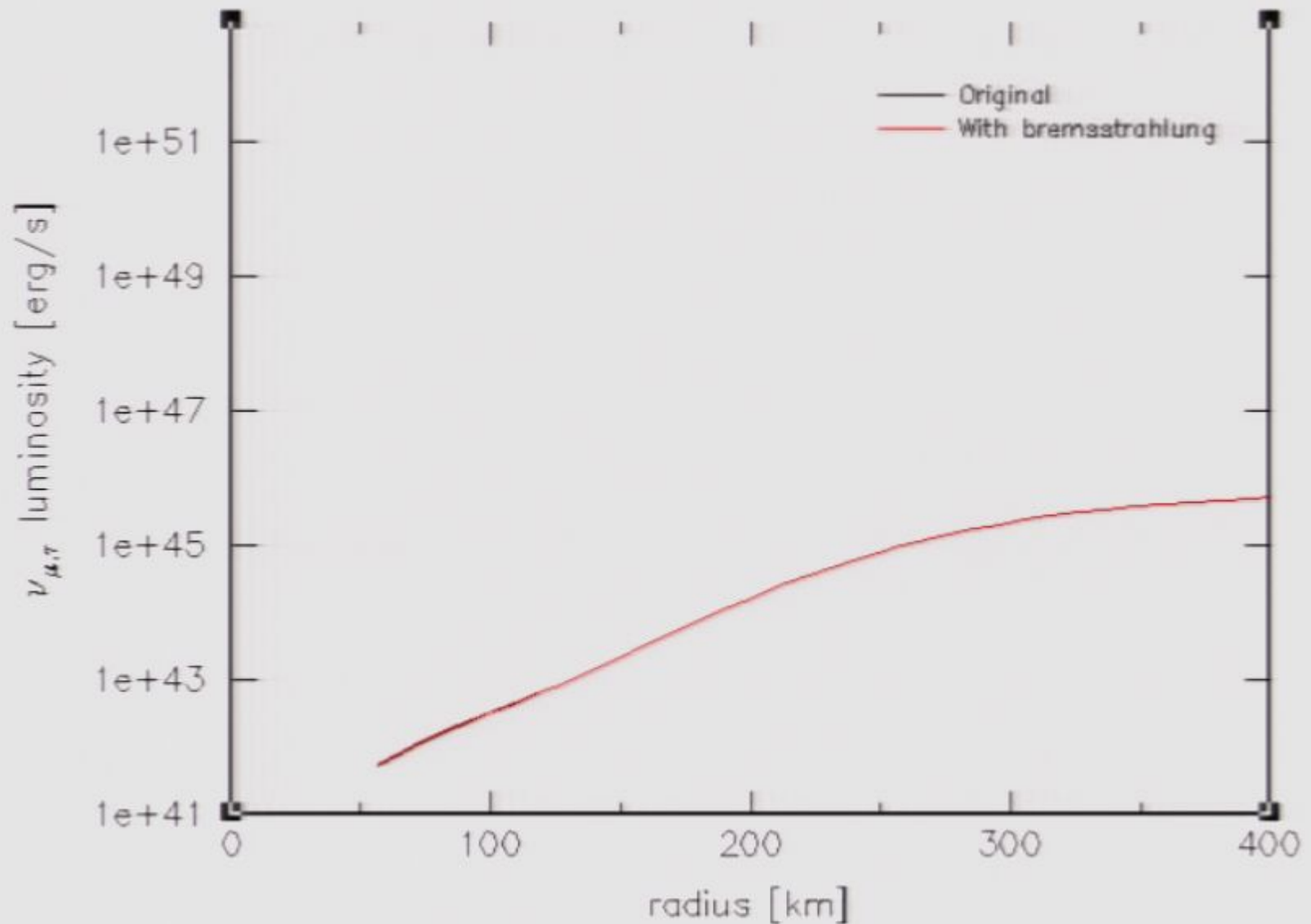
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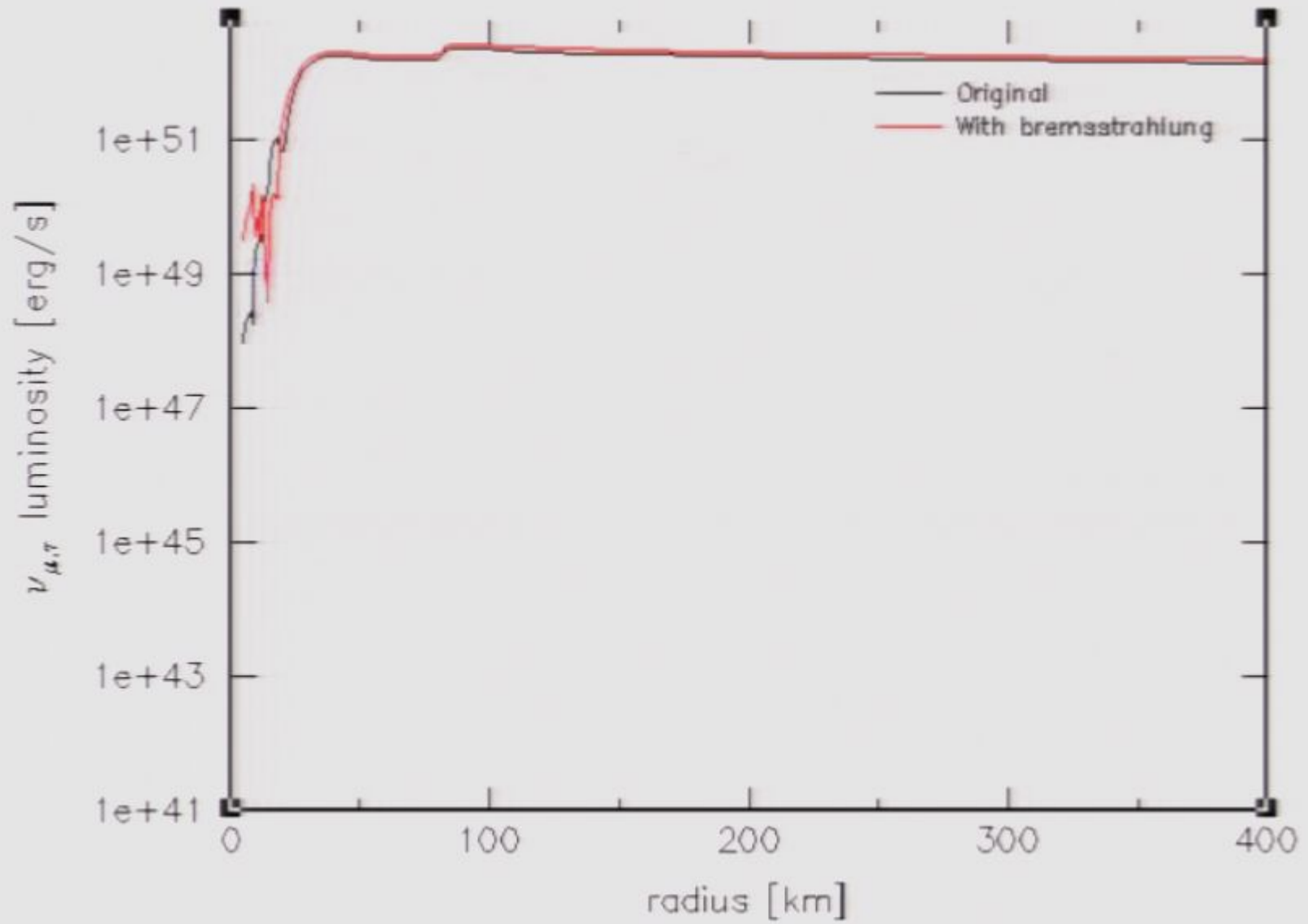


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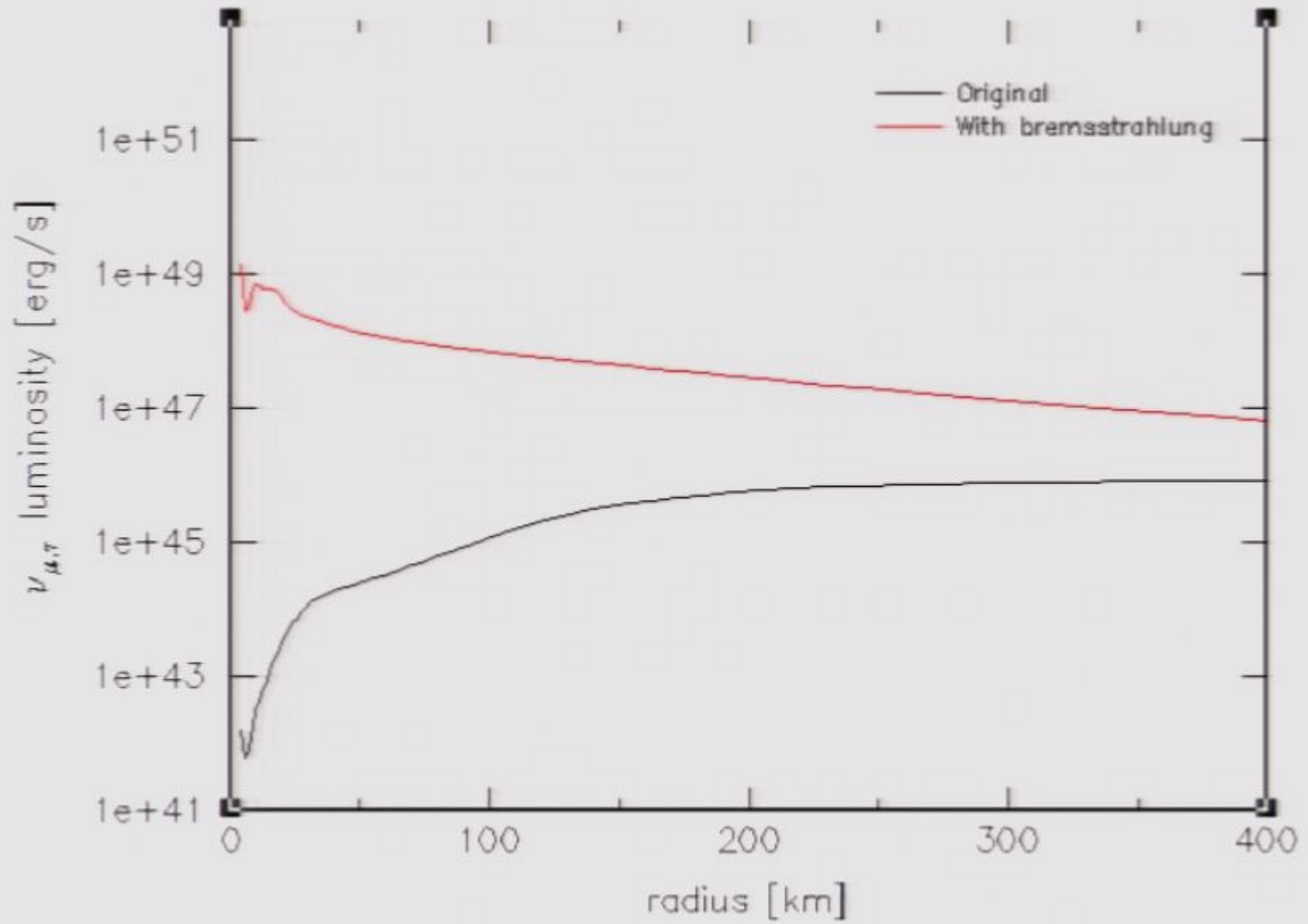


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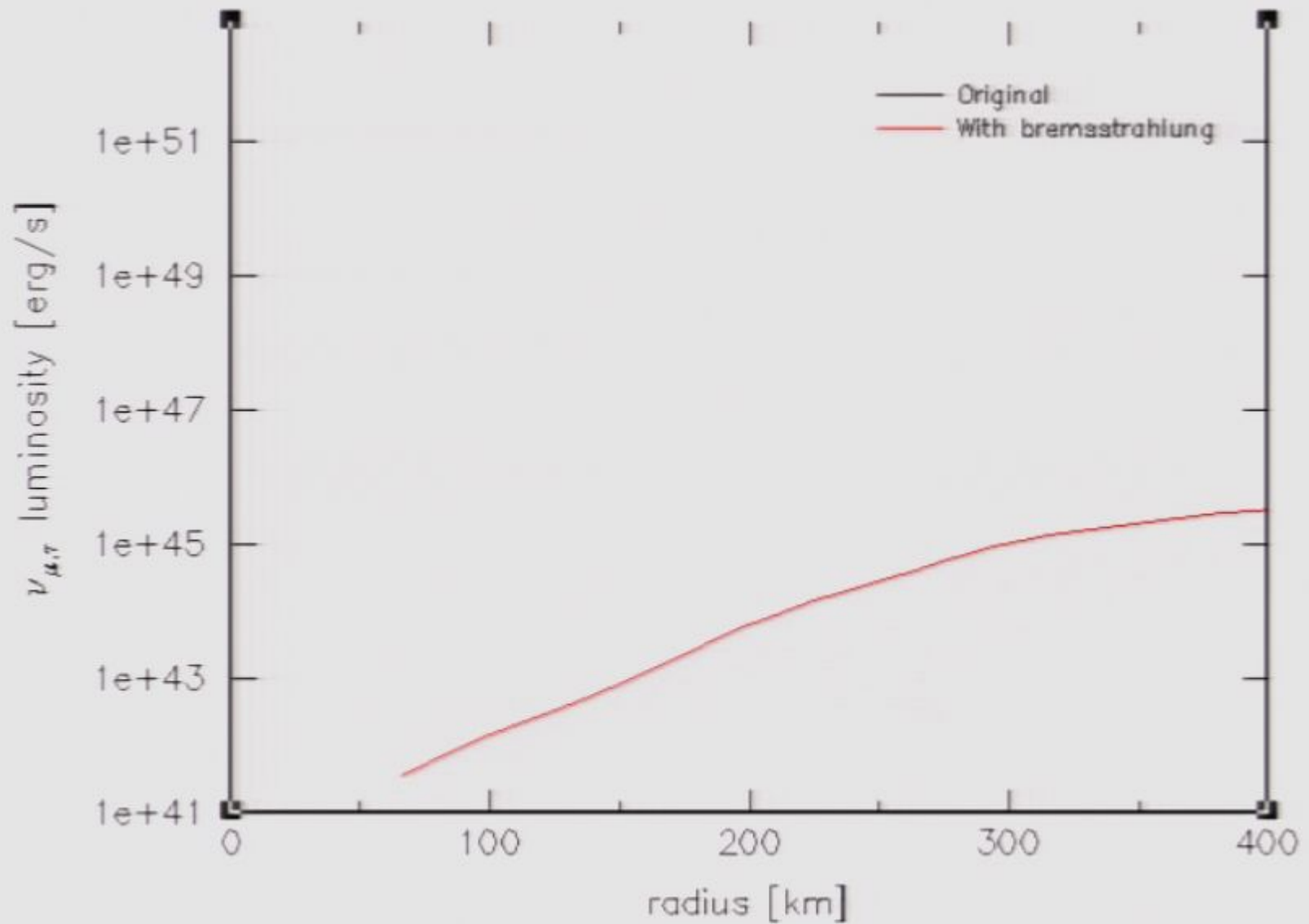
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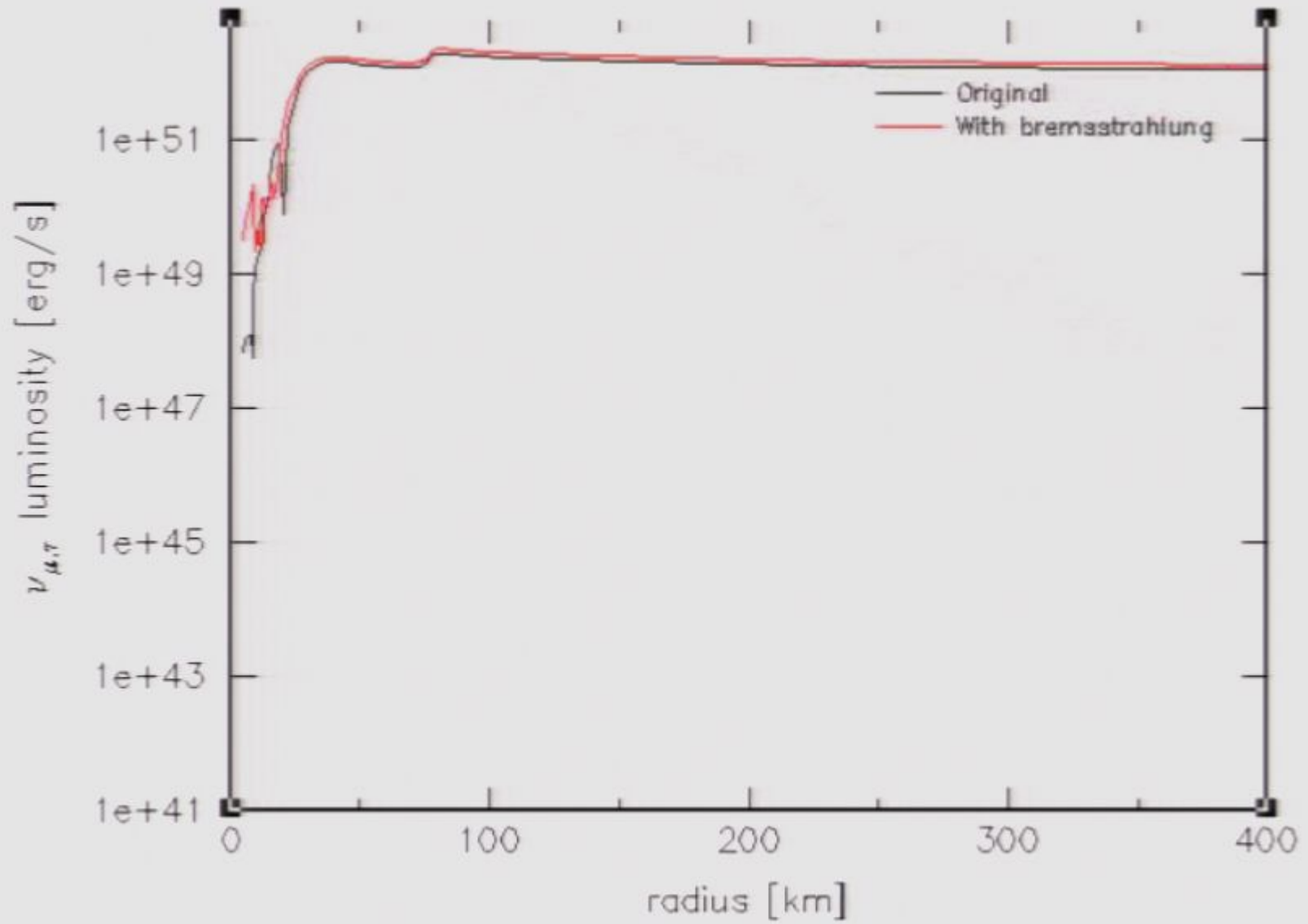


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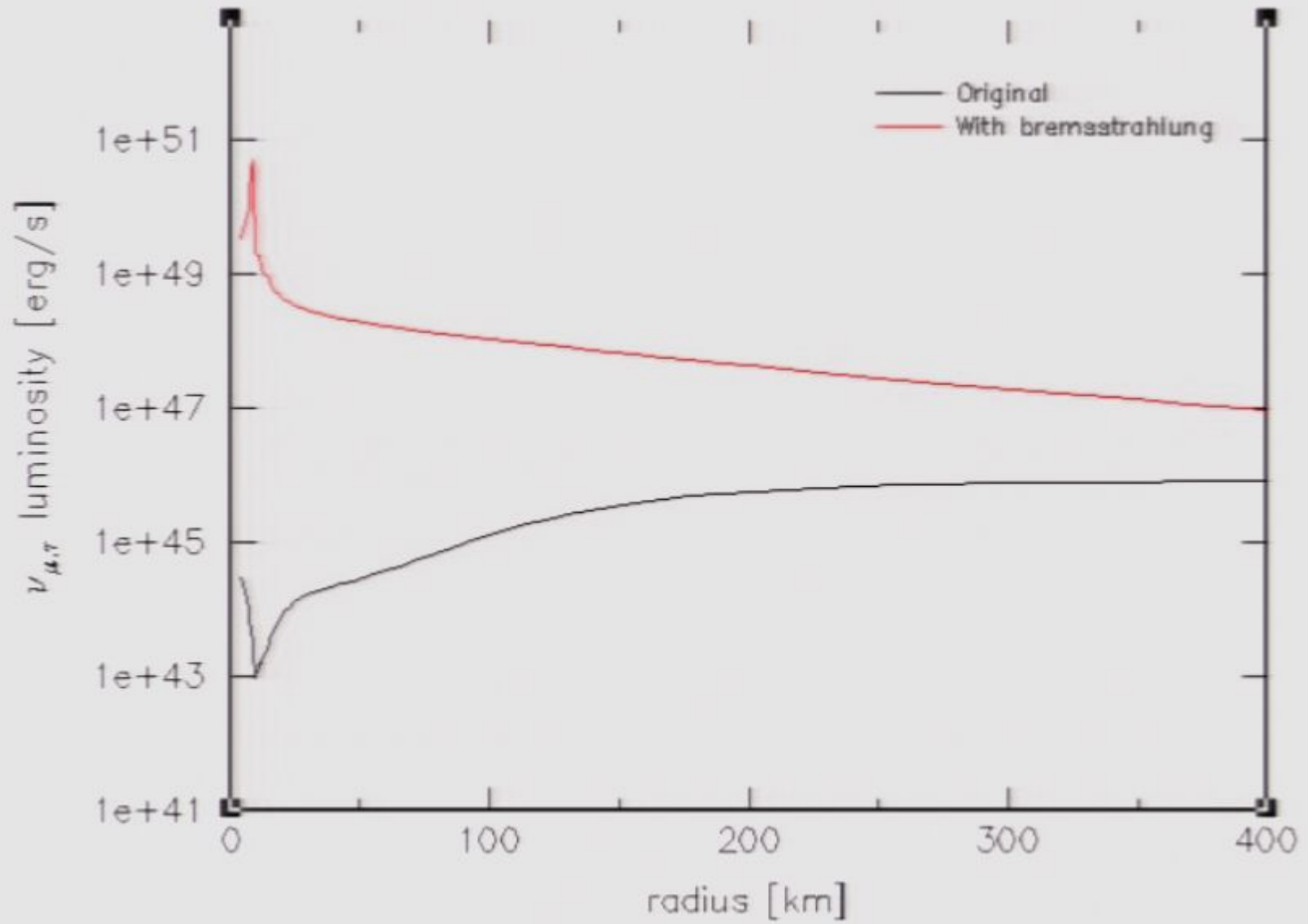


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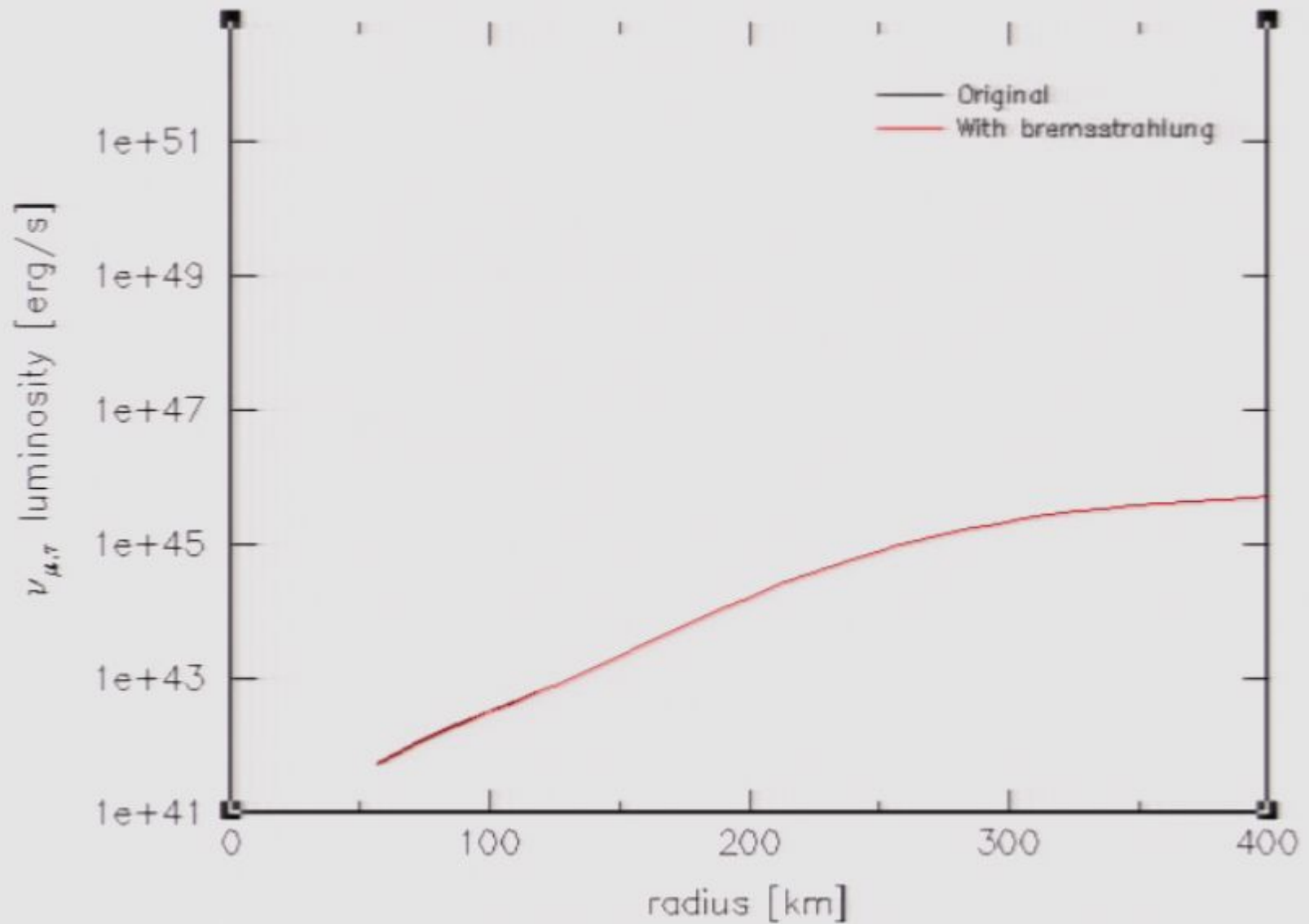


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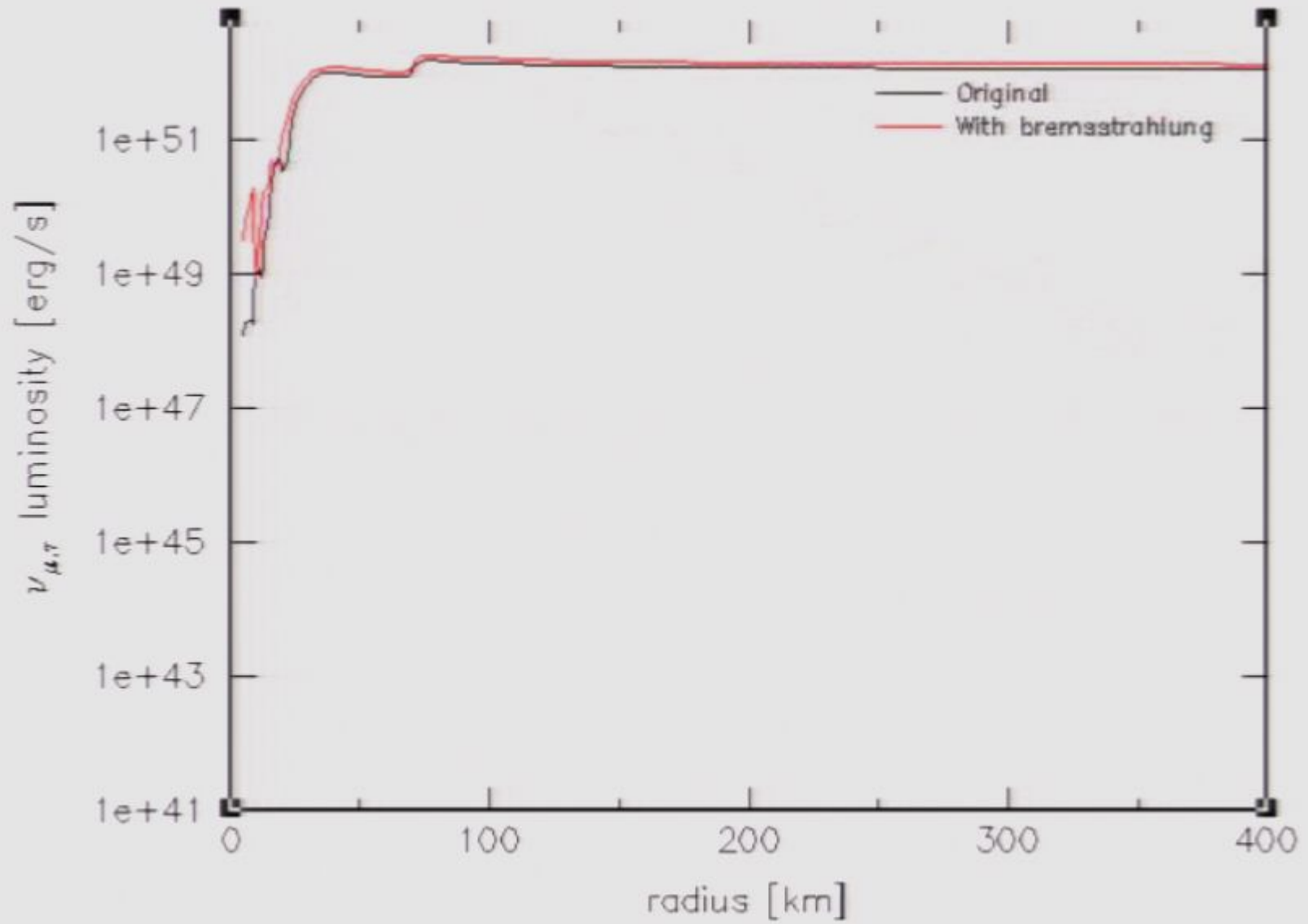


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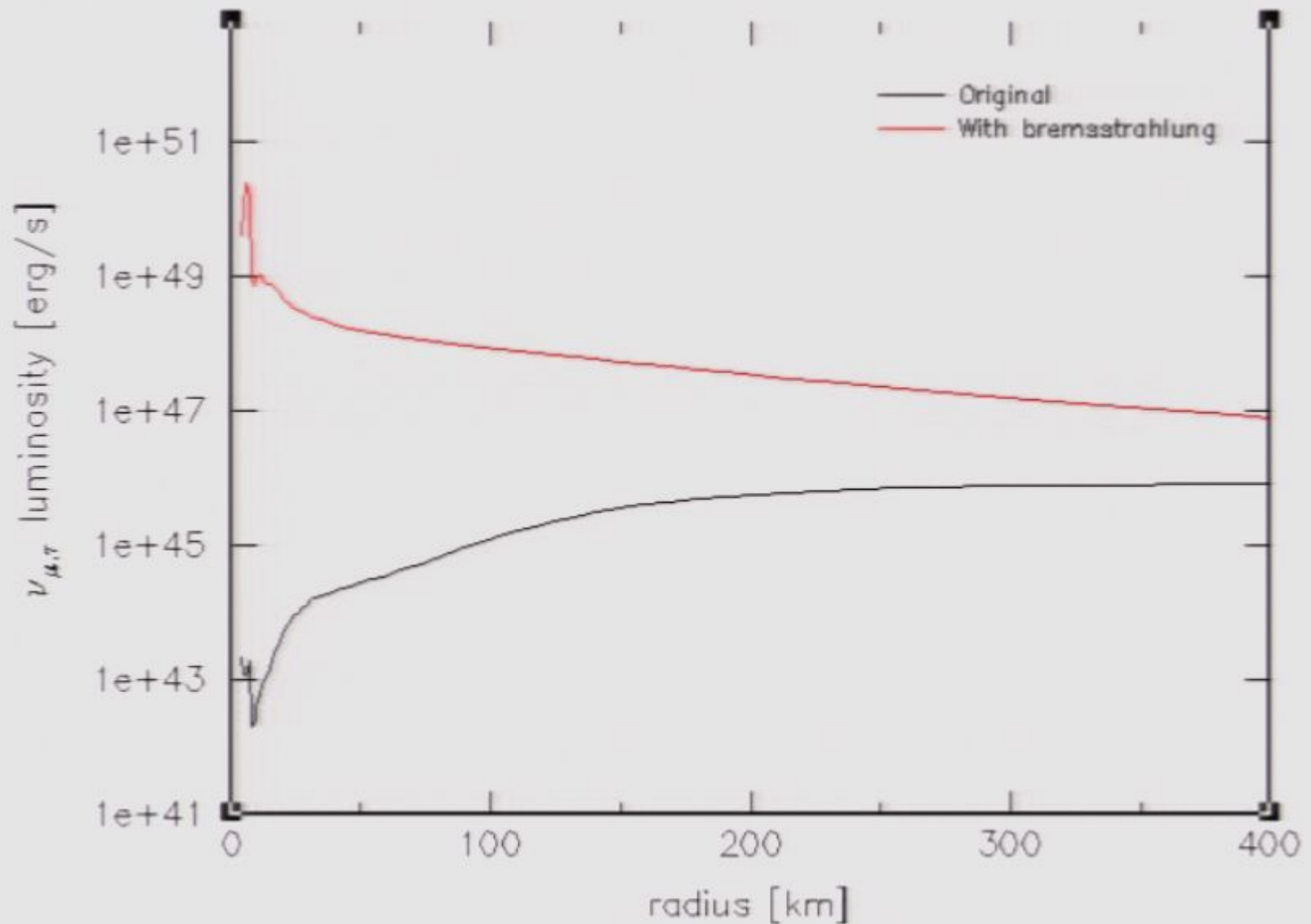


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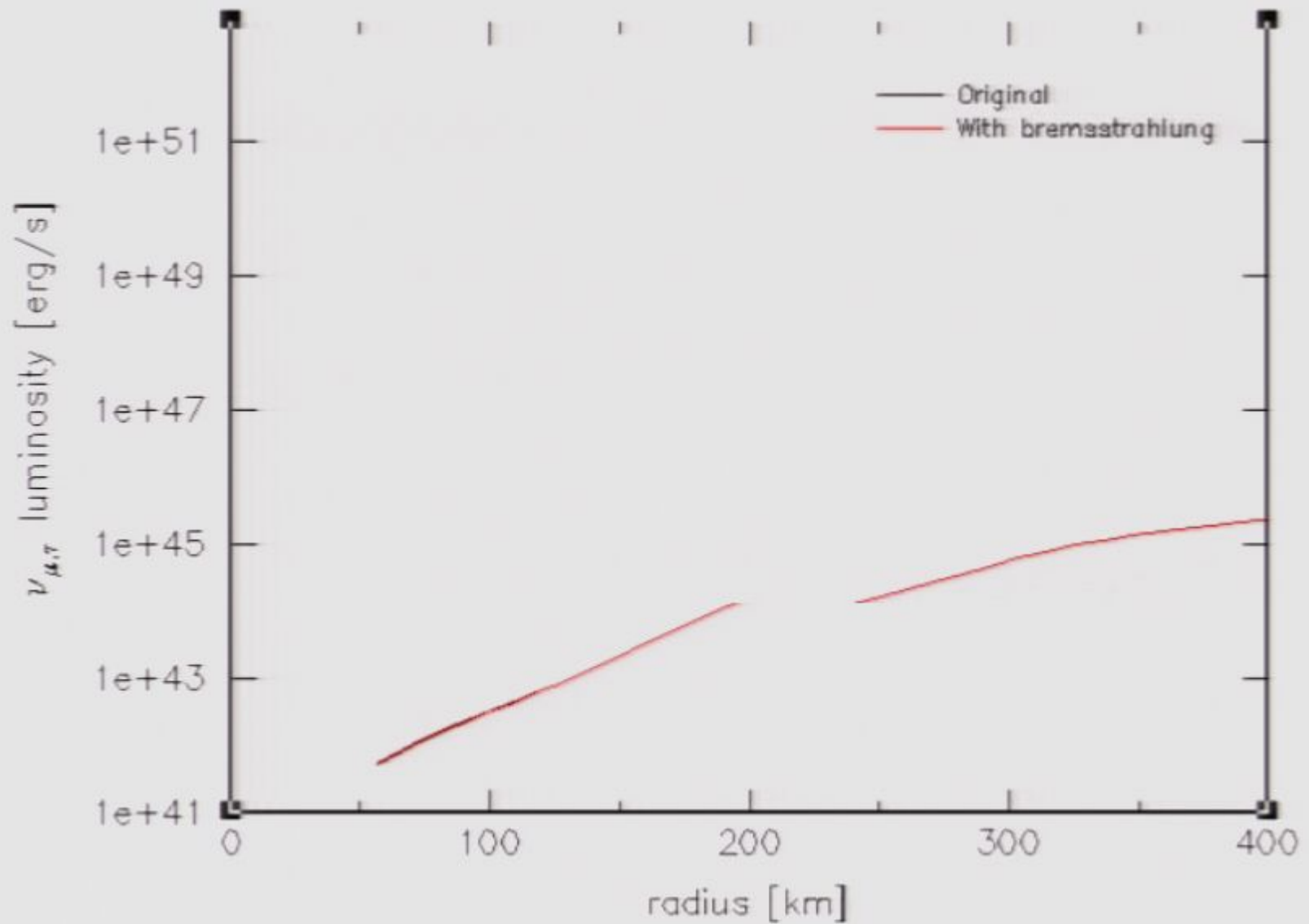
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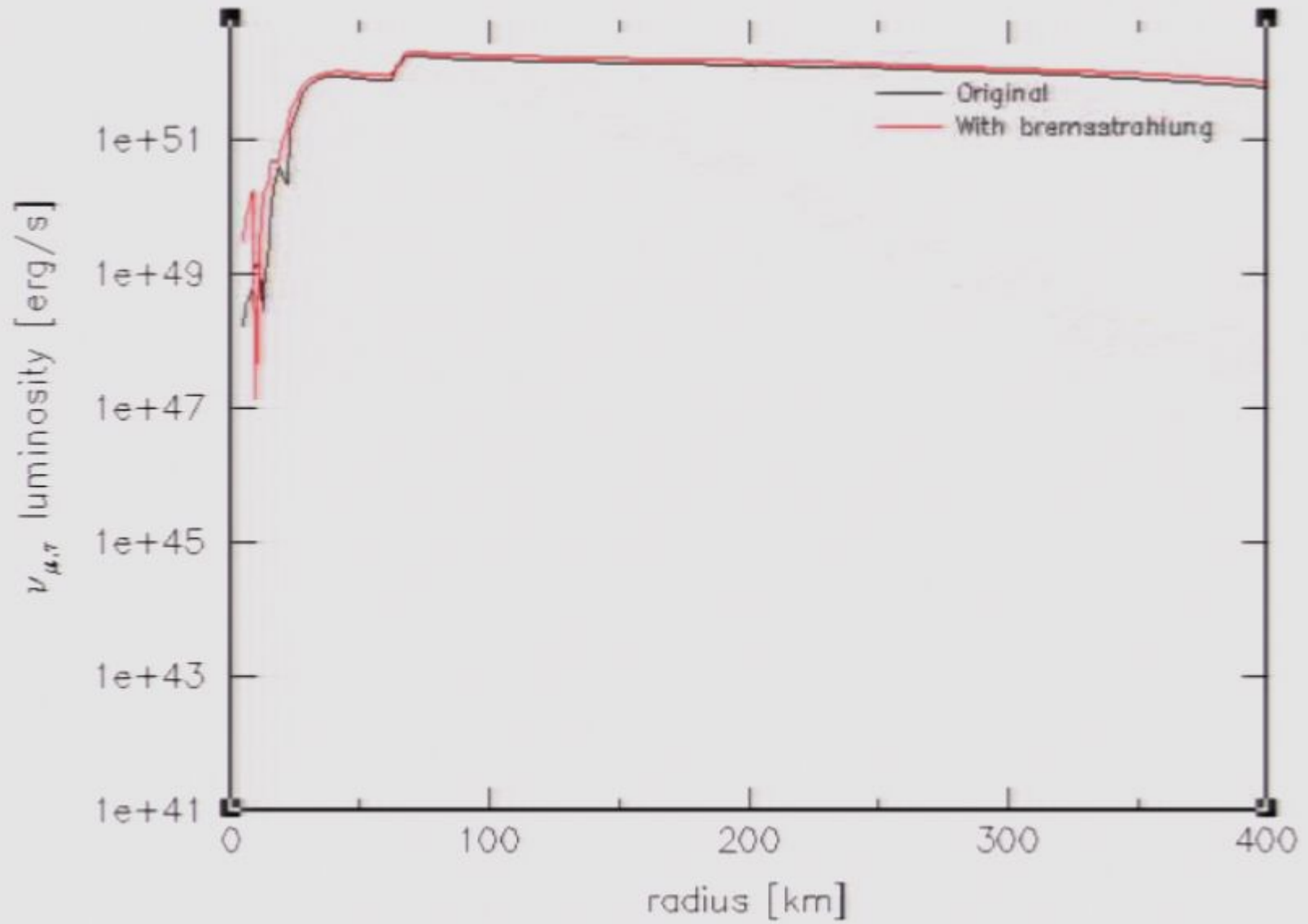


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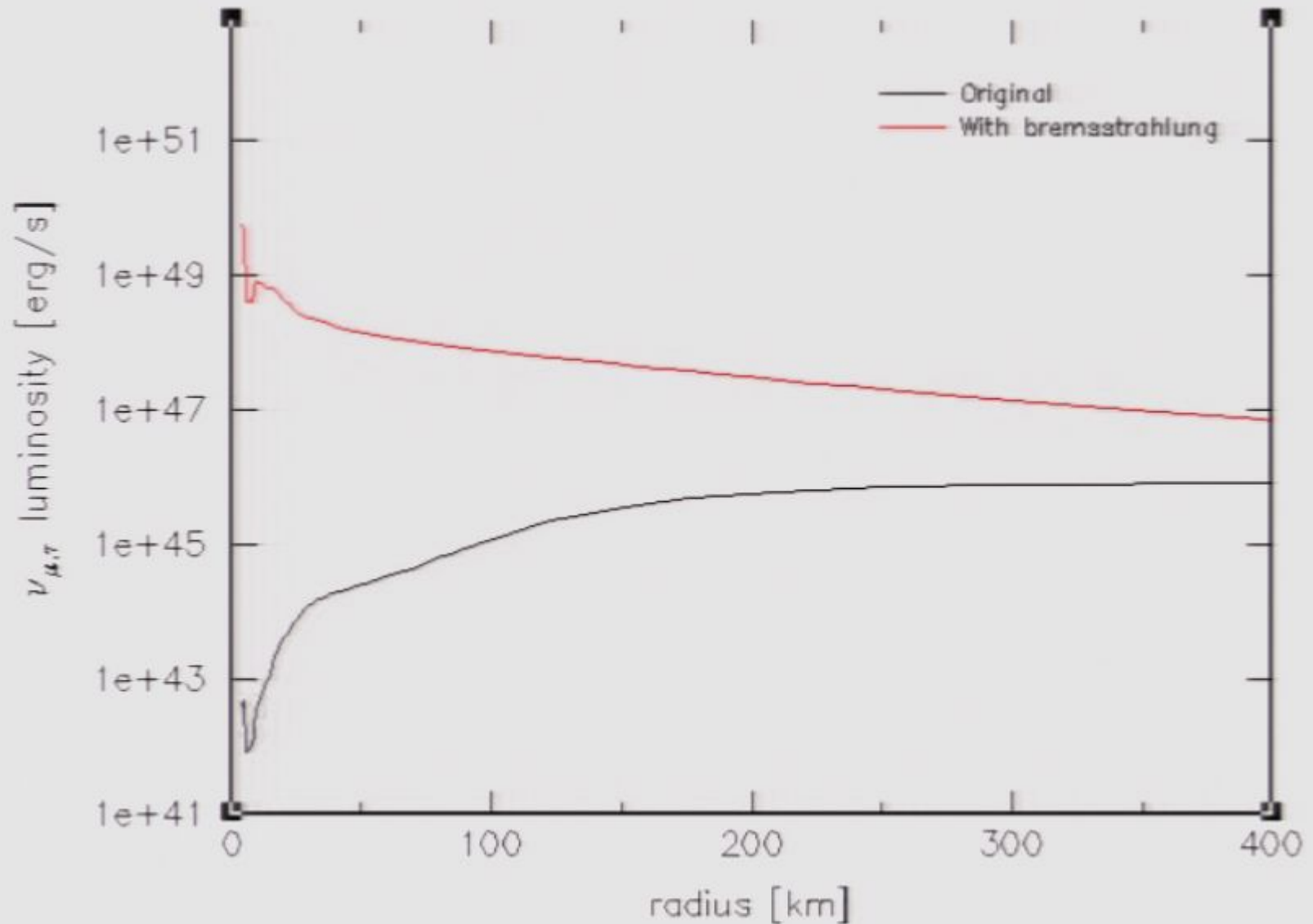


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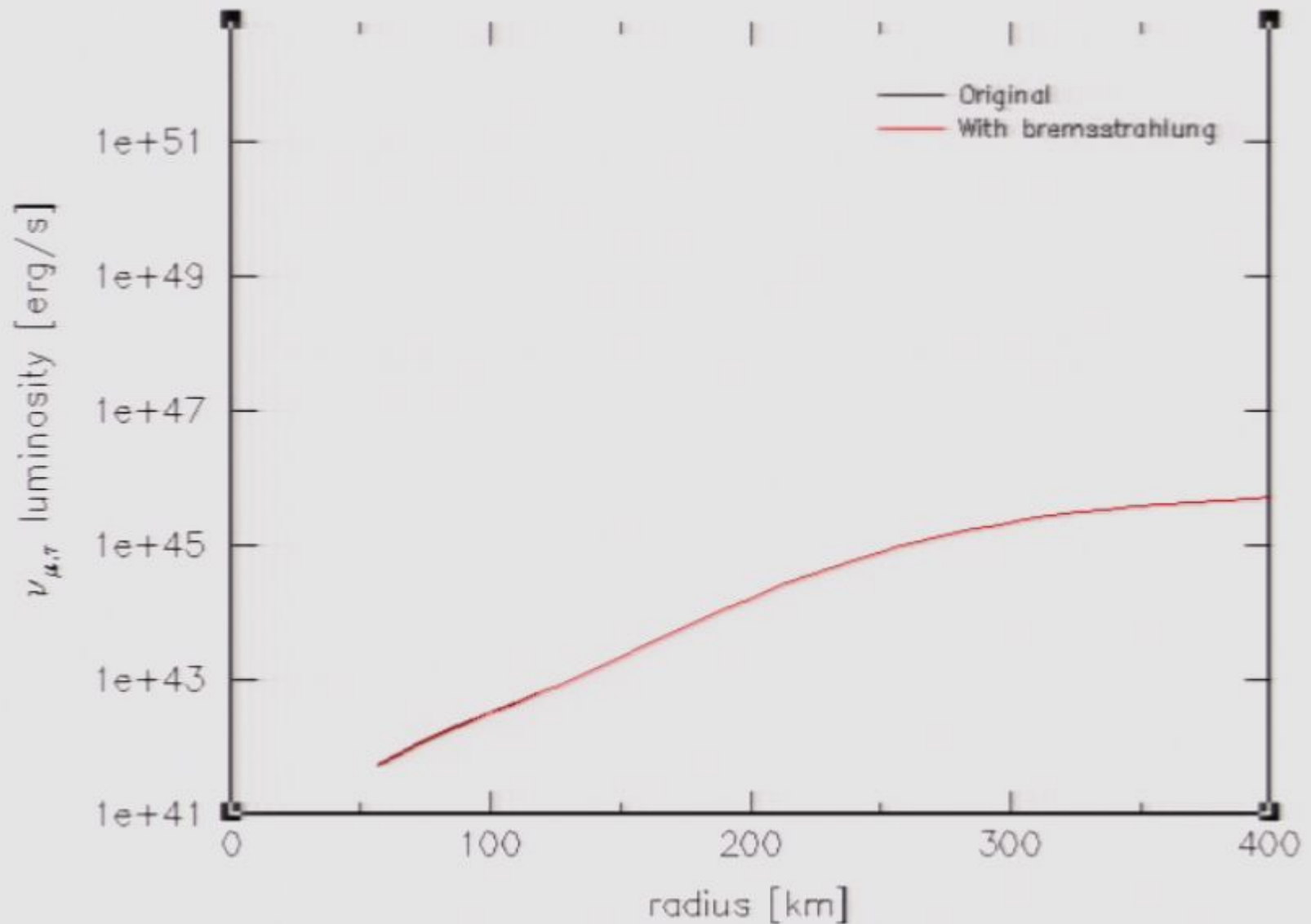
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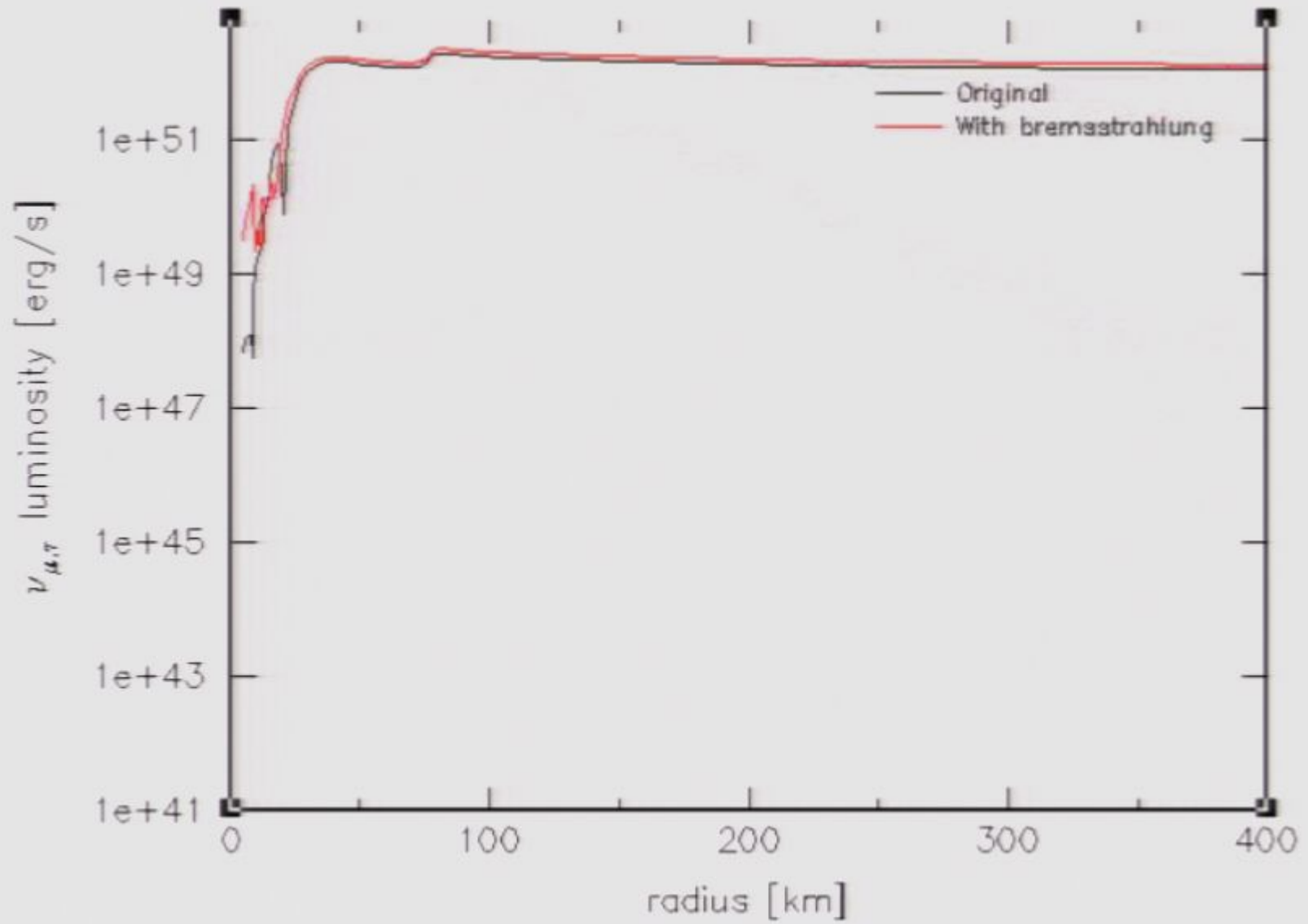
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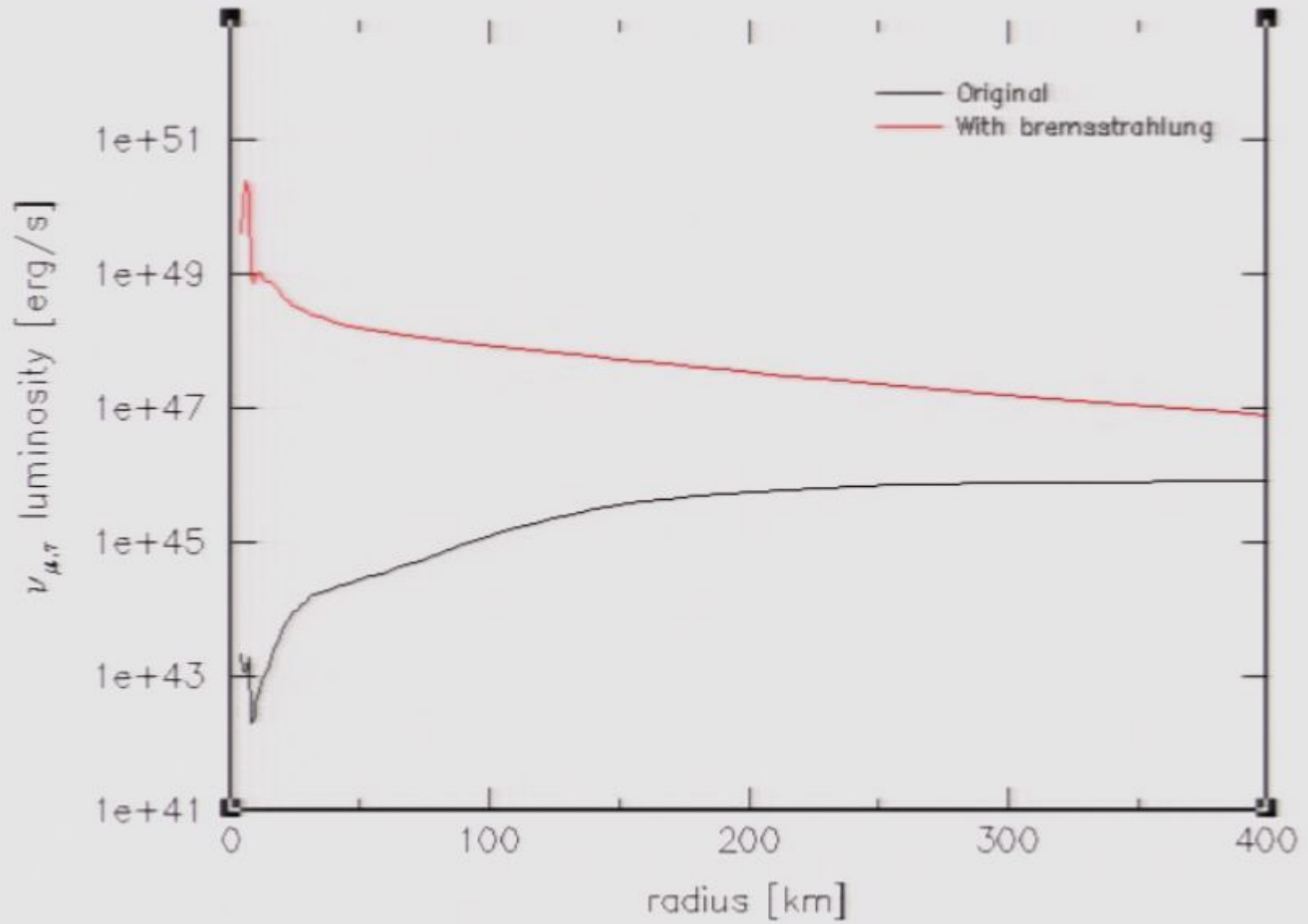




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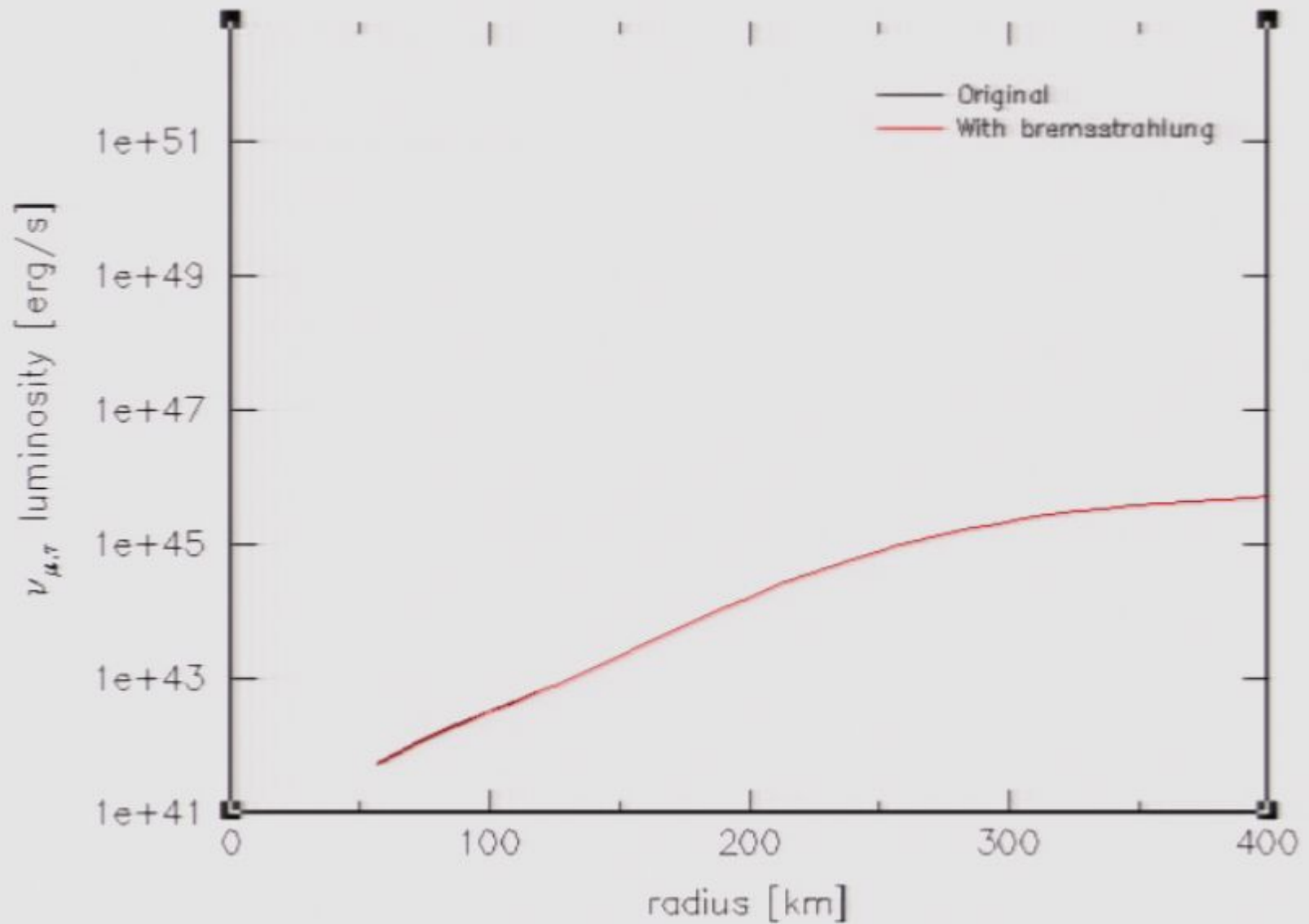


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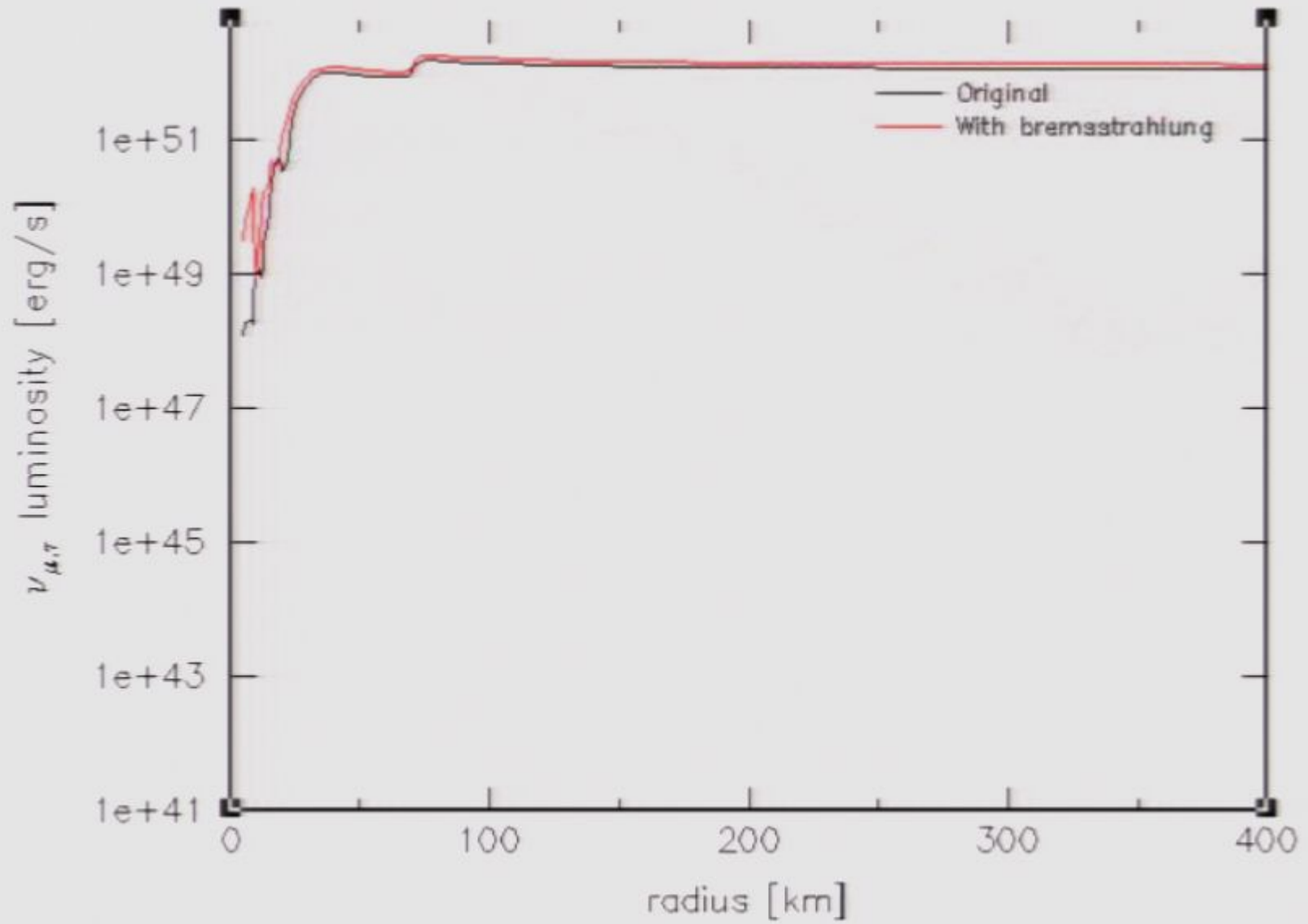


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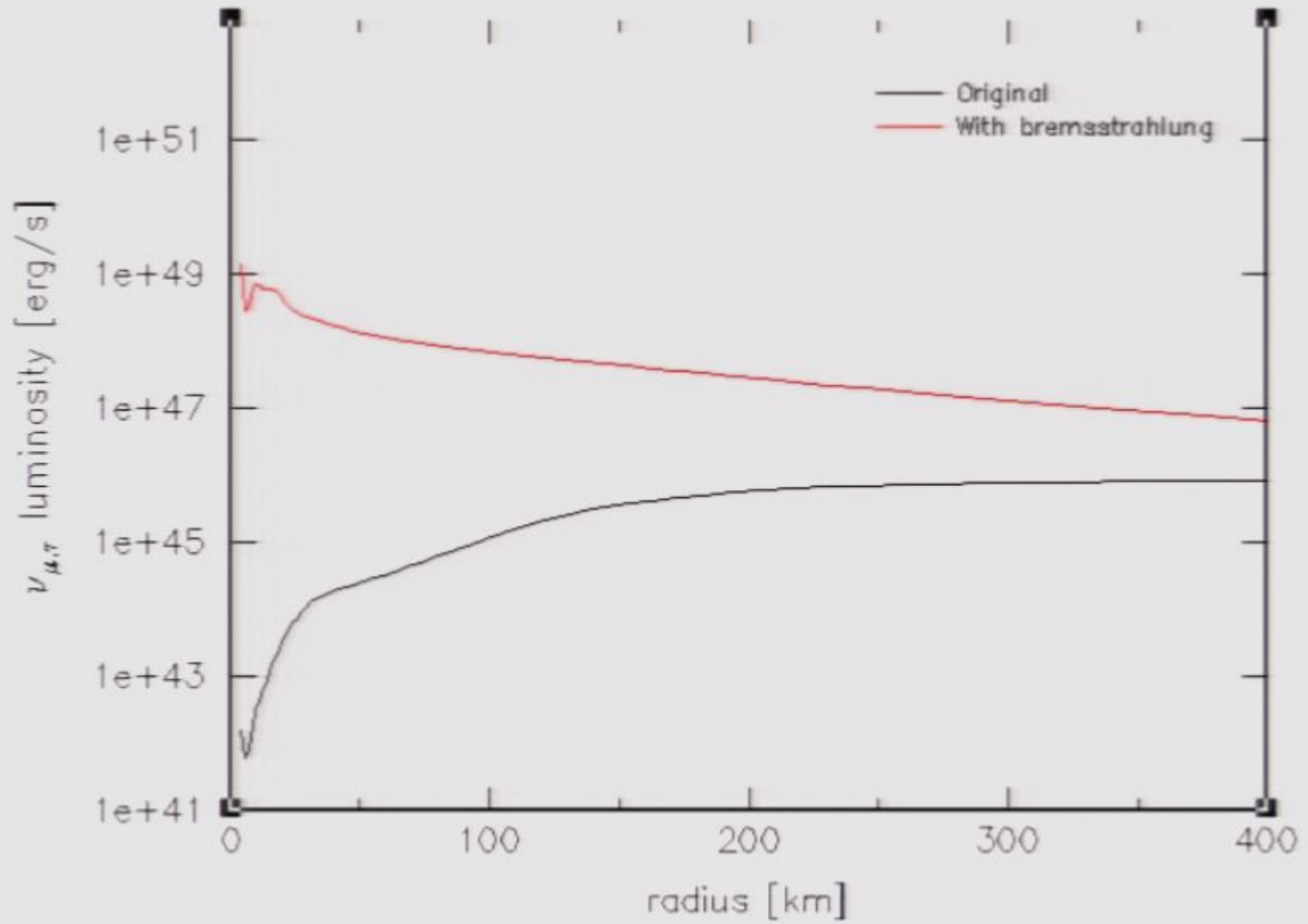
# NN bremsstrahlung (AGILE-Boltztran)



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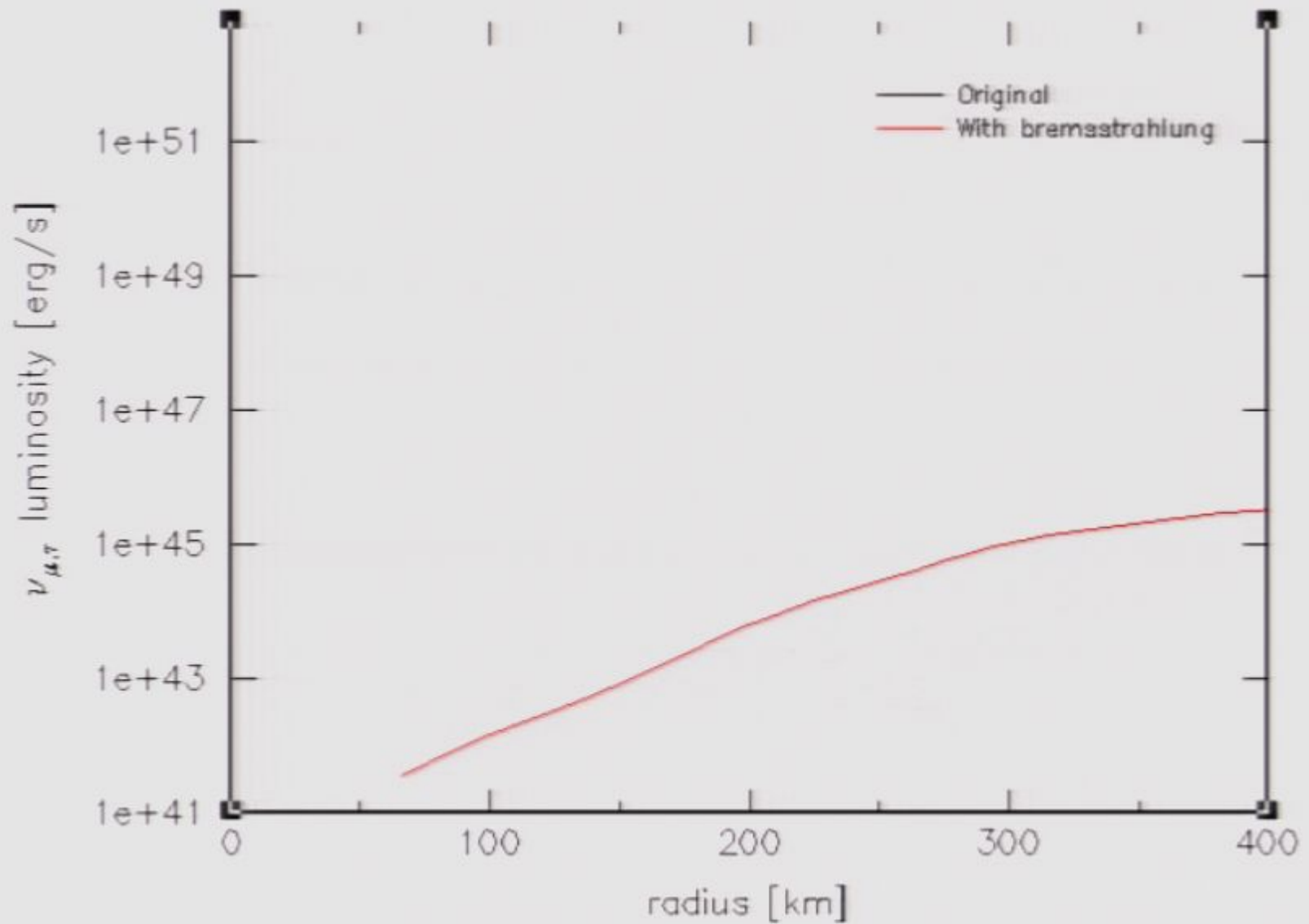


# NN bremsstrahlung (AGILE-Boltzman)

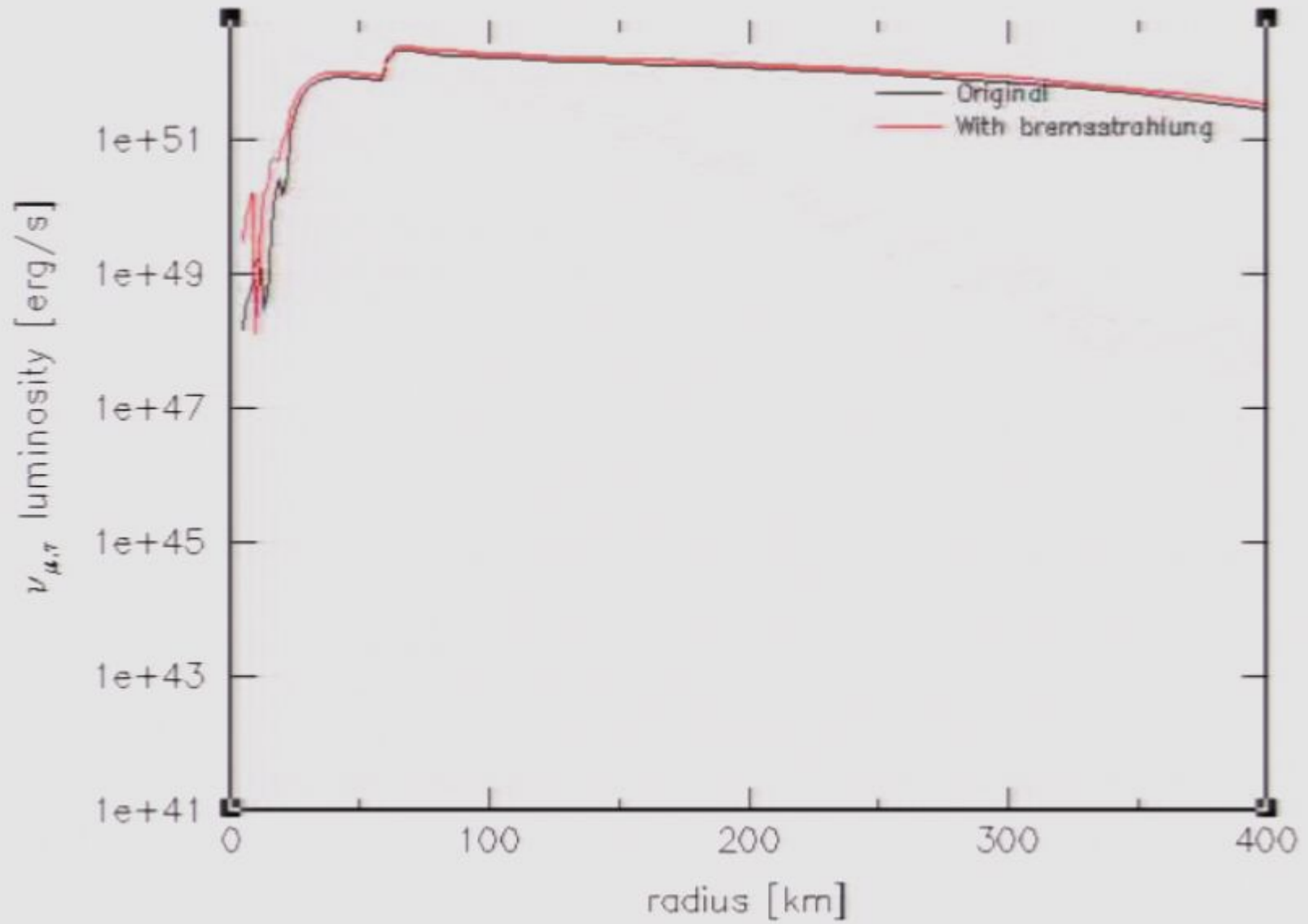


onset of bounce -----> ~50 ms post-bounce

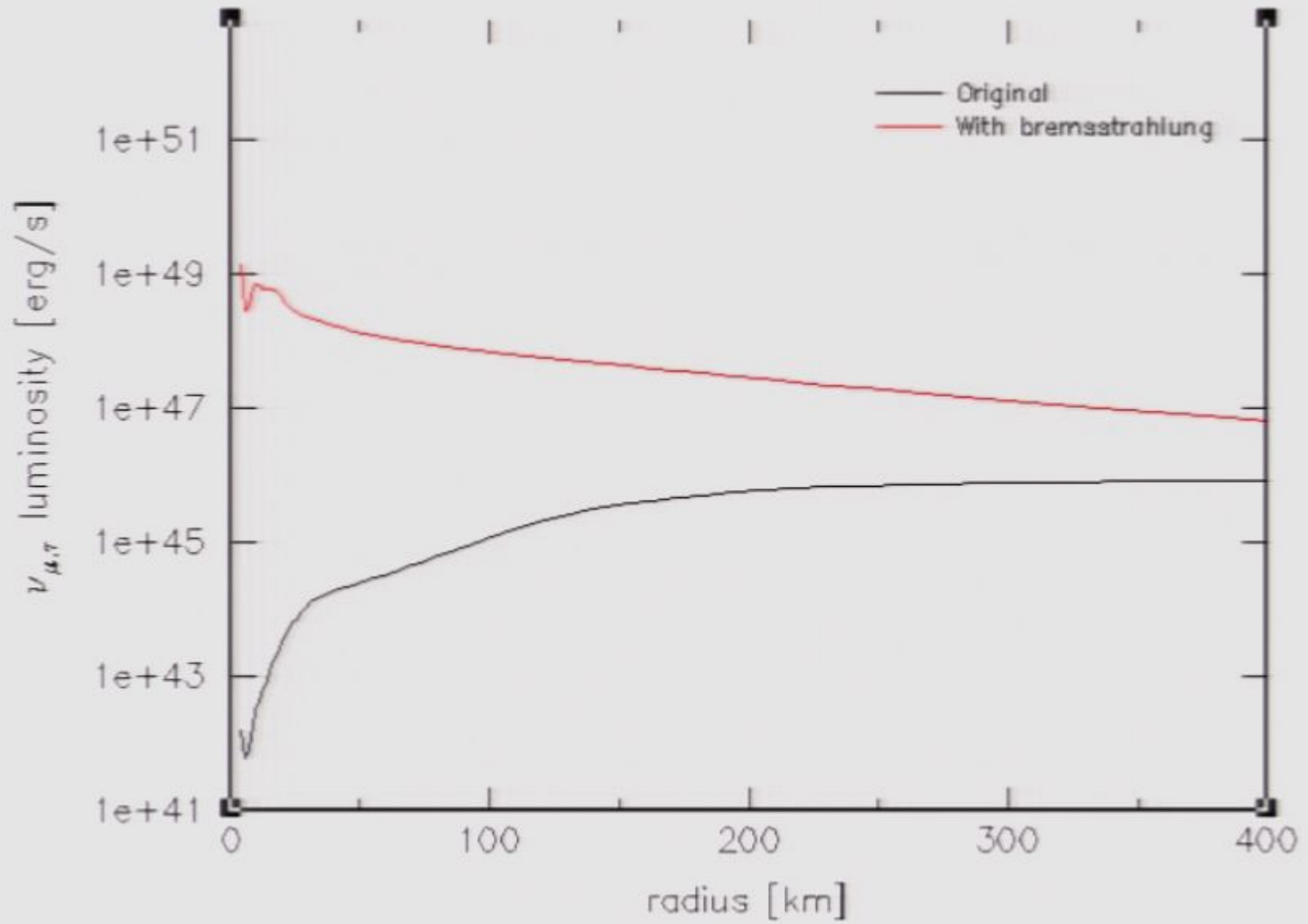
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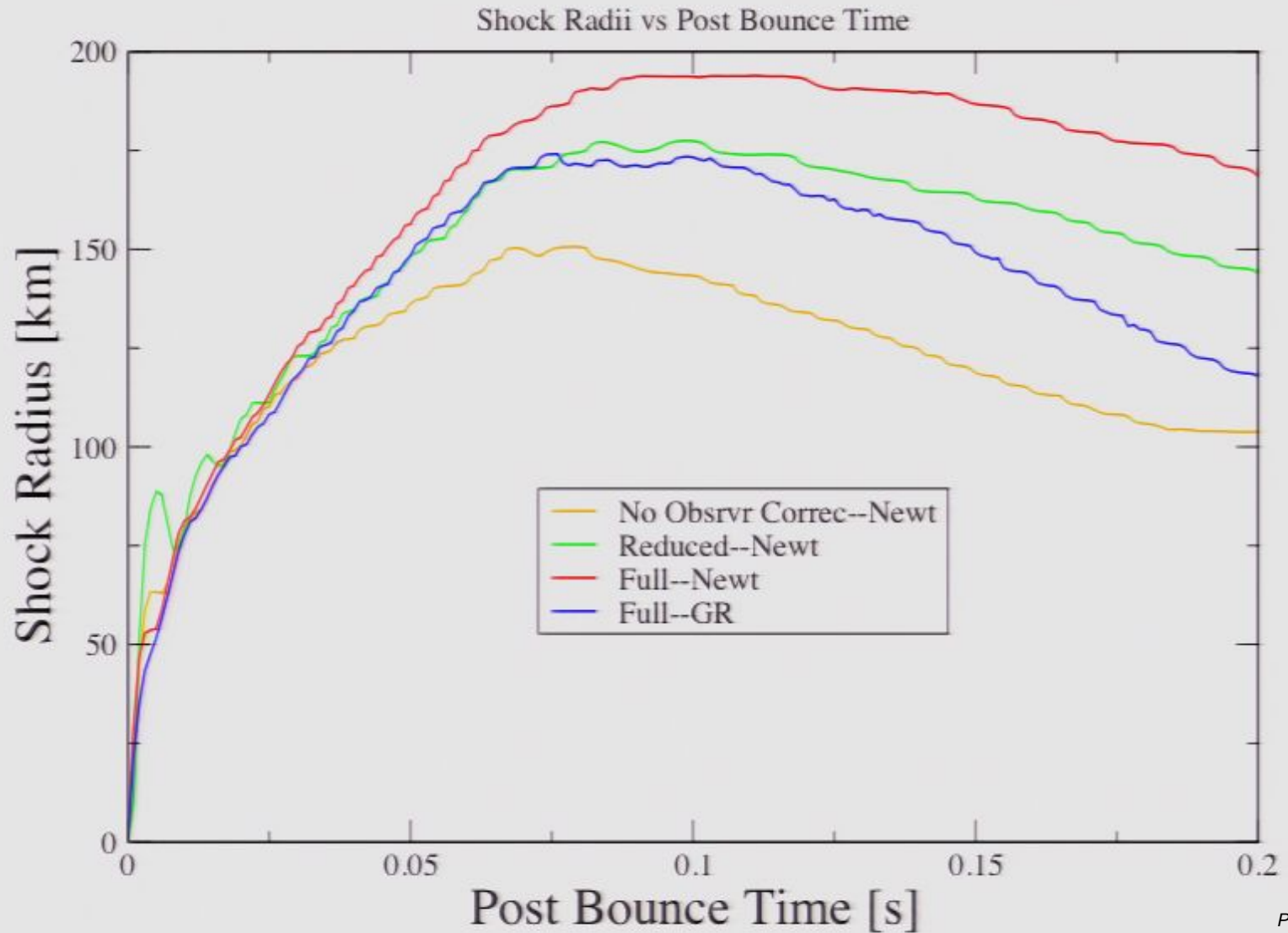


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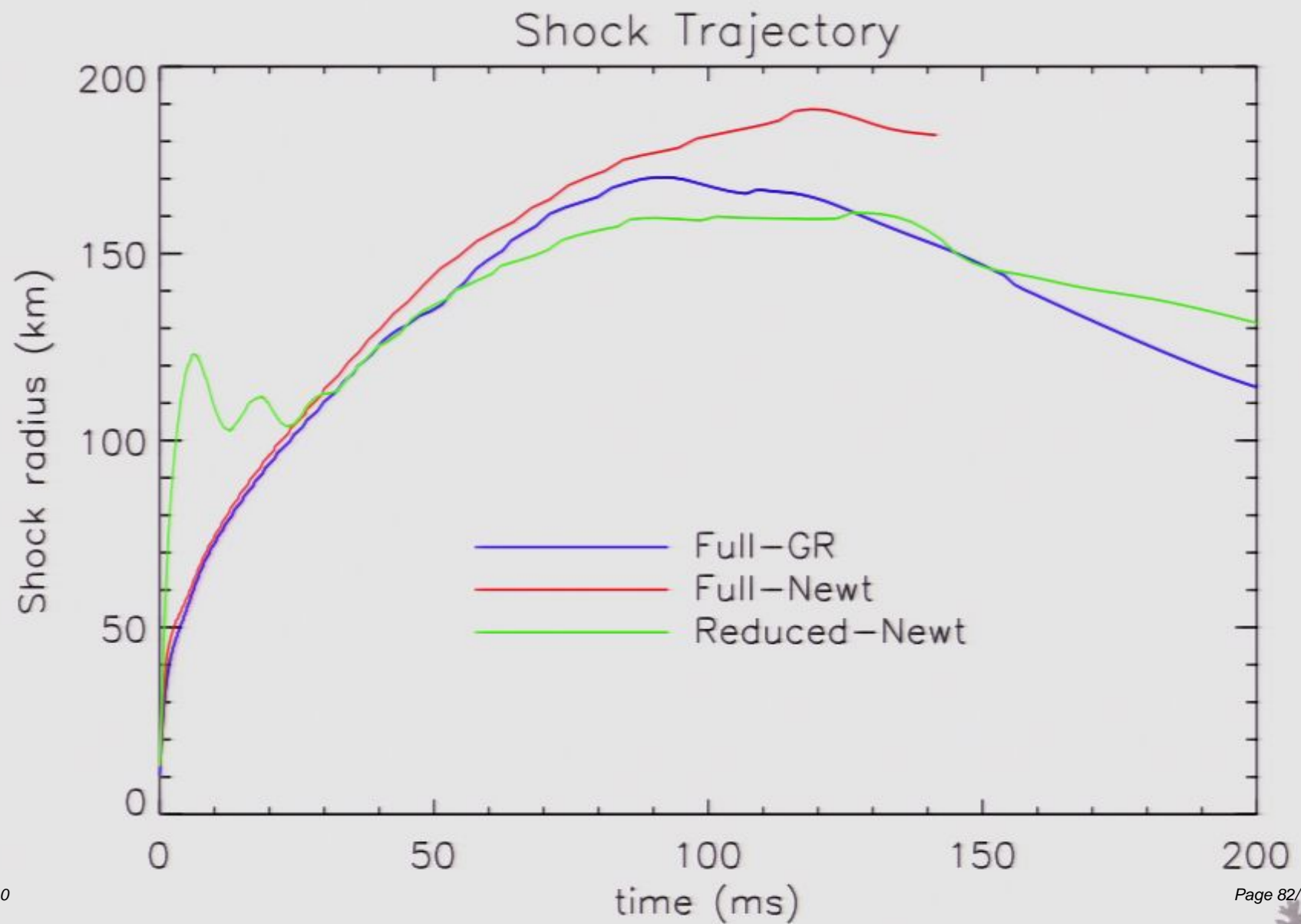


# CHIMERA 1D simulations

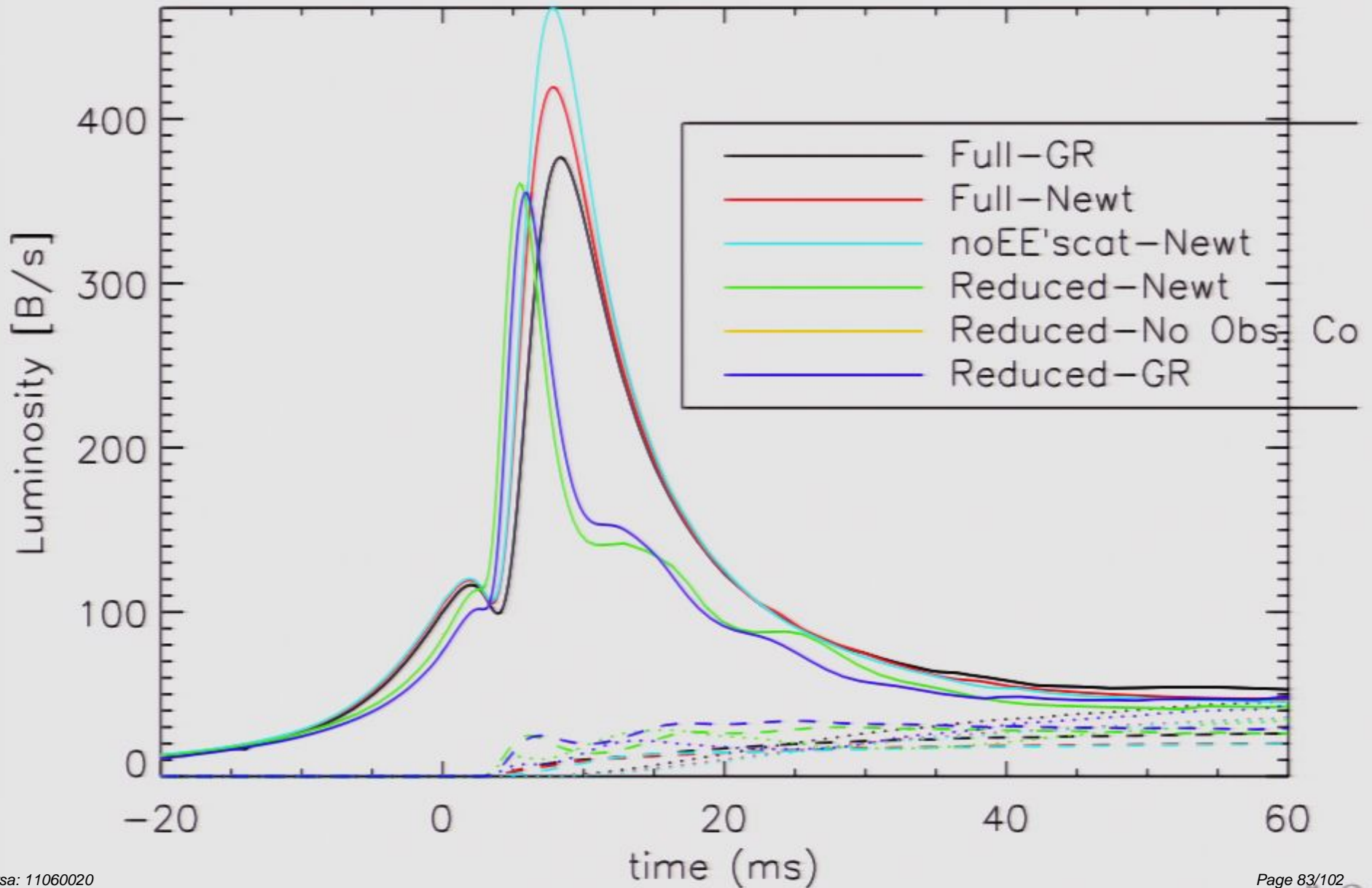
## Comparison of 1D Simulations; 15 W-H Progenitor



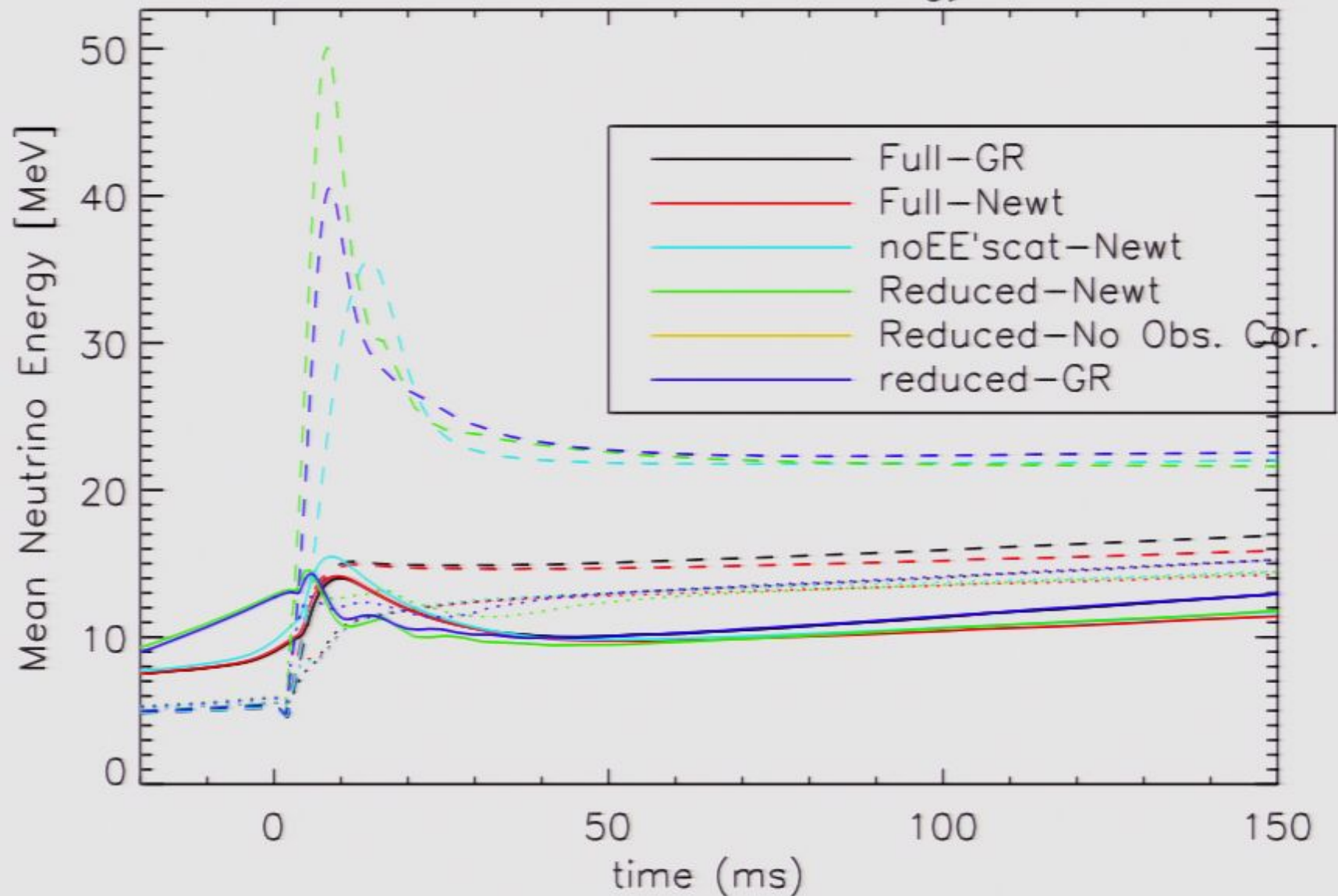
# AGILE-Boltztran



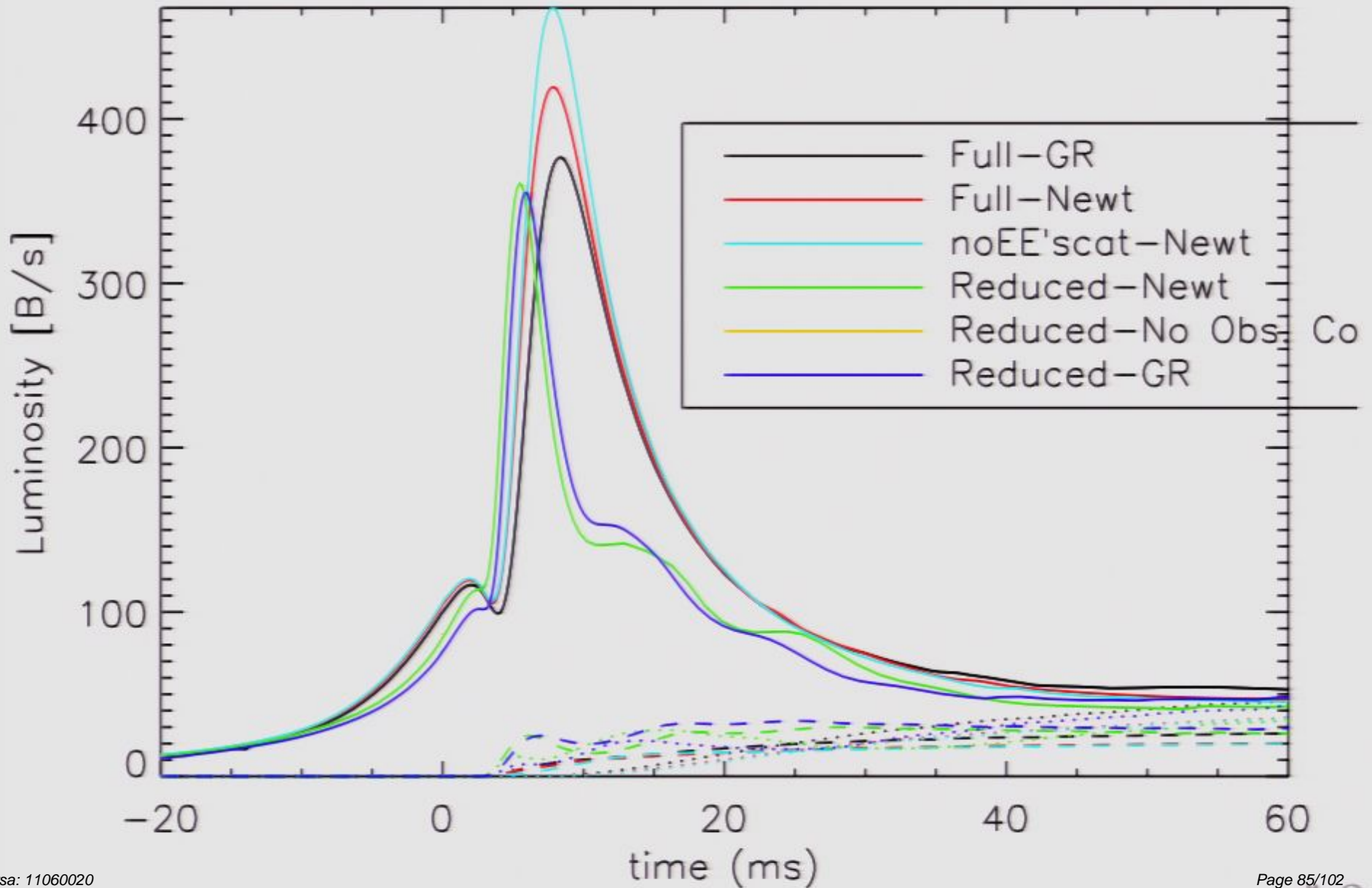
# AGILE-Boltztran neutrino luminosity



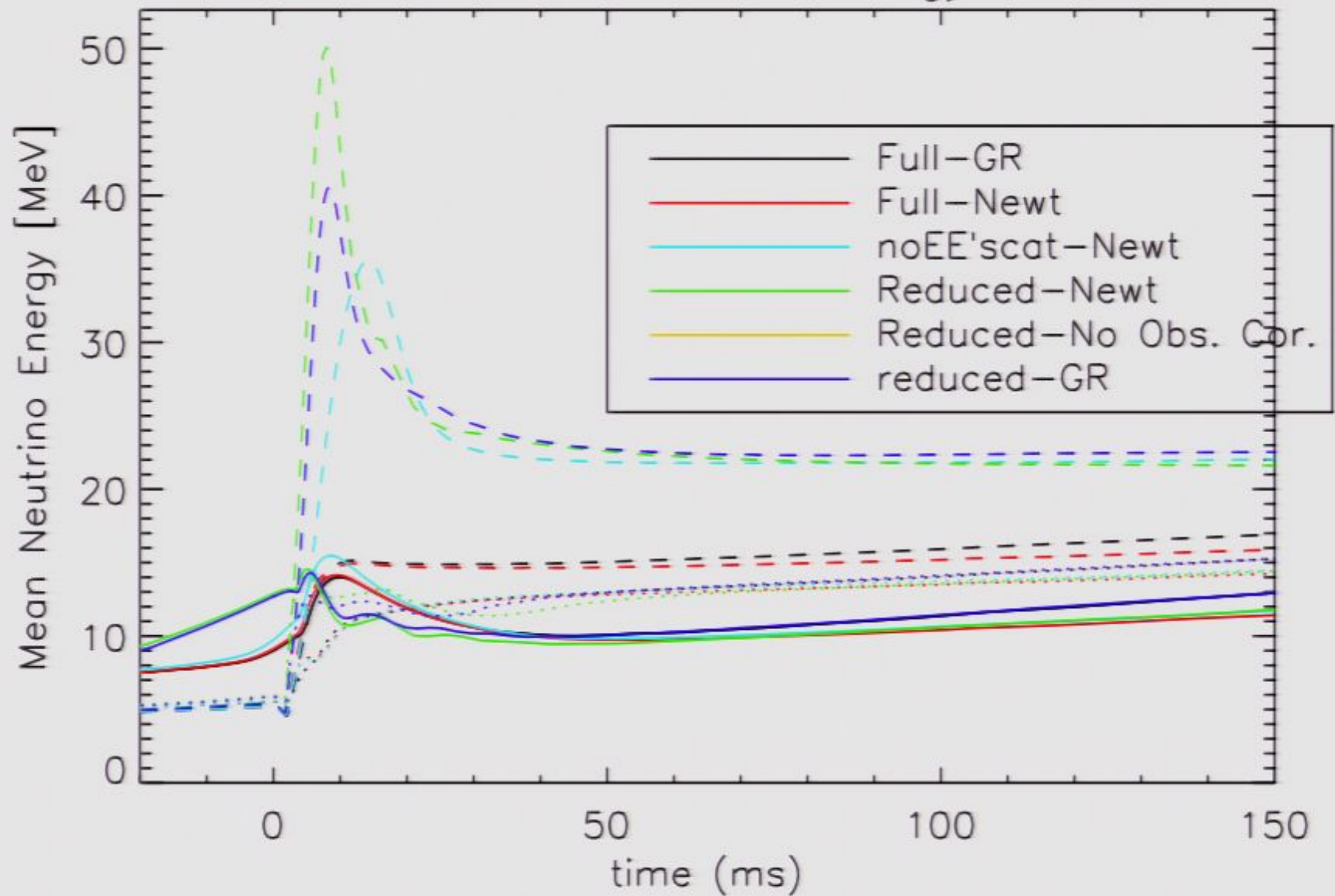
# AGILE-Boltztran neutrino energies



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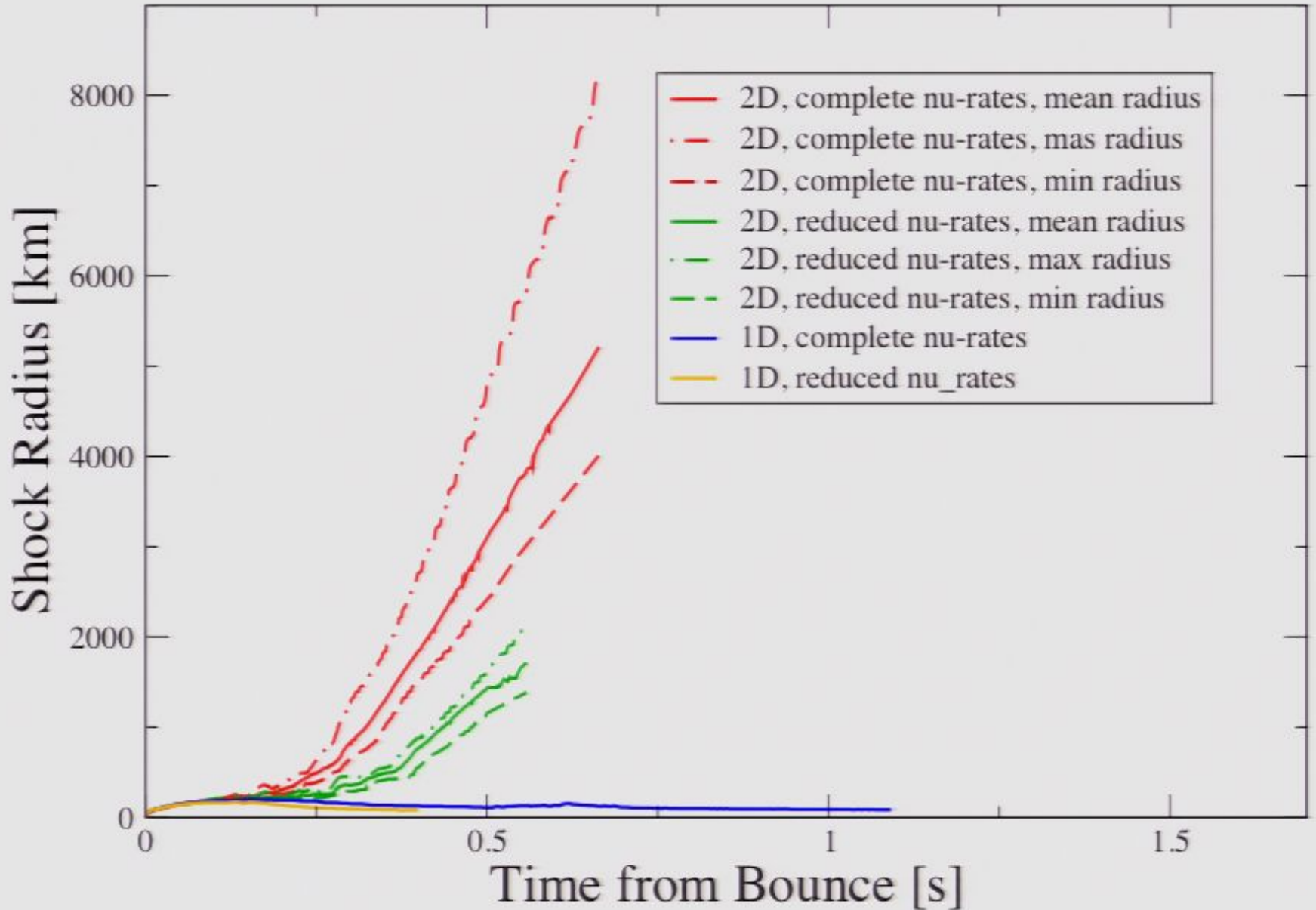


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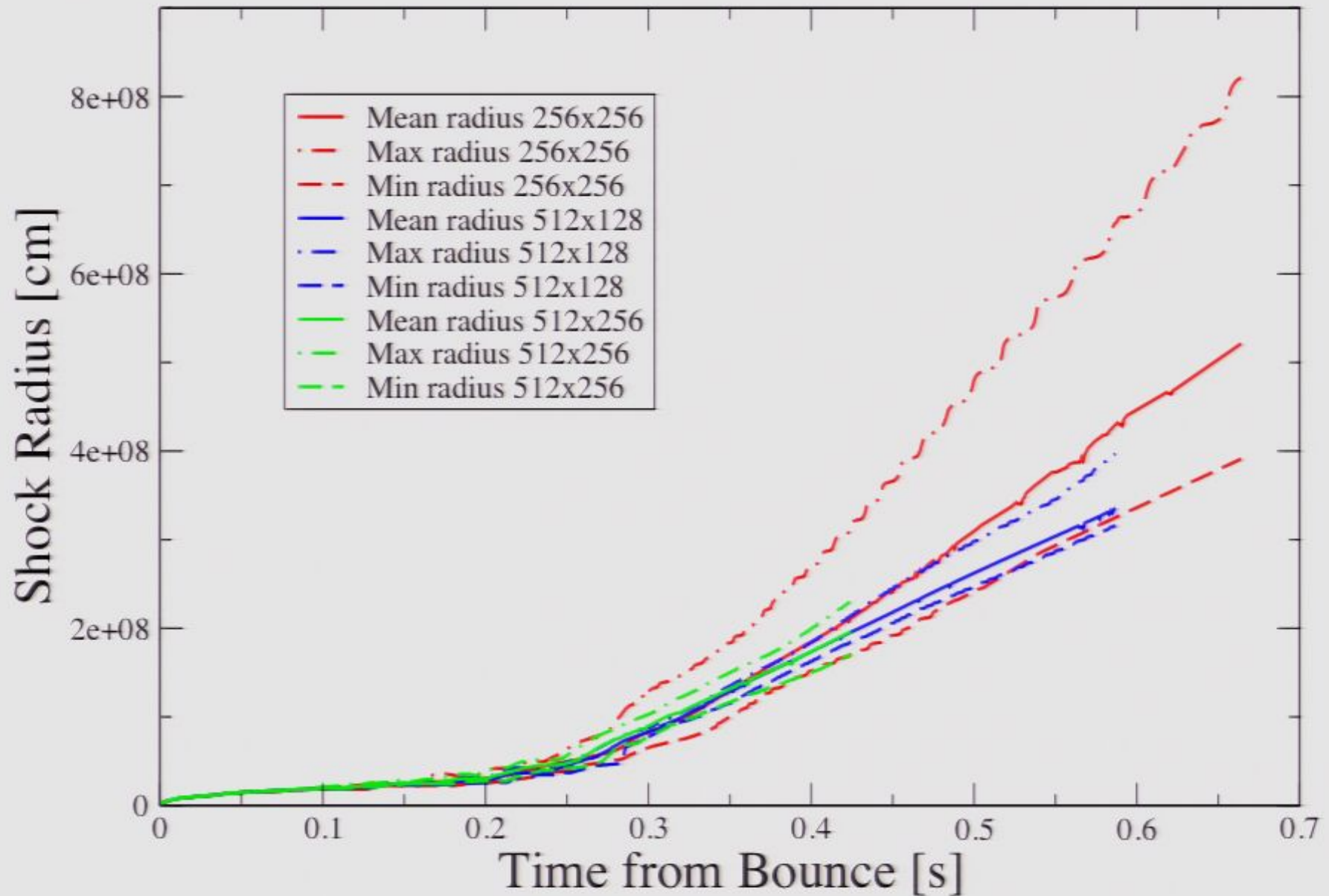


# Shock Radii vs Time from Bounce

W-H 15 Solar Mass Progenitor; Effect of Dimensionality and Neutrino Rates



# Impact of resolution





## WeakLib

- ❑ GenASiS currently uses Global Arrays to store and copy from global interaction table
  - ◆ Compute and store also implemented, i.e. if cube needed is not present, calculate and store it
  - ◆ Only n,p emission/absorption included currently (reduced dimensionality)
  
- ❑ Needs to be 'back-ported' to CHIMERA
  - ◆ recomputation of local interaction physics is the primary source of load imbalance in CHIMERA
  
- ❑ Ultimately (and several groups working on this) weak interaction kernels must be fully integrated into EoS
  
- ❑ Hope to make this available to all and Open Source

## WeakLib

- ❑ 4 flavors x 20 E groups x 4 kinematic 'types' x  $16^2$  angles (at worst)
- ❑ "typical" EoS table resolutions - 50x100x100 or so
- ❑ ---> ~ 40GB
  
- ❑ This will fit on any reasonably sized-cluster, but must be distributed across nodes
- ❑ Global Arrays, Co-Arrays, UPC, Chapel, ... Many options for one-sided atomic memory operations now exist and perform
- ❑ Assumption: use would include a node-local cache of table points

# Summary

## Microphysics

- Energy-transferring neutrino interactions have a profound effect on shock dynamics.
- Charged and neutral current interactions on nuclei (and larger, correlated structures) need better implementations and integration with EoS.

in

## Computational

- Near-future (like, NOW!), large-scale (and smaller scale as well) computational platforms will not lend themselves to, e.g., increased spatial resolution, but will be able to deliver better physical fidelity if microphysics is parallelized at the node level.
- EoS+neutrino interaction tables are small enough to be distributed across a modest number of cluster nodes.

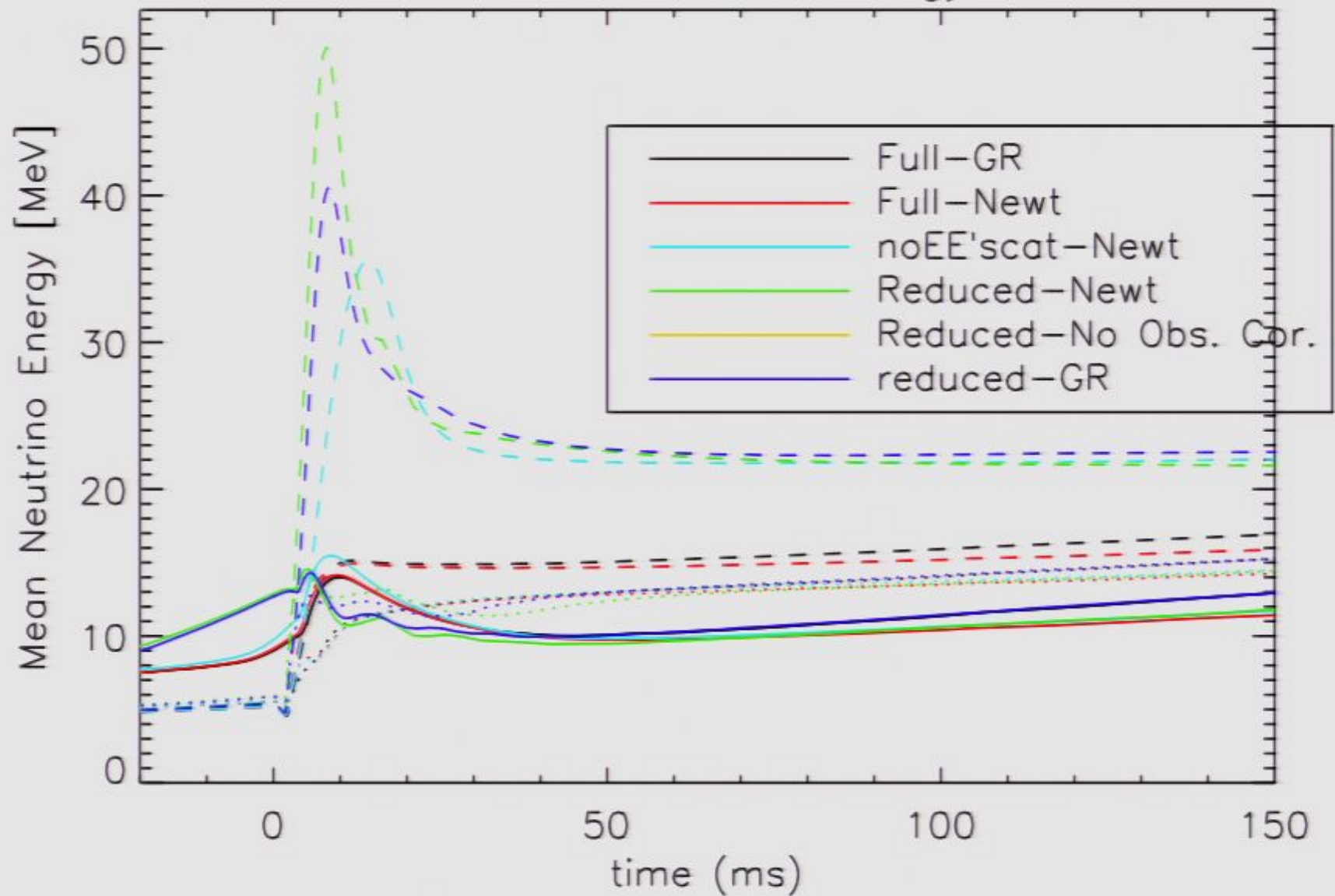
## Relativistic

Incorporating GR gravity into core-collapse simulations is roughly as important as incorporating energy-transferring weak interaction physics for shock dynamics.

## Astrophysics

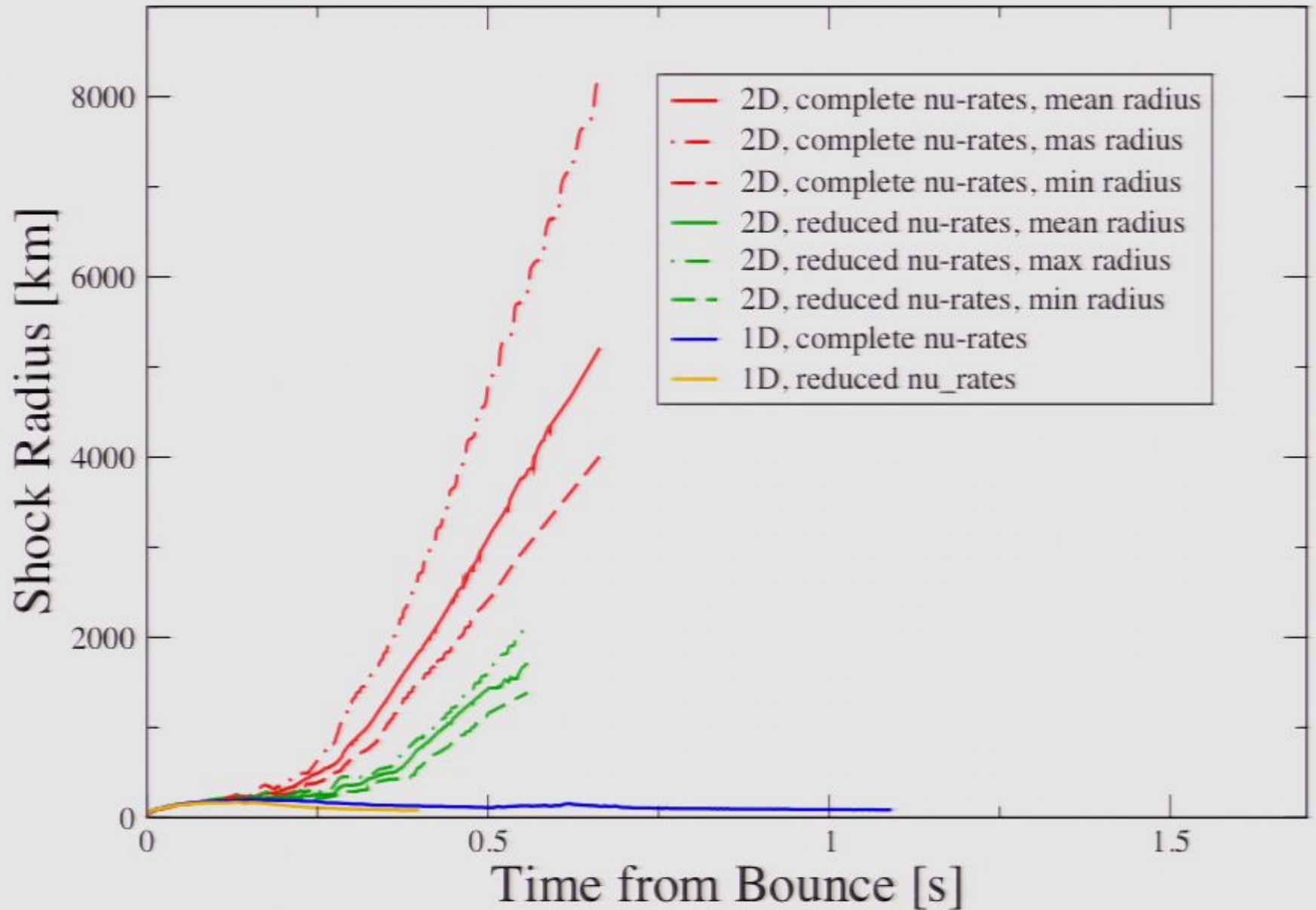
Regardless of dynamic effect, known physics that can impact observables must be included for simulations to successfully confront observations.

# AGILE-Boltztran neutrino energies

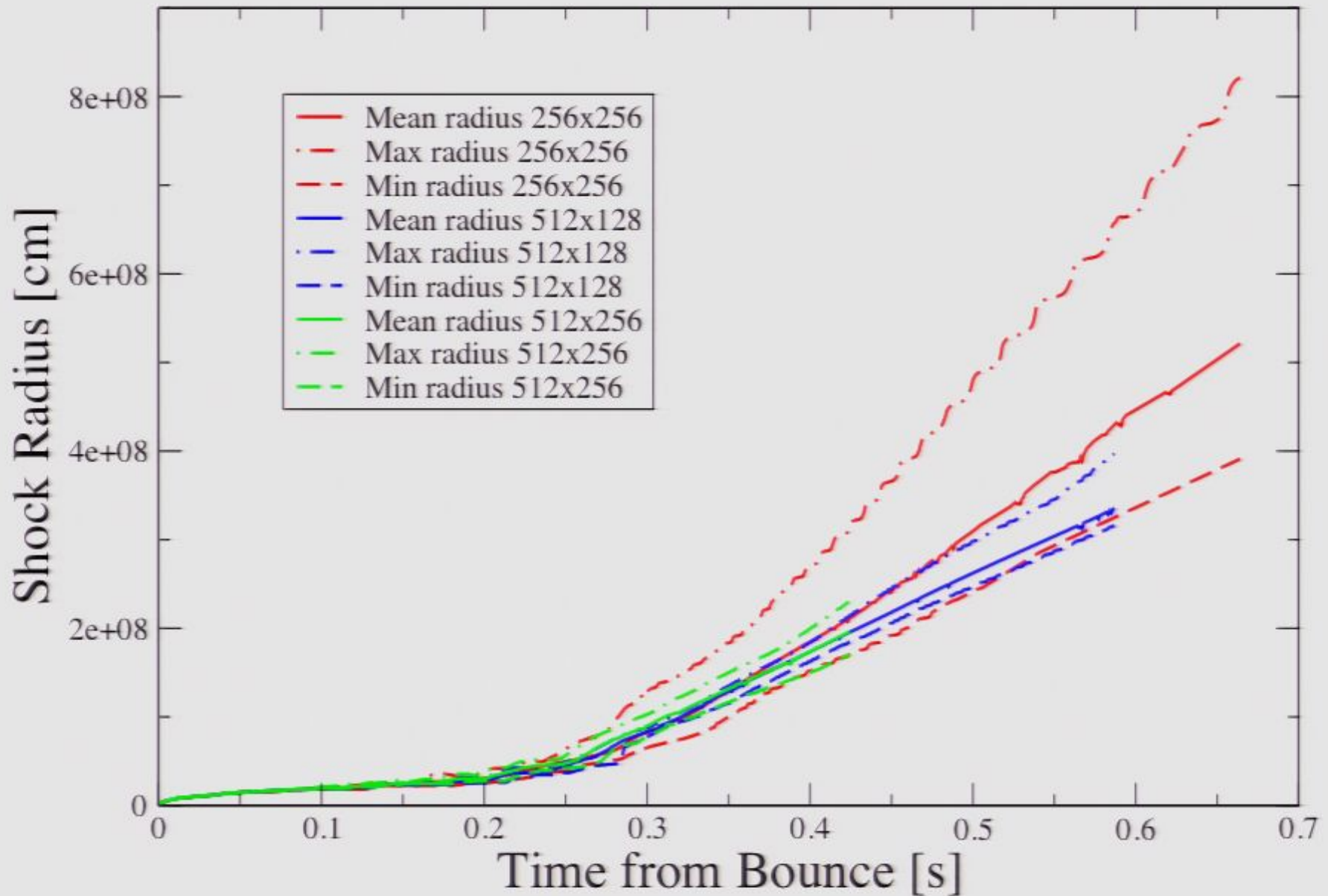


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## WeakLib

- ❑ GenASiS currently uses Global Arrays to store and copy from global interaction table
  - ◆ Compute and store also implemented, i.e. if cube needed is not present, calculate and store it
  - ◆ Only n,p emission/absorption included currently (reduced dimensionality)
- ❑ Needs to be 'back-ported' to CHIMERA
  - ◆ recomputation of local interaction physics is the primary source of load imbalance in CHIMERA
- ❑ Ultimately (and several groups working on this) weak interaction kernels must be fully integrated into EoS
- ❑ Hope to make this available to all and Open Source

# Important Neutrino Emissivities/Opacities

$$\star e^{-(+)} + p(n), A \leftrightarrow \nu_e(\bar{\nu}_e) + n(p), A'$$

Bruenn, *Ap.J. Suppl.* (1985)

- Nucleons treated as independent in nuclei
- No energy exchange in nucleonic scattering

Langanke et al. *PRL*, **90**, 241102 (2003)

- **Included correlations between nucleons in nuclei.**

$$e^+ + e^- \leftrightarrow \nu_{e,\mu,\tau} + \bar{\nu}_{e,\mu,\tau}$$

$$\star \nu + n, p, A \rightarrow \nu + n, p, A$$

Reddy, Prakash, and Lattimer, *PRD*, **58**, 013009 (1998)

Burrows and Sawyer, *PRC*, **59**, 510 (1999)

- (Small) **Energy is exchanged due to nucleon recoils**
- Many such scatterings.

$$\nu + e^-, e^+ \rightarrow \nu + e^-, e^+$$

Janka et al. *PRL*, **76**, 2621 (1996)

$$\star N + N \leftrightarrow N + N + \nu_{e,\mu,\tau} + \bar{\nu}_{e,\mu,\tau}$$

Hannestad and Raffelt, *Ap.J.* **507**, 339 (1998)

Hanhart, Phillips, and Reddy, *Phys. Lett. B*, **499**, 9 (2000)

Thompson et al., *Phys.Rev.* **C62**, 035802 (2000)

- **New source of neutrino-antineutrino pairs.**

$$\nu_e + \bar{\nu}_e \leftrightarrow \nu_{\mu,\tau} + \bar{\nu}_{\mu,\tau}$$

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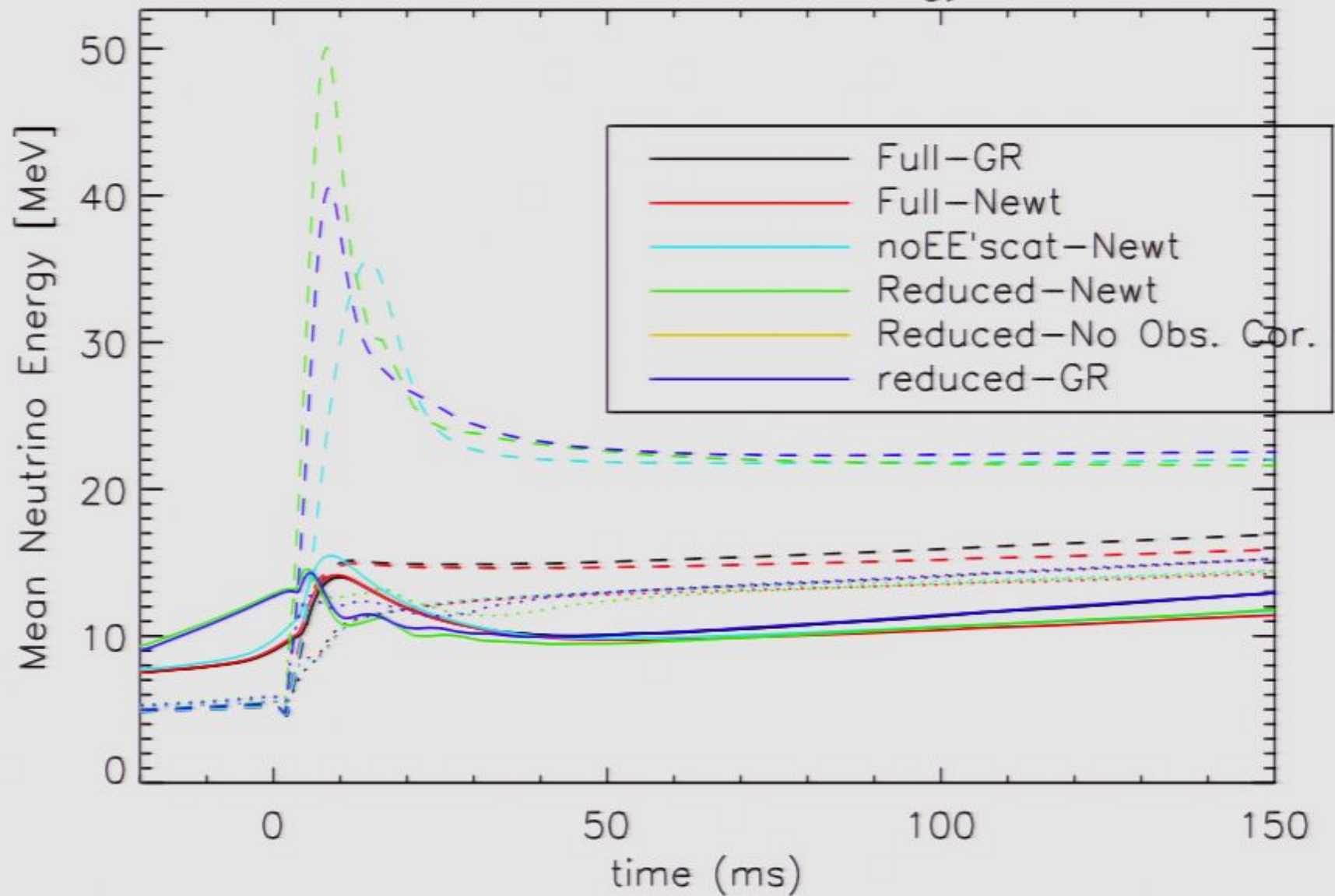
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# AGILE-Boltztran neutrino energies



# Impact of resolution

