



Impact of Community Codes on Astrophysics

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Can NOT be
overestimated!

Benefits of Community

- Open source is a good thing in science!
- Reproducibility
- No need to reinvent the wheel
- More science per funder dollar!
- Greater impact of methods development!
- Better documentation (?)

“Community” Astro Codes

FLASH
MESA
Enzo
yt
Gadget
CASTRO
MAESTRO

Athena
Ramses
Zeus
Einstein Toolkit
Pluto
many, many more....

see Astrophysics Source Code Library, ascl.net
>800 codes listed!

Comm. Codes Have Greater Impact

Code	Approx. Publications
Gadget	3000
Zeus	1000
FLASH	800
Enzo	400
MESA	300

Why Astro Comm. Codes?

- Monetization unlikely...
- Problems are complex and difficult for the lone coder
- Communal coding leads to greater return on investment

Why Astro Comm. Codes?

- More eyes on the code means more bugs found...
- Testing more rigorous

Multiphysics Complexity

Astrophysics Has It!

- Compressible hydrodynamics
- Magnetic fields
- Radiation transport/hydro
- Self-gravity
- Chemistry
- Nuclear burning
- Multifluids
- Detailed EOS
- Relativity
- ...

Multiphysics Complexity

Mathematically...

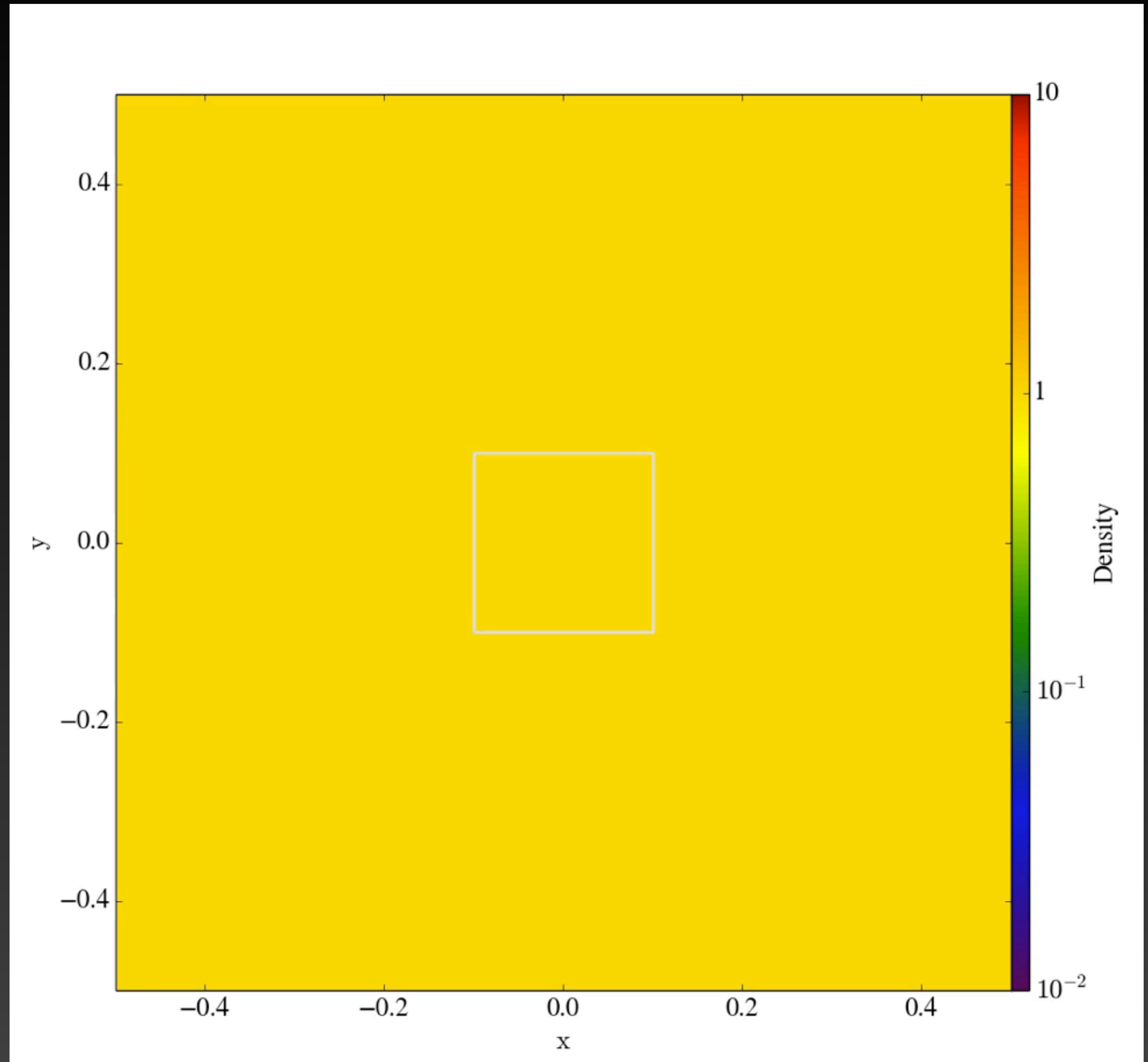
- Mix of:
- Hyperbolic PDEs
- Elliptical PDEs
- Parabolic PDEs
- Stiff equations
- etc., etc.

Infrastructure Complexity

- Extremely high dynamic range in space and time!
- Adaptive mesh techniques common
- BIG problems => extreme scale computing
- Infrastructure (IO, grid, build, analysis)
- Many different classes of operators

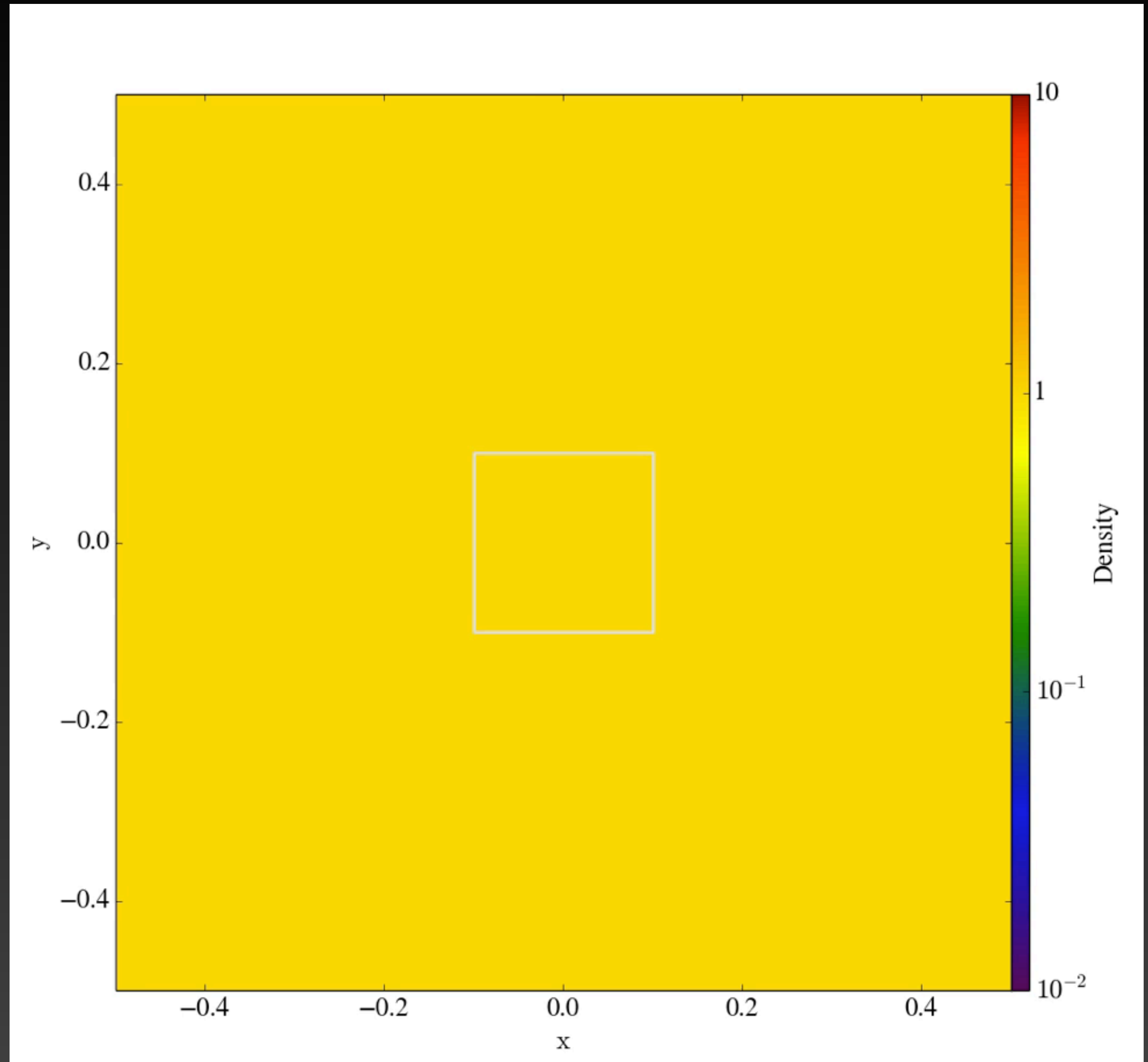
AMR

- Prolongation/restriction
- Guard (ghost) cell filling
- Fine/coarse flux correction
- Parallel load balancing



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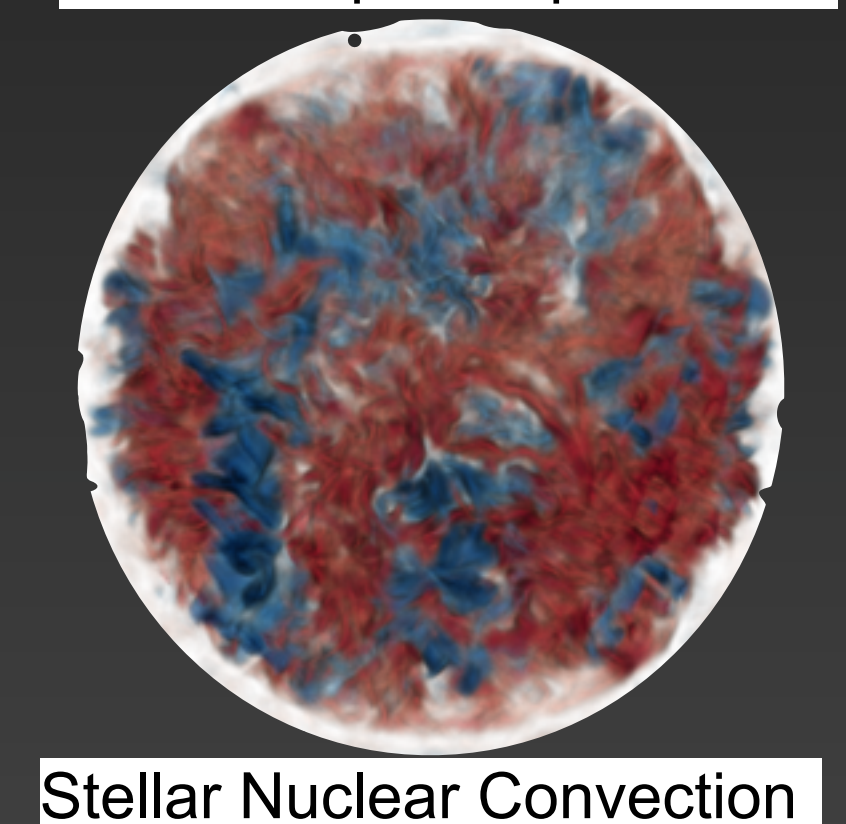
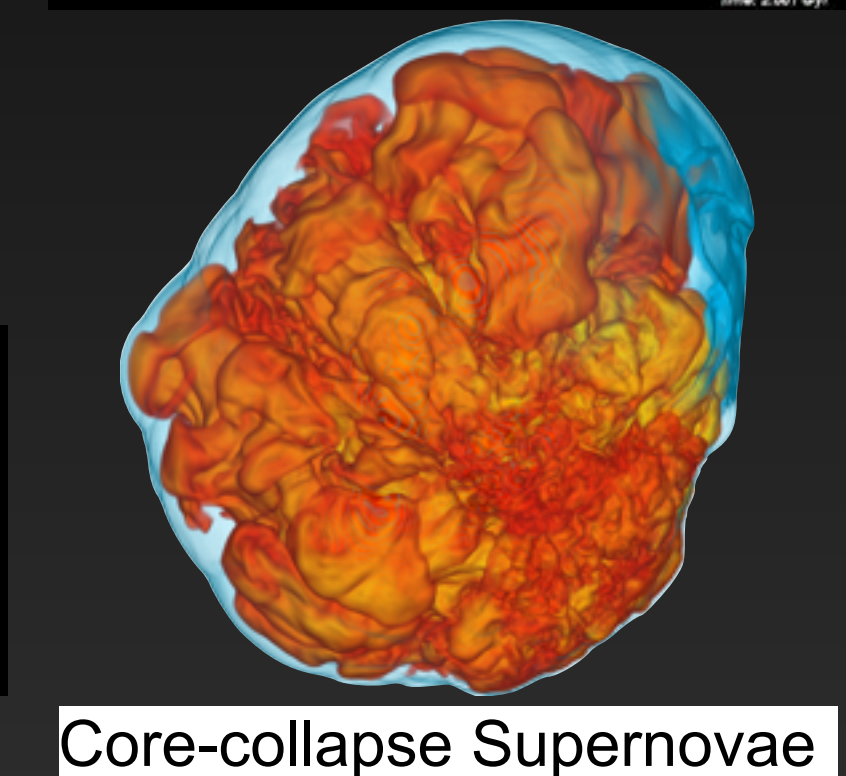
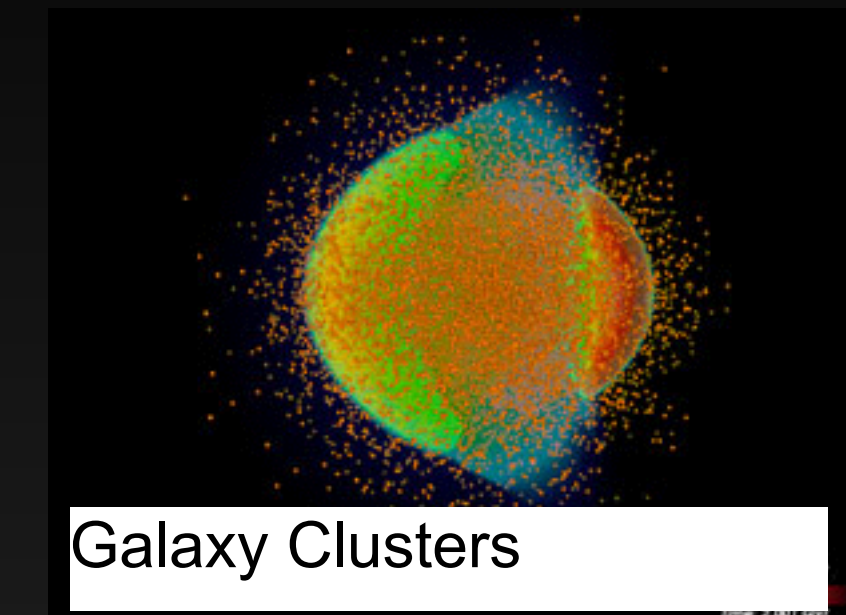
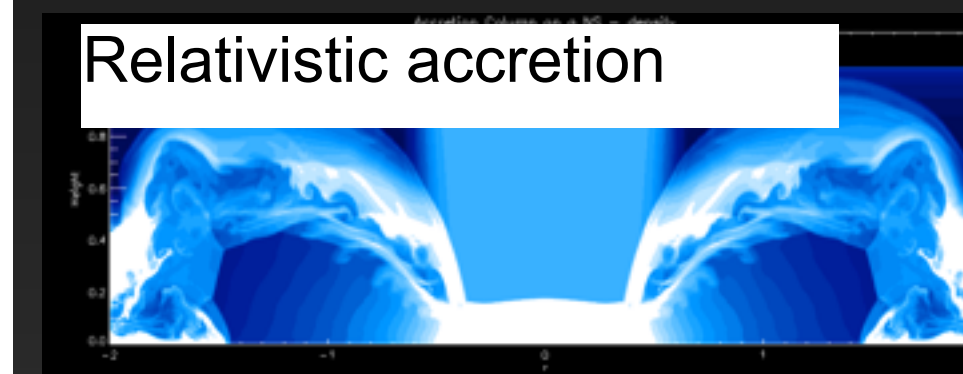
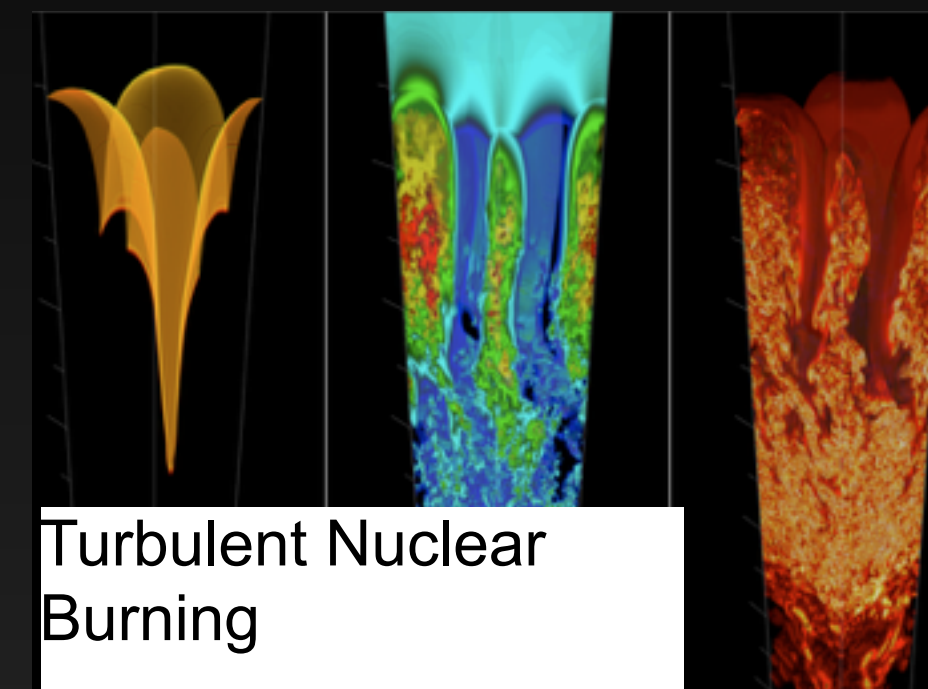
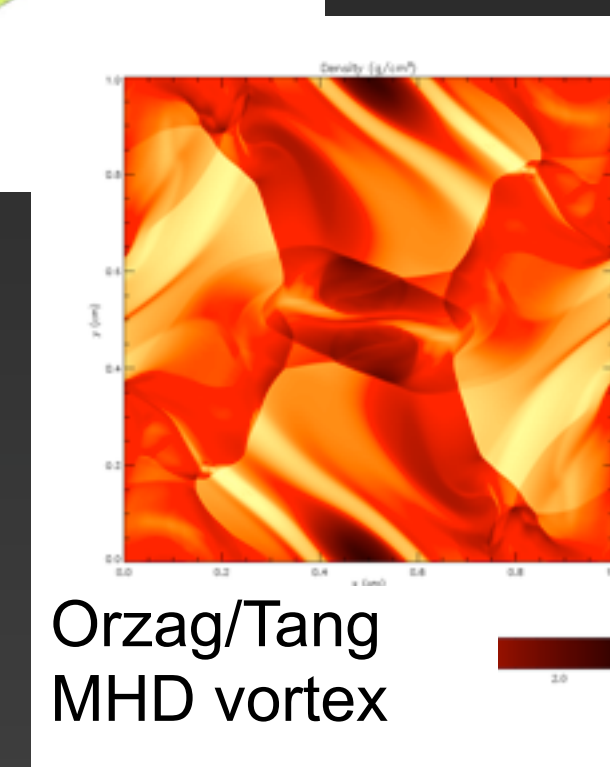
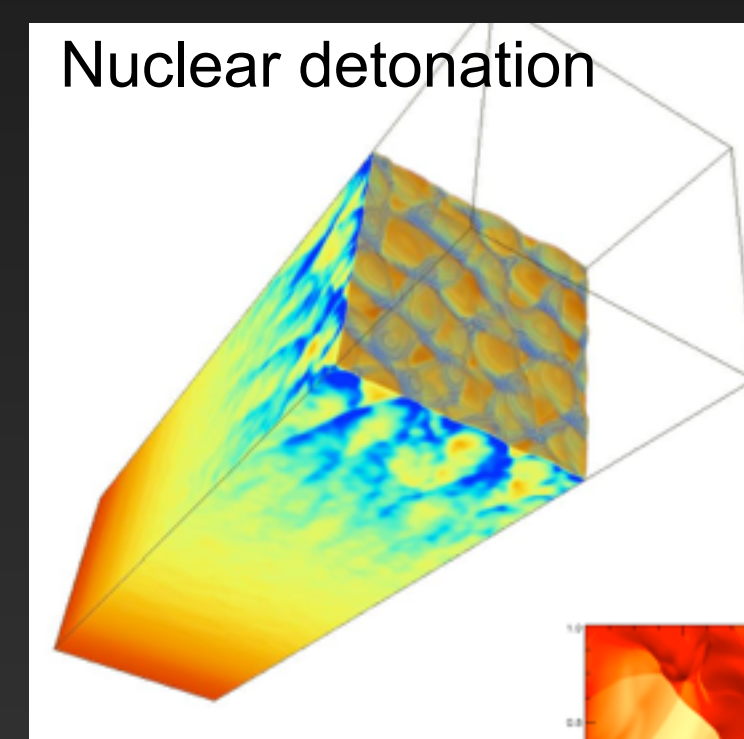
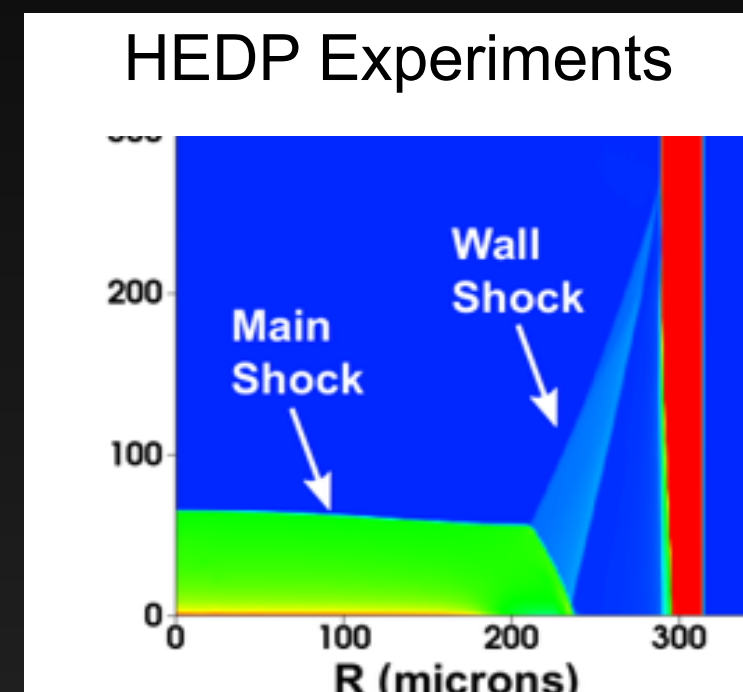
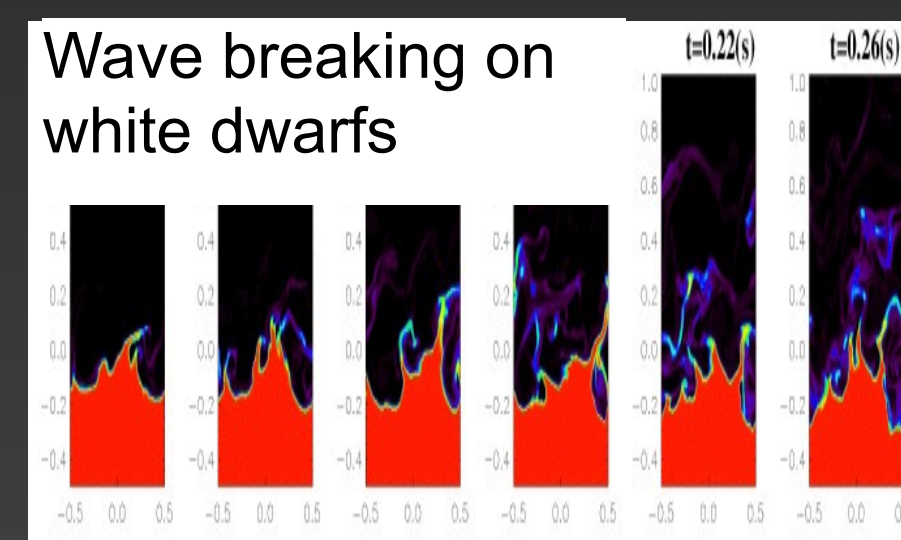
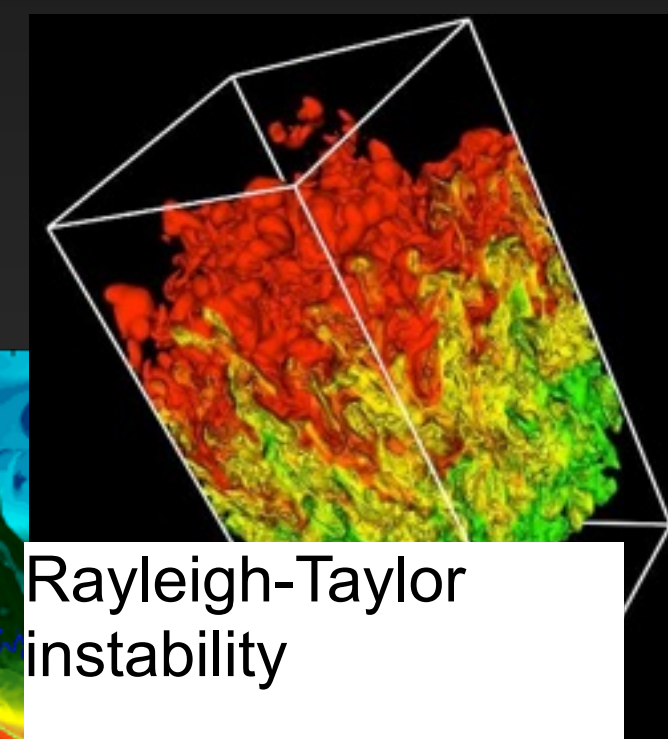
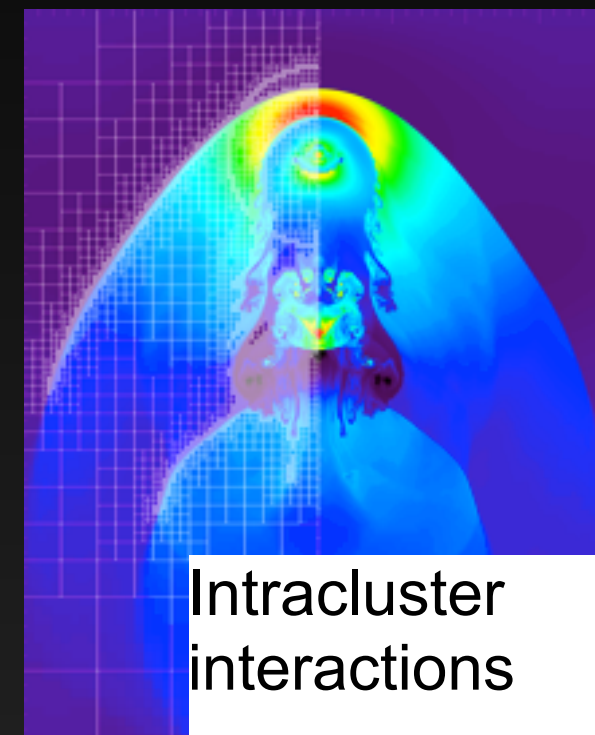
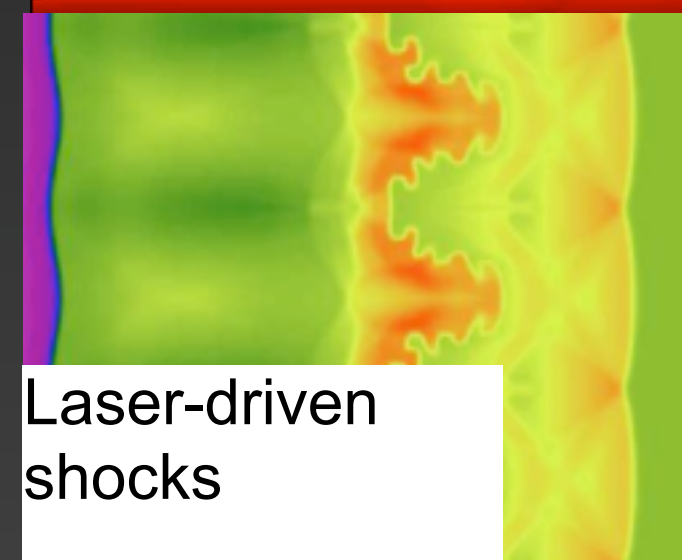
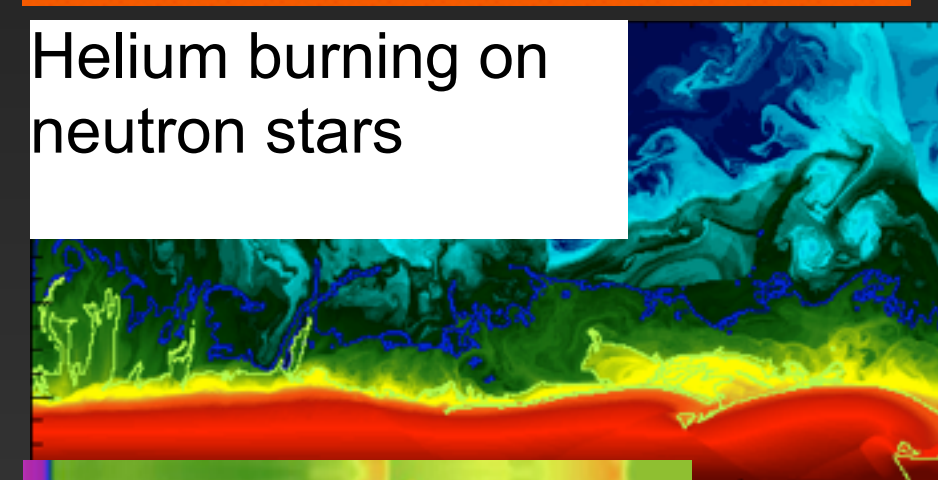
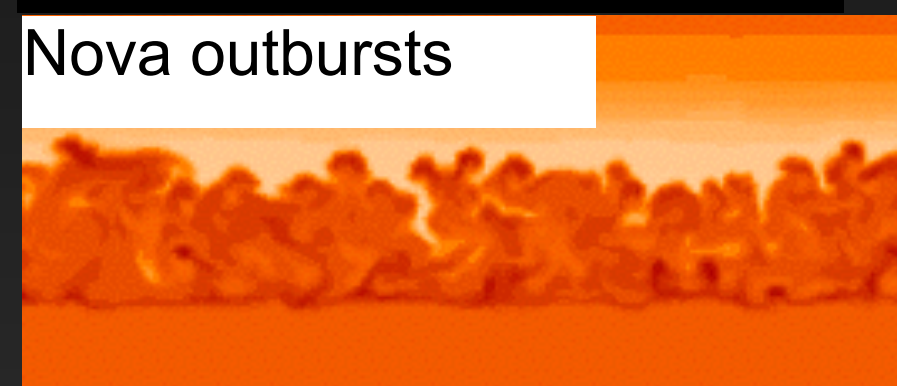
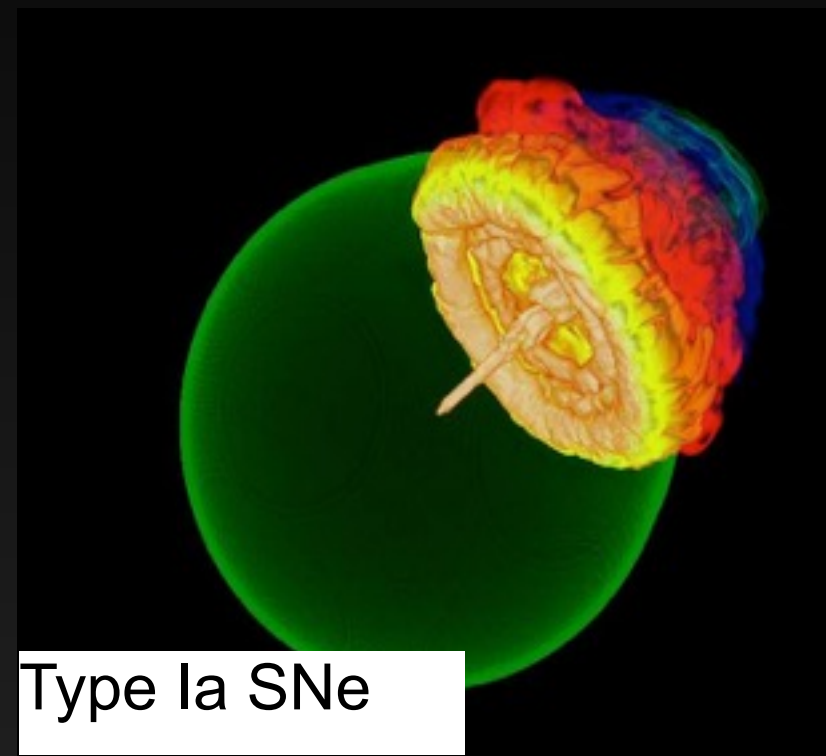
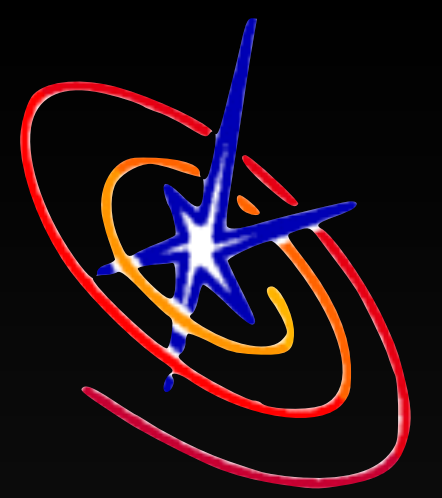
I/O

- Writing to disk from $>100k$ cores is beyond me.
- 100's of TB's of output for a project
- 100's of GB's per write
- Big savings from machine-specific tuning

Particles

- Lagrangian tracers
- Active (i.e., gravitating, SPH)
- Laser ray tracing
- Fluid-structure interactions

FLASH: A Multiphysics Simulation Framework

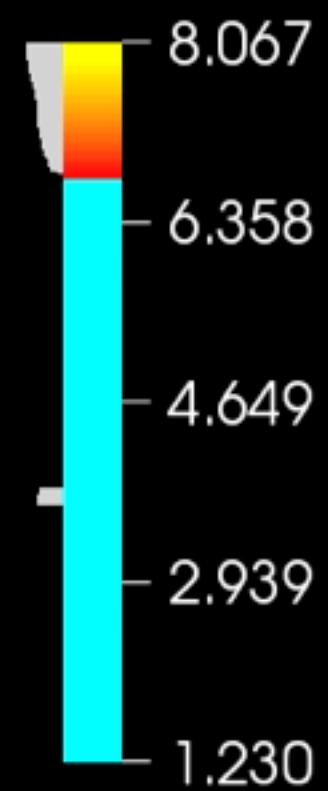


Adaptability: FLASH

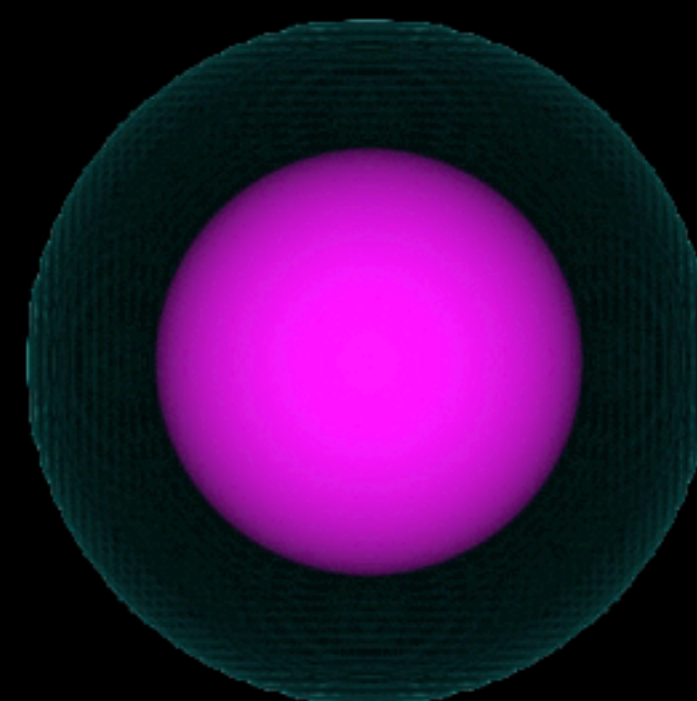
- Originally: thermonuclear burning in degenerate stars
- Then many other problems in Astro!
- Not for the core-collapse supernova mechanism

Adaptability: FLASH

- FLASH had: Hydro, gravity, AMR, I/O, data analysis/viz tools
- I could focus on just new stuff: nuclear equation of state, neutrino physics

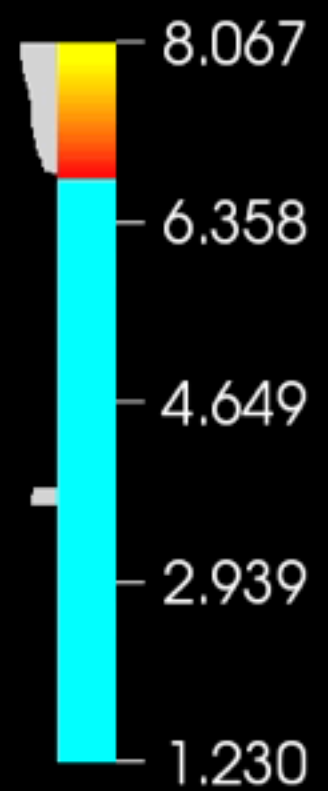


Time = 2 ms

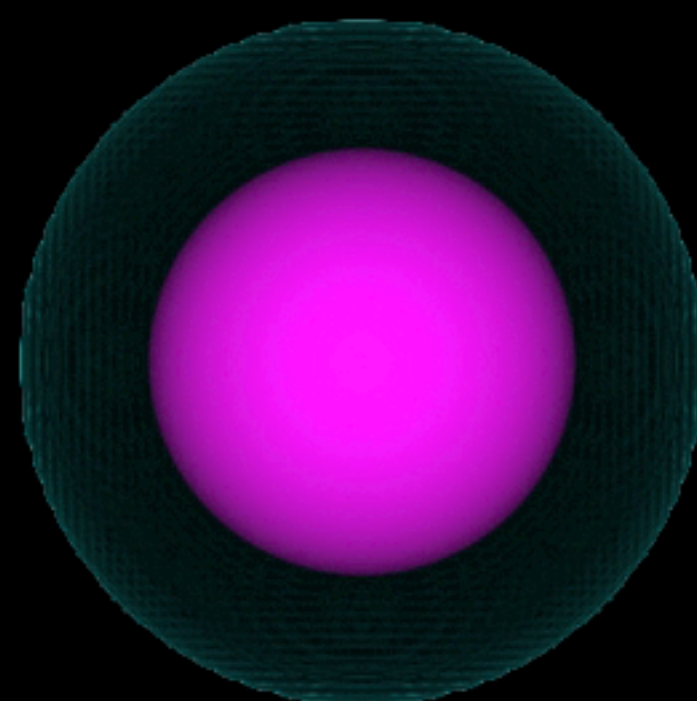


200 km

SMC & Ott 2013, ApJL, 778, L7



Time = 2 ms



200 km

SMC & Ott 2013, ApJL, 778, L7

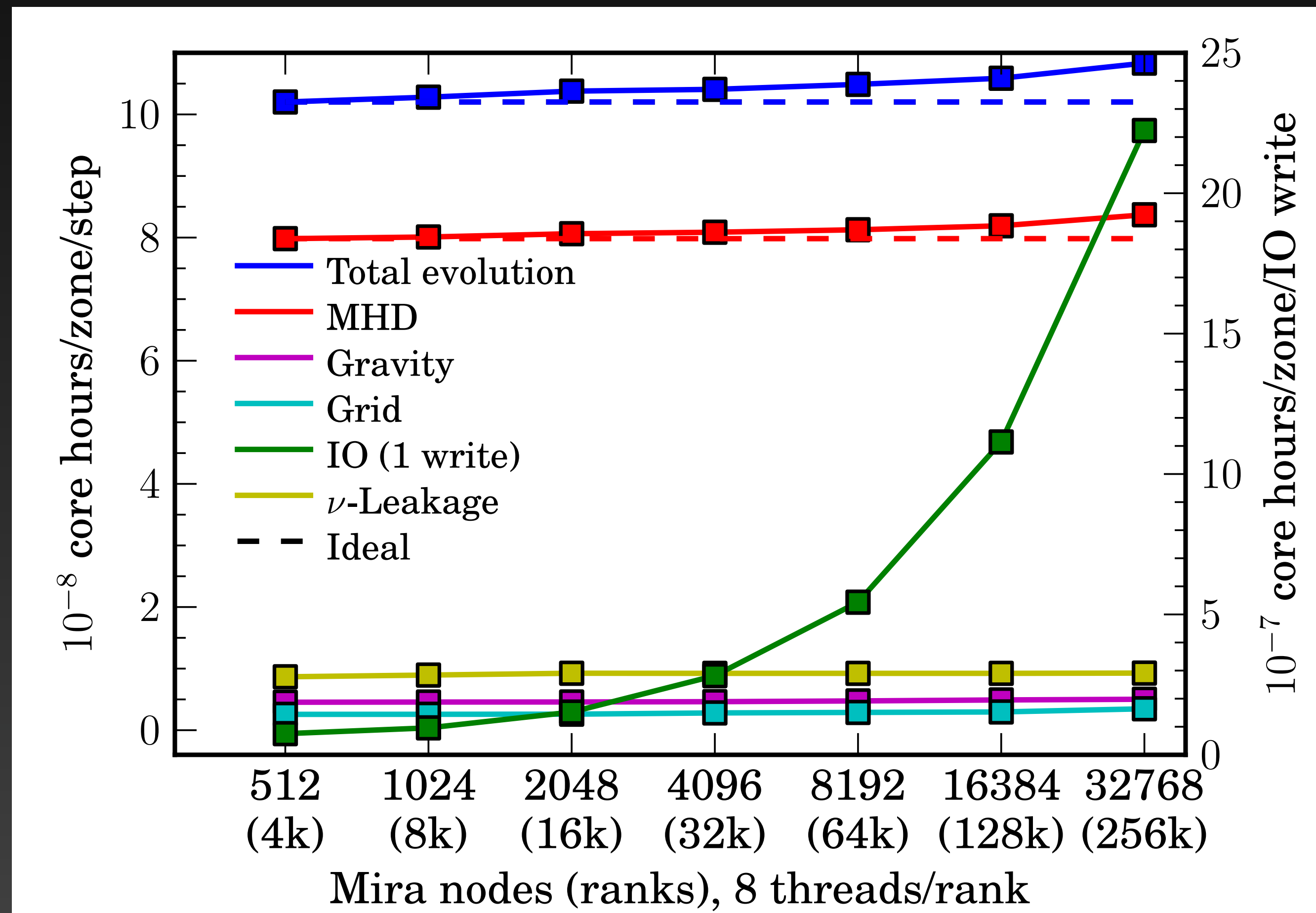
Petascale Simulation of Magnetorotational CCSNe

- Argonne Leadership Computing Facility: **Mira**
- 30 million DD hours per year in 2013 & 2014.
- Awarded **DOE INCITE** allocation of 50 million core-hours per year for 2015-2017.



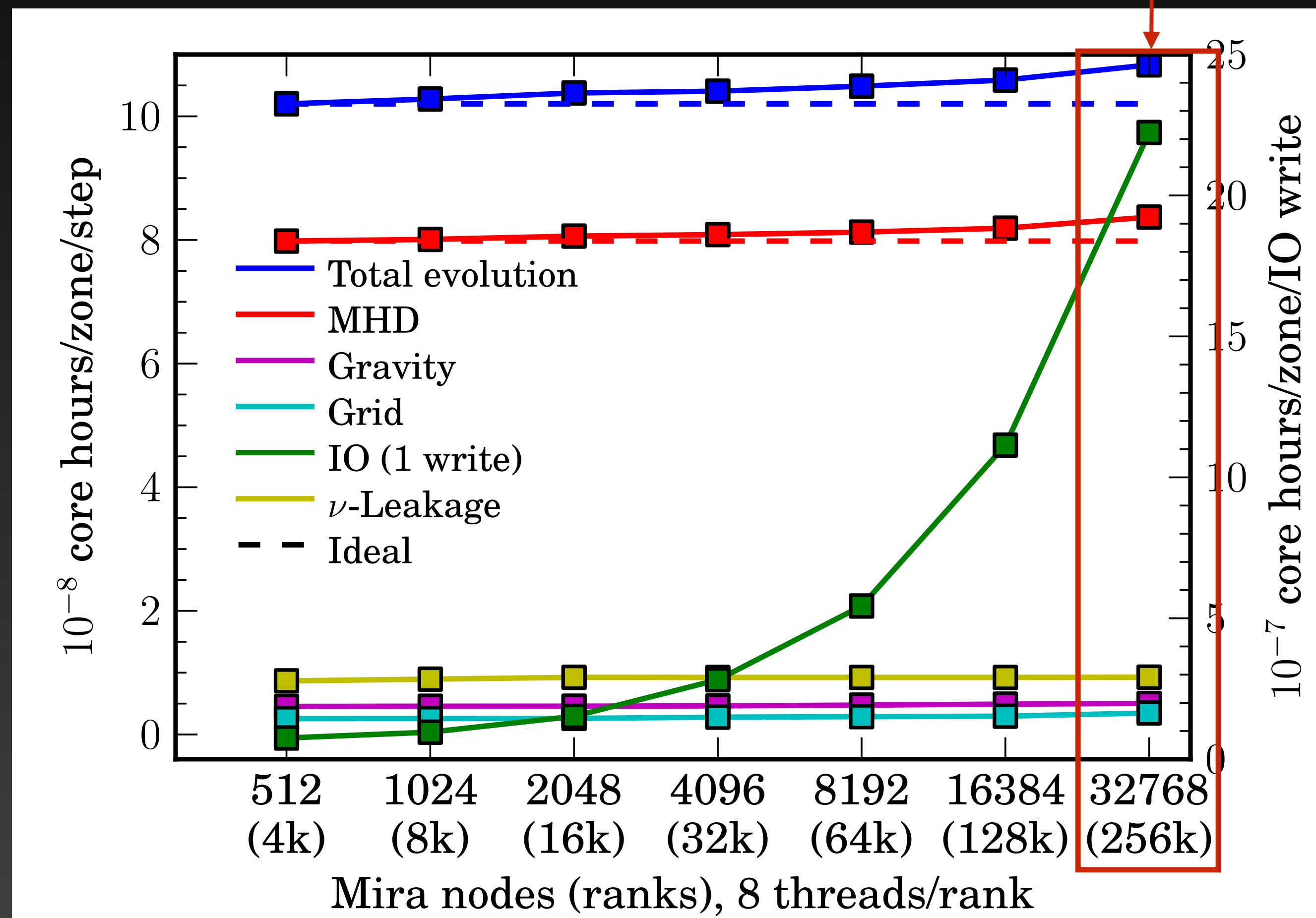
SMC (PI, MSU)
Almudena Arcones (Darmstadt)
Manos Chatzopoulos (Chicago)
Carla Frohlich (NC State)
Dongwook Lee (UCSC)
Evan O'Connor (NC State)
Daan van Rossum (Chicago)
Petros Tzeferacos (Chicago)
J. Craig Wheeler (Texas)

E.g. FLASH Scaling



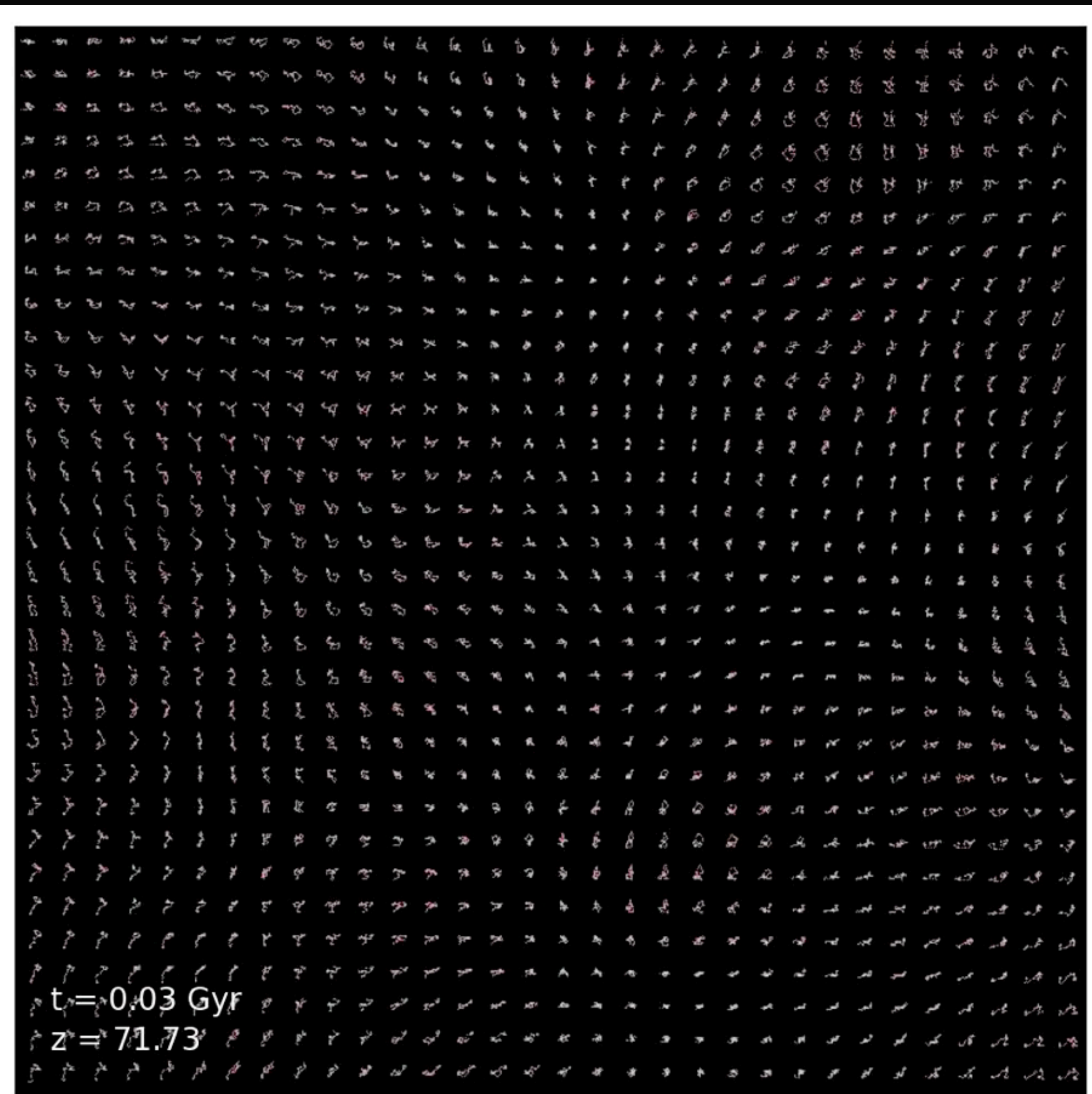
E.g. FLASH Scaling

524k cores!
>2 Million
threads!

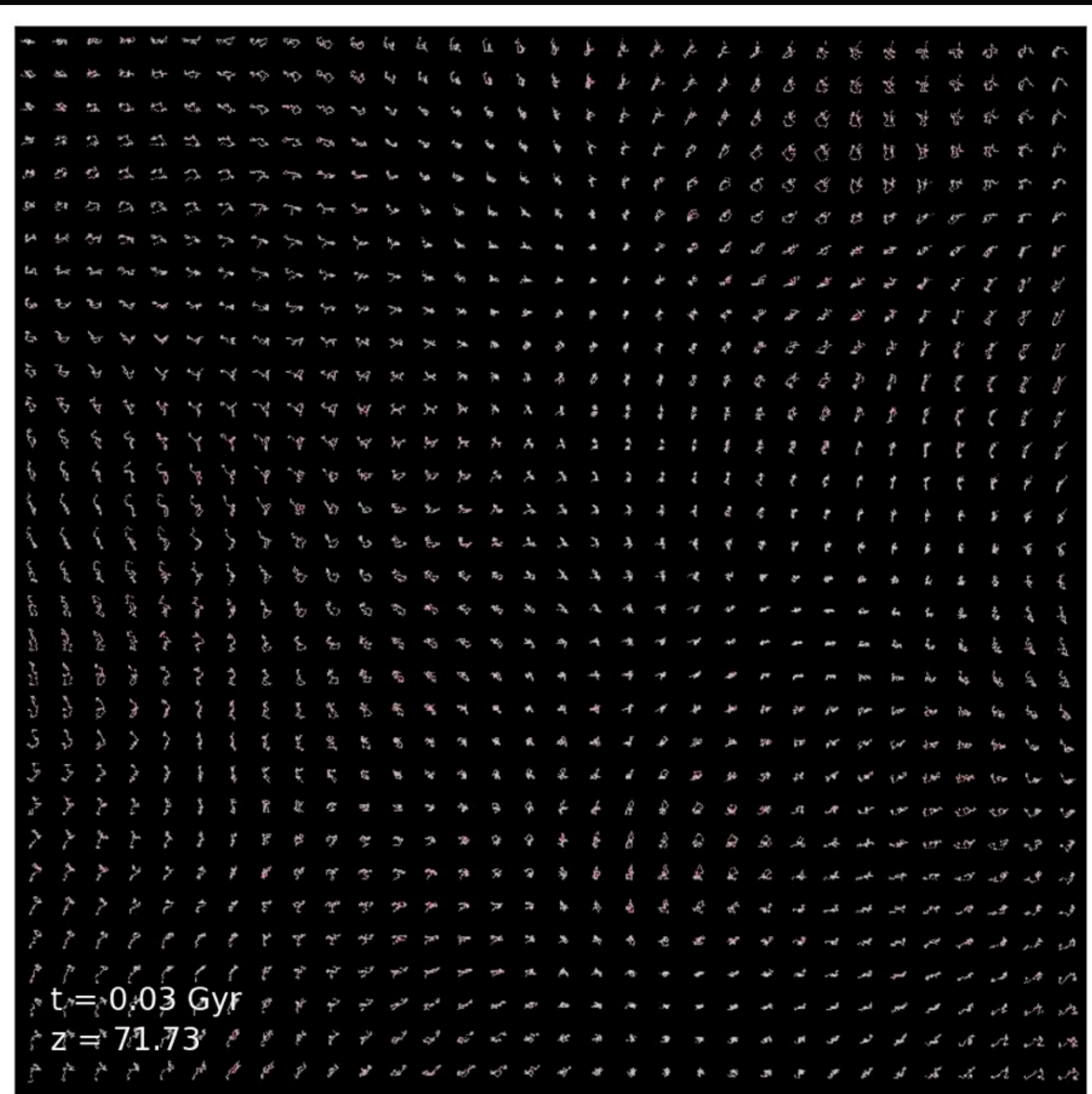


FLASH is Special

- Well-funded development for ~20 years
- Professional design/maintenance
- Core group of devs in central location
- Most astro codes done “on the cheap”



- Compressible MHD
- Cosmology
- Active (gravitating) particles
- Self-gravity
- Heating/cooling
- Radiation

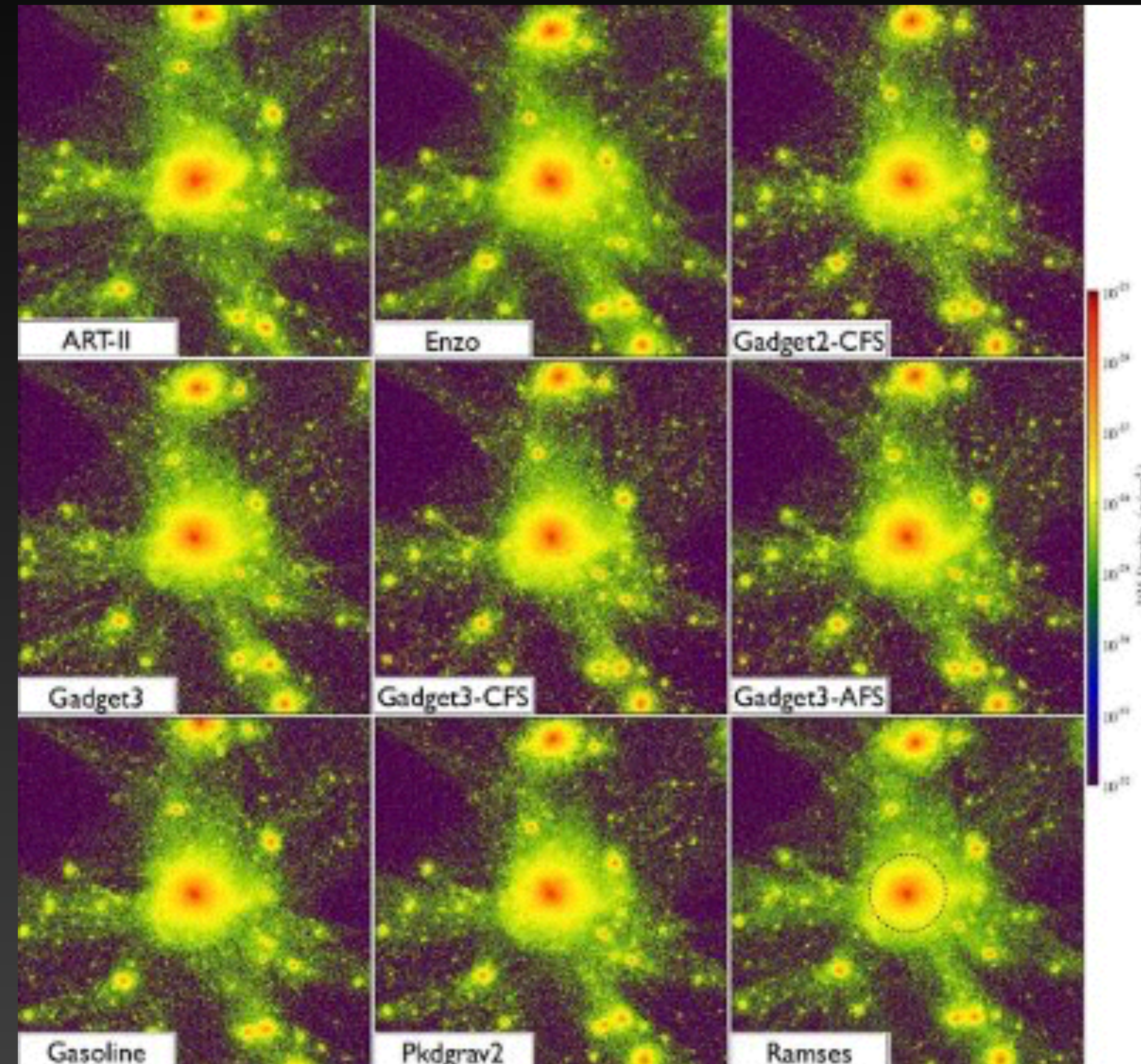


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Enzo

- ~12 core developers in very different locales
- Heavy use of online collaboration tools
- distributed version control (!)

- Started as part of Enzo collaboration
- Data analysis and visualization
- Glued together with Python
- Grew to many other codes
- Amazing dev community



Not all areas of Astro

- Stellar evolution
- Radiation transport

Massive Stars

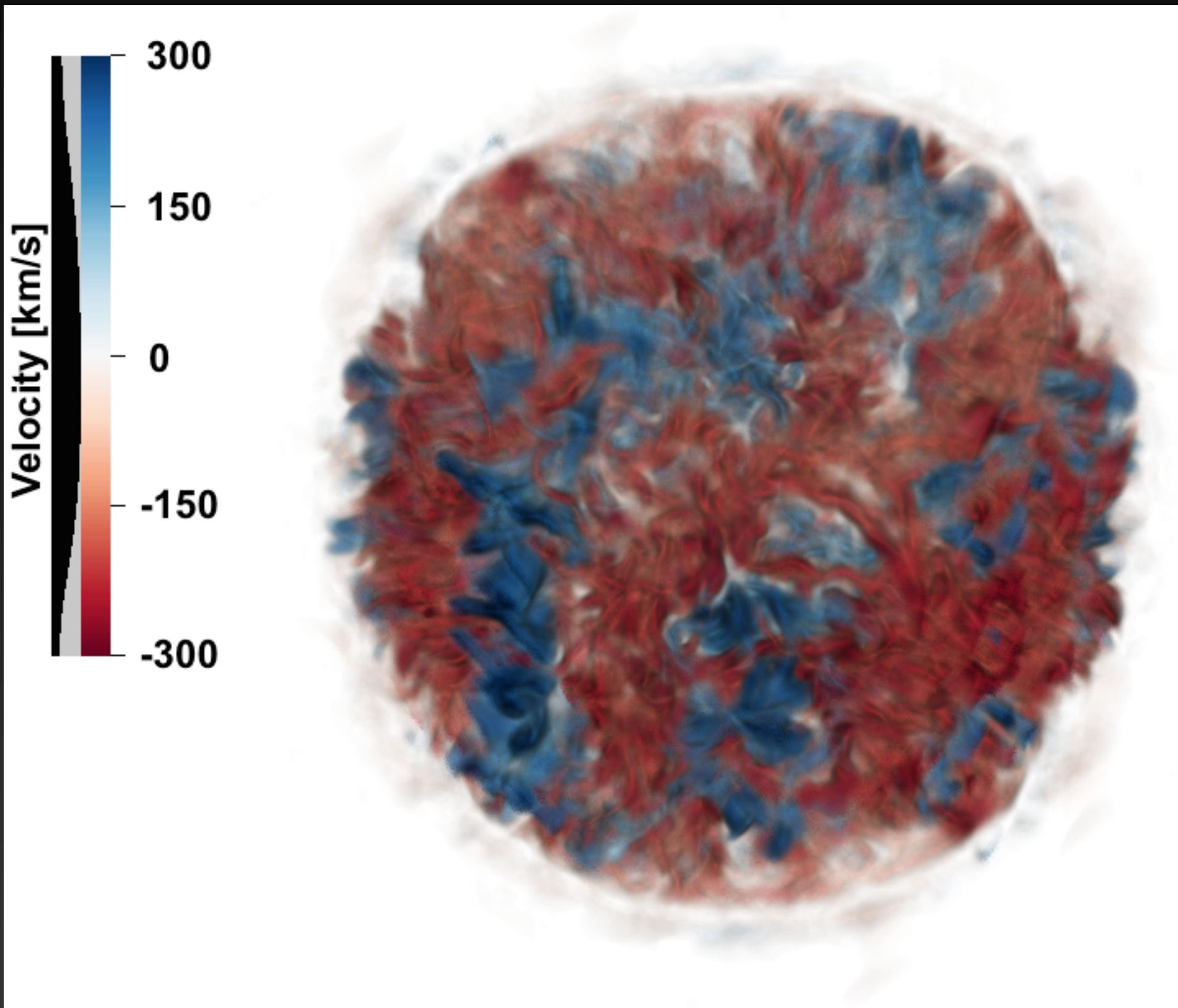
- Core-collapse supernova progenitors
- One code, one group for decades!
- New community code: MESA

MESA

Modules for Experiments in Stellar Astrophysics

- mesa.sourceforge.net
- Started with one principal dev (Bill Paxton)
- Grown into large, active community
- Distributed development
- Contributions generally go through Bill

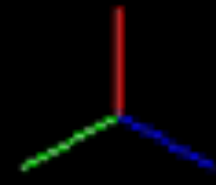
MESA Enabling New Science



SMC et al. 2015, ApJL, 808, L21

- Combine two different community codes: FLASH + MESA
- Can address new problems!

0 s



3×10^8 cm



3.00×10^7

1.80×10^7

6.00×10^6

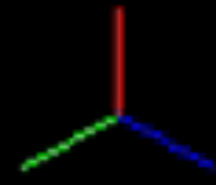
-6.00×10^6

-1.80×10^7

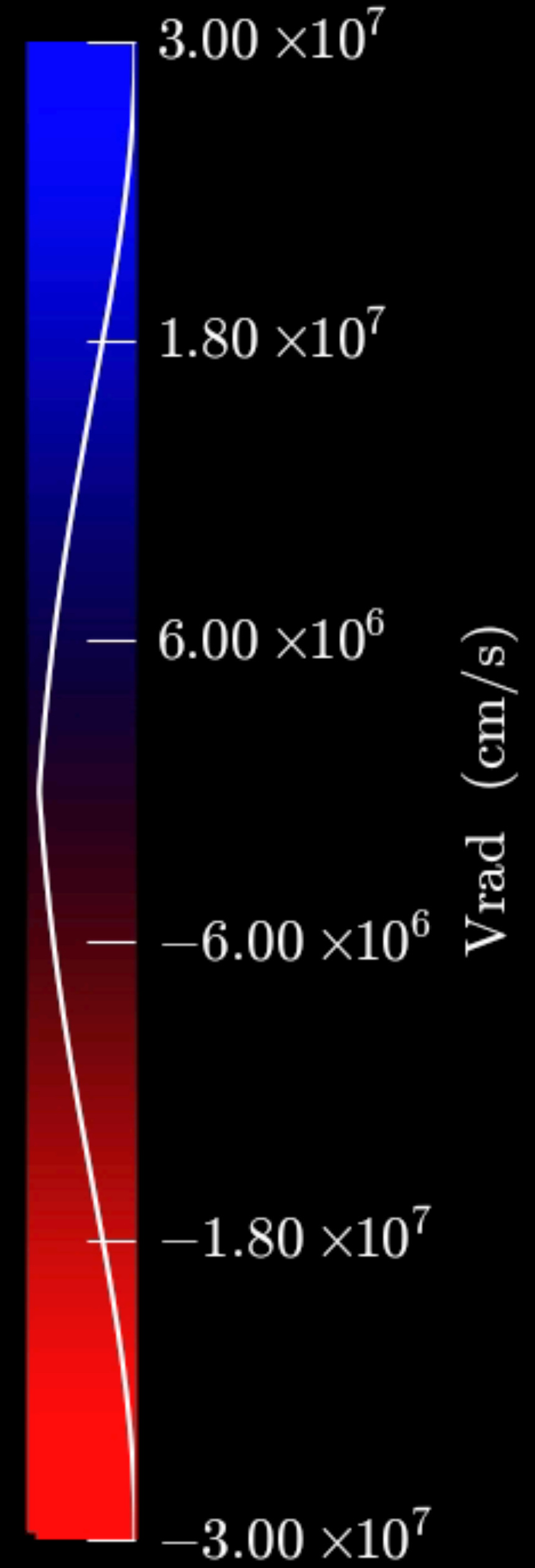
-3.00×10^7

V_{rad} (cm/s)

0 s



3×10^8 cm

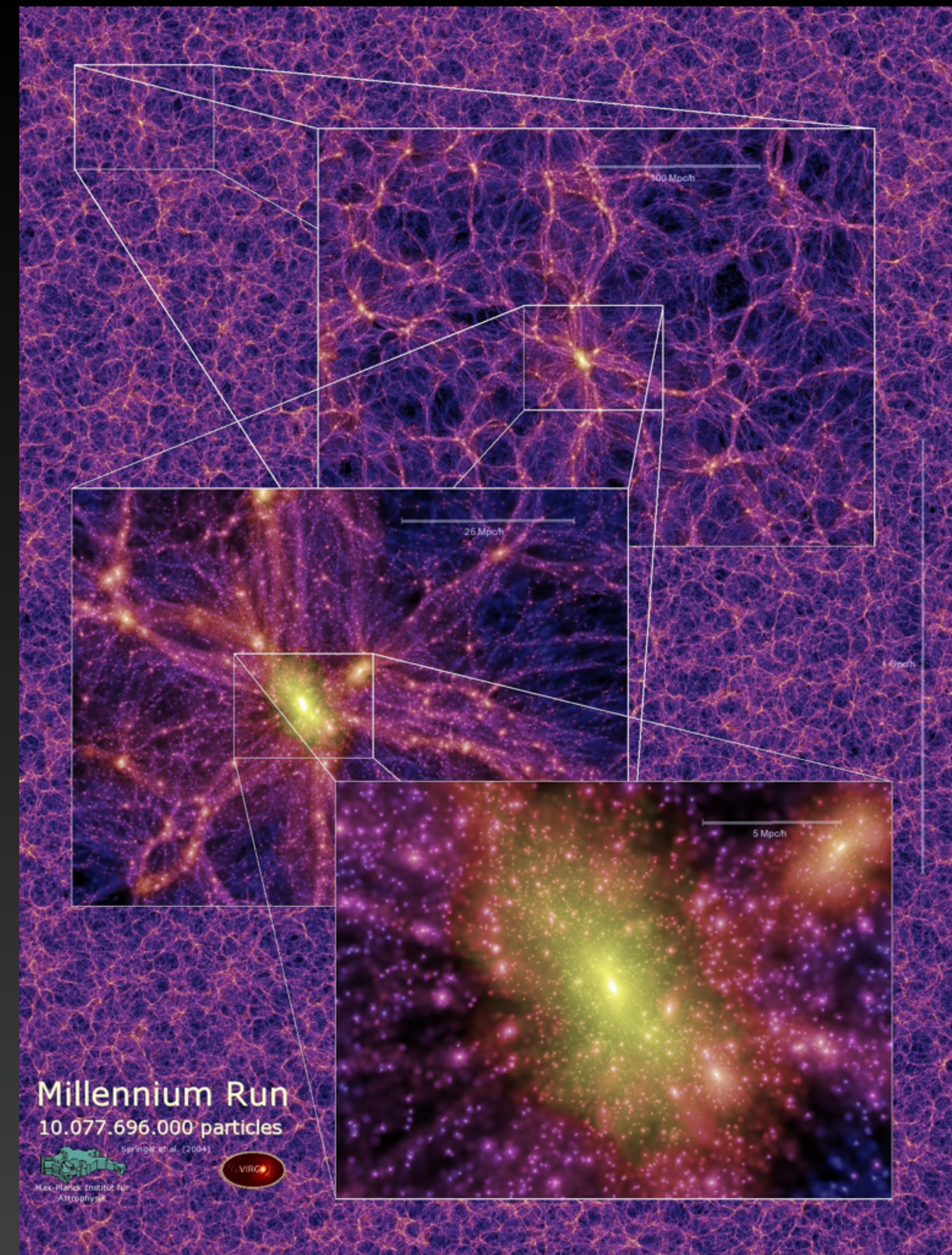


Some pitfalls

- If you make it too easy to use, or too stable, everybody will use it.

Gadget

- N-body (active particles)
- Smoothed particle hydro (SPH)
- Various heating/cooling
- Very centralized development: V. Springel

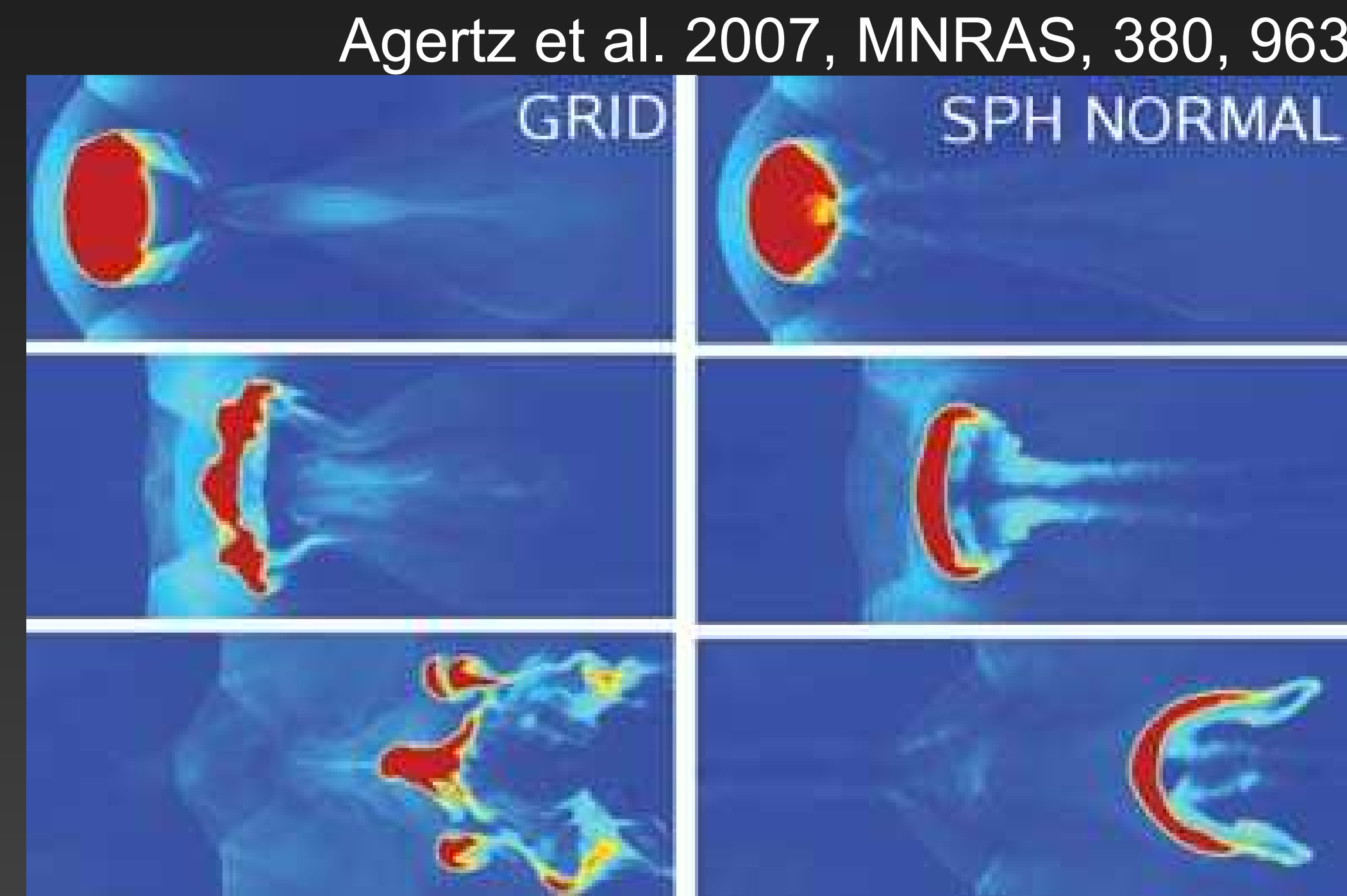


Cautionary Tale: Gadget

- Easy to use, stable, open =>
- Enormous impact on galaxy formation!
- But.... Problem with original implementation of SPH

Cautionary Tale: Gadget

- Easy to use, stable, open =>
- Enormous impact on galaxy formation!
- But.... Problem with original implementation of SPH
- Distribution model meant slow adoption of fix (a la *Stagefright*)
- Proliferation of proprietary versions



Some pitfalls

- Code divergence (balkanization)
- Can be a problem in all development models

Some pitfalls

- Assigning credit
- Codes are “instruments” and builders deserve credit
- Traditional academic mechanisms (publications, citations, etc.) often don't fit

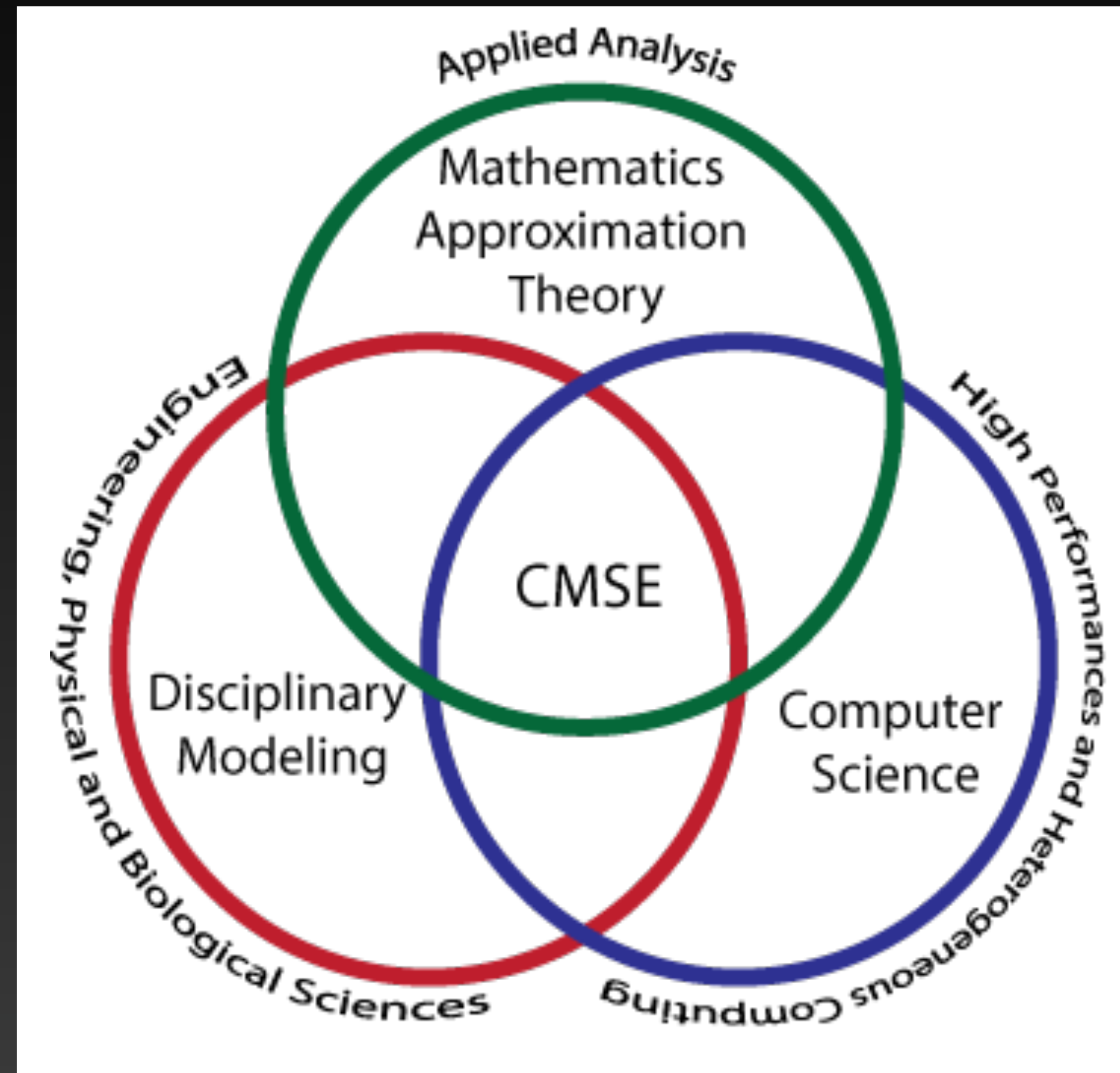
The Future

- Hardware complexity increasing...
- Today's codes may be living on borrowed time
- Need portability
- Abstraction of tasks may be critical!
- Need professional architecture and design

The Future

- But... funding for professional development of astrophysics codes has **DECREASED**
- No way to exascale without it.
- May be no way to 100 petaflops without it!

Computational Math, Science, Engineering at MSU



Overview

Code	License	Dev Model	Distribution	Language	
FLASH	Custom*	Central	tarball	F90/C	
Enzo	Uofl/NCSCA	Distributed	hg	F90/C++	
Gadget	GPL	Central?	tarball	C	
CASTRO	BSD	Distributed*	git	F90/C++	
Cactus	~GPL	open/devs	tarball	C++/F90	
Zeus	?	disparate	tarball	C	
MESA	GPL	open*	svn	F90	
Athena	GPL	open*	tarball	C/F90	
yt	BSD	open	hg	Python/C	
Pluto	GPL	open	tarball	C++	