AMUSE kickoff meeting – MODEST 9d

Science with AMUSE

Sterrewacht
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Outline

- Introduction

- experience with (A)MUSE

- Scientific validation: Signpost applications

- First Science:
  Clusters evolution in realistic galaxy environments
  Radiation hydrodynamics with AMUSE

- Conclusion

Introduction

- AMUSE: package to do multiphysics/
  multiscale simulations using legacy codes
- successor to/derived from MUSE
- development started May 2009, so early phases

use for research from the beginning:

- what is needed to make AMUSE an effective tool?
- what are the lessons for the design of AMUSE?
- what are the problems AMUSE is most suited for?

Introduction: modules as classes

- modules provide classes

different ways of extending:

- functional
- derived classes (new modules)

Coupling codes

ways of coupling codes:

- data passing: end point as start
- returning state info: particle queries
- expose state(e.g. gravity): interface?
- functional (callbacks)
- make solvers available

import code experience:

- interactive code testing with python is useful!

- some coding will normally be necessary:
helper functions, unimplemented interface functions,
bookkeeping, handling parameters, initialization

- f2py+SWIG benefits: memory access, callbacks

- f2py+SWIG drawbacks: tricky implementation,
global data collisions (problem for instances)

- MPI benefits: parallel ready, independent instances

- import of MPI codes not a problem

- GPU issues (reinitialize every step to be safe)

Introduction: codes to be included

Gravitational Dynamics

phiGRAPE
octgrav
BHtree

Hydrodynamics*

fISM-stars
VINE
Athena3D
Pencil

Stellar Evolution

EZ/EZier
SSE
TYCHO*
STARS

Radiative Transfer*

MOCASIN
Simplex
RADMC3D
SPHray

* under consideration/ pending evaluation

Scientific validation

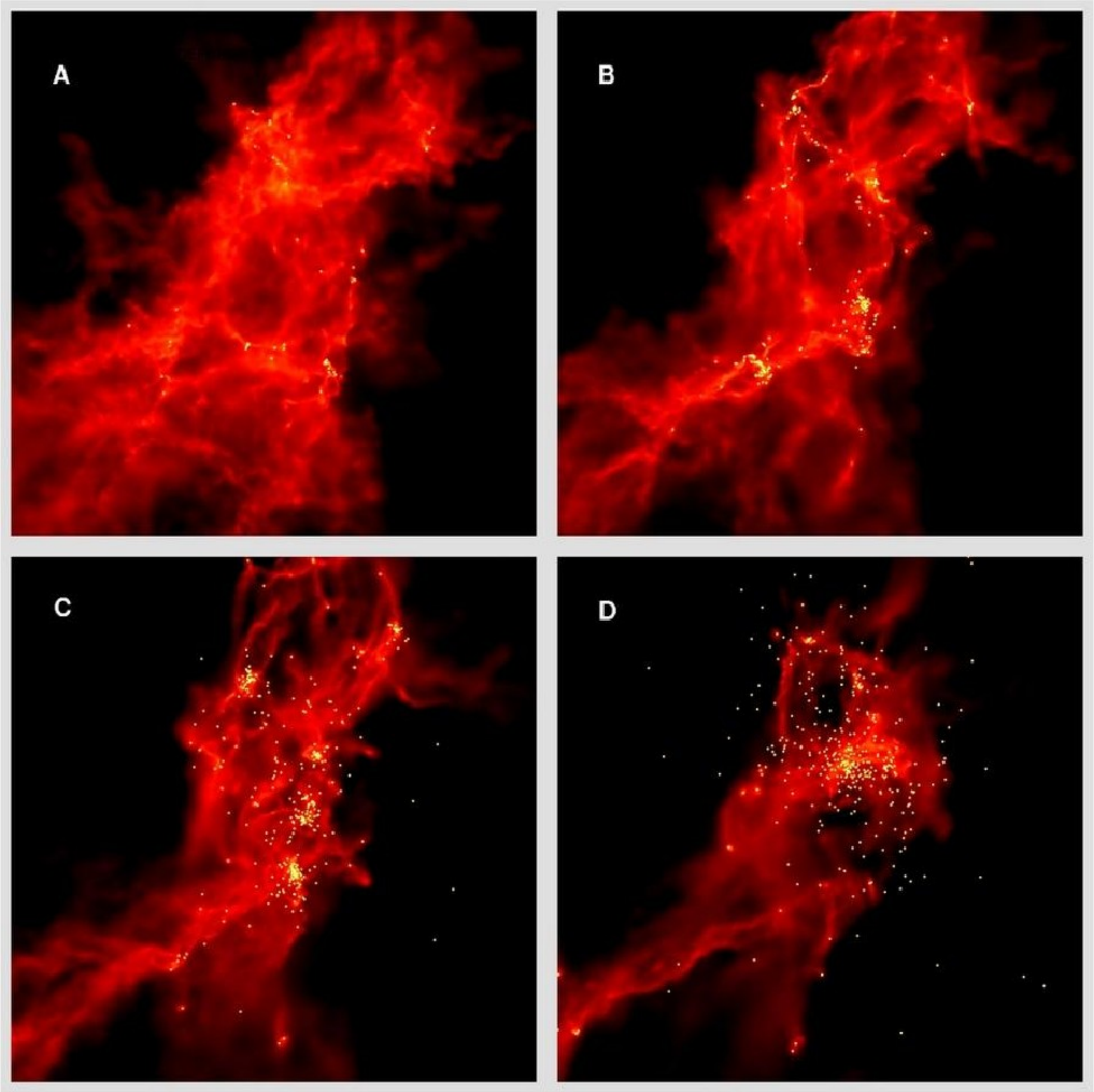
How do we demonstrate the utility of AMUSE?

> we will develop "Signpost" applications:

- tests that go beyond unittests
- reproduce results in the literature
- multiple physical modules
- well defined, small (now at least!), problems
- quantitative and qualitative comparison

so lets go through our current wishlist....

Hierarchical Cluster formation



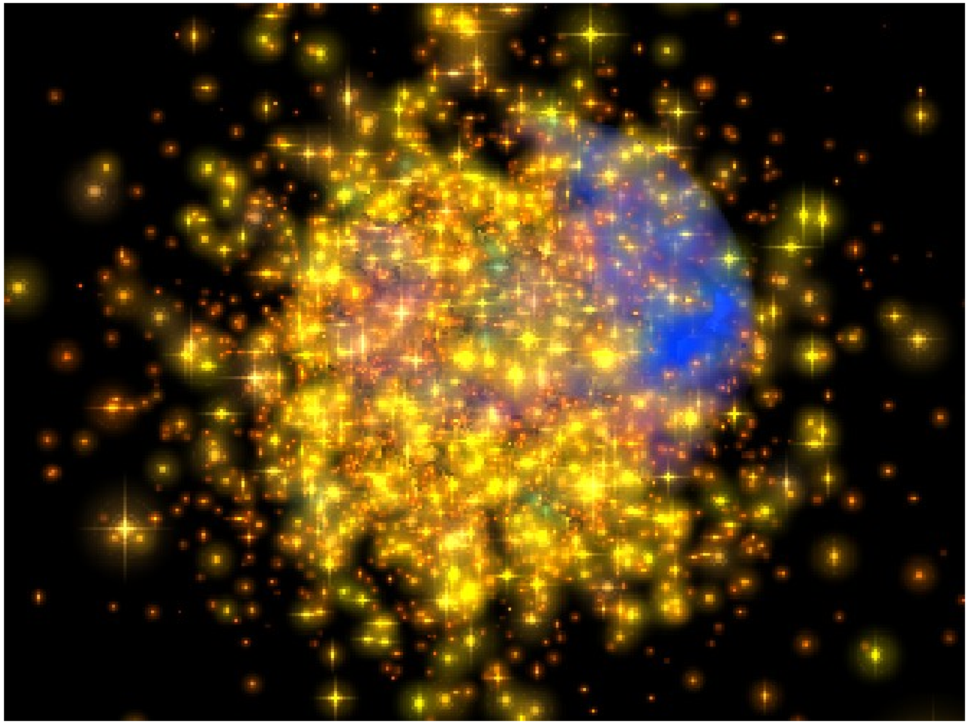
Bonnell et al 2003.

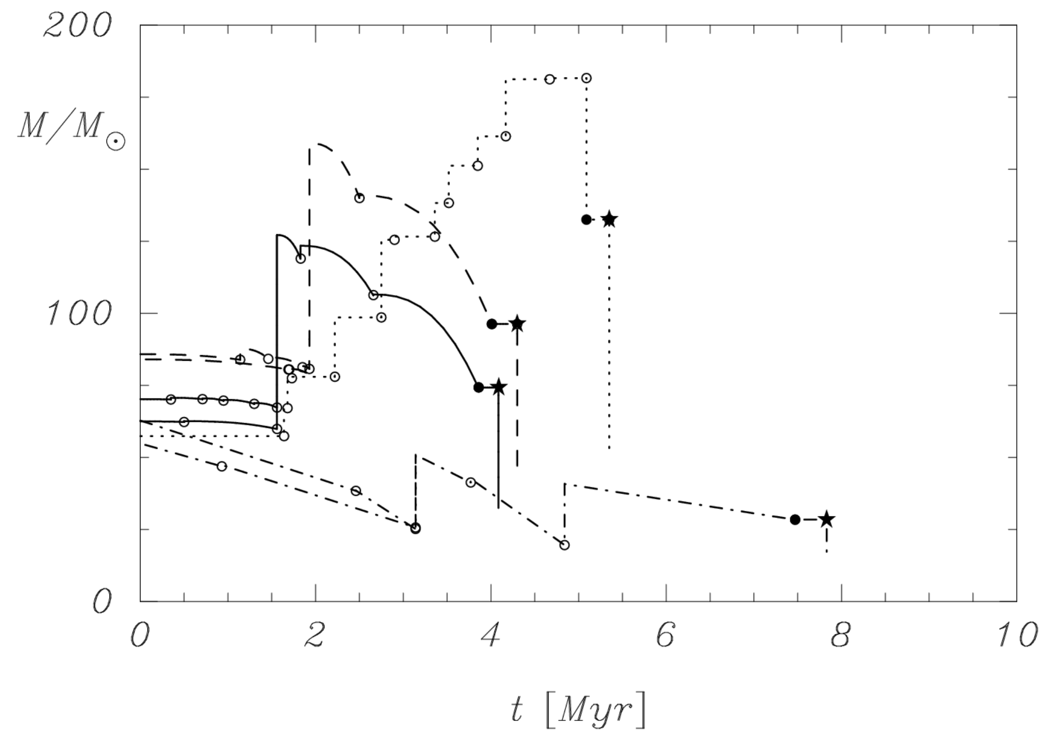
hierarchical collapse of a molecular cloud and formation of cluster

uses
- Gravitational dynamics
- Hydrodynamics
- simple binaries/ collisions

compare
- stellar mass function
- densities

Cluster Ecology





Portegies Zwart et al. 1997,1999

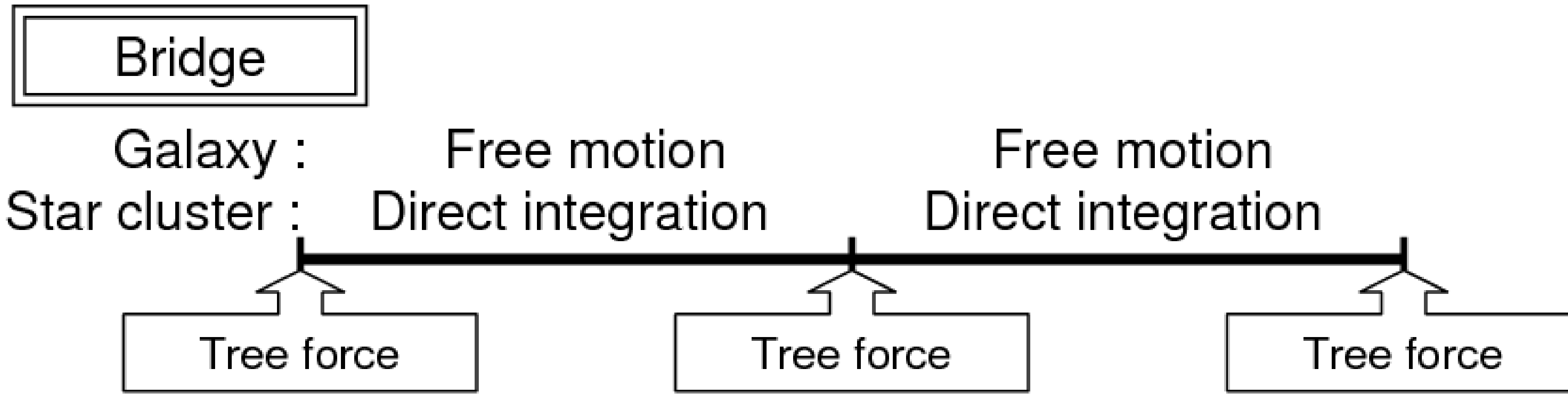
evolution a cluster with realistic stellar evolution

- Gravitational dynamics
- Stellar evolution
- Binaries
- Stellar collisions

compare: merger histories, binary energy, cluster structure

Bridge N-body integrator

Fujii et al. 2007



Combine two N-body integrators - implementation in AMUSE:

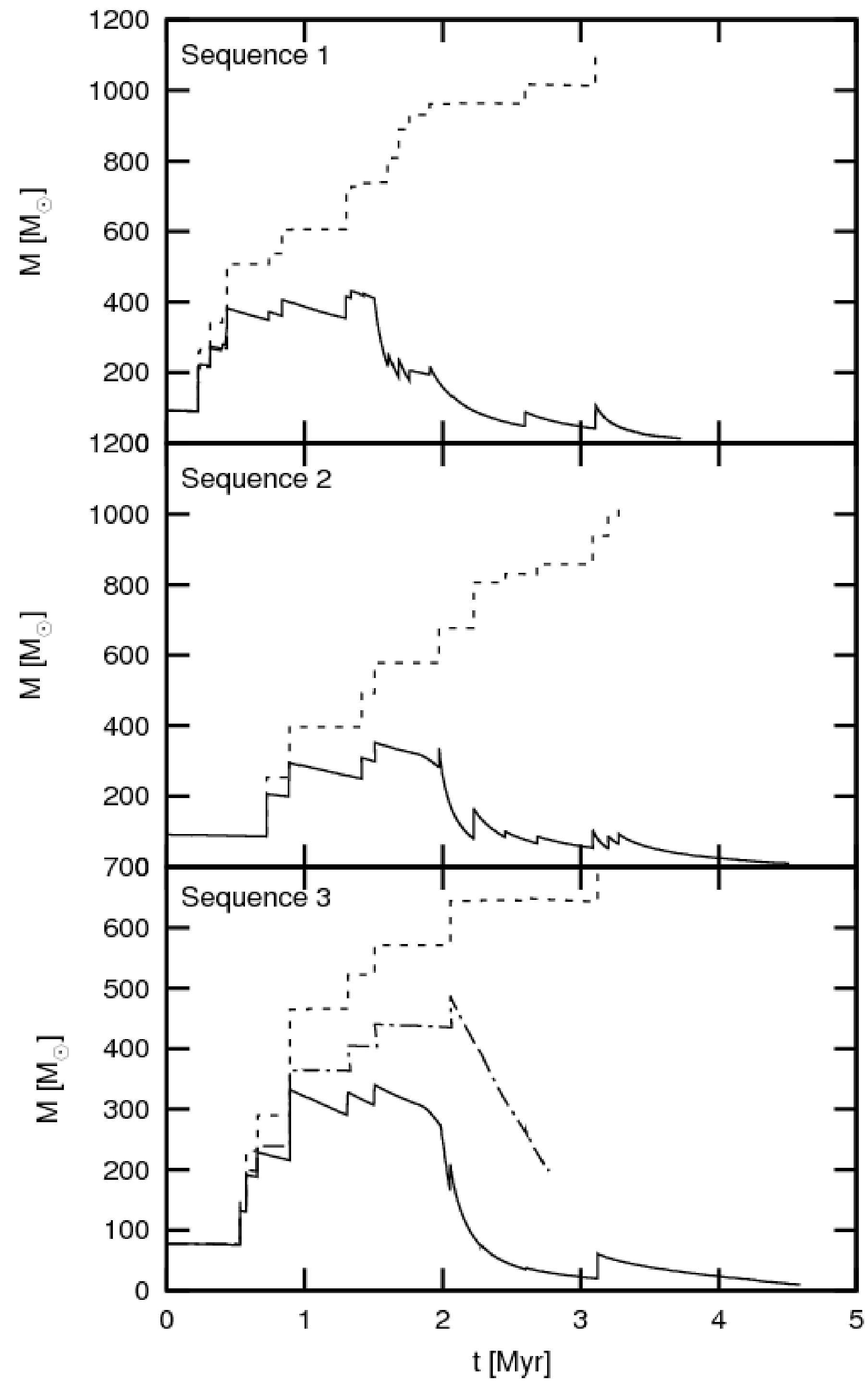
- interface function for gravity function
- kicks in python
- combine treecode and direct hermite integrator

Runaway Collisions
in dense stellar clusters

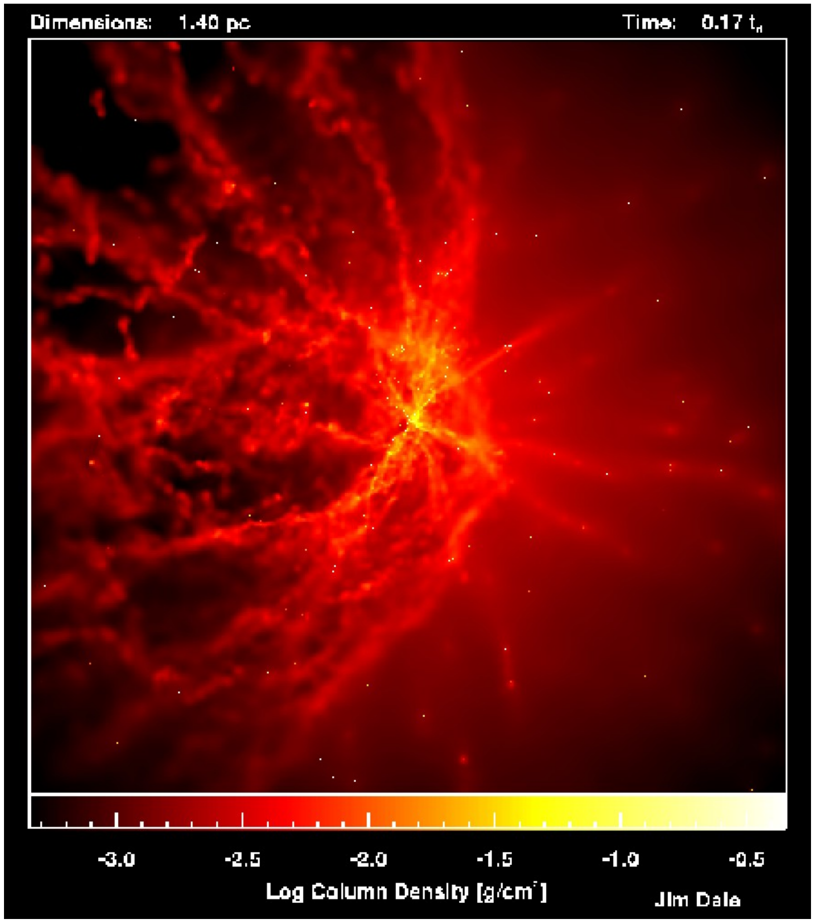
Glebbeek et al. 2009

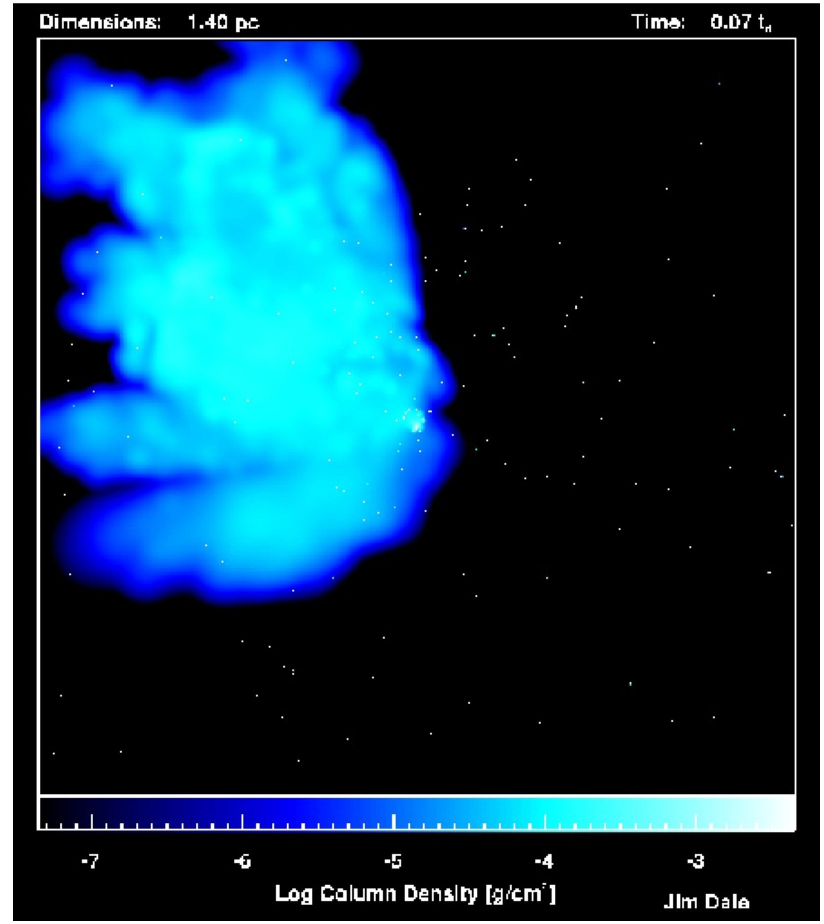
- Gravitational dynamics
- Stellar Collisions
- Stellar evolution

compare:
evolution of merger remnants



Cluster Formation with Photo-Ionization Feedback



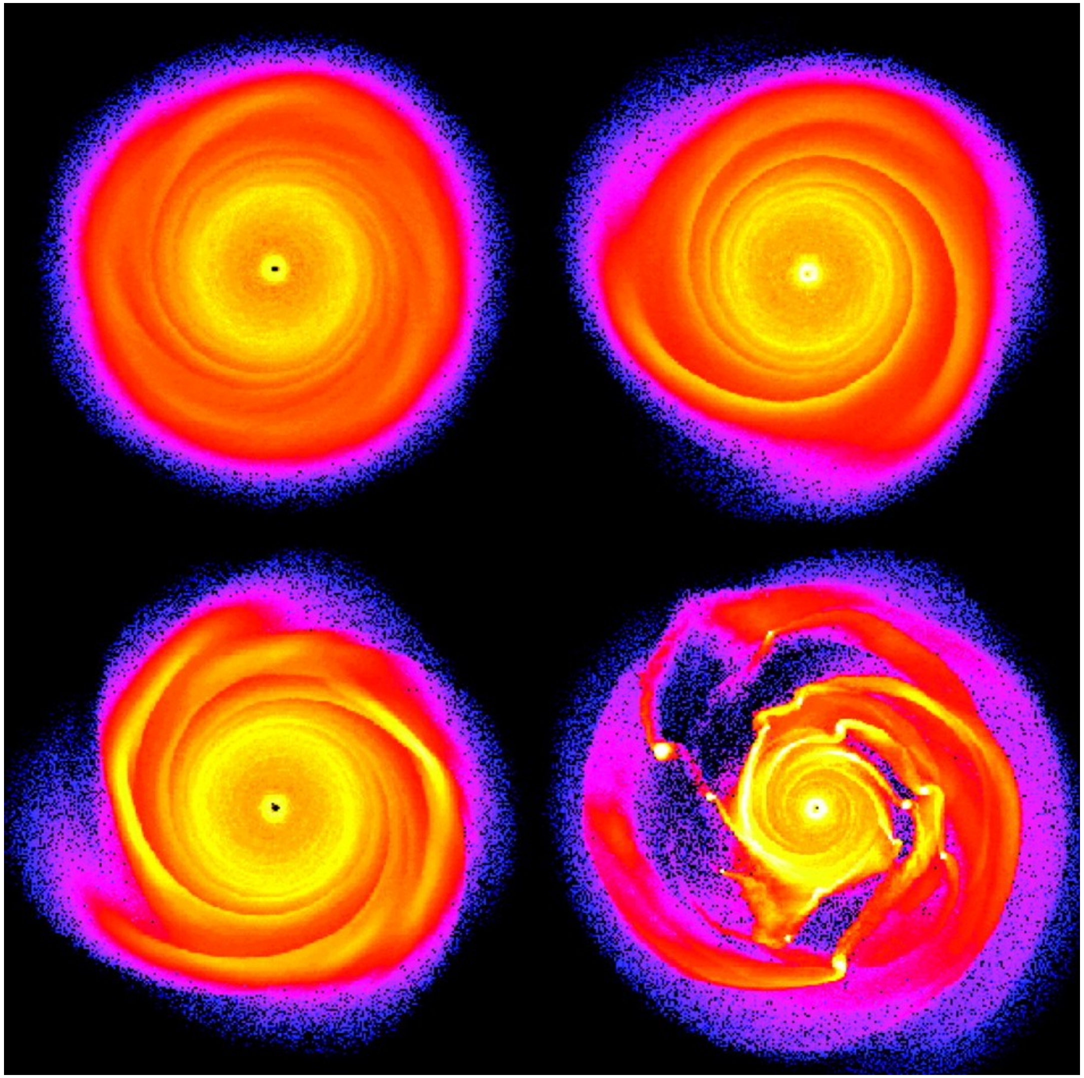


Dale et al. 2005

- Gravitational dynamics
- Hydrodynamics
- Radiative transfer

compare: ionization fraction, Jeans mass

Collapse of an unstable proto-Planetary Disk



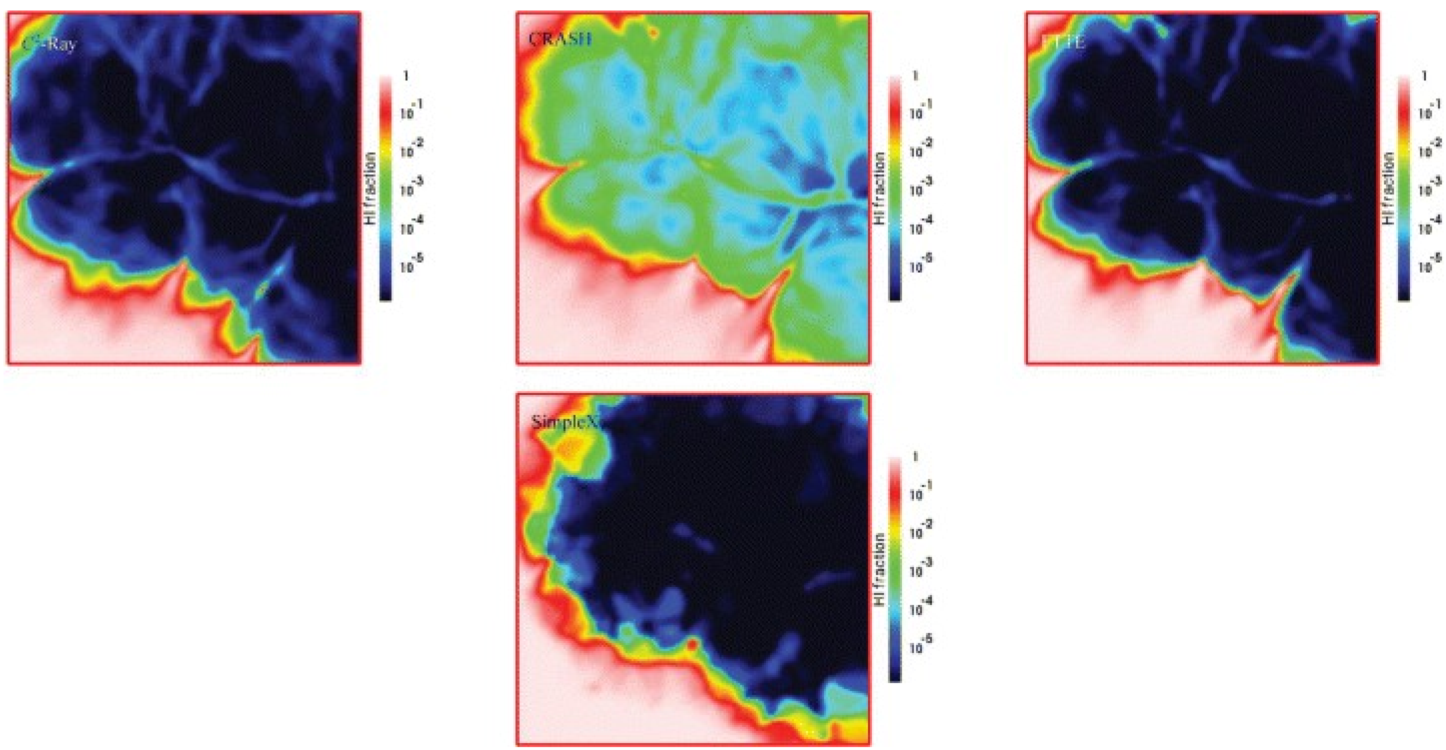
Mayer et al. 2002

- Gravitational dynamics
- Hydrodynamics
- Simplified thermodynamic description

compare:
overdensities
properties of proto-planets

Radiative Transfer Comparison tests

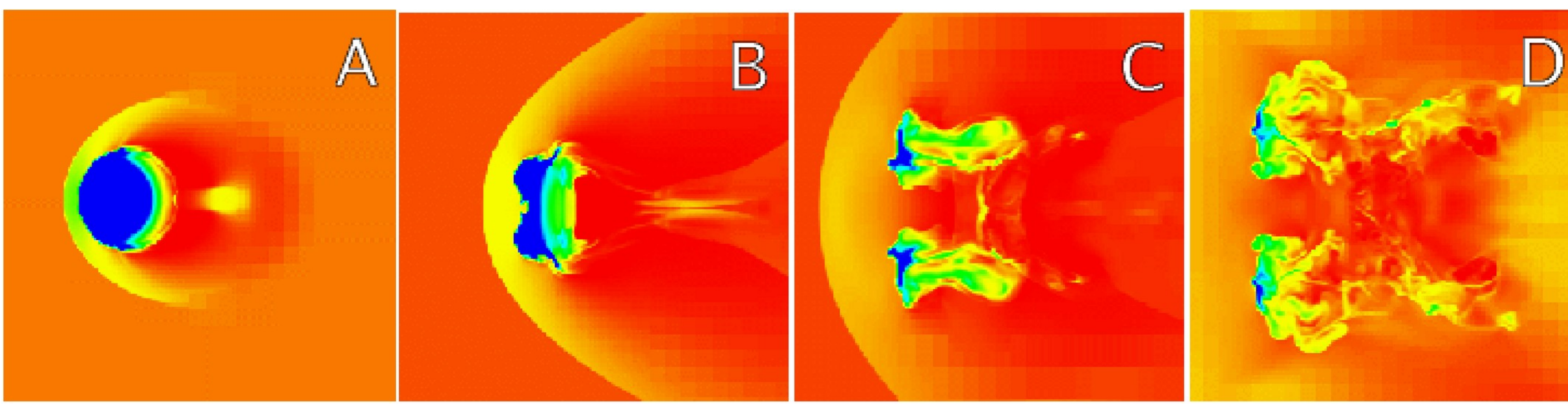
- Radiative transfer relatively immature
- tests in Iliev et al. 2006,2009
- continuum transfer
- simple chemical model: H,He

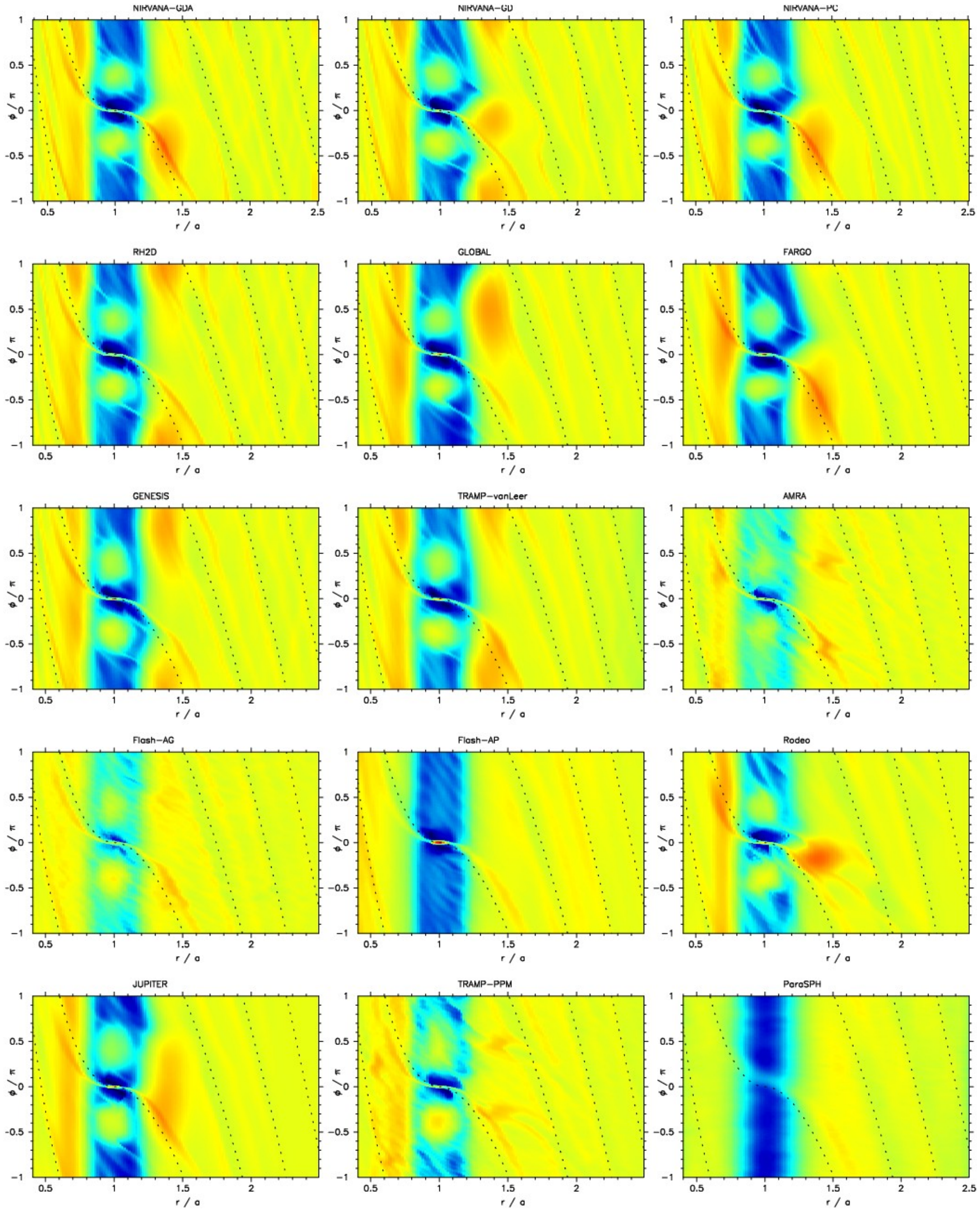


Cloud-shock interaction

Agertz et al. 2007

- pure hydrodynamic test
- sensitive test of Kelvin-Helmholtz instabilities
- comparison of particle/ grid methods





Disc-Planet Interaction

De Val-Borro et al. 2006

- Gravitational dynamics
- Hydrodynamics

- 2D/3D?

- more challenging than unstable collapse test

compare:
- density contrast
- planetary torques

Overview of Signpost applications:

	grav. dyn.	stellar evolution		hydro-dynamics		radiative transfer	
		single	binary	coll.	gas/ISM		
Cluster formation	x			x	x		Bonnel et al. 2003
Cluster ecology	x	x	x	x			Portegies Zwart et 1999
Galaxy+cluster	tree/direct						Fujii et al. 2007
Runaway Collisions	x	x		x			Glebbeek et al. 2009
Cluster formation and radiative feedback	x				x	x	Dale et al. 2005
Protoplanetary disks	x				x		Mayer et al. 2002
Comparison tests					x	x	Iliev et al 2006/2009
Cloud/shock interact.					x		Agertz et al. 2007, Mellema et al. 2002
Disc-planet interact.	x				x		De Val-Borro et al. 2006

- Not all combinations of modules (need to be) present

- Suggestions?

Science with AMUSE:
Cluster dissolution in realistic galaxy environments

problem: theoretical disruption timescales are longer than the observed disruption timescales of clusters

Environmental effects have been studied extensively:
(e.g. Spitzer 1958, Ostriker et al. 1972, Baumgardt & Makino 2003 Gieles et al. 2006,2007)

- **Galaxy potential**
- **Disk crossing shocks**
- **Spiral arms**
- **Giant Molecular Clouds**

increased detail = shorter disruption timescales

are the analytic estimates that form the basis of these studies reliable?

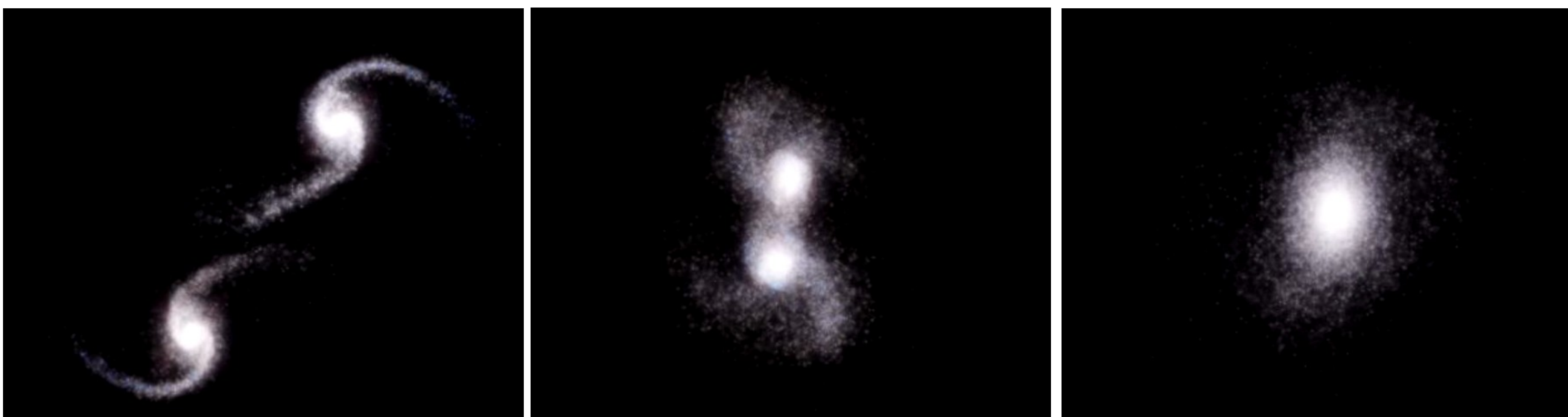
our current approach:

1 run full N-body/hydrodynamic models of galaxies
2 determine local tidal field tensor
3 use this as input to (semi) analytic cluster models

- takes the guess work out of modeling collision rates, tidal interaction strength
- realistic potentials instead of semi-analytic approximations
- exploration of more complicated configurations: galaxy interactions, mergers

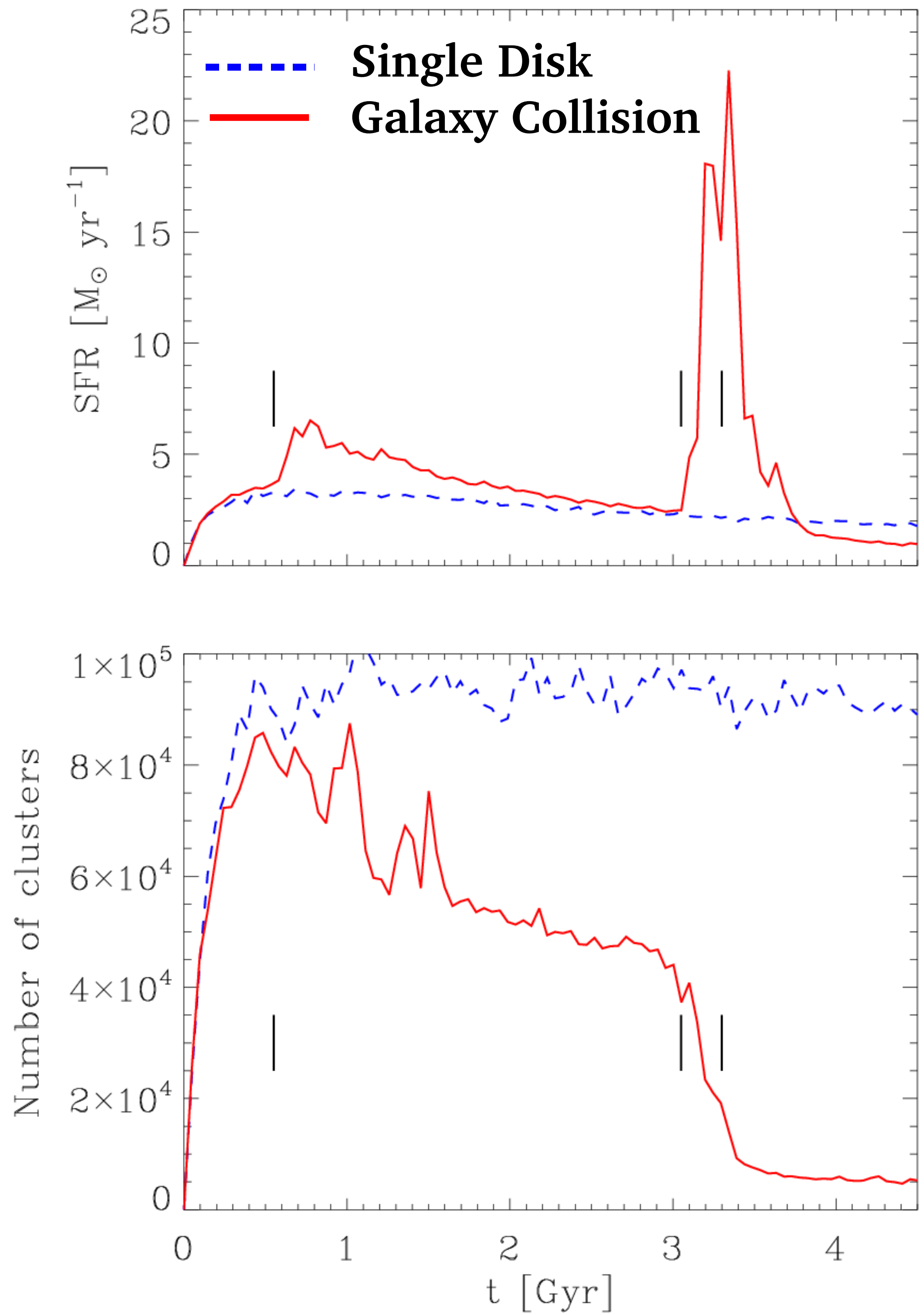
(However: still limited by cluster evolution model)

Merger runs
- **Nbody/SPH code**
- **ISM model, Star Formation, Feedback**
- **code coupled (outside AMUSE) to star cluster dissolution model** **(Kruijssen et al 2008, 2009)**
- ***semi-analytic*** **prescription includes stellar evolution, remnants and formula for effects of two-body relaxation, tidal shocks**

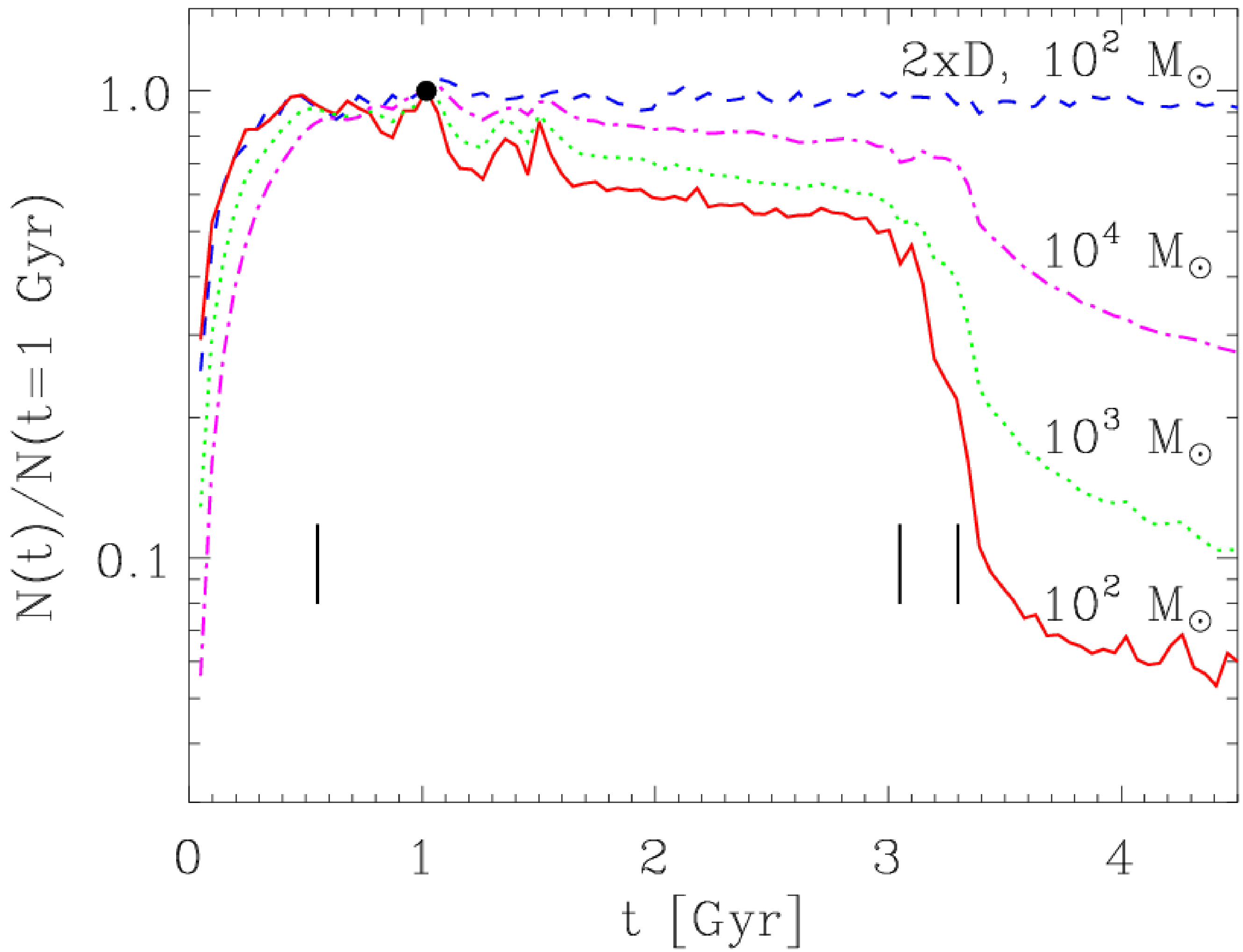


Star formation

No. of Clusters



Evidence for mass dependency:
formation of heavy mass cluster population?



Can we move beyond analytic estimates?
difficult: difference in scales between galaxy and star clusters

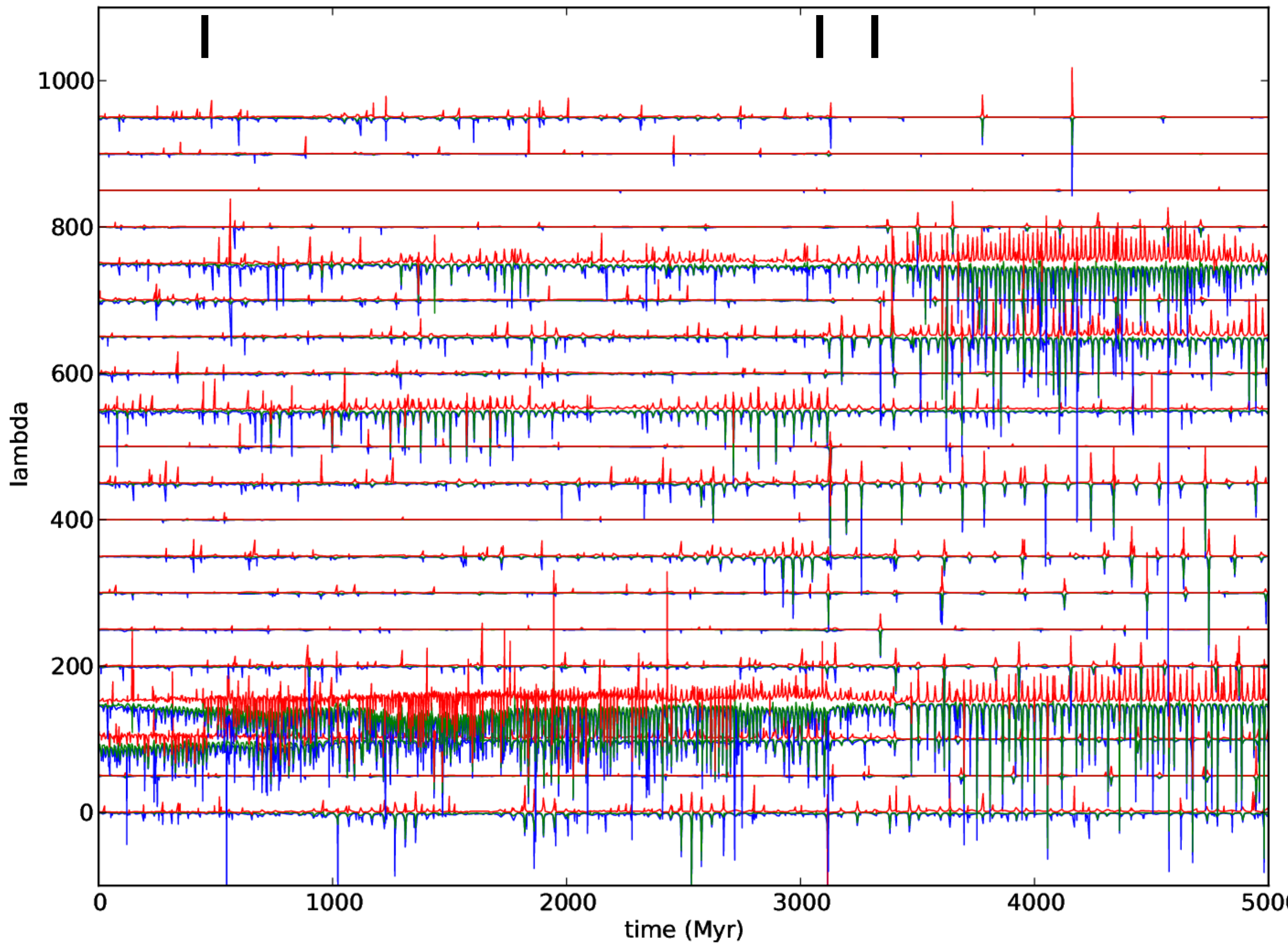
> ideal application for AMUSE

1
- extract tidal history for star particles from the simulation
- subject N-body clusters to this (time dependent) tidal tensor

2
run cluster simulations embedded in full galaxy model
(bridge scheme)

work in progress......

Tidal tensor (eigenvalues) of merger sim.



(blue, green, red: smallest to largest eigenvalues)

Science with AMUSE:
Radiation Hydrodynamics with AMUSE & Simplex

Biggest challenge: incorporating radiative transfer

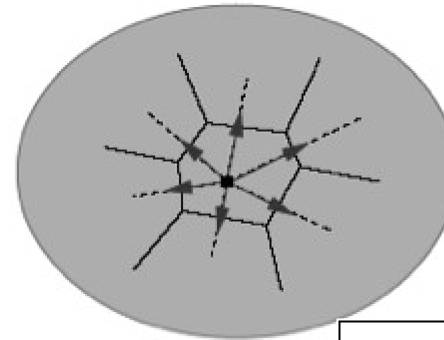
- different radiative transfer: line transfer, continuum

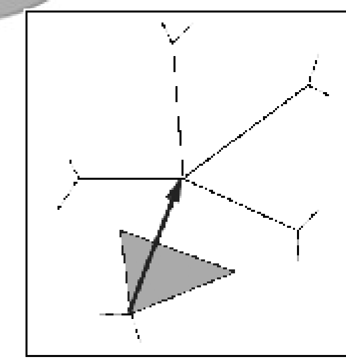
- Solving for the chemistry or detailed line transfer (for virtual observations)

- post-processing vs dynamic coupling

- easy coupling to hydrodynamic codes?

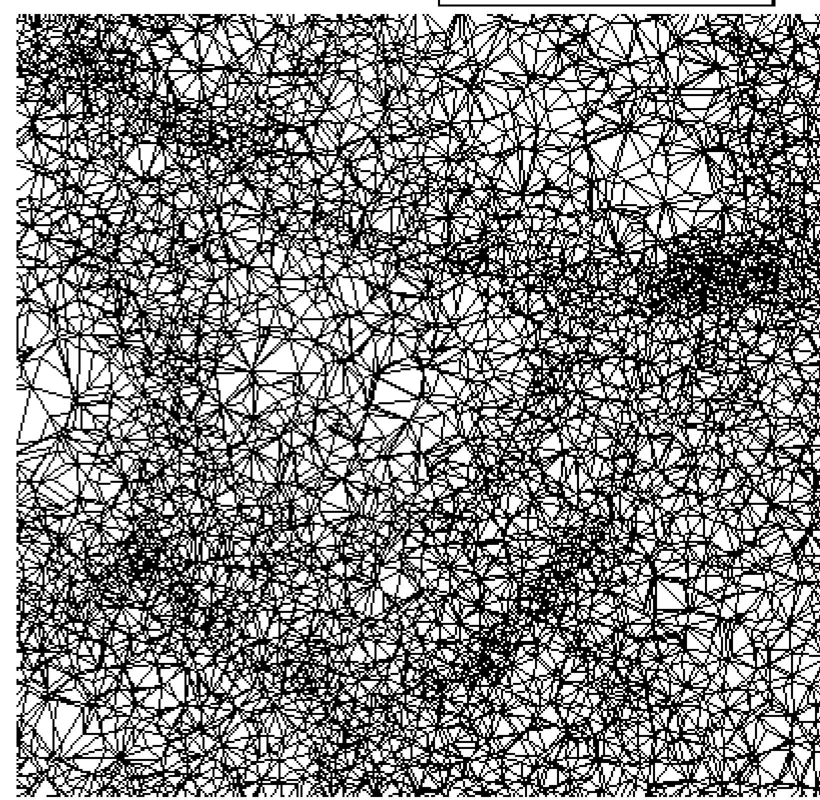
SimpleX





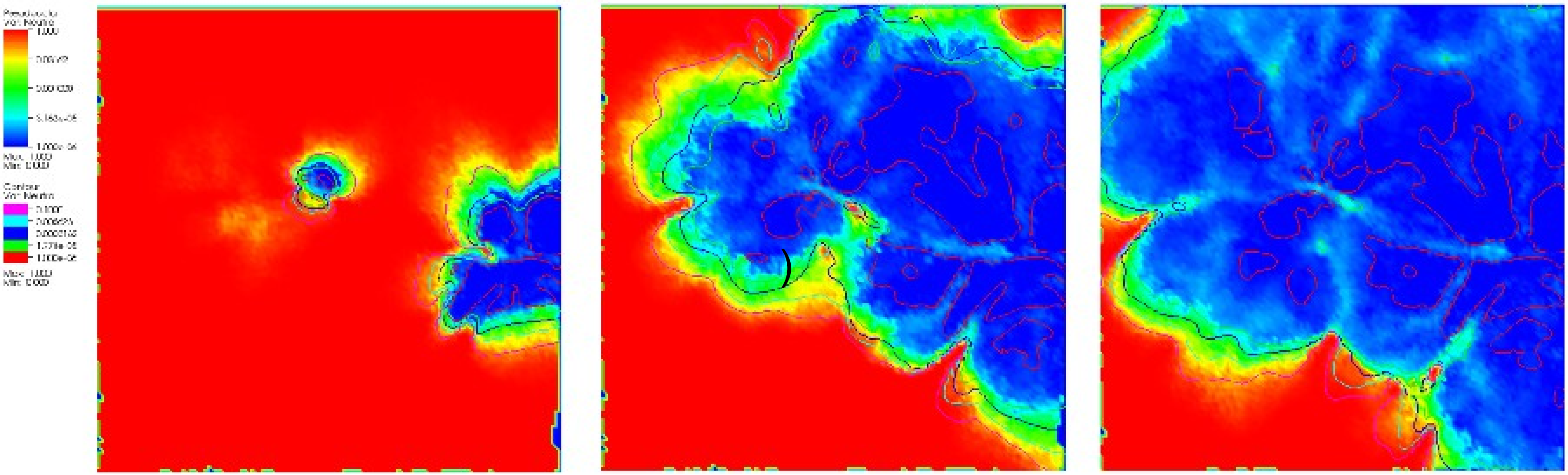
code for radiative transfer:

- Paardekooper et al. 2009
- Delaunay tesselation/
  Voronoi cell based
- High dynamic range, adaptive grid
- Computationally efficient:
  independent of number of sources
- diffuse recombination radiation
  included



Incorporating Simplex into AMUSE

- mature&tested code
- need to define interface (work in progress)
- based on "vertices" (particles)
- (almost) immediate coupling with particle hydro codes?
- C++: one main simulation class -> interface based on a derived class



0.05 Myr 0.2 Myr 0.4 Myr

Summary

- we are developing AMUSE and applying it in our research at the same time

- validation of the project using "Signpost" applications

- AMUSE applied to environmental effects in cluster evolution

- first attempt at radiative transfer started

- Doing science with AMUSE is fun!