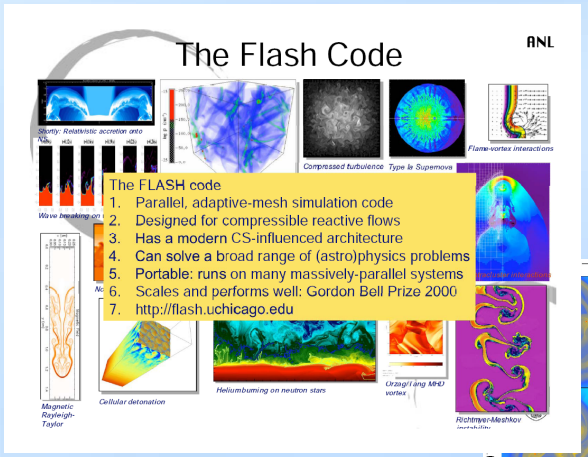
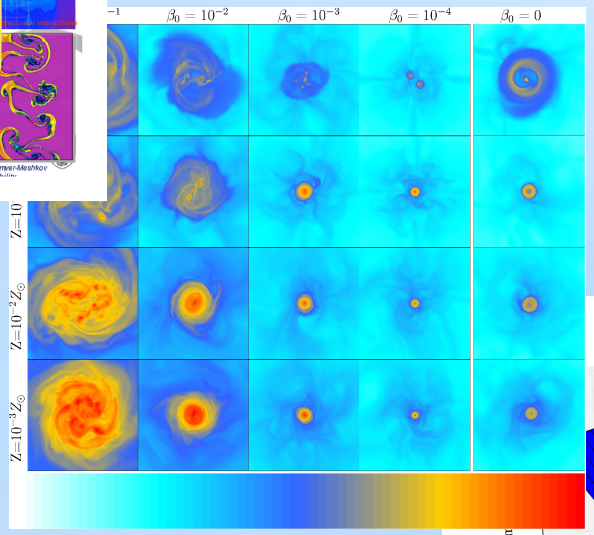
Star Formation under non-Milky Way conditions with Flash

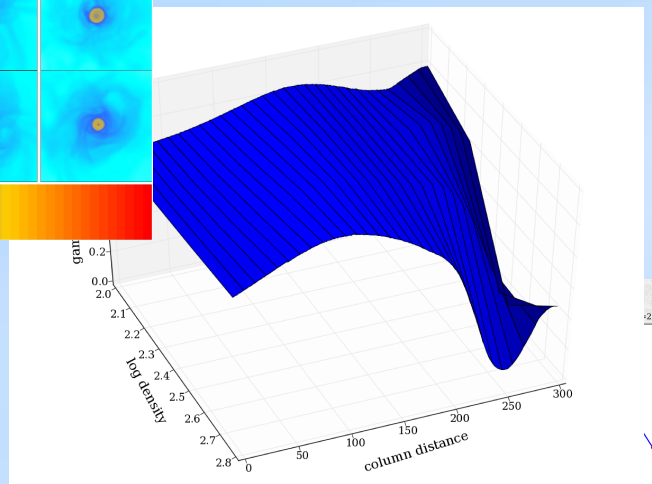
Seyit Hocuk
Kapteyn Astronomical Institute
Ph.D.

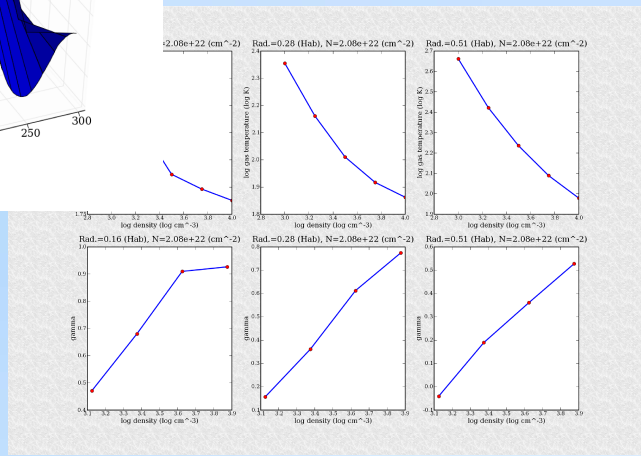
Prof. M. Spaans
Supervisor

Overview

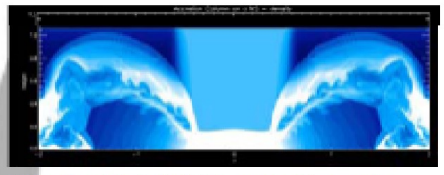

The Flash Code
ANL
The FLASH code
1. Parallel, adaptive-mesh simulation code
2. Designed for compressible reactive flows
3. Has a modern CS-influenced architecture
4. Can solve a broad range of (astro)physics problems
5. Portable: runs on many massively-parallel systems
6. Scales and performs well: Gordon Bell Prize 2000
7. http://flash.uchicago.edu
Flame-vortex interactions
Compressed turbulence
Type Ia Supernova
Cellular detonation
Helium burning on neutron stars
Richtmyer-Meshkov


$\beta_0 = 10^{-2}$
$\beta_0 = 10^{-3}$
$\beta_0 = 10^{-4}$
$\beta_0 = 0$
$Z = 10^{-1} Z_\odot$
$Z = 10^{-2} Z_\odot$
$Z = 10^{-3} Z_\odot$

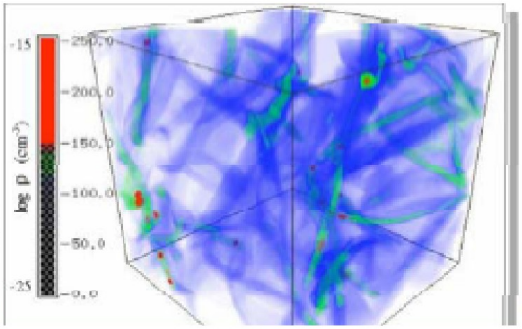

log density
column distance

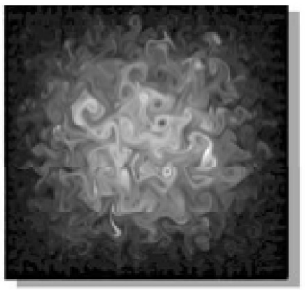

Rad.=0.28 (Hab), N=2.08e+22 (cm^-2)
Rad.=0.51 (Hab), N=2.08e+22 (cm^-2)
Rad.=0.16 (Hab), N=2.08e+22 (cm^-2)
log density (log cm^-3)
gamma

The FLASH Code

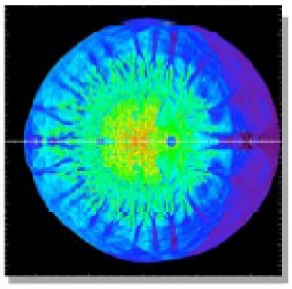


Shortly: Relativistic accretion onto N.S.

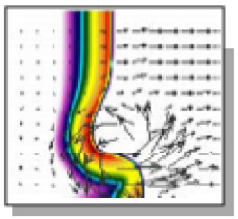




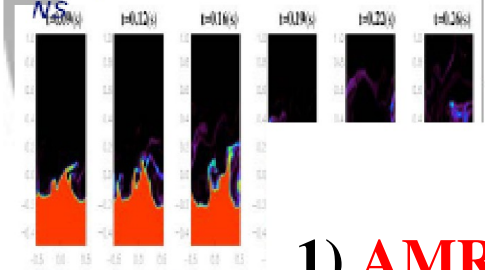
Compressed turbulence



Type Ia Supernova



Flame-vortex interactions

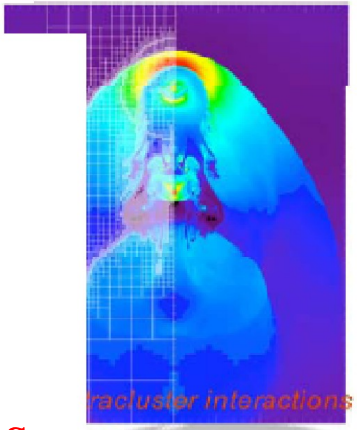


Wave breaking on

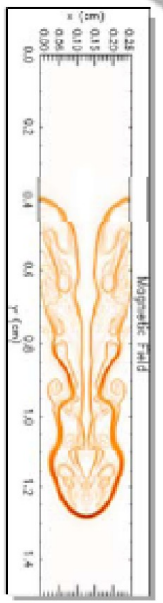
1) AMR parallel simulation code (Grid)

2) Designed for compressible flow problems

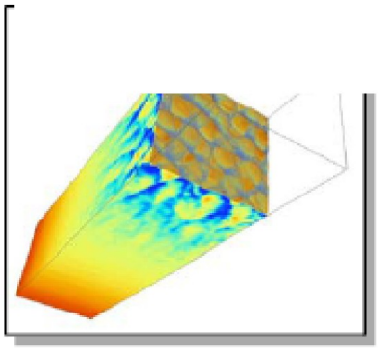
3) Can solve broad range of Astro-Physics problems



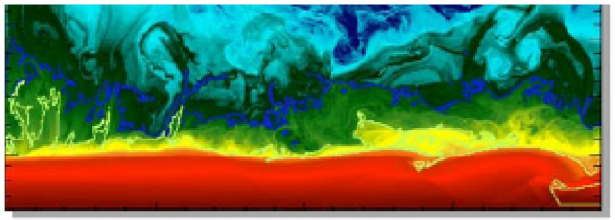
racluster interactions



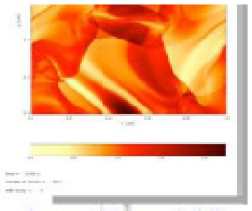
Magnetic Rayleigh-Taylor



Cellular detonation



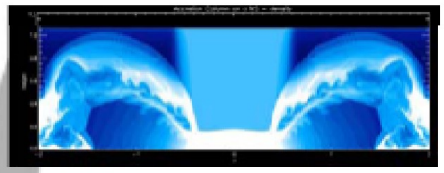
Heliumburning on neutron stars



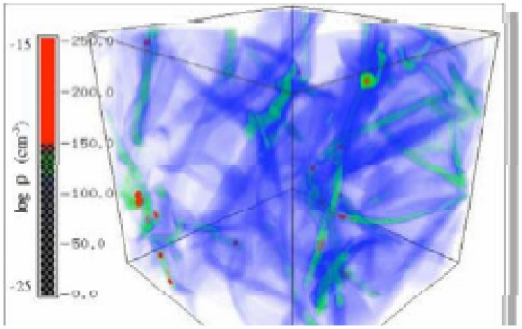
Orzag/Tang MHD vortex

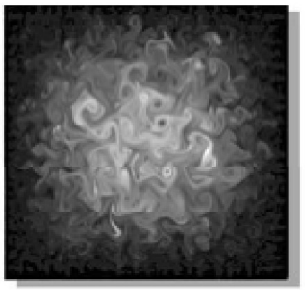
Richtmyer-Meshkov instability

The FLASH Code

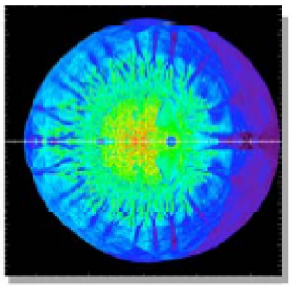


Shortly: Relativistic accretion onto NS

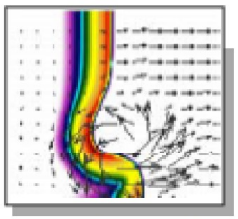




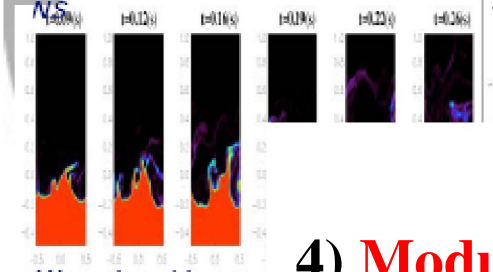
Compressed turbulence



Type Ia Supernova



Flame-vortex interactions

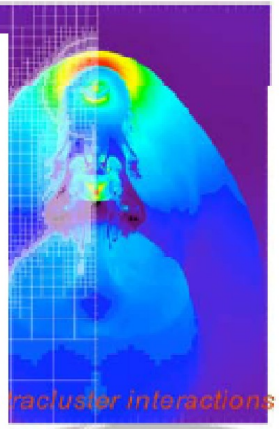


Wave breaking on

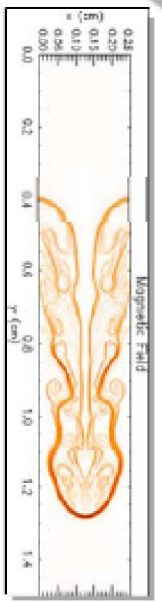
4) Modular Design

5) Portable: runs on many massively parallel systems

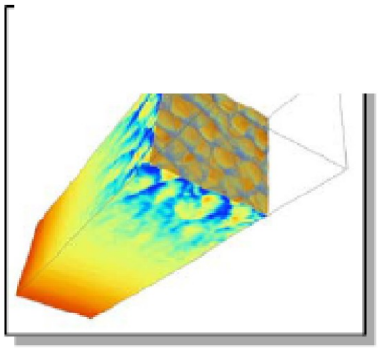
6) Capable of handling extreme resolution



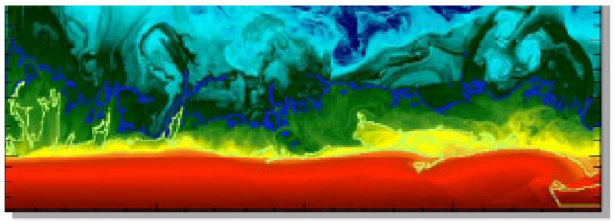
racluster interactions



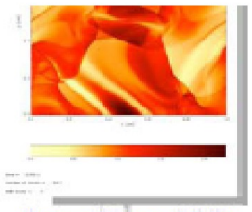
Magnetic Rayleigh-Taylor



Cellular detonation



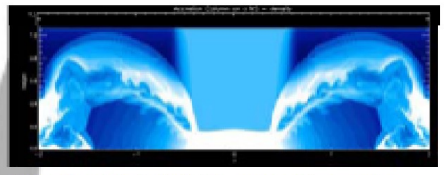
Heliumburning on neutron stars



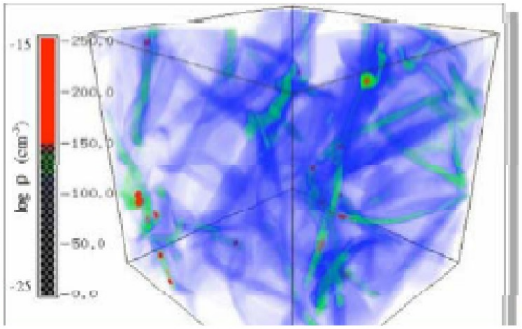
Orzag/Tang MHD vortex

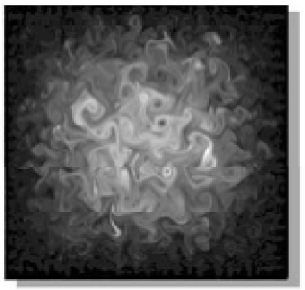
Richtmyer-Meshkov instability

The FLASH Code

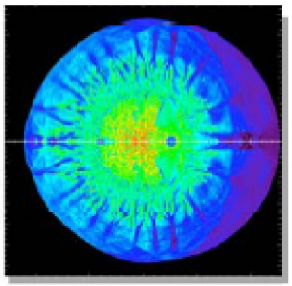


Shortly: Relativistic accretion onto NS

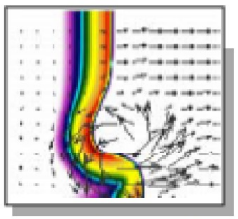




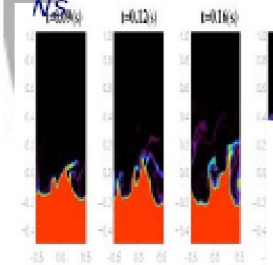
Compressed turbulence



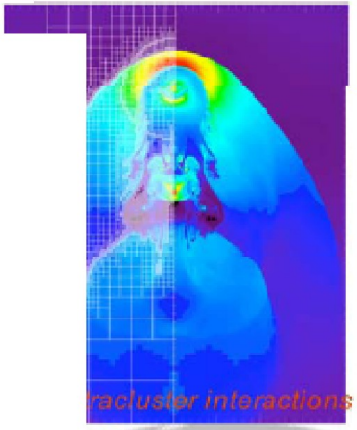
Type Ia Supernova



Flame-vortex interactions



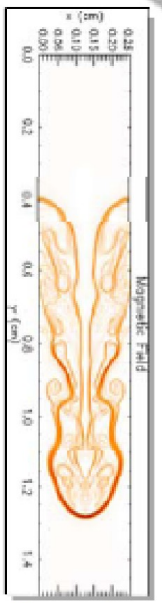
Wave breaking on



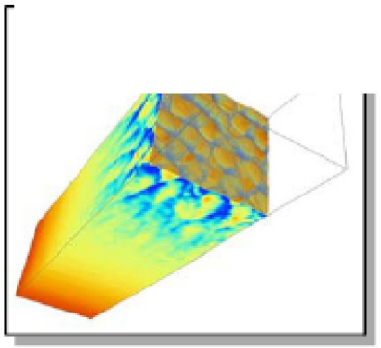
racluster interactions

7) Scales and performs well

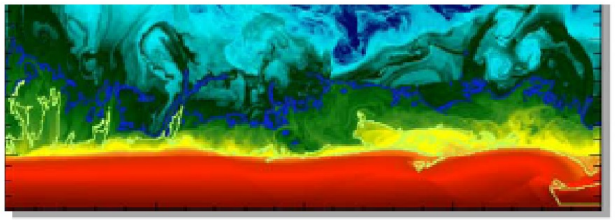
8) Extendable: components can be combined to create many different applications



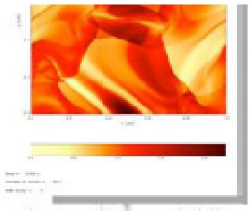
Magnetic Rayleigh-Taylor



Cellular detonation



Heliumburning on neutron stars



Orzag/Tang MHD vortex

Richtmyer-Meshkov instability

Background

- FLASH Centre at the University of Chicago
- Started in 1997
- US Department of Energy and ASC Programme
- Thermonuclear flashes on the surface of compact stars (neutron stars and white dwarfs) and type Ia supernovae.

From the University of Chicago *Chronicle*, 31 July, 1997

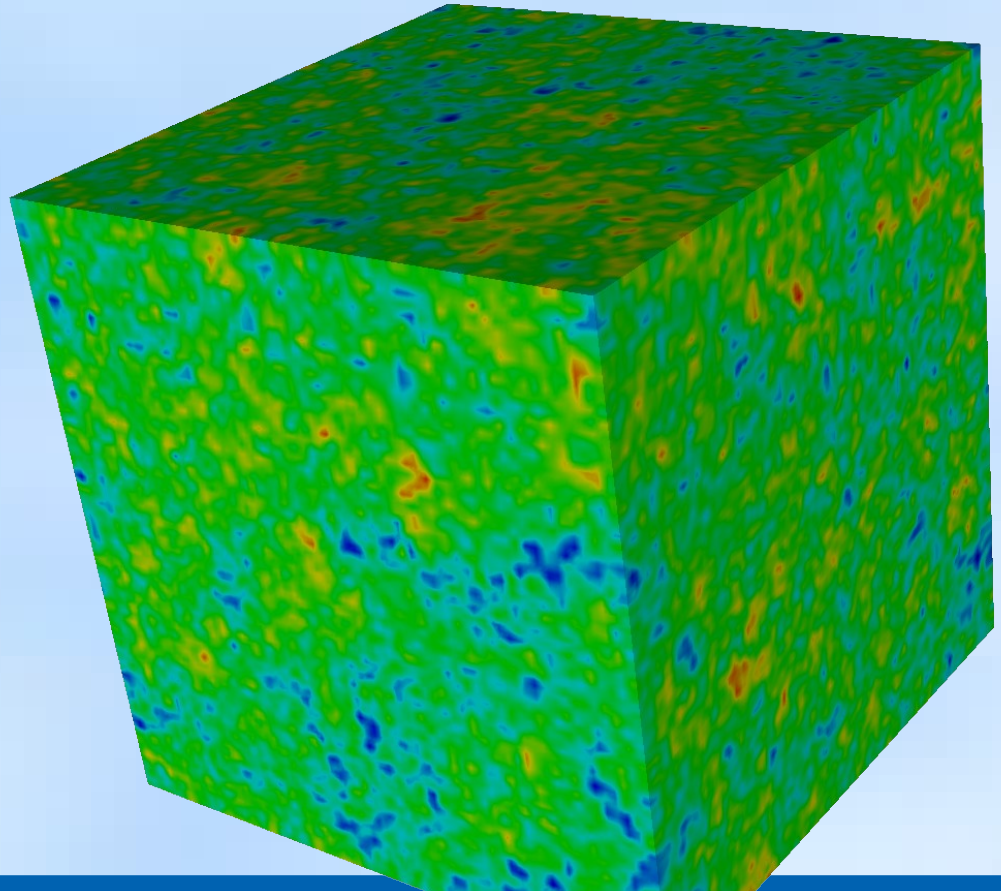
$50 million dollar supercomputer grant to University of Chicago to explore exploding stars and size of universe

University of Chicago scientists have received a grant of nearly $50 million from the Department of Energy to use the world's most powerful supercomputers to study the explosive deaths of massive stars. The ten-year project is also expected to help better understand how to keep the nation's nuclear weapons stockpile reliable without nuclear testing. Nuclear tests are now forbidden by the comprehensive nuclear test ban treaty announced in 1995 by President Clinton.

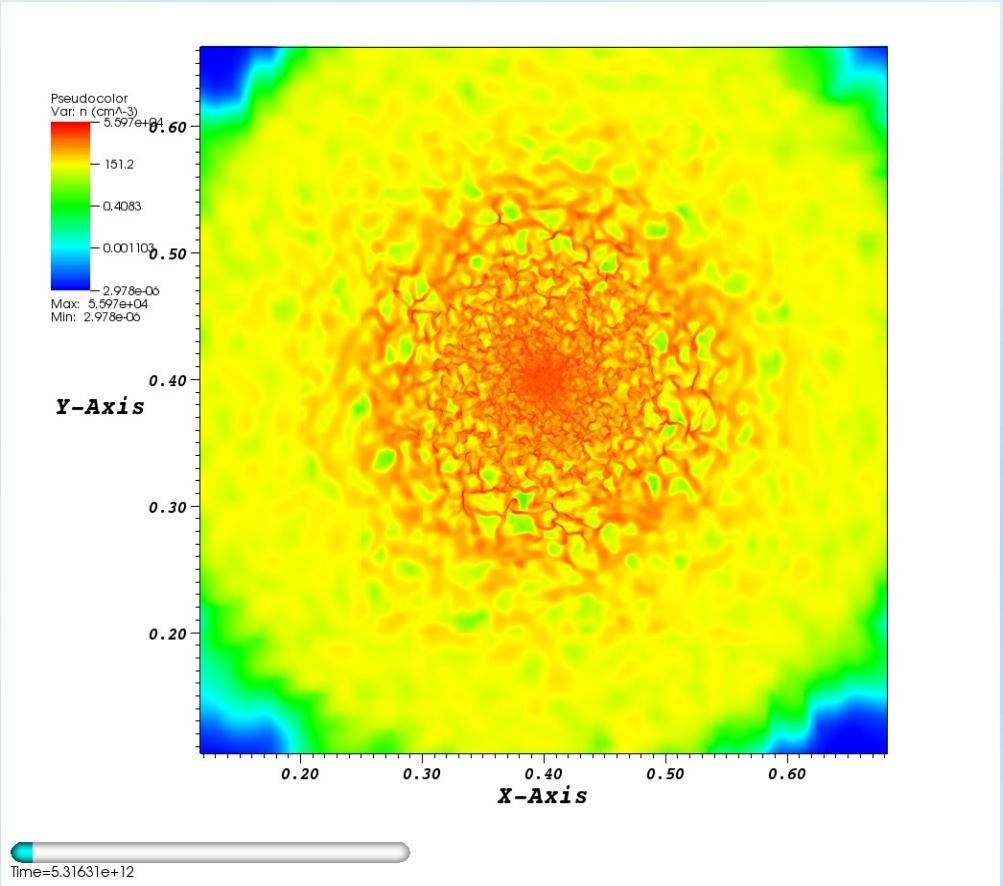
"This is an unprecedented opportunity for our scientists and our students to use the most powerful computers in existence to solve some of the most complex and interesting problems in astrophysics," said David Schramm, Vice-President for Research and a Professor of Astrophysics at the University of Chicago. "At the same time, we will be helping contribute to our nation's technological strength."

Requirements

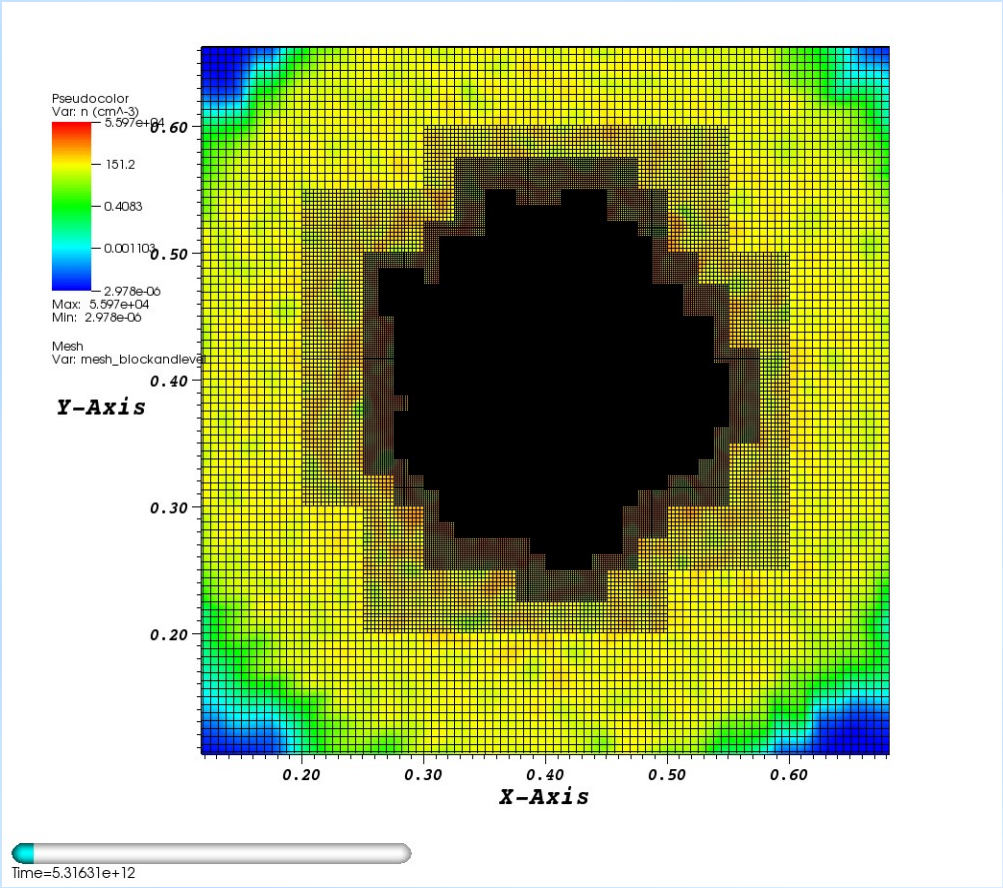
- Written mainly in Fortran 90, a little bit of C and Python
- Message Passing Interface
- Hierarchical Data Fomat
- Tested on various platforms, compilers, libraries, etc.



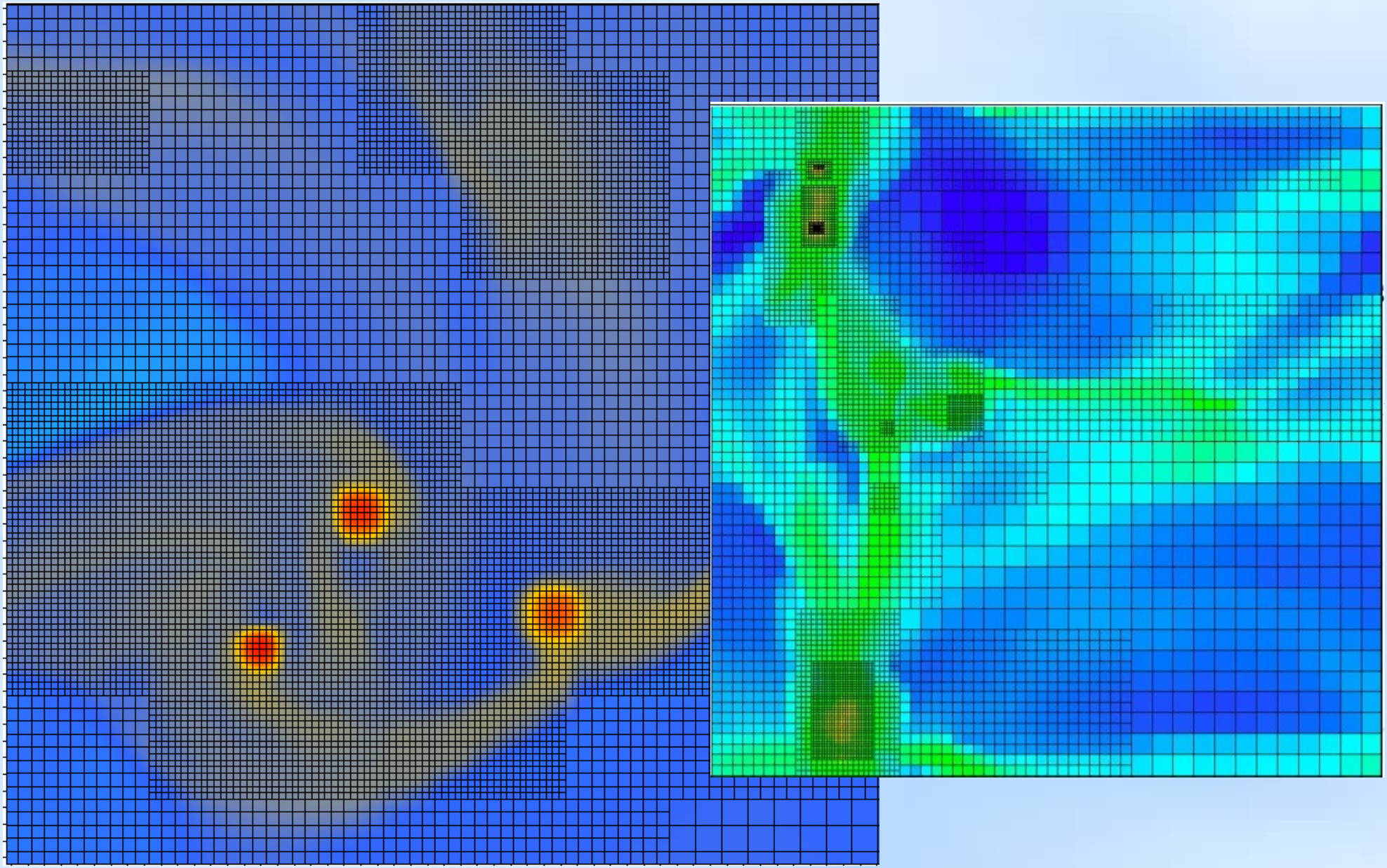
FLASH AMR Example



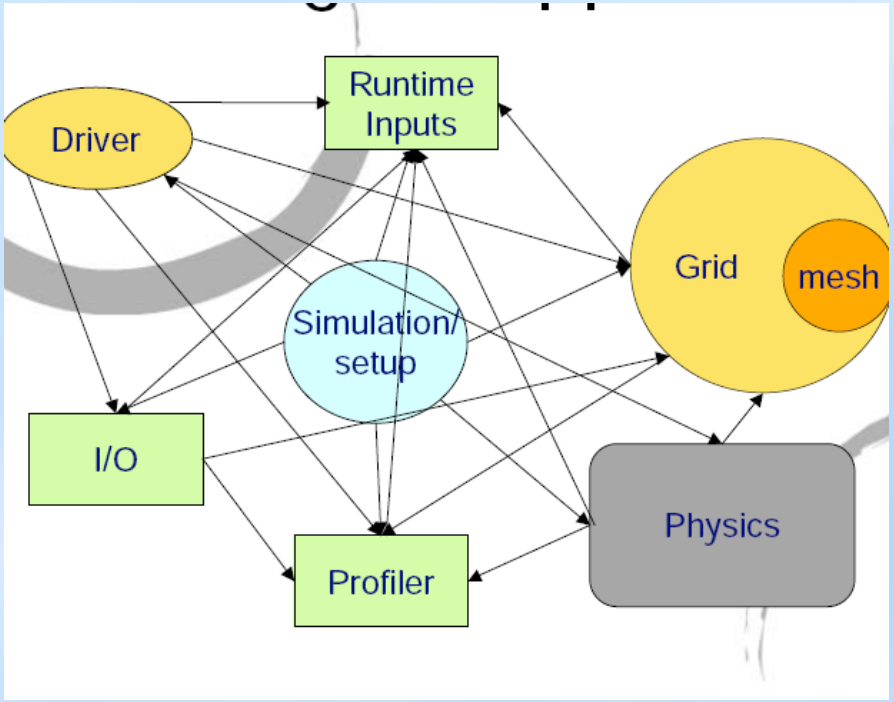
Oct-tree based grid

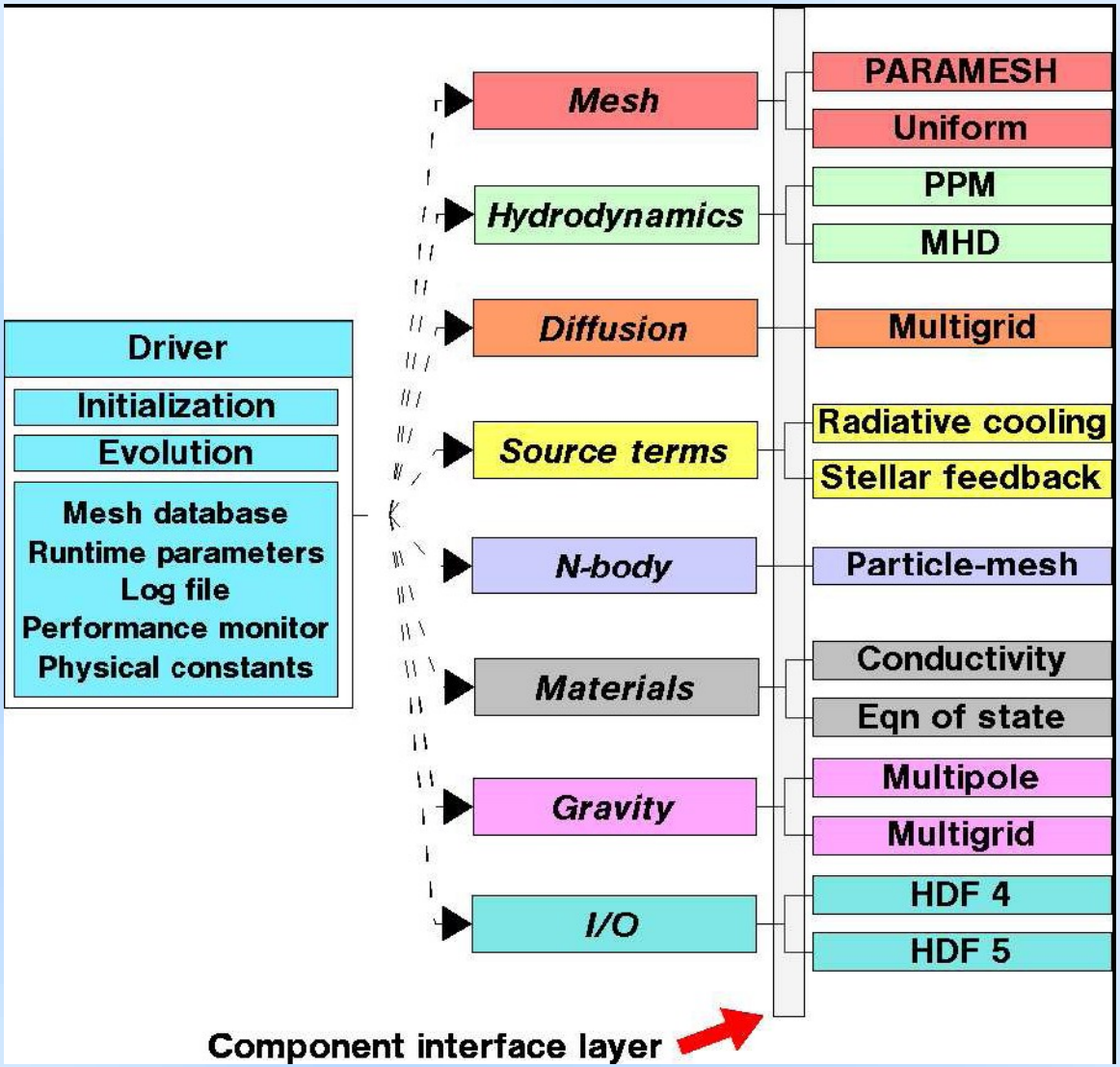


Refinement



Architecture & Structure





Hydrodynamics Module

- ✔ Solves Euler equations for gas dynamics
- ✔ Shocks and contact discontinuites
- ✔ Use of (Hybrid) Riemann and HLLE solver
- ✔ Suitable for coupling with gravity
- ✔ Solves MHD equations for magetised fluids
- ✔ Provides support of special RHD

Gravity Module

- Solves Poission equation for self gravity
- Multipole Poission solver
- Multigrid Poisson solver
- External Fields
- Constant
- Plane parallel
- Point mass

Particles Module

- ✔ Active Particles
- ✔ Passive Particles
- ✔ PM Method
- ✔ N-body simulations
- ✔ Long range forces
- ✔ Sink particles

Research

Star Formation under non-Milky Way conditions

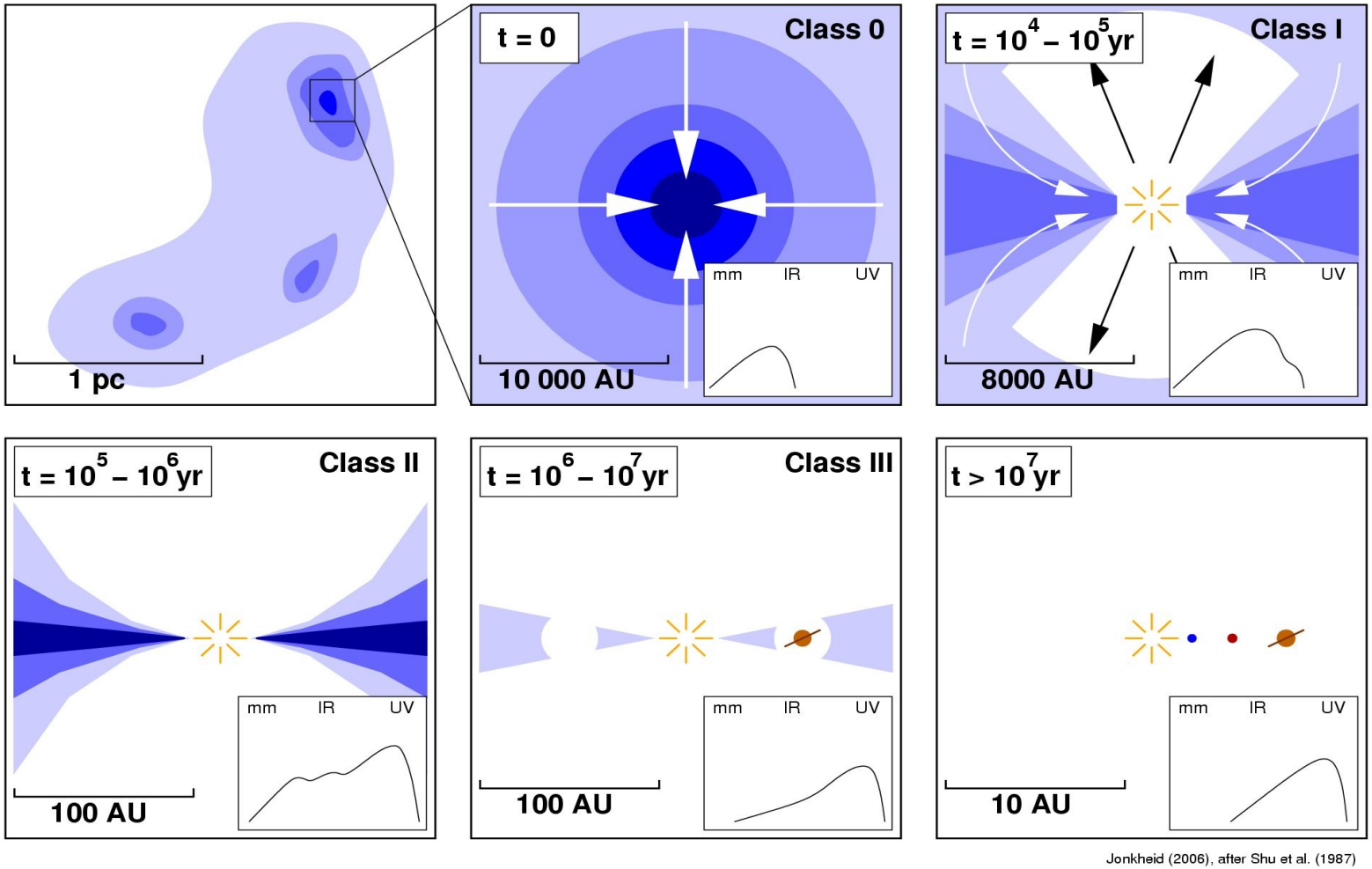
Molecular Cloud Fragmentation:

Thermodynamics

AGN Feedback:

X-Ray and UV radiation

Cloud Evolution



Jonkheid (2006), after Shu et al. (1987)

The Physics Involved

Hydrodynamics *(PPM solver)*

Gravity *(Multigrid solver)*

Rotation

Turbulence

Shocks

Adiabatic and shock Heating*

Metallicity dependent Cooling*

(non-)LTE effects included

Some Initial Conditions

We are looking at starburst galaxies with different metallicities (also dwarfs)

$n = 10^4$ cm^{-3}

R = 10 pc

Gas T = 100 K (Spaans & Silk 2000)

Dust T = 39 K (Wiklind & Henkel)

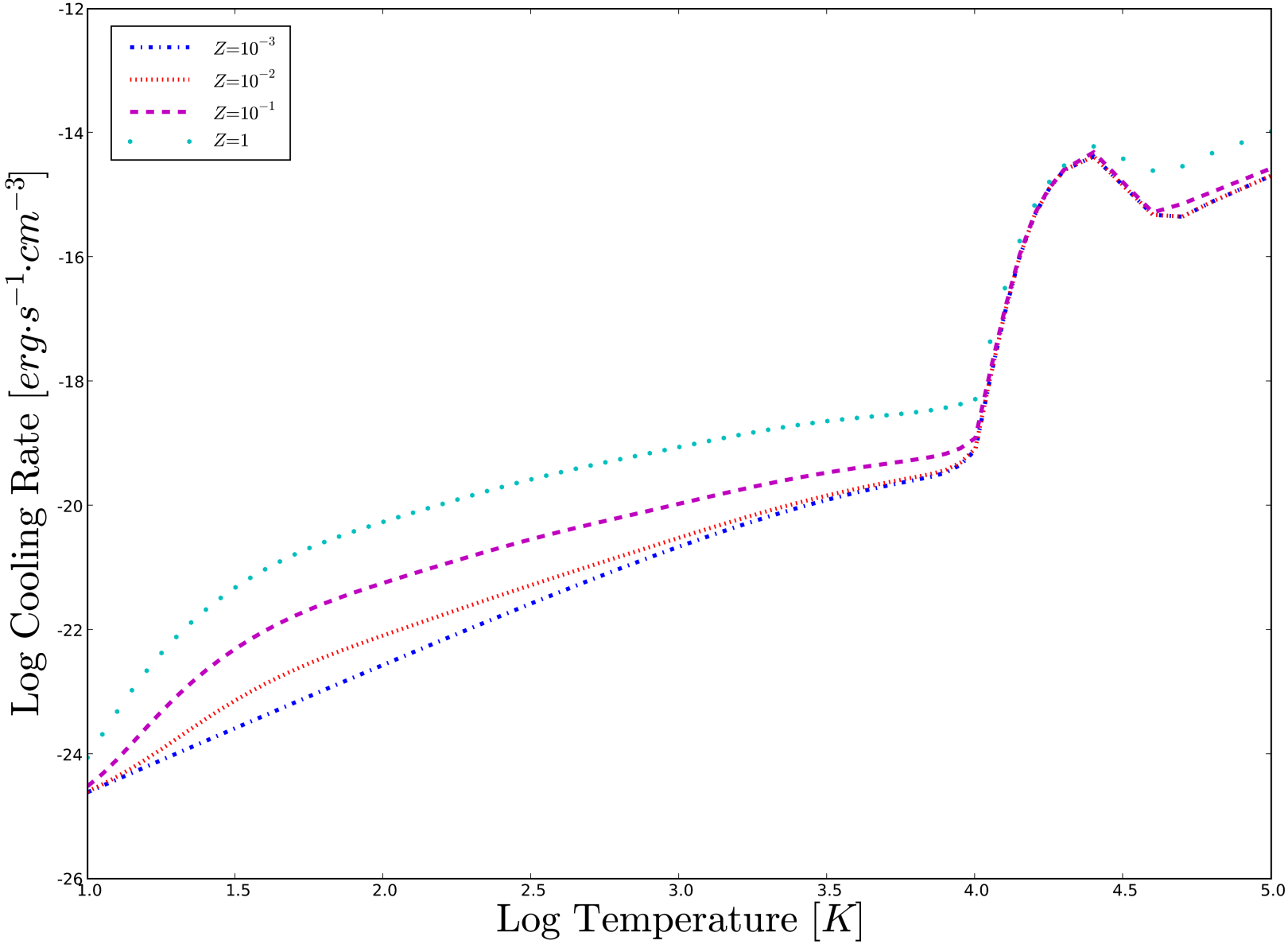
CR ionization Rate per $H_2 = 9x10^{-16}$ s^{-1} (Spaans & Silk 2005)

Turbulence б = 2 Km/s (Falgarone et al. 2001, Bonnell 2001)

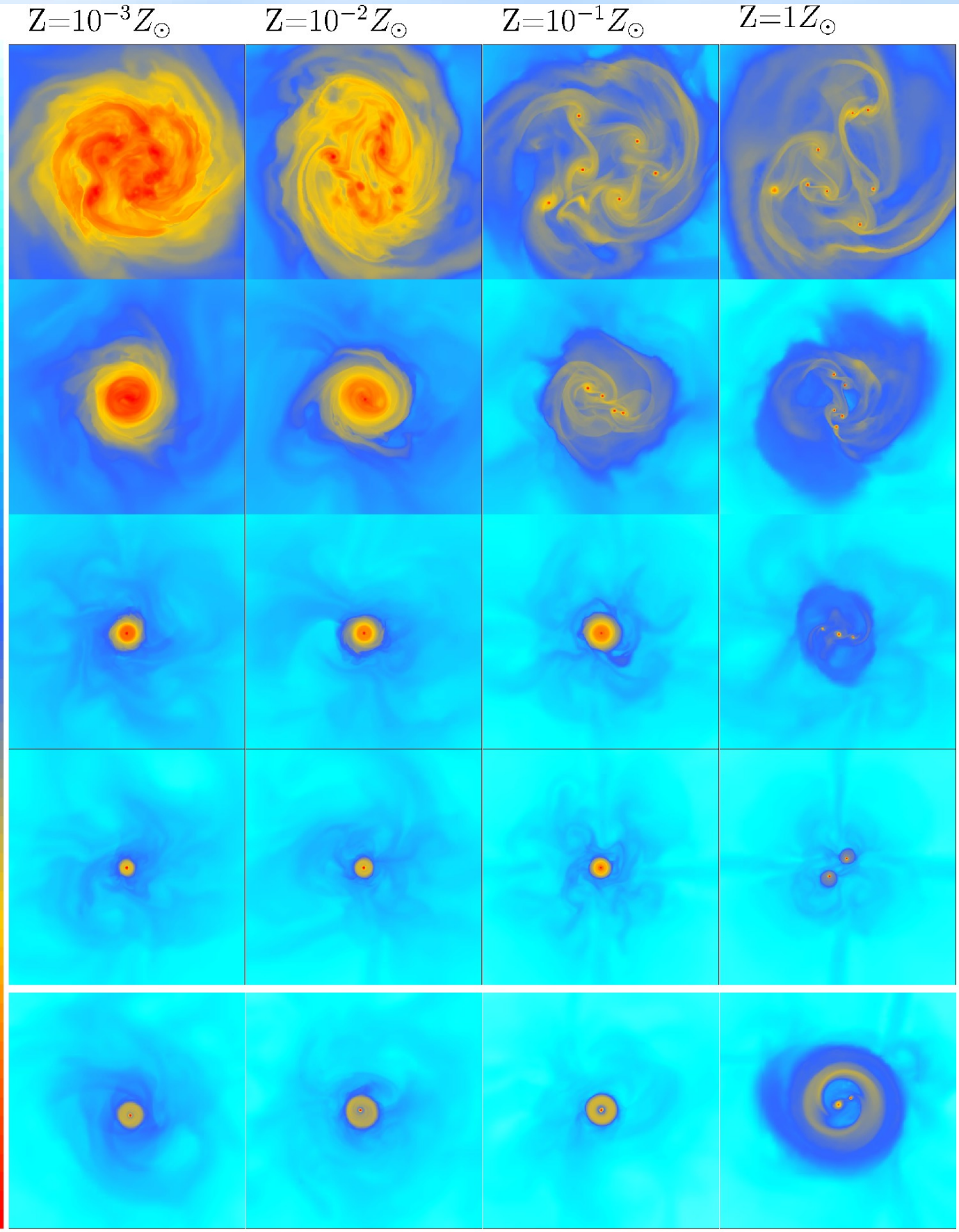
Four Metallicities: 1, 10^{-1}, 10^{-2}, 10^{-3} Solar

Five Rotational Energies: 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}, 0

Cooling Function

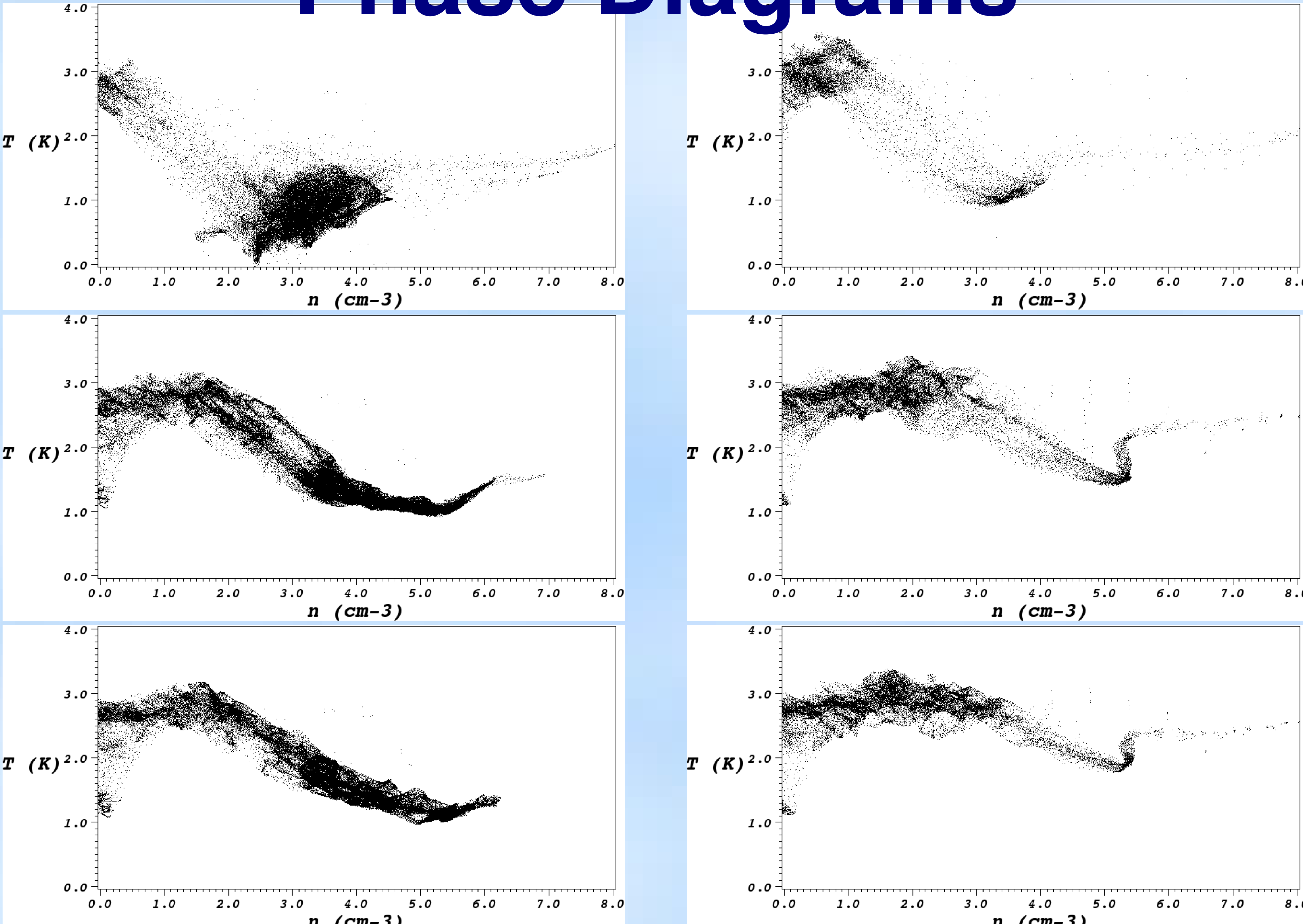


Some Results

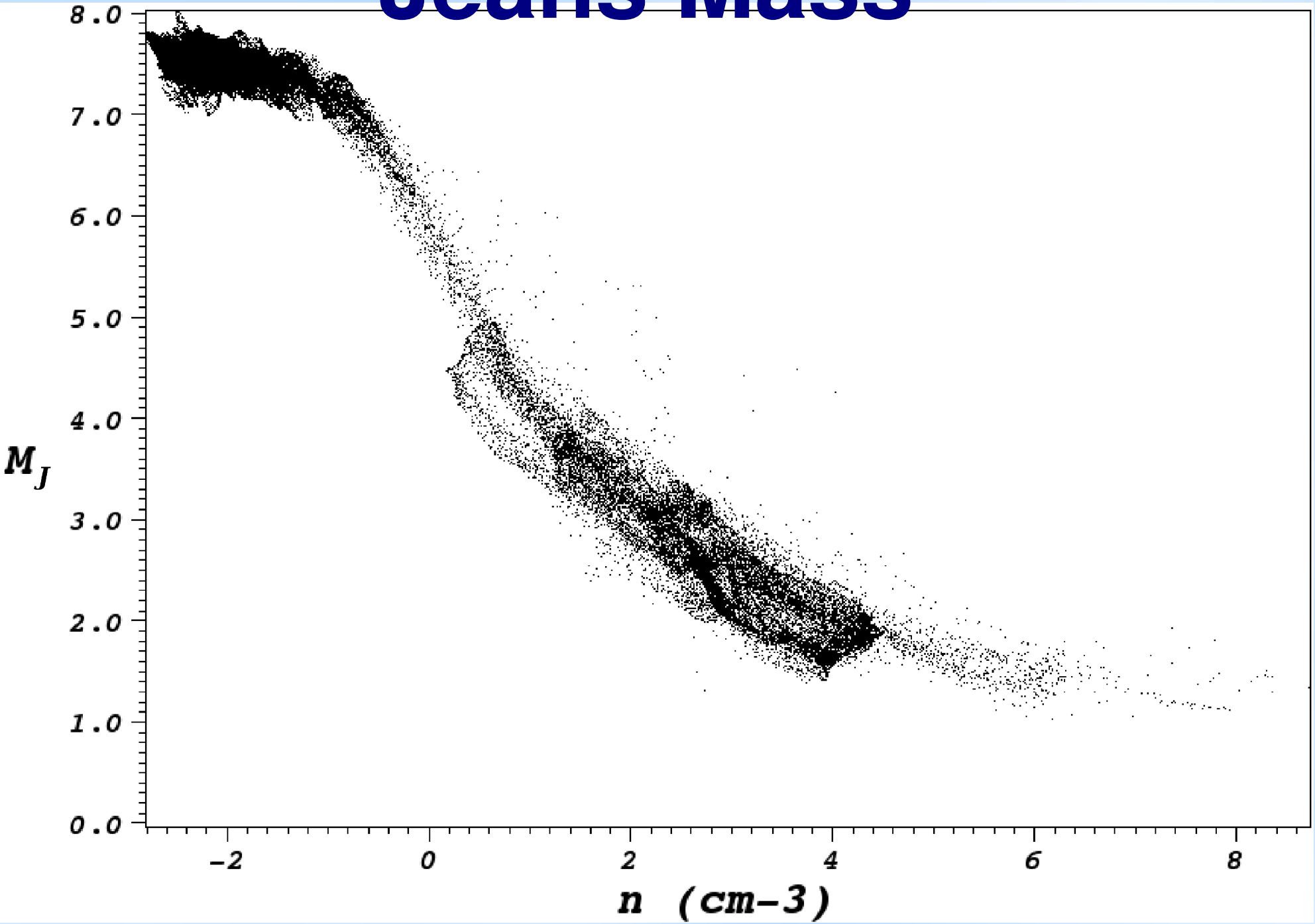


Phase Diagrams

Research

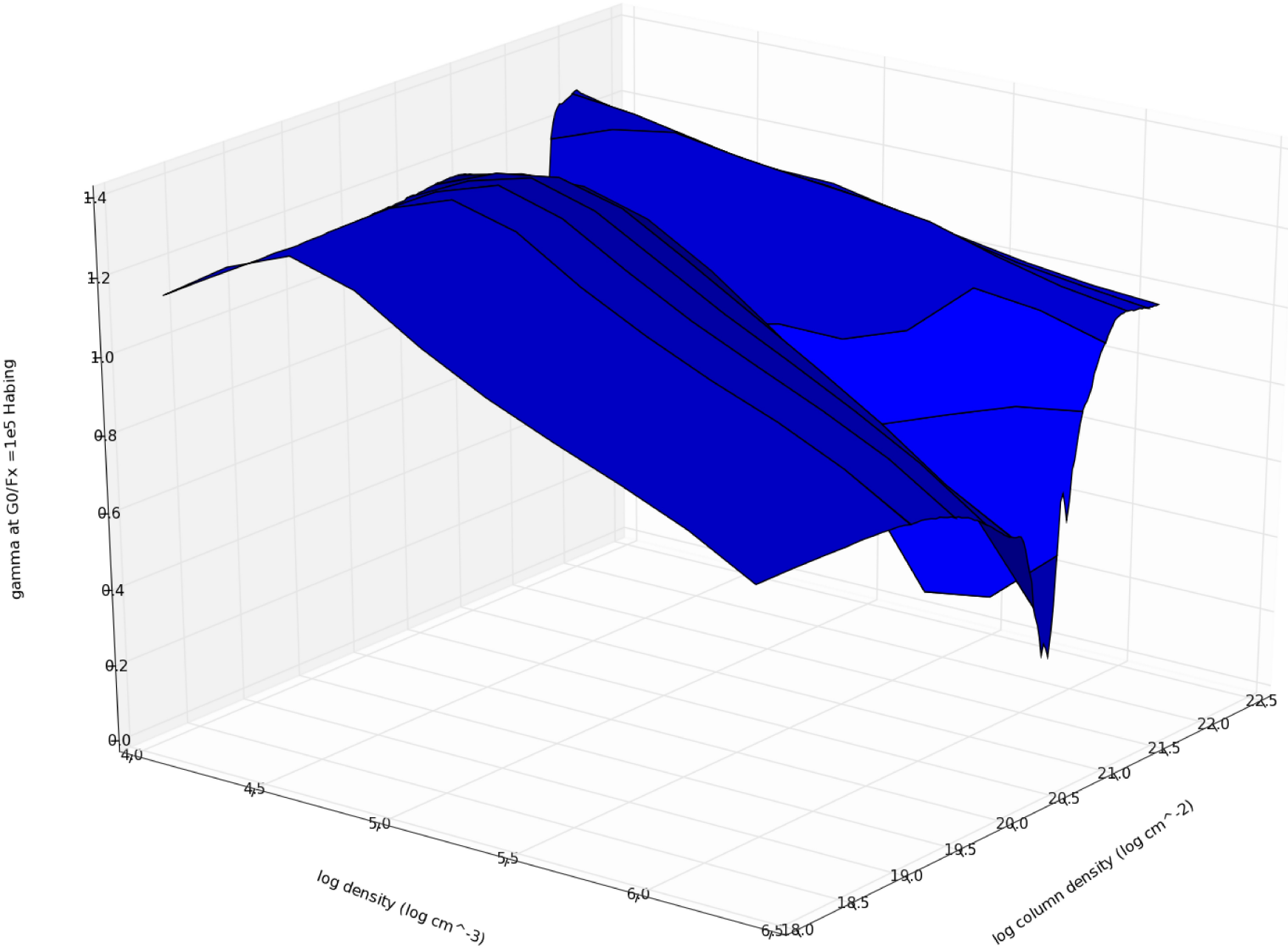


Jeans Mass



Recent Work

We are looking at the effect of radiative feedback from a Black Hole on to a molecular cloud and follow its evolution.


gamma at G0/Fx =1e5 Habing
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4.0
4.5
5.0
5.5
6.0
6.5
log density (log cm^-3)
18.0
18.5
19.0
19.5
20.0
20.5
21.0
21.5
22.0
22.5
log column density (log cm^-2)

Concluding Words

- **Metallicity strongly influences the fragmentation process.**
  - → Higher metallicity causes more fragmentation and results in a better compressible gas.
- **High initial rotational energy enhances fragmentation.**

Concluding Words

- **Metallicity strongly influences the fragmentation process.**
  - ➔ Higher metallicity causes more fragmentation and results in a better compressible gas.
- **High initial rotational energy enhances fragmentation.**
- **Heating by cosmic rays and dust are strong enough to slow down cooling and reduce fragmentation.**
- **Isothermal cases show decrease in fragmentation.**
  - ➔ It's the change in temperature with respect to the change in density that improves fragmentation.

Work in Progress

- **We expect that X-ray feedback will influence fragmentation strongly.**
  - → The interplay between hydrodynamics, gravity, chemistry and radiation is crucial.