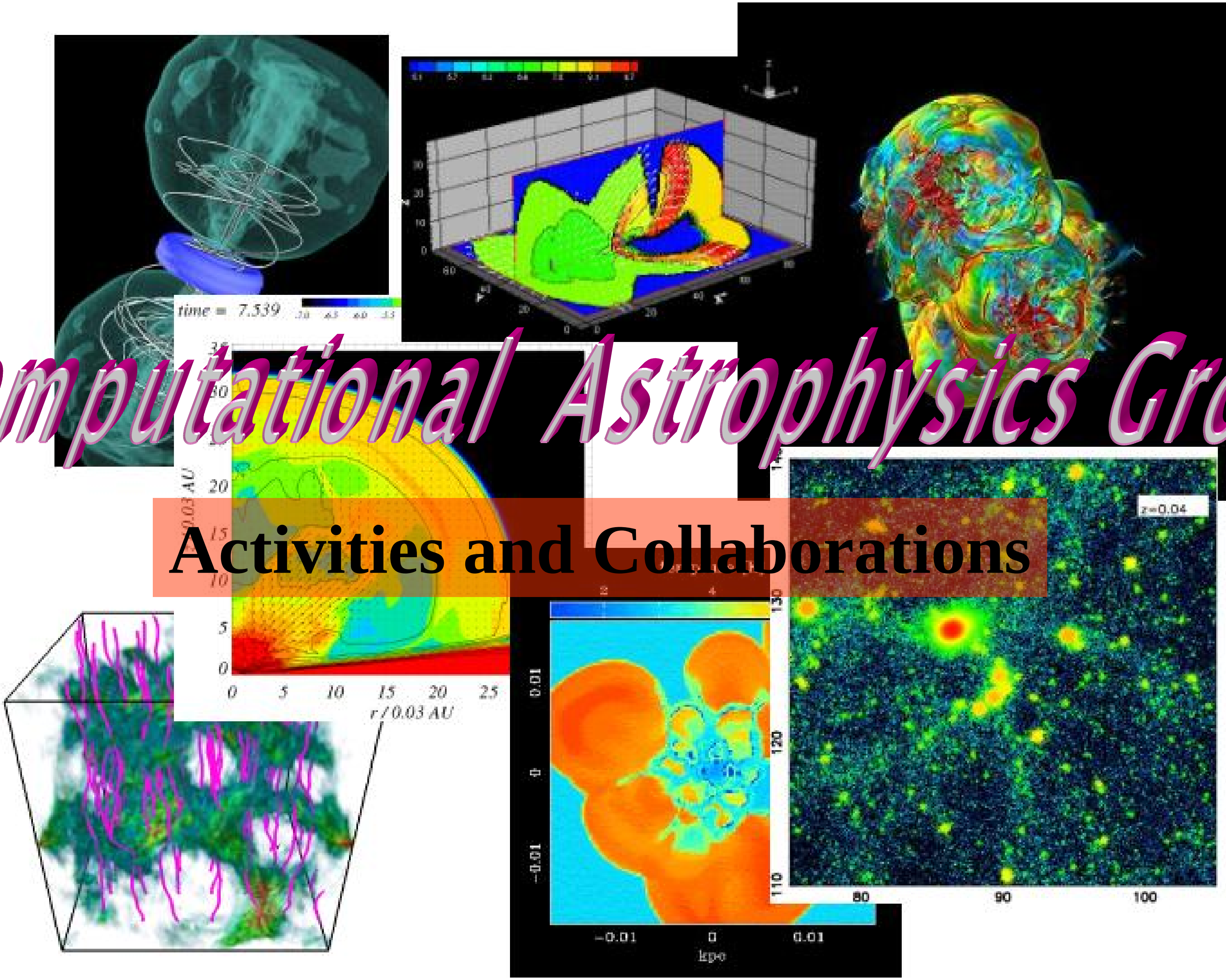
2007. 10. 31

Computational Astrophysics Group

Activities and Collaborations



Group Members

Faculty (3)

Masayuki Umemura (Professor)
Hiroyuki Hirashita (Assistant Professor)
Kohji Yoshikawa (Assistant Professor)

Postdoctral Fellows (4)

Yoshiaki Kato
Tamon Suwa
Takuya Akahori
Yasuyuki Watabe (in Italy)

Graduate Students (15)

Ikko Shimizu (D3)
Kenji Hasegawa (D3)
Seiji Yasuda (D2)
Rogel Mari D. Sese (D2)
Chizuru Akizuki (D1)
Masaru Sakuma (D1)
Daisuke Sato (D1)
Hidenobu Yajima (D1)
Takayuki Koizumi (M2)
Mayumi Chiba (M2)
Masao Doi (M2)
Tomohiro Ichikawa (M1)
Makoto Takenaka (M1)
Ryota Narita (M1)
Takayuki Wada (M1)

Undergraduate Students (4)

Yuki Kubota (B4)
Yuko Kurotori (B4)
Keiki Saitoh (B4)
Masahito Matsumine (B4)

History

1993: Masayuki Umemura from NAOJ
1994: Taishi Nakamoto from NAOJ (moved to TiTech, 2006)
Joined CP-PACS Project
Collaboration with particle physicists and computer scientists
Started 3D Radiative Transfer
1997:
“Development of Next Generation Massive Parallel Computer Project” started (1997 - 2001)
Collaboration with particle physicists and computer scientists
HMCS (Heterogeneous Multi-computer System) constructed
Started 3D Radiation Hydrodynamics
2000:
International Conference, The Physics of Galaxy Formation
2004:
Center for Computational Sciences set up
FIRST Project started
Collaboration with computer scientists
2005: Hiroyuki Hirashita from Nagoya U.
2007: Kohji Yoshikawa from Tokyo U.

Radiative Transfer with CP-PACS

$$\frac{1}{c}\frac{\partial I_\nu}{\partial t} + \mathbf{n} \cdot \nabla I_\nu = \chi_\nu (S_\nu - I_\nu)$$

Freedom: 3D in space, 2D in directions, 1D in frequency = 6D problem

3D Radiative Transfer with CP-PACS

$N^3 = 128^3$, $N_\theta = N_\phi = 128$, $N_\nu = 6$

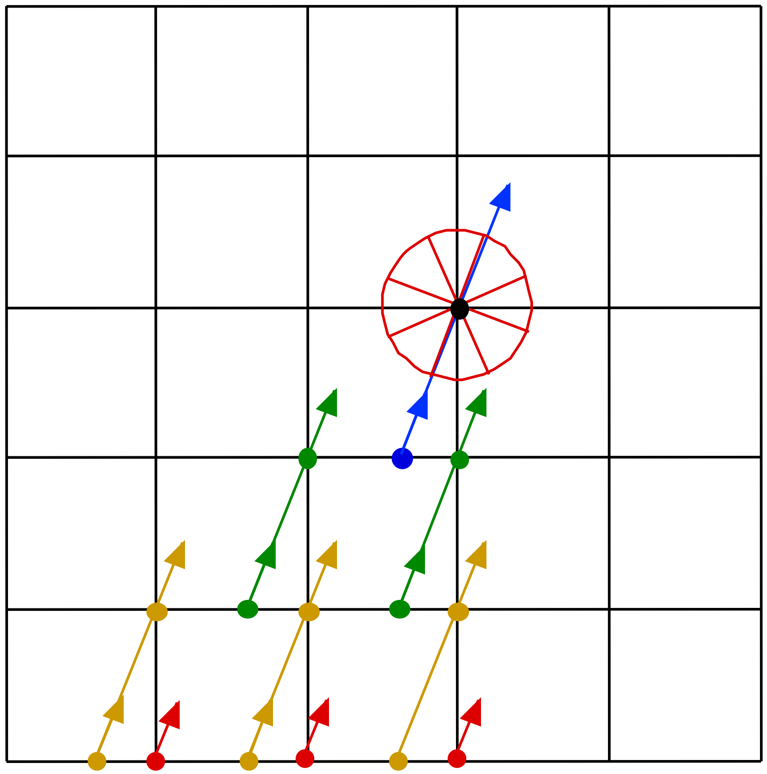
Total memory: $23N^3 + 3N^2 N_\theta N_\phi N_\nu = 38.7\text{GB}$

Total operations: $f N_{iter} N^3 N_\theta N_\phi N_\nu = 1.14\ \text{Tflops} \cdot \text{hr}$ ($f \approx 200$, $N_{iter} = 100$)

Short Characteristics method

(Kunasz&Auer1988)

Transfer is solved along a short ray across each grid



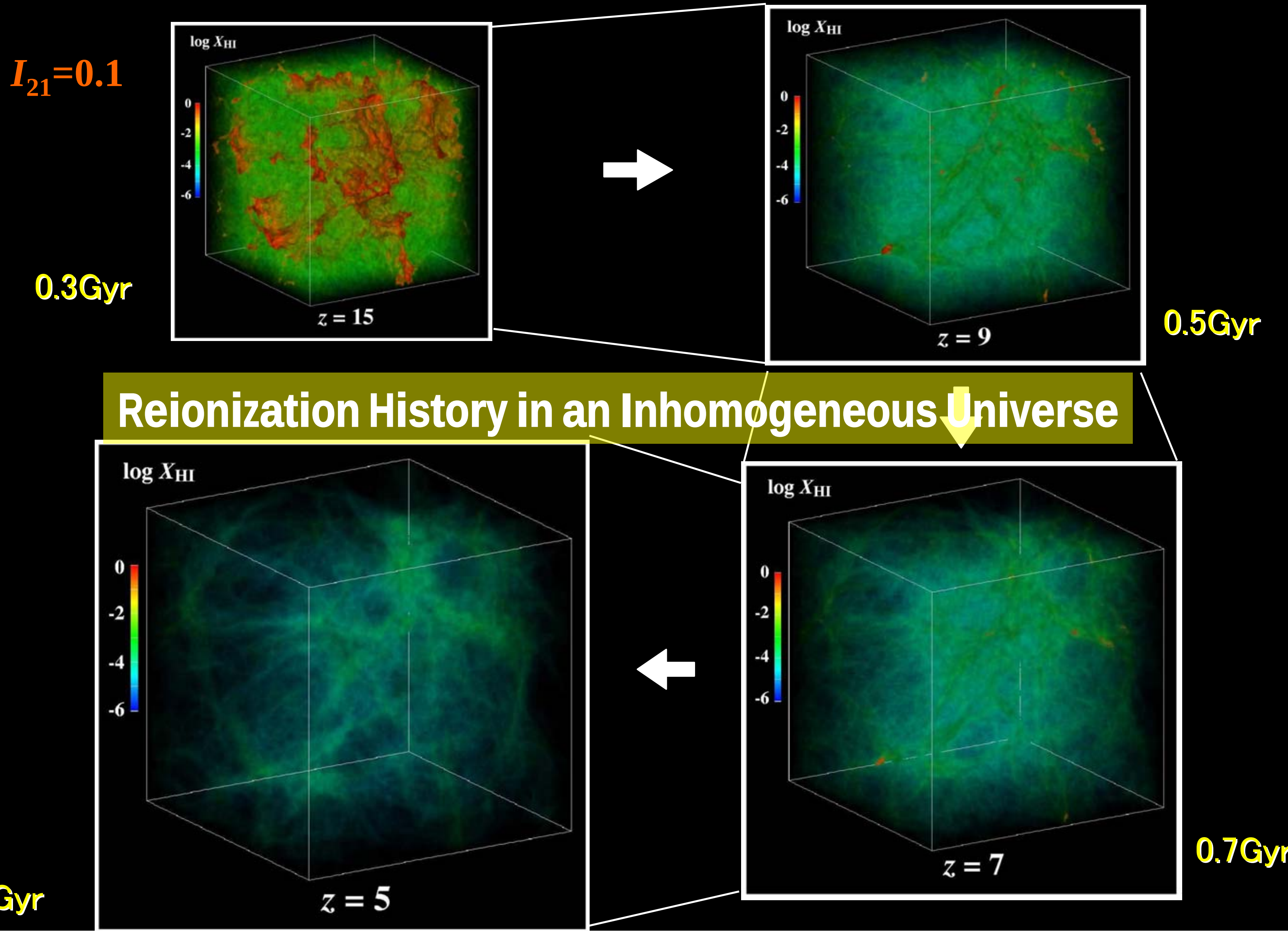
- Simple coding
- Operations are fewer than long char.

$$\sim \; N_x N_y N_z \cdot N_\theta N_\varphi N_\nu$$

- Interpolation between adjacent grids causes numerical diffusion.

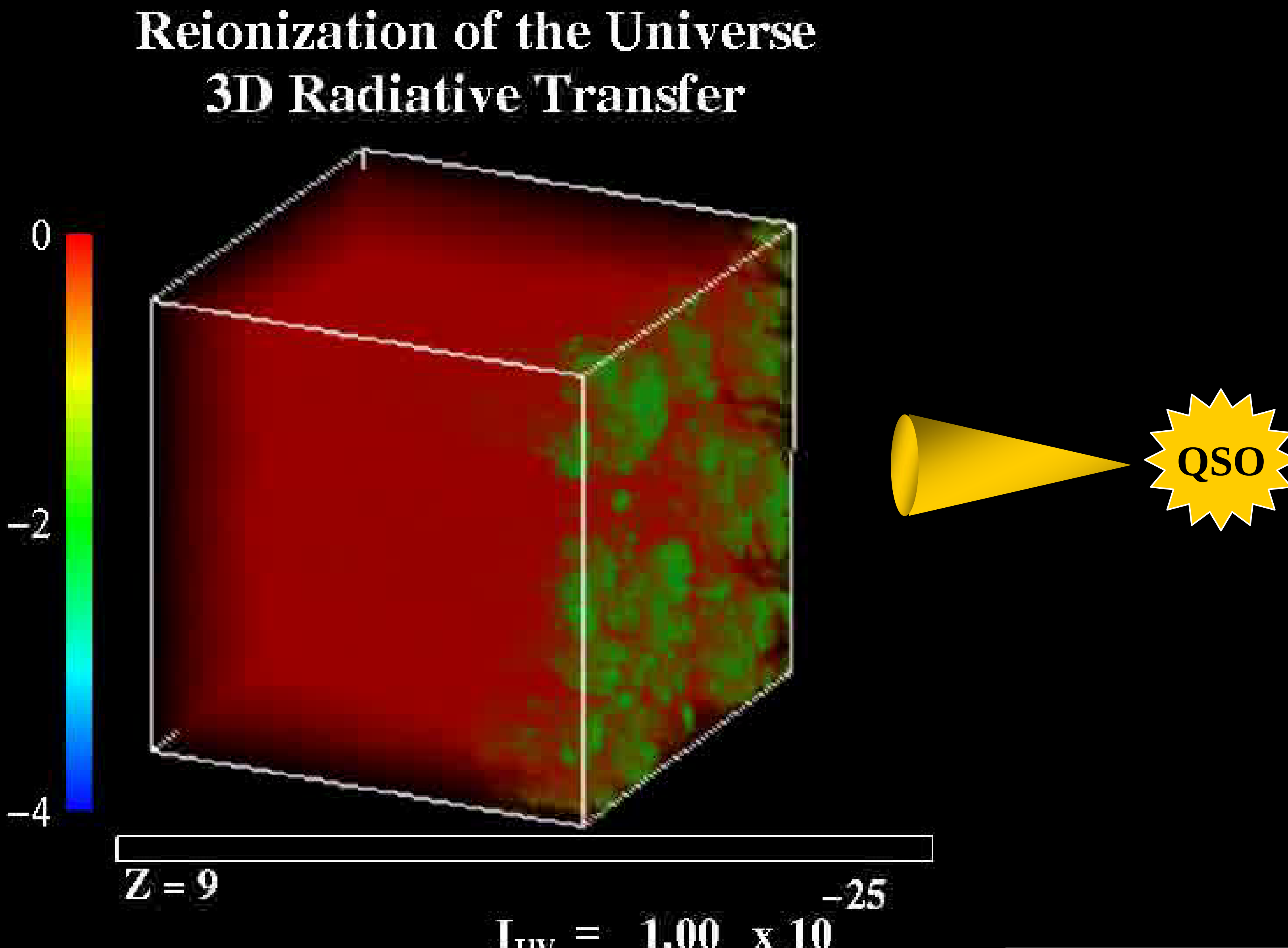
3D Radiative Transfer with Scattering

Nakamoto, Umemura, Susa 2001



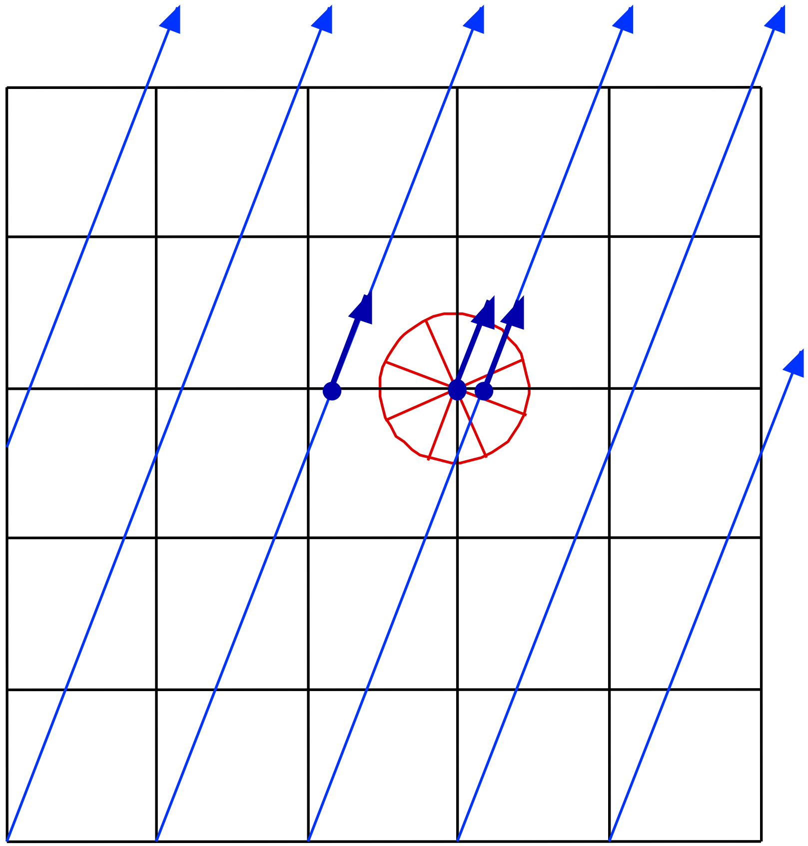
PAVEMENT - Parallel I/O & Parallel VR

"Development of Next Generation Massive Parallel Computer Project"



ART
(Authentic Radiative Transfer)

Transfer is solved along a long ray across the domain

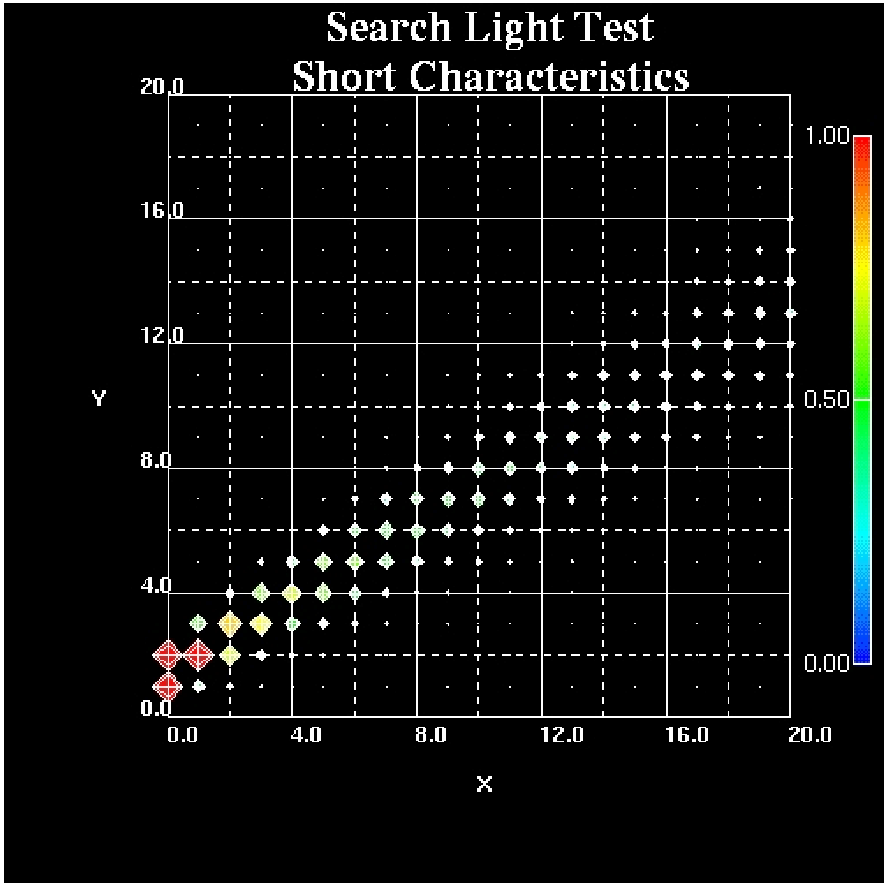


- Physical quantities are interpolated at each grid
- A bit complex coding
- No numerical diffusion (accuracy equivalent to long char.)
- Operations (same as short char.)

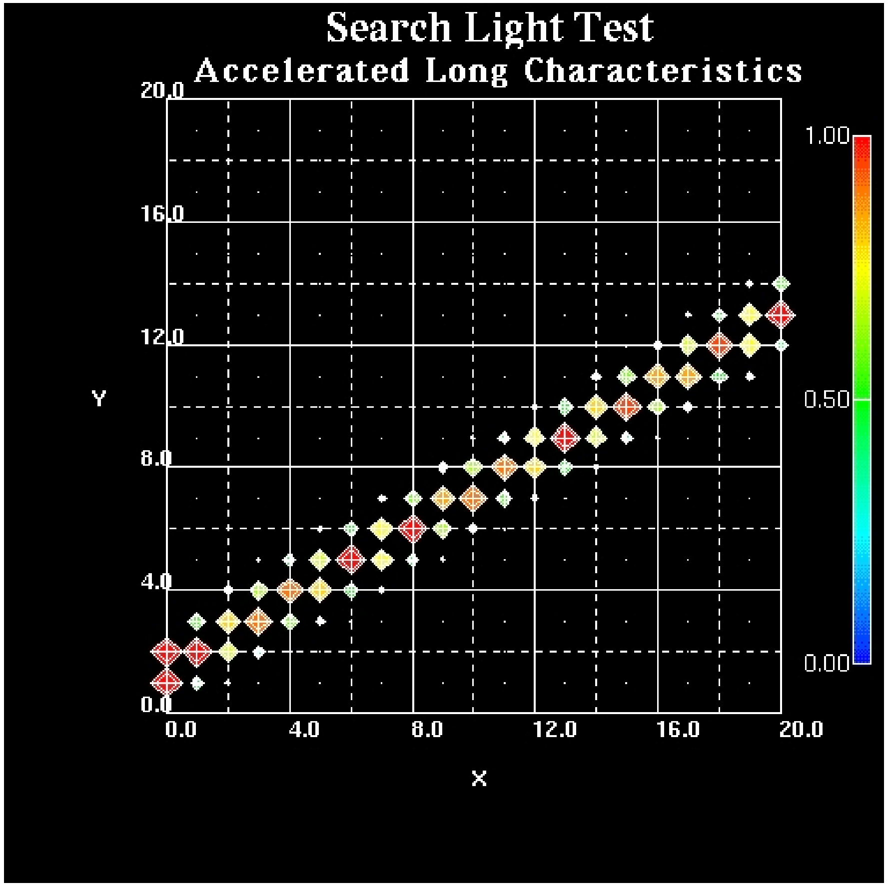
$$\sim \; N_x N_y N_z \cdot N_\theta N_\varphi N_\nu$$

TEST OF BEAMING

Short Char.



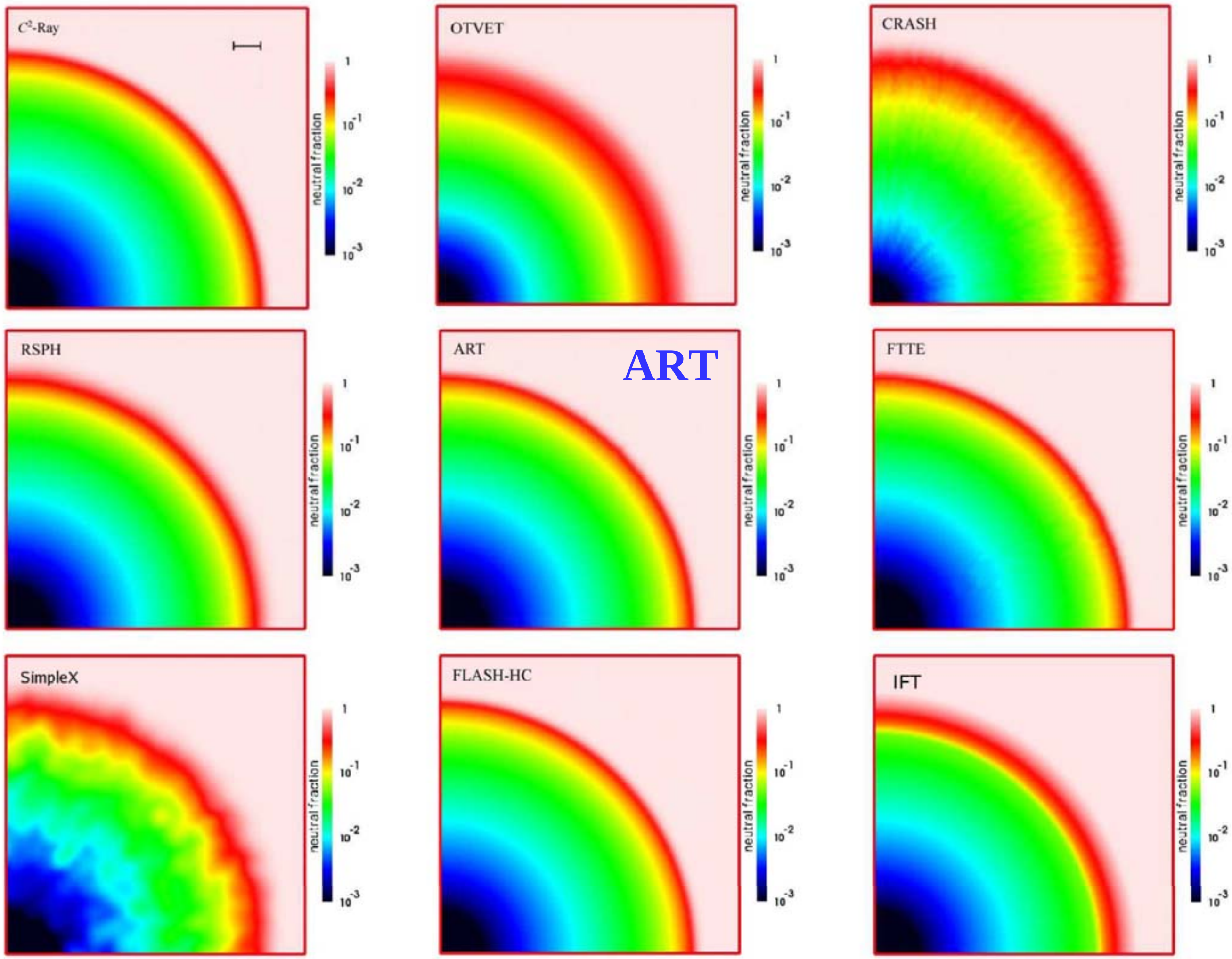
ART



Cosmological Radiative Transfer Codes Comparison Project I: The Static Density Field Tests

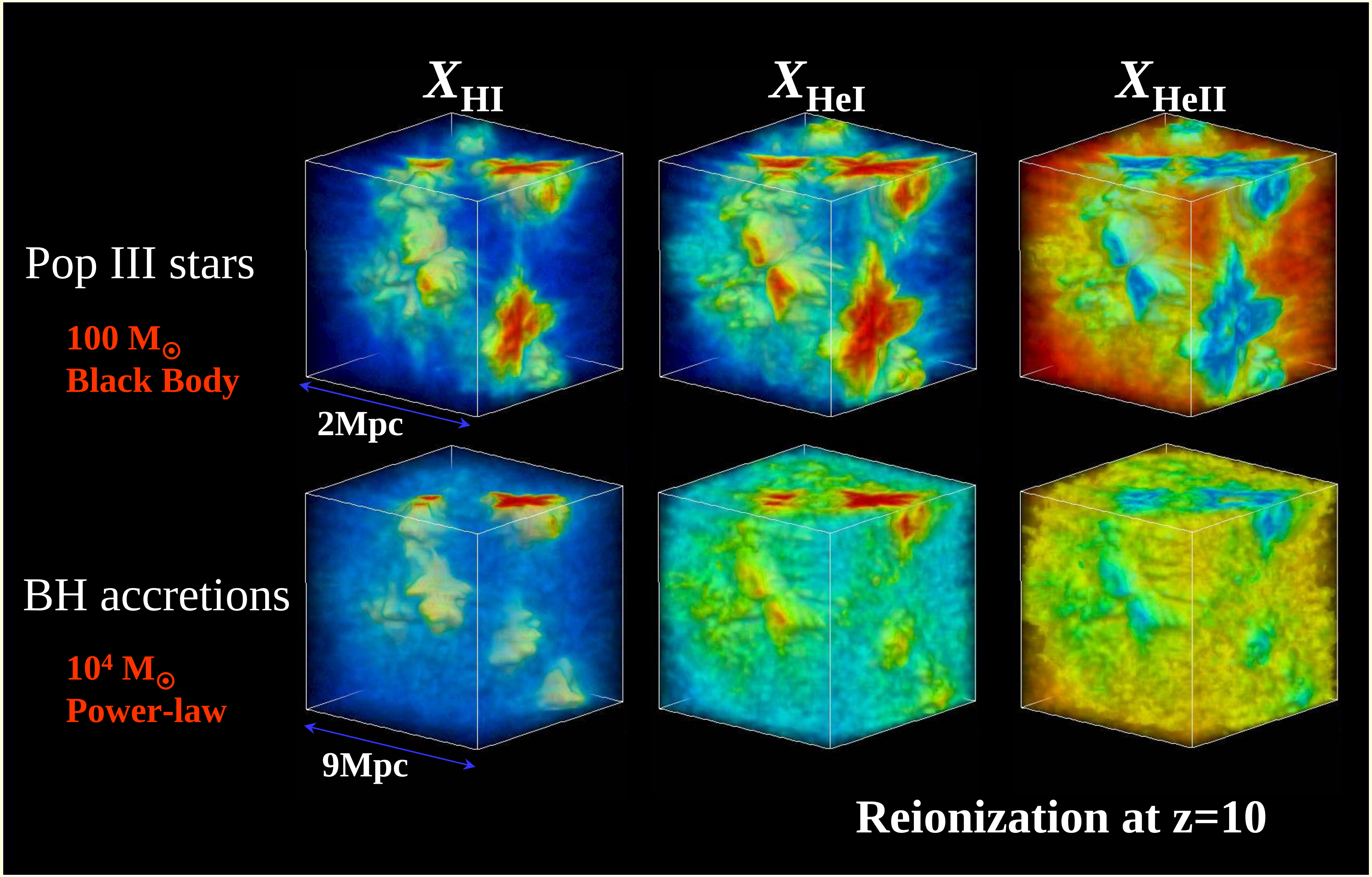
2006, MNRAS, 371, 1057

Ilian T. Iliev, Benedetta Ciardi, Marcelo A. Alvarez, Antonella Maselli, Andrea Ferrara, Nickolay Y. Gnedin, Garrelt Mellema, Taishi Nakamoto, Michael L. Norman, Alexei O. Razoumov, Erik-Jan Rijkhorst, Jelle Ritzerveld, Paul R. Shapiro, Hajime Susa, Masayuki Umemura, Daniel J. Whalen



Direct Photons + Diffuse Photons

Hiroi, Umemura, Nakamoto, in prep



Galaxy Formation with UV Background

Three Elements for Galaxy Formation

CDM Fluctuations

Random Gaussian Density Fields

Cooling Diagram (Rees & Ostriker 1977)

+

star formation $$\frac{d\rho_*}{dt} = c_* \frac{\rho_{gas}}{t_{ff}}$$

+

Self-Shielding

No stars form unless baryonic matter is self-shielded from UVB !

Formation of Dwarf Galaxies during the Cosmic Reionization

Susa & Umemura 2004, ApJ, 600,1

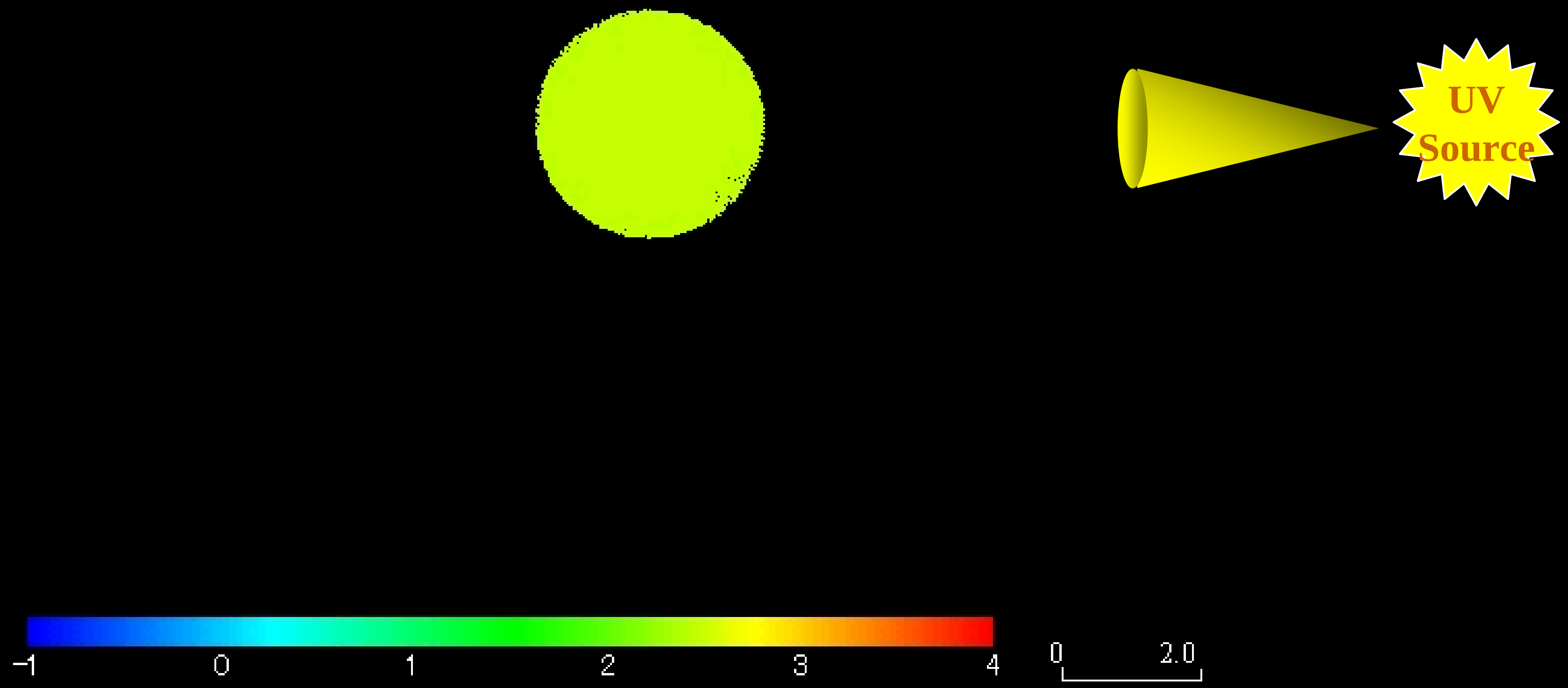
1.007E+02

TREE-SPH + Radiation Transfer + Non-equilibrium Chemistry

$N_{DM}=N_{SPH}=131072$

$$M_{\mathrm{vir}} = 6\times10^{8} M_{\odot}$$

$$z_c = 7.6$$



Final Stellar Fraction

$M_{vir} = 10^{8-9} M_\odot$

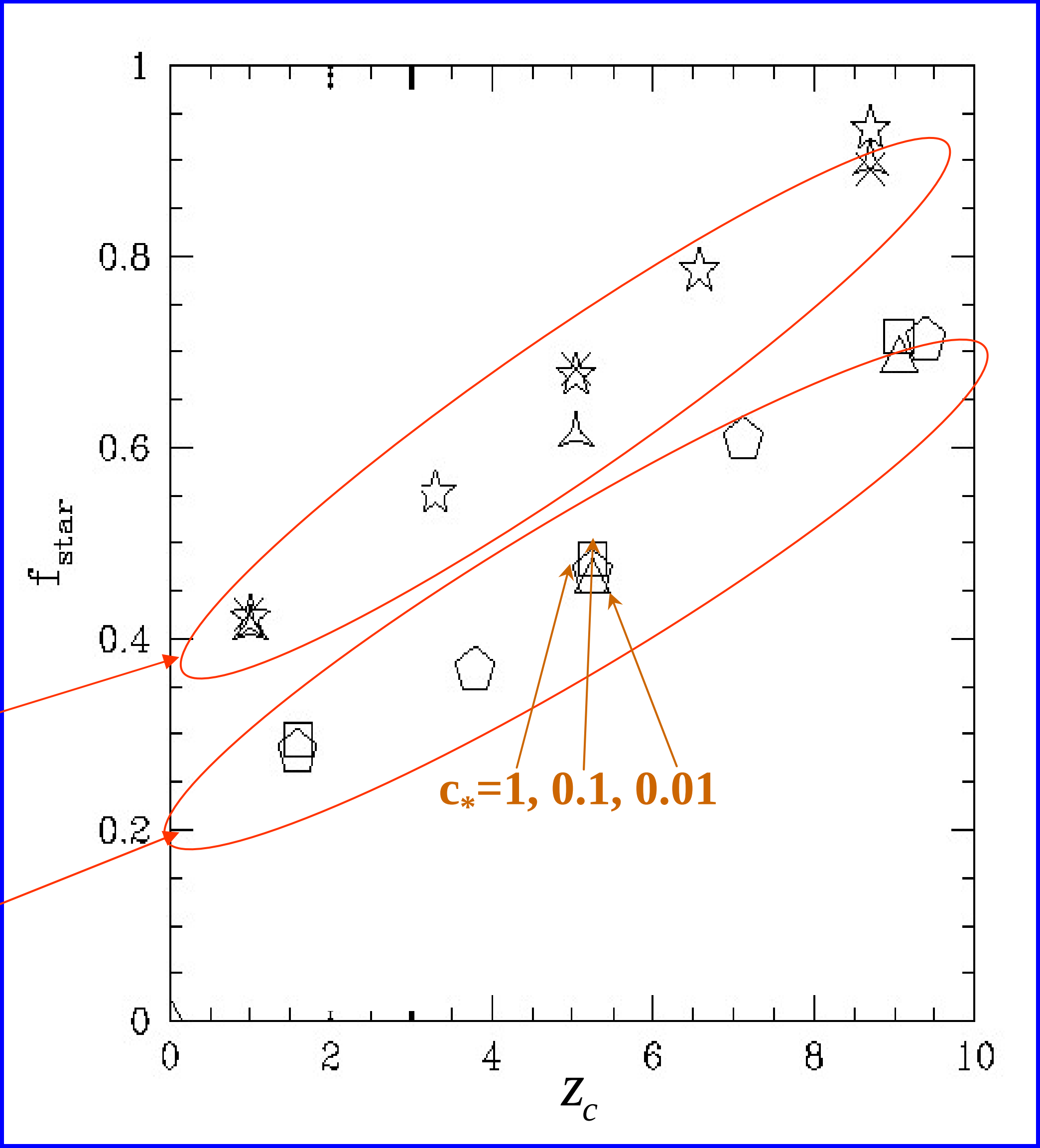
$20\ \mathrm{km\,s^{-1}}$ d v_{circ} d $40\ \mathrm{km\,s^{-1}}$

Dwarf galaxies do form even during reionization

almost regardless of c_* !

$M_{vir} = 10^9 M_\odot$
$c_* = 0.01, 0.1, 1$

$M_{vir} = 10^8 M_\odot$
$c_* = 0.01, 0.1, 1$



$$f_{star} \approx 7\times10^{-2}(1+z_c) + b(M) \quad b(10^9 M_\odot) = 0.35,\ b(10^8 M_\odot) = 0.15$$

Galaxy Evolution by Multiple SN Explosions

By Earth Simulator & CP-PACS

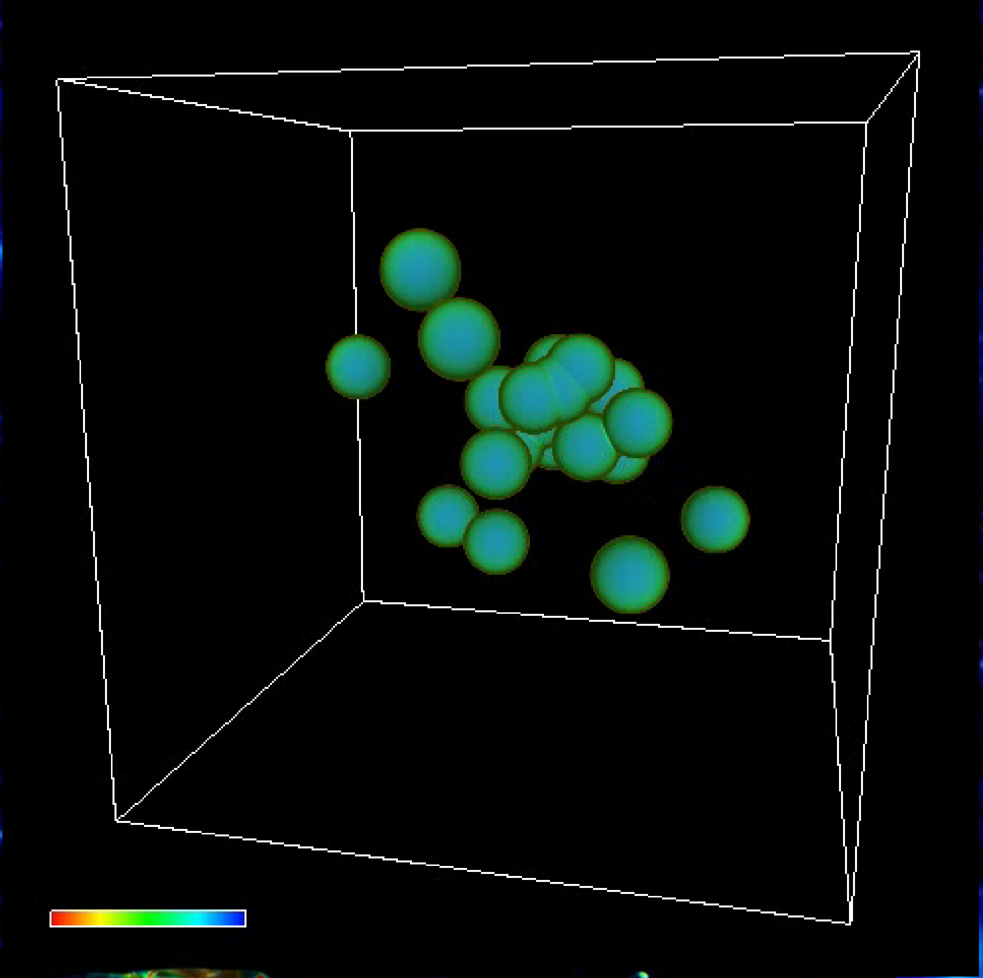
1024^3 Hydrodynamic Calaculations
80,000,000 SN explosions

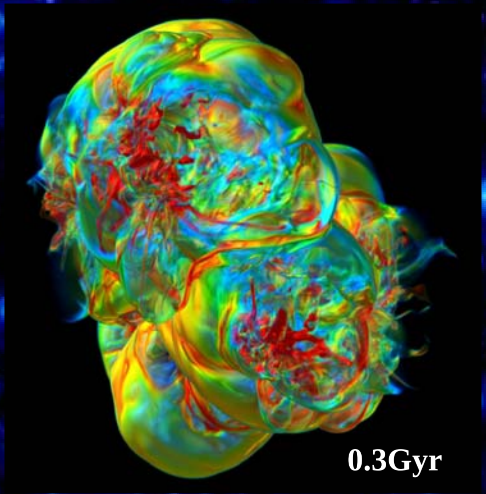
Mori and Umemura, 2006, Nature, 440, 644

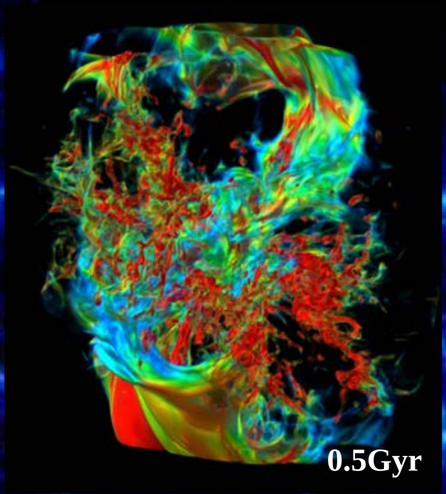
Cover page of Nature (March 30, 2006)

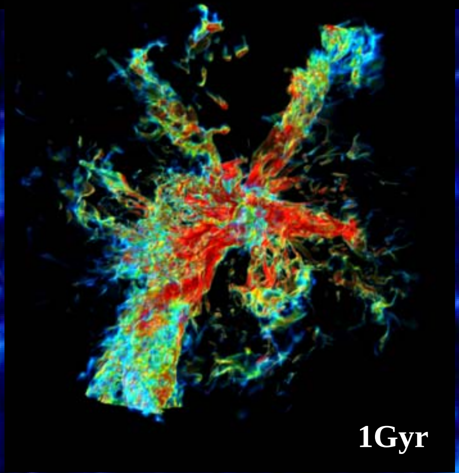
Evolution of Gas Density

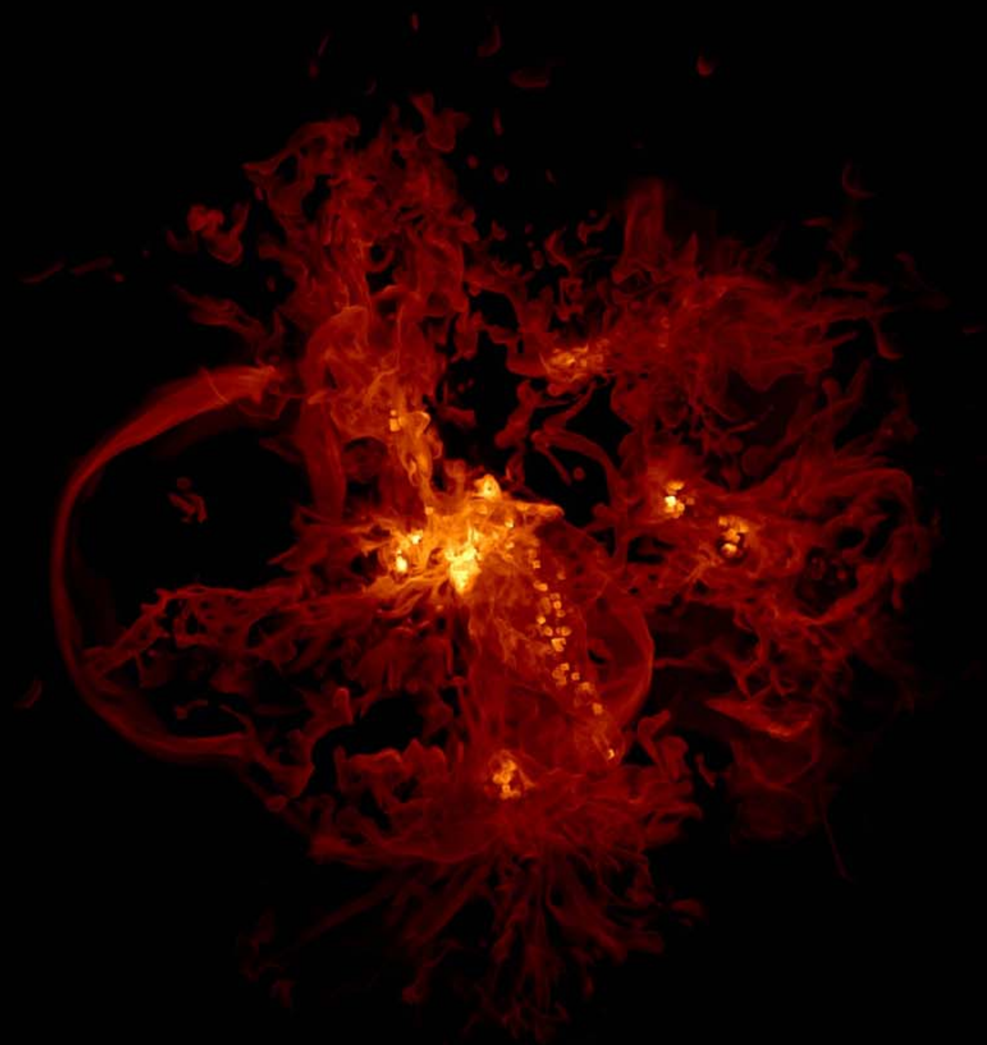
Total Mass: $10^{11}\ M_{\odot}$
Gas Mass: $1.3 \times 10^{10}\ M_{\odot}$
# of Subunits: 20
Box Size: 134 kpc
Grid Points: 1024^3

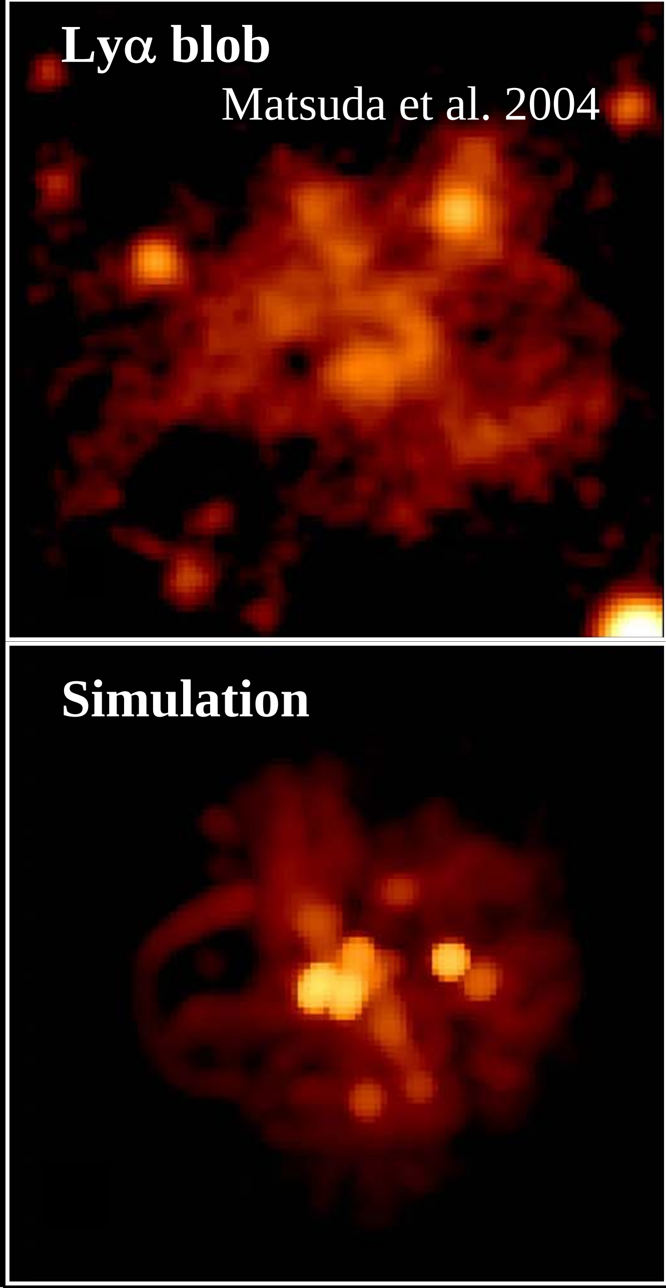








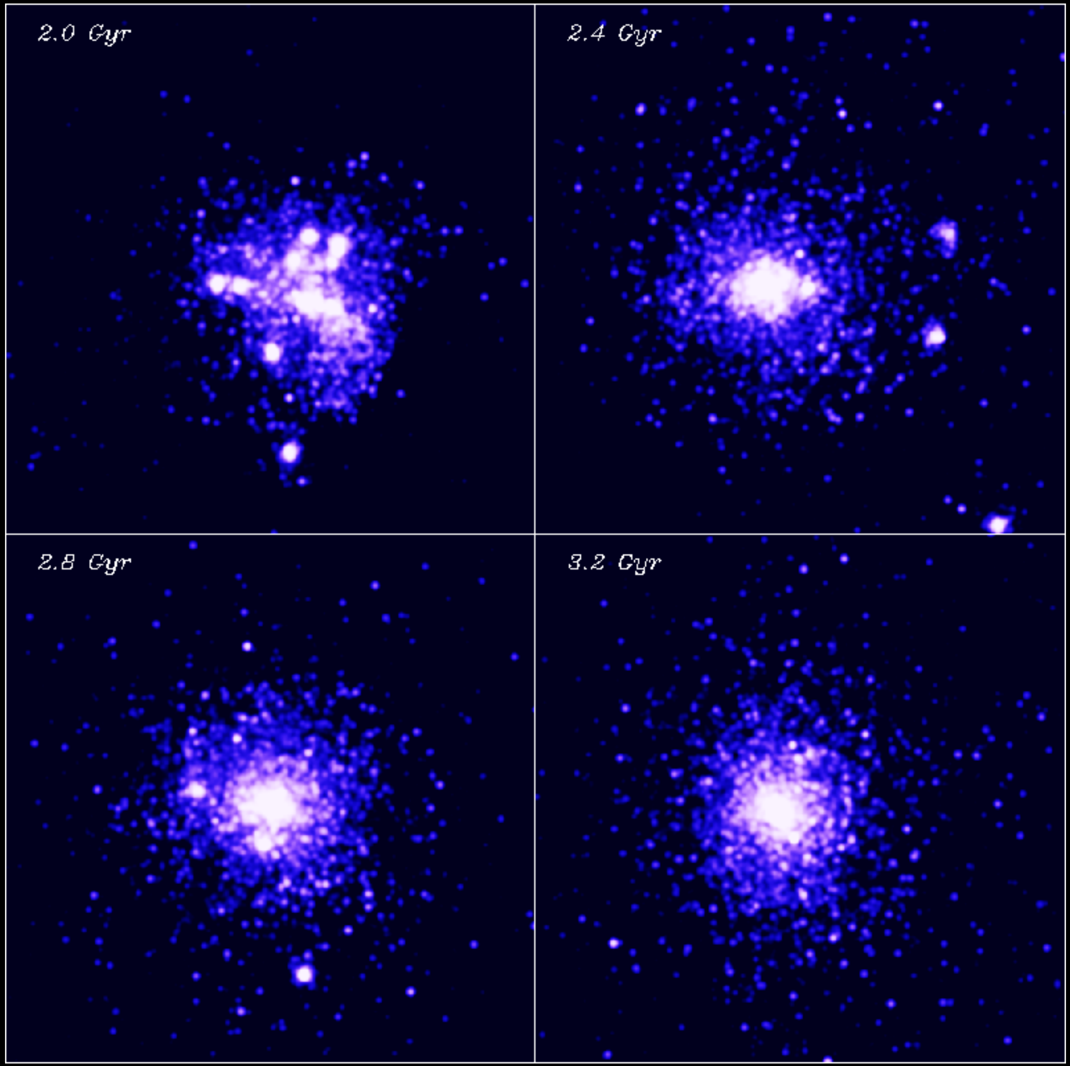




Comparison of the simulation with observation

Left: Projected distribution of Ly α emission derived by numerical results.
Right upper: Ly α image of the LABs observed by Matsuda et al. (2004)
Right lower: Simulation result smoothed with a Gaussian kernel with a FWHM of 1.0”.

Subsequent Dynamical Evolution with *N*-body Simulation with Million Particles



The virializaion of the total system is almost completed 3 Gyrs.

The resultant system at 13 Gyrs (redshift z=0) :

Stellar mass: $M_{*}=1.1\times 10^{10}\ M_{\odot}$

Central velocity dispersion: V_0=133 km s^{-1}

Effective radius: R_e=3.97 kpc

B-band mag.: M_B= -17.2

V-band mag.: M_V= -18.0

Color: *U*-*V*=1.15

V-*K*=2.85

These values are consistent with the properties of the present-day less-massive elliptical galaxies.

Pop III Binary Formation

Saigo, Matsumoto, Umemura, 2004, ApJL, 615, L65

Present-day Stars

over 50% are binaries !

Pop III Stars

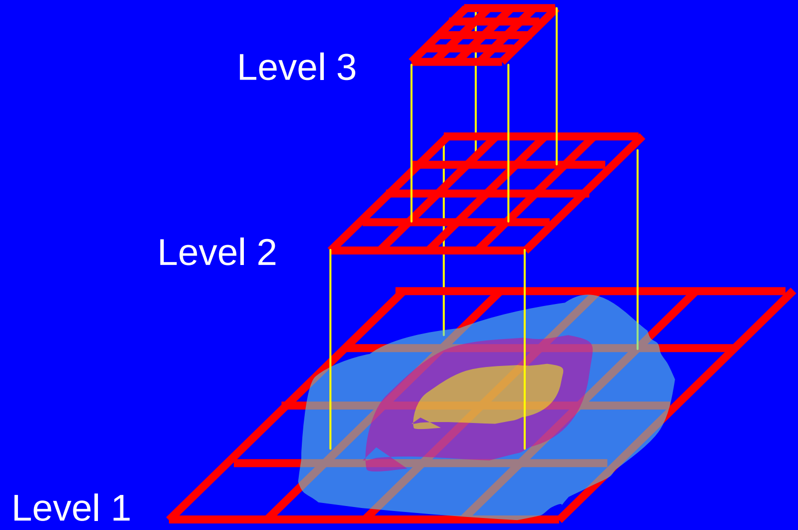
massive binaries

↓

3D Simulation with nested grids

3D nested grid with 20 Levels

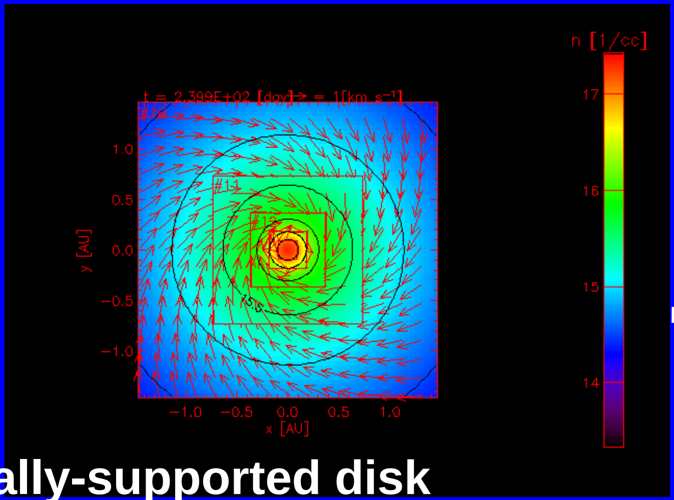
$\Delta x = L / 128\times 2^{19} = 8.3\times 10^{-5}$AU



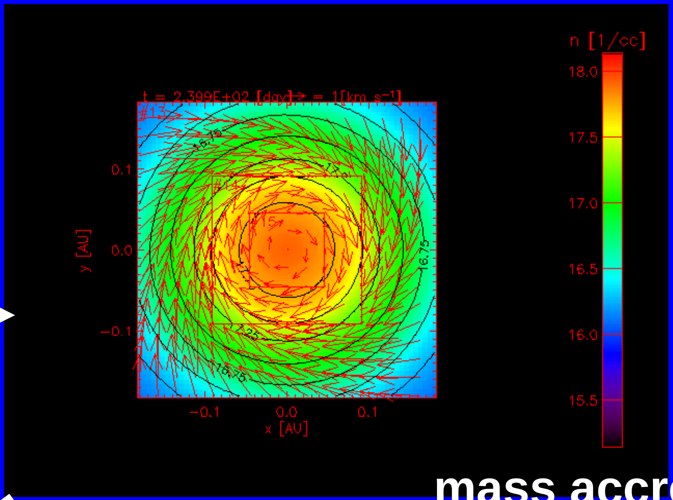
Binary Formation

Low rotation case

$$\beta \equiv \frac{\text{centrifugal force}}{\text{pressure force}} = 0.1$$



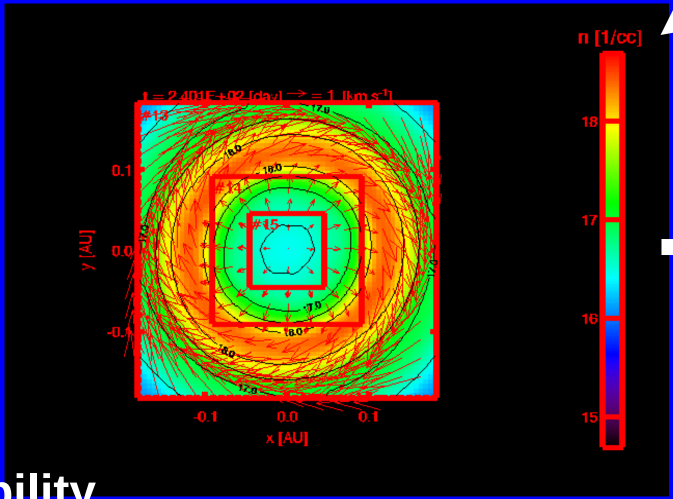
rotationally-supported disk



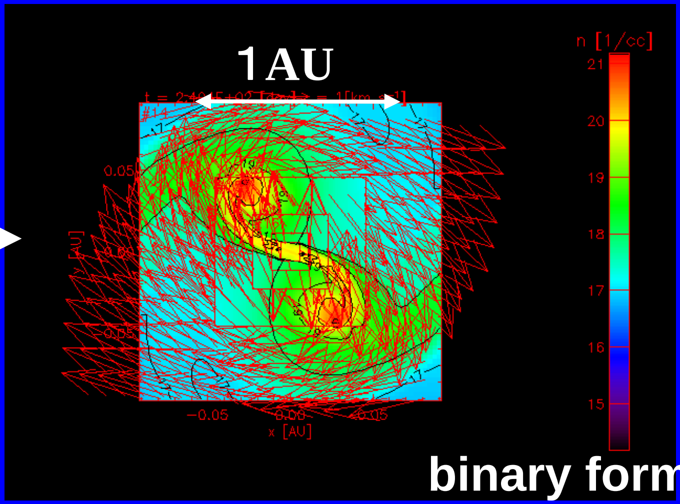
mass accretion

$$\frac{T_{rot}}{|W|} = 0.245$$

$$< 0.27$$



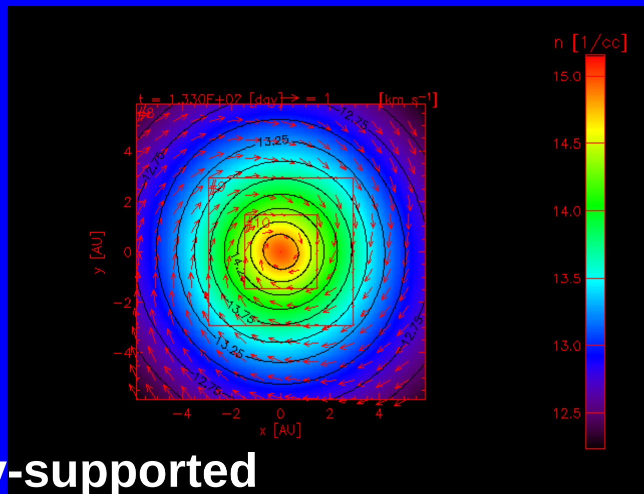
ring instability



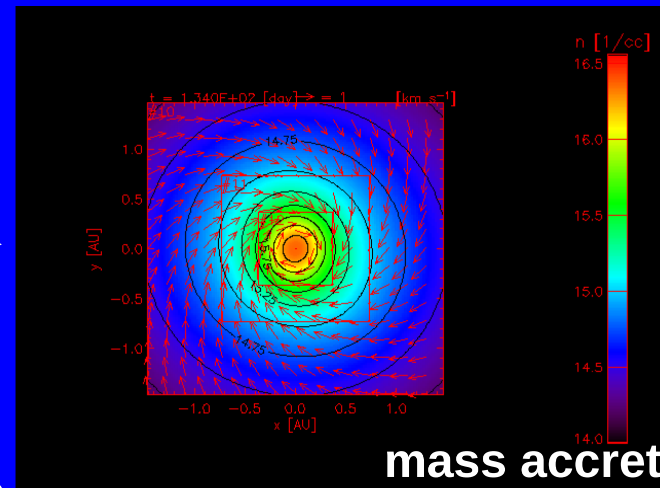
binary formation

High rotation case

$$\beta \equiv \frac{\text{centrifugal force}}{\text{pressure force}} = 1$$



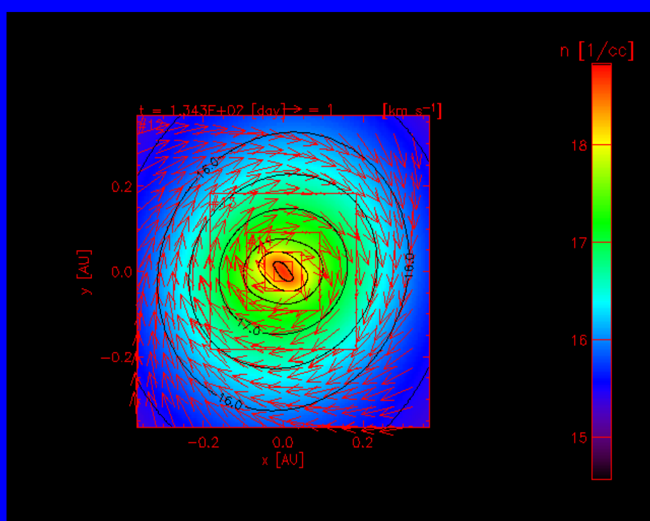
rotationally-supported disk



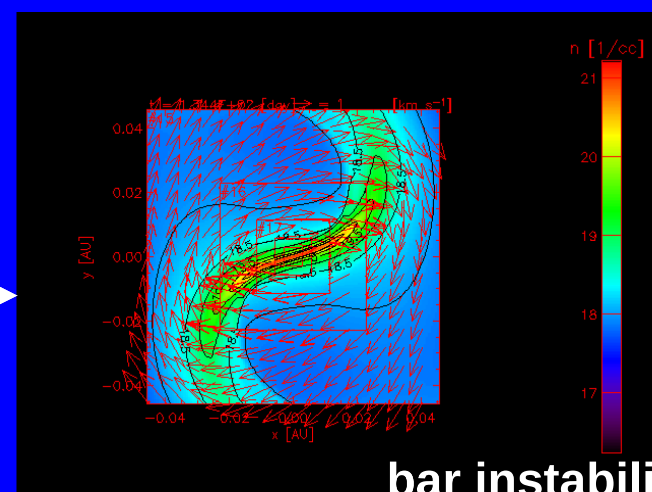
mass accretion

$$\frac{T_{rot}}{|W|} = 0.327$$

$$> 0.27$$



no ring

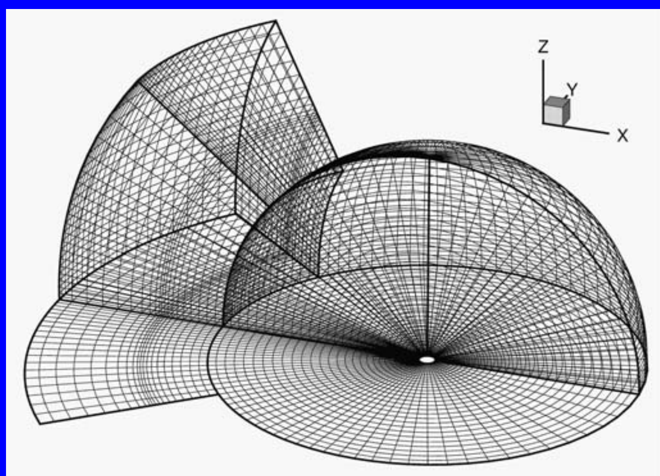


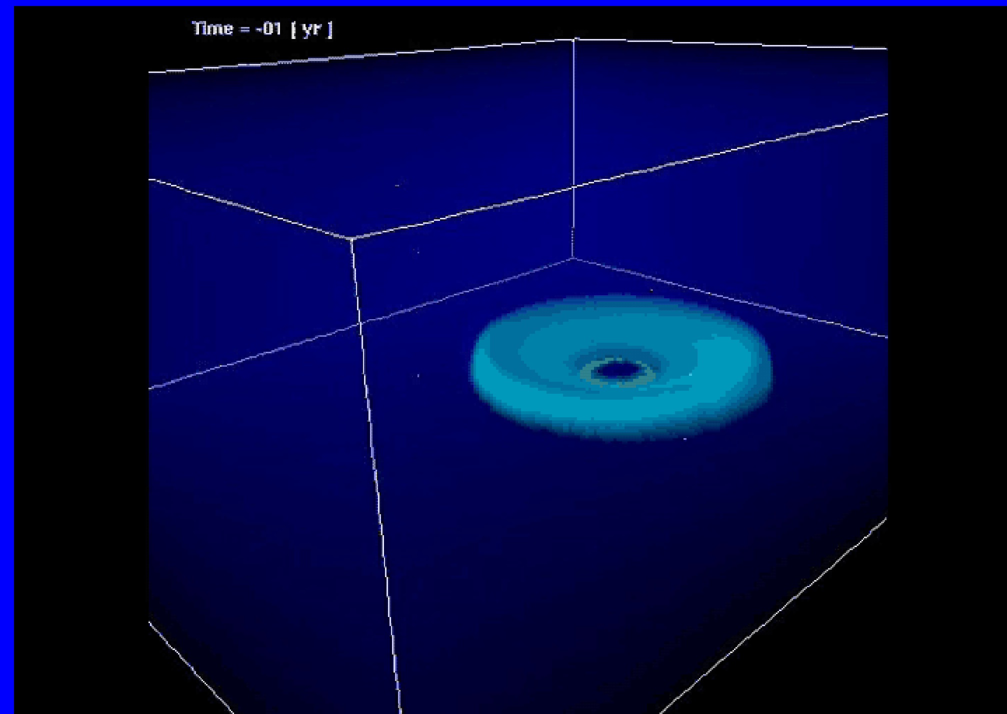
bar instability (single star)

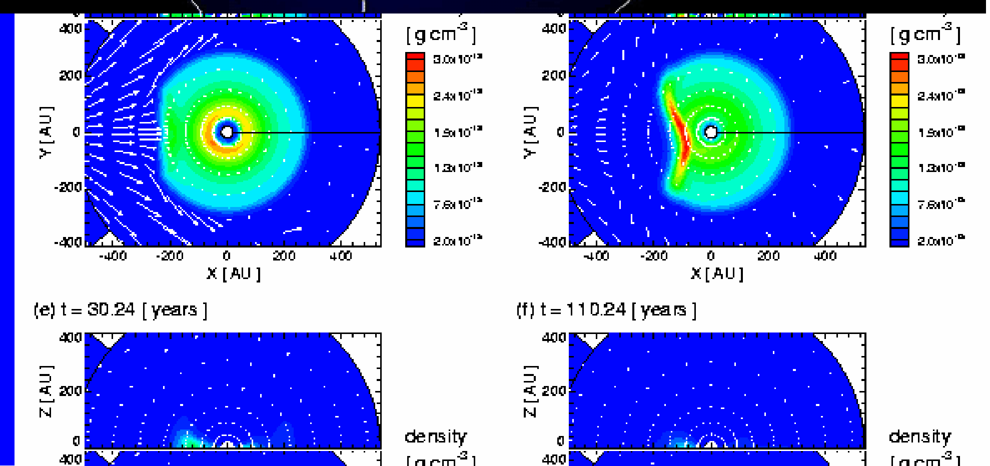
Survival of BH Accretion Disk from SN

Sato & Umemura 2007

$M_{SN}=100M_{\odot}$, $M_{BH}=1000M_{\odot}$
$E_{SN}=30E_{disk}$







70% of accretion disk is left

Future Plan

1. Intensive Simulations with FIRST simulator

Operation of FIRST continues after 2007 as well

2. Collaborations with Other Divisions

- ***with* Division of High Performance Computing Systems**

  Multiple Architecture Seamless System (MASS)

  - Extension of FIRST simulator (with SSE, Graphic board, etc.)

- ***with* Division of Materials and Life Sciences**

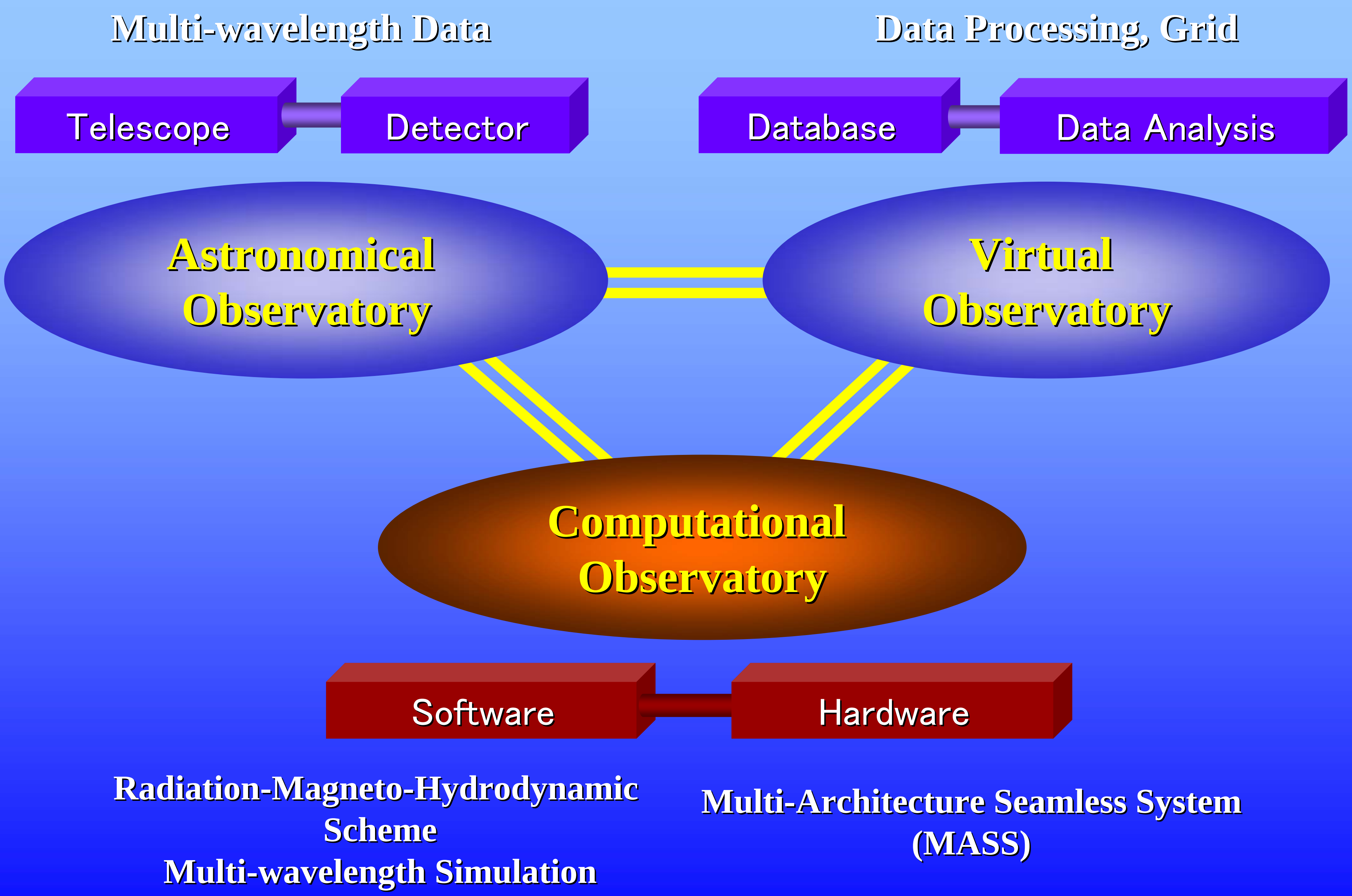
  ***ab initio* (DFT) calculations of hydrogen molecule reactions**

  (H+H+H $\leftrightarrow$ H_2+H) -- First star formation

  $\Rightarrow$ Quantum Astrophysics

3. "Computational Observatory" Project

Computational Observatory Project



Thank you

Computational Science Colloquium
15:30, Nov 1, 2007
Workshop Room

Activities at the Laboratory for Computational Astrophysics, UCSD

Prof. Michael L. Norman
University of California, San Diego