The improvement of START

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Outline

- Introduction
  - What is "START"
  - Previous Studies with START
- Improvements
  - New Ray-tracing
    - Test & Scalability
  - Additional Process (Roles of Dust)
    - Preliminary Results
- Summary

What is "START"

SPH with Tree-based Accelerated Radiative Transfer
(KH & Umemura 2010)

- **Hydrodynamics**

  SPH (Smoothed Particle Hydrodynamics) method

- **Non-equilibrium chemistry**

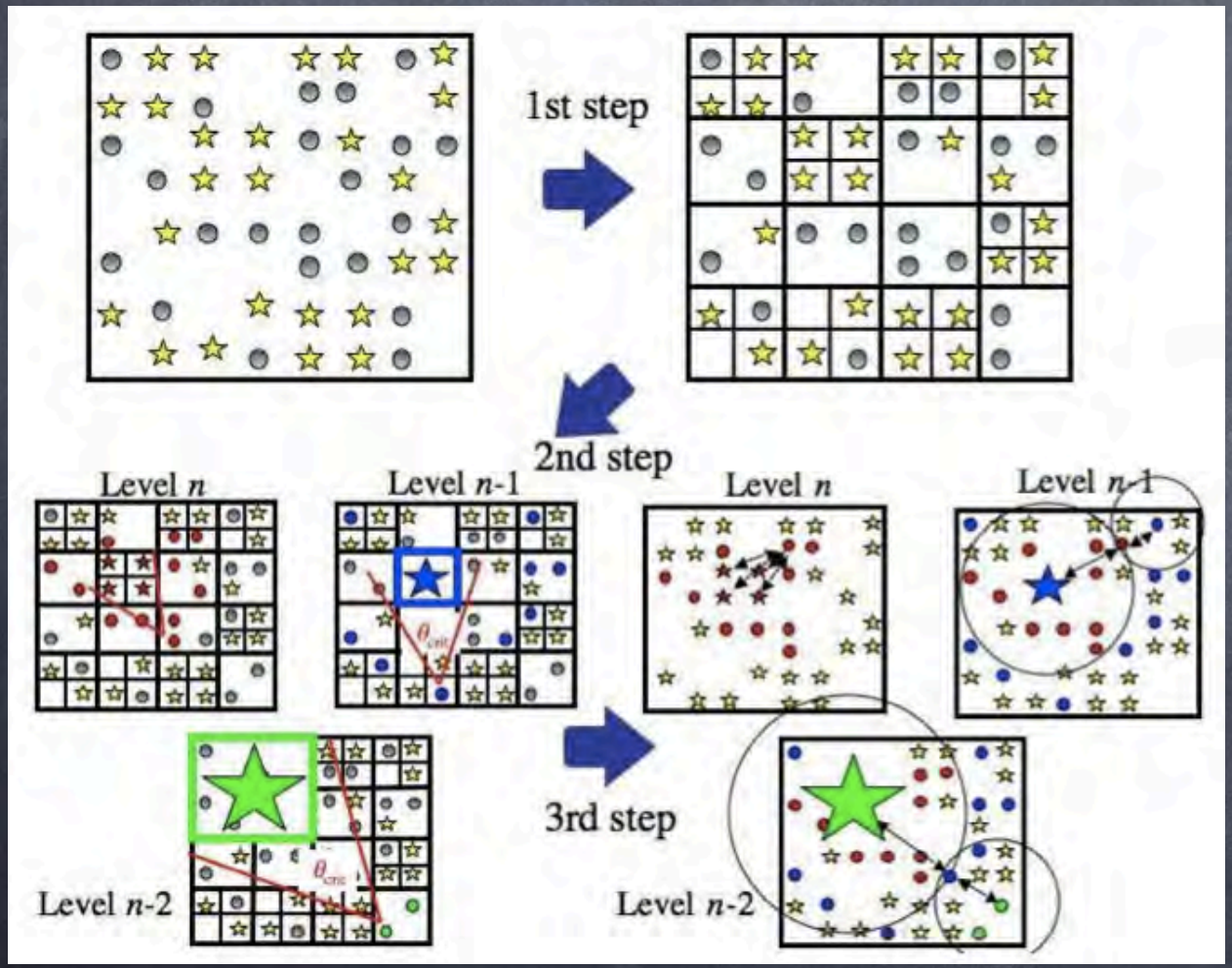
  e^-, H^+, H, H^-, H_2, H^{2+}, He, He^+, and He^{2+}

- **Radiative Transfer**

  HI, HeI, HeII ionizing photon, and
  H_2 photodissociating photon.
  SPH particles are directly used as grids for RT
  → Spatial resolution changes adaptively.
  RT Calculation is accelerated by Tree Algorithm

What is "START"

SPH with Tree-based Accelerated Radiative Transfer (KH & Umemura 2010)



1) Make an oct-tree structure for sources.

2) If a cell which contains sources is far enough away from an SPH particle, the cell is regarded as a virtual luminous sources.

What is "START"

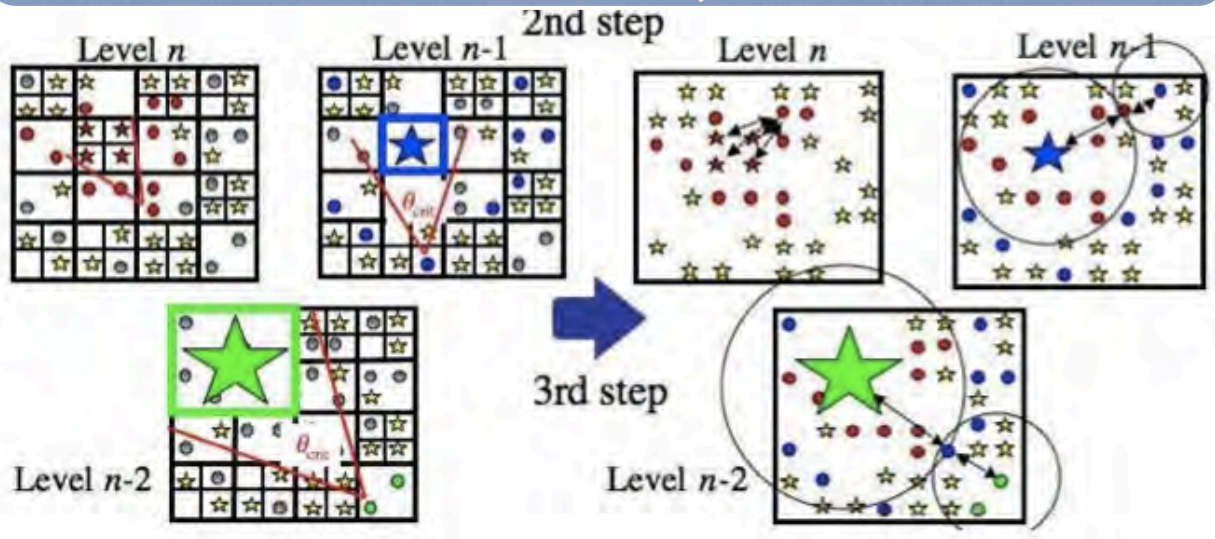
SPH with Tree-based Accelerated Radiative Transfer (KH & Umemura 2010)

$$\frac{l}{d} < \theta_{\rm crit}$$

In the limit of $\theta_{\rm crit} = 0.0$, the scheme corresponds to RSPH (Susa 2006)

l: size of a cell

d: distance between a SPH particle and a cell



1)Make an oct-tree structure for sources.

2) If a cell which contains sources is far enough away from an SPH particle, the cell is regarded as a virtual luminous source.

calculation cost is proportional to $\log(N_s)$ (Not N_s)

What is "START"

Similar method for grid-based RT

ARGOT:

Accelerated Radiative Transfer on grids using oct-tree

(Okamoto, Yoshikawa & Umemura 2012)

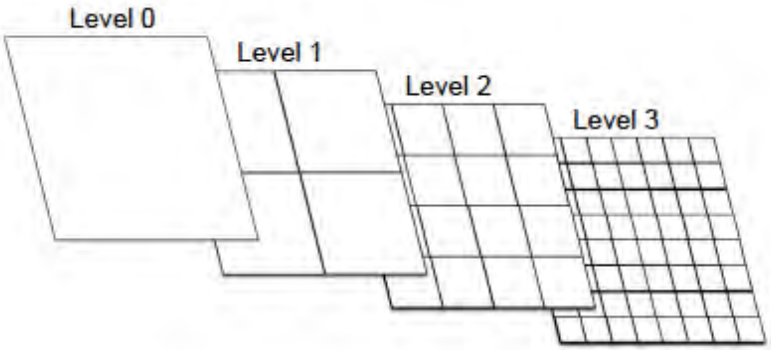
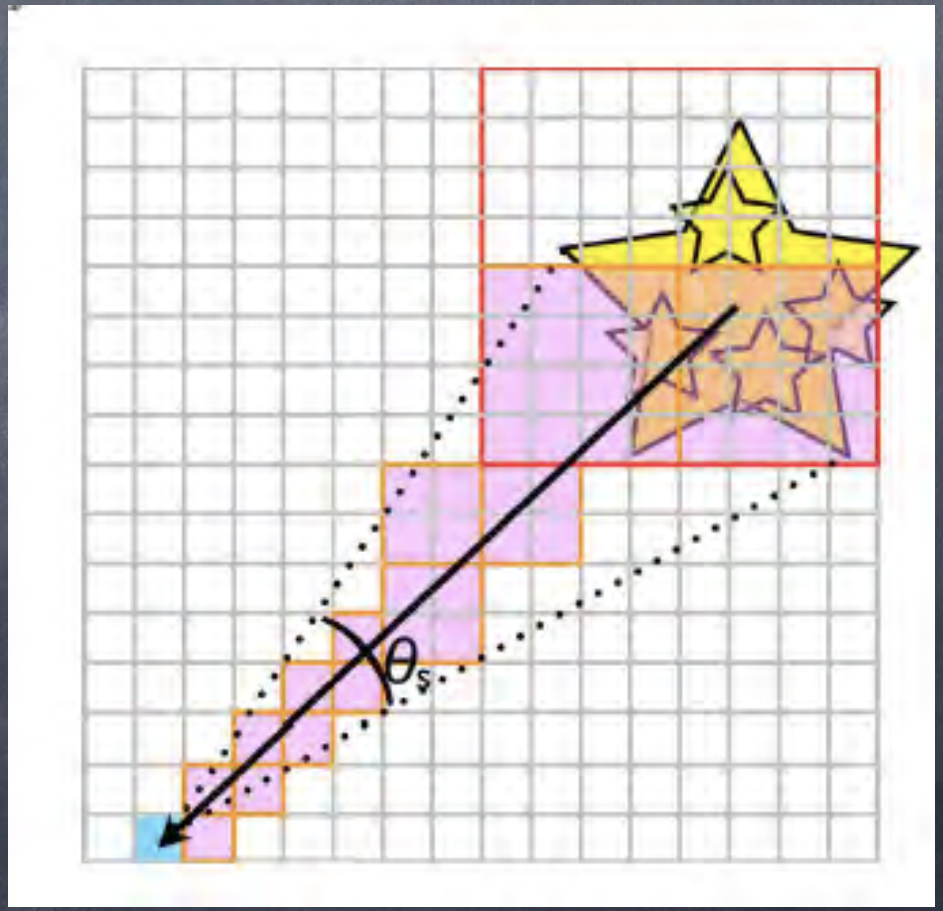


Figure 1. Schematic illustration of the supermesh structure for 8×8 two-dimensional meshes. In this case, the maximum level, $l_{\rm max}$, is 3 and the meshes themselves can be used as the highest level supermeshes. A level l supermesh contains $2^{2(l_{\rm max}-l)}$ meshes. For three-dimensional meshes, a level l supermesh consists of $2^{3(l_{\rm max}-l)}$ meshes.



Previous Work with START

KH, Umemura & Suwa (2010), Umemura, Susa, KH, Suwa, & Semelin (2012)

UV feedback on a secondary collapsing Pop III halo

- RHD simulation including the transfer of diffuse recombination photons. ⇒ $N_{source} = N_{SPH} = 2\text{million}$

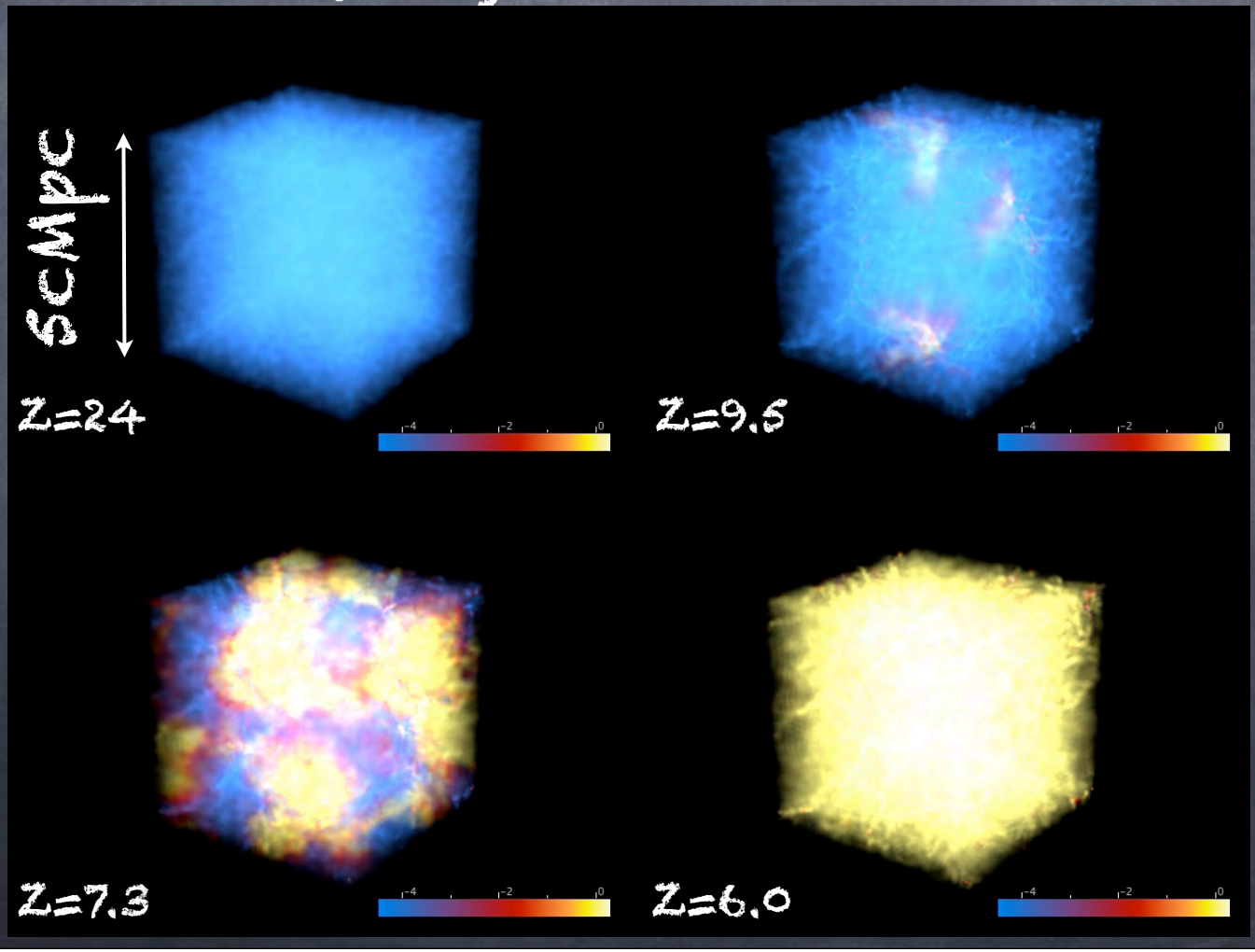
The secondary core can survive!!

Previous Work with START

KH & Semelin (2012)

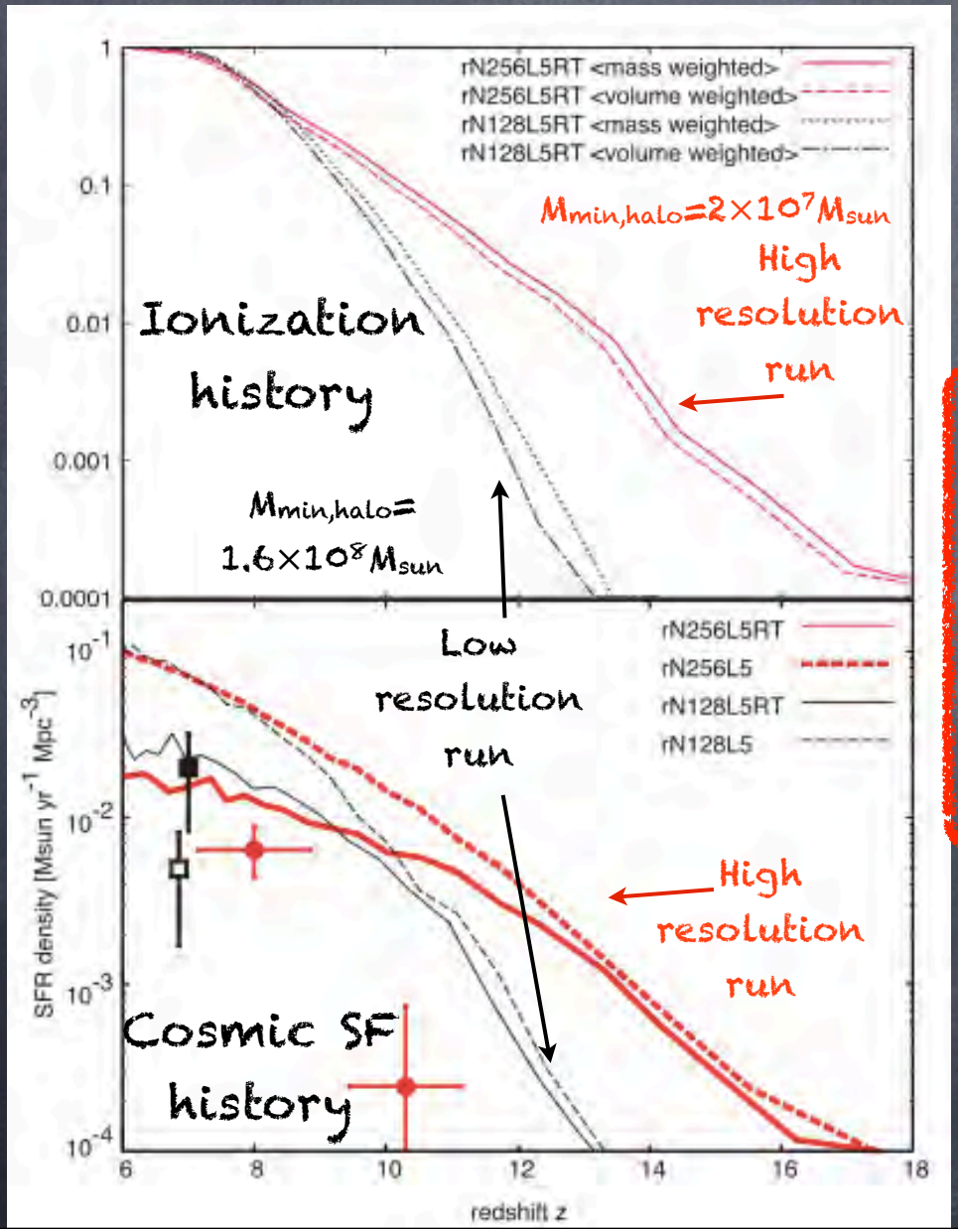
UV feedback on galaxies during the Epoch of Reionization

- RHD simulation including internal UV (ionization and LW) feedback in each galaxy.



Previous Work with START

KH & Semelin(2012)



We found:

- The formation of galaxies during the EoR is controled by internal UV & SN feedback.
- Ionization and Cosmic SF histories are very sensitive to the mass resolution.

Box size is too small to show cosmic reionization history...

Much larger number of particles are required

What we need are

★Powerful Super Computer

★RHD code which enables us to perform massive parallel simulations

K Computer

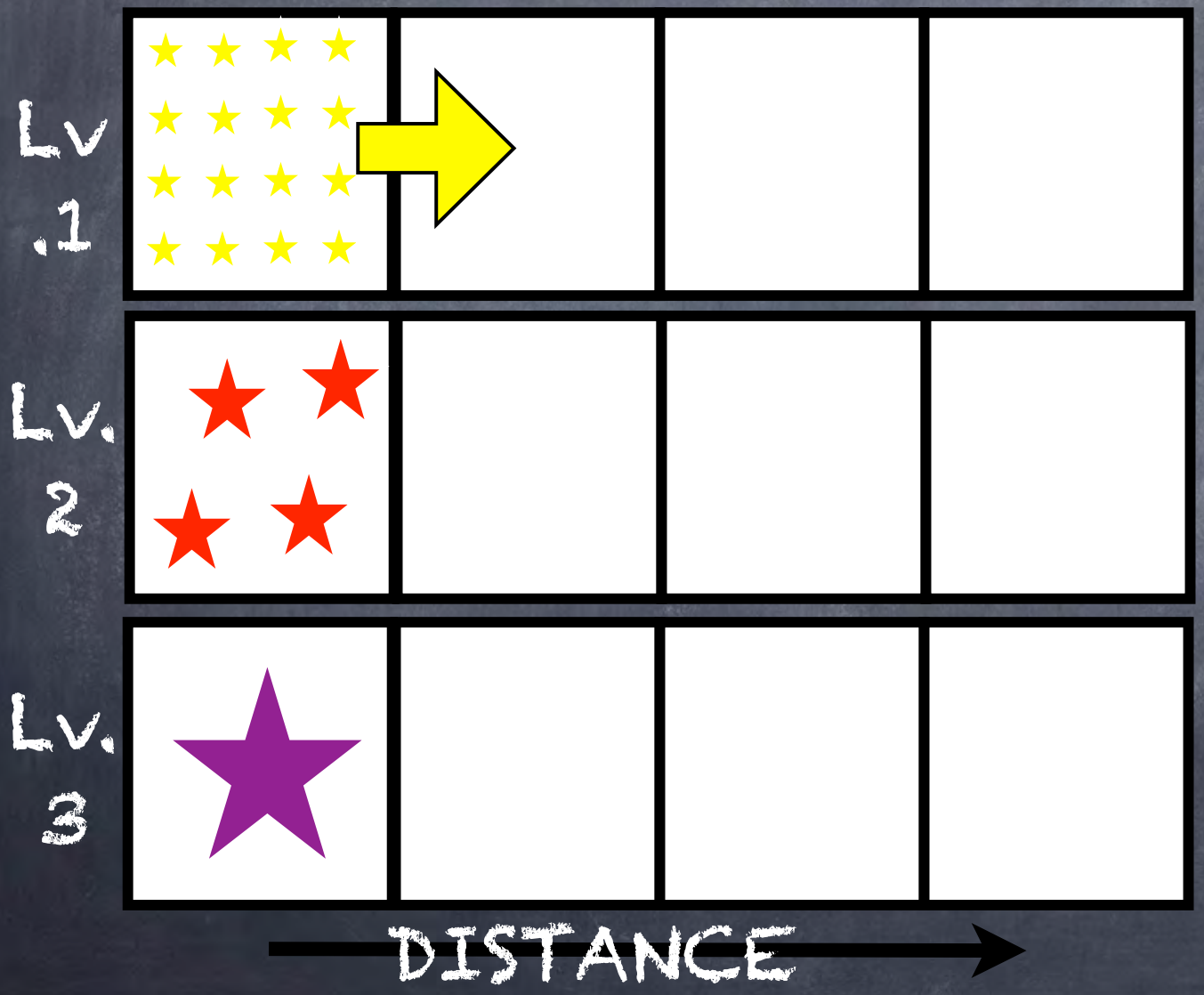
Top500 List Nov. 2012 http://www.top500.org

Rank	Site	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	DOE/SC/Oak Ridge National Laboratory United States	Titan - Cray XK7 , Opteron 6274 16C 2.200GHz, Cray Gemini interconnect, NVIDIA K20x Cray Inc.	560640	17590.0	27112.5	8209
2	DOE/NNSA/LLNL United States	Sequoia - BlueGene/Q, Power BQC 16C 1.60 GHz, Custom IBM	1572864	16324.8	20132.7	7890
3	RIKEN Advanced Institute for Computational Science (AICS) Japan	K computer, SPARC64 VIIIfx 2.0GHz, Tofu interconnect Fujitsu	705024	10510.0	11280.4	12660

~82k nodes (650k cores) available

Peak Performance ~ 10PFlops

Ray-Tracing: Old version.



Ray-tracings are solved from all sources in all levels.

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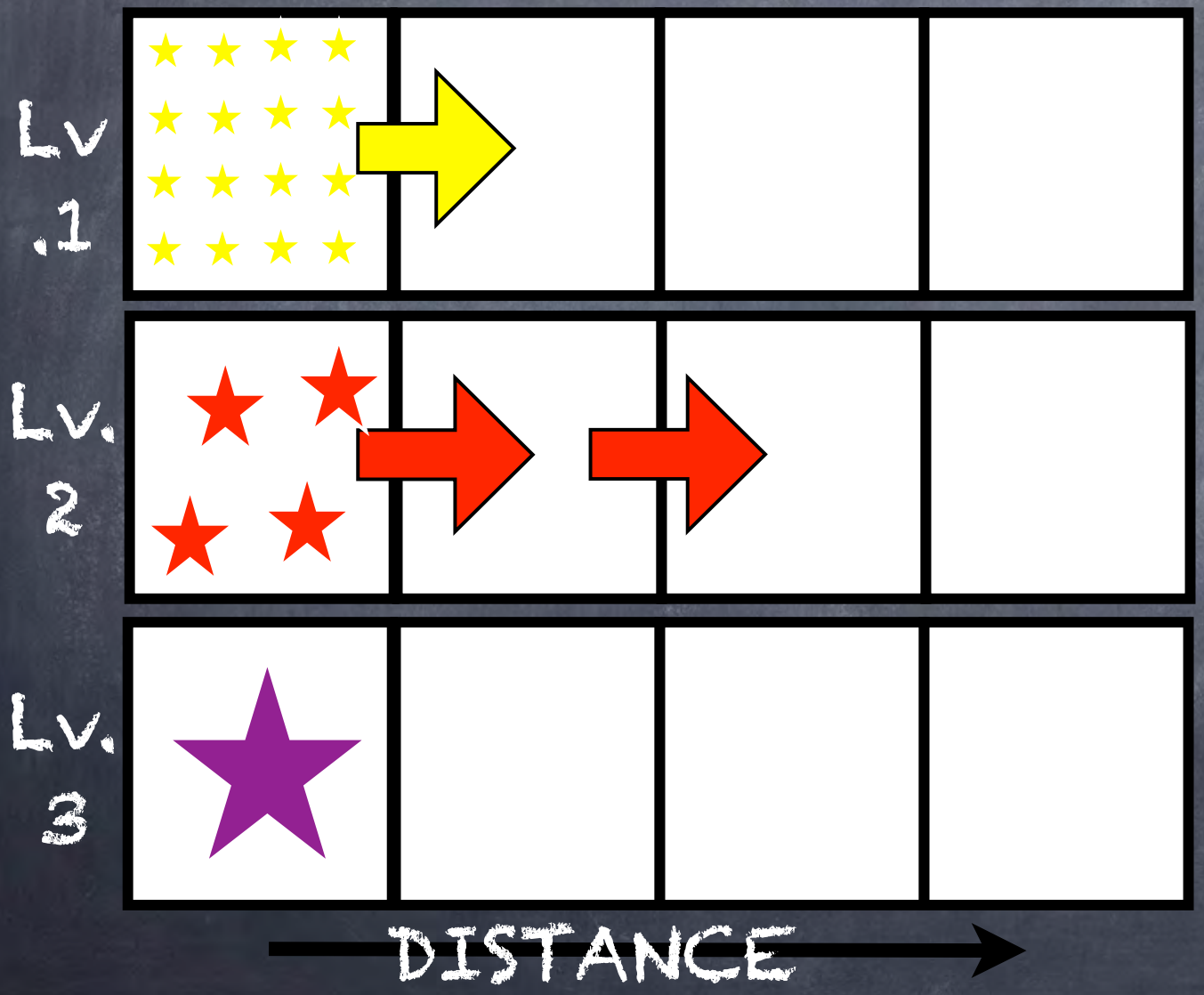

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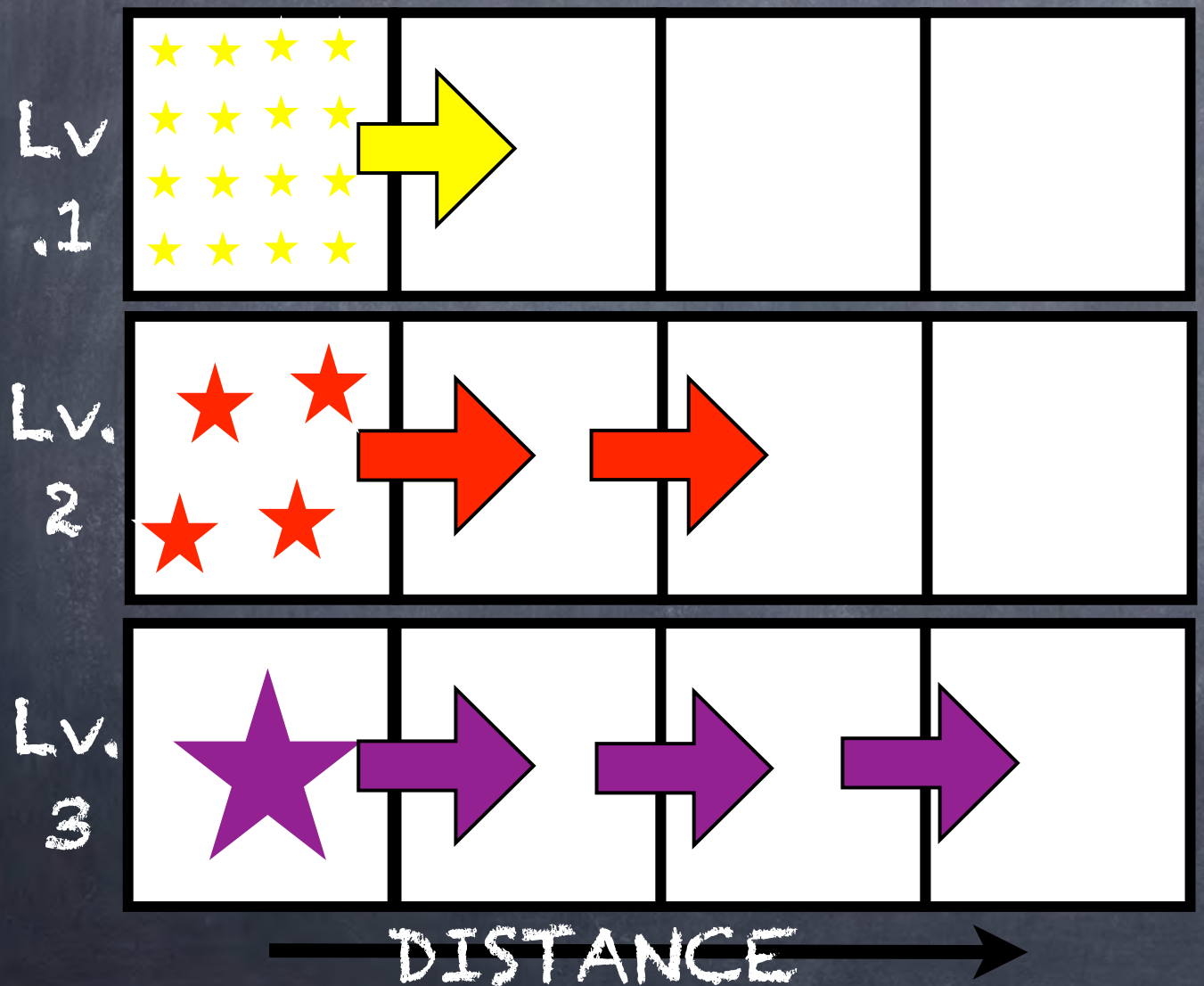
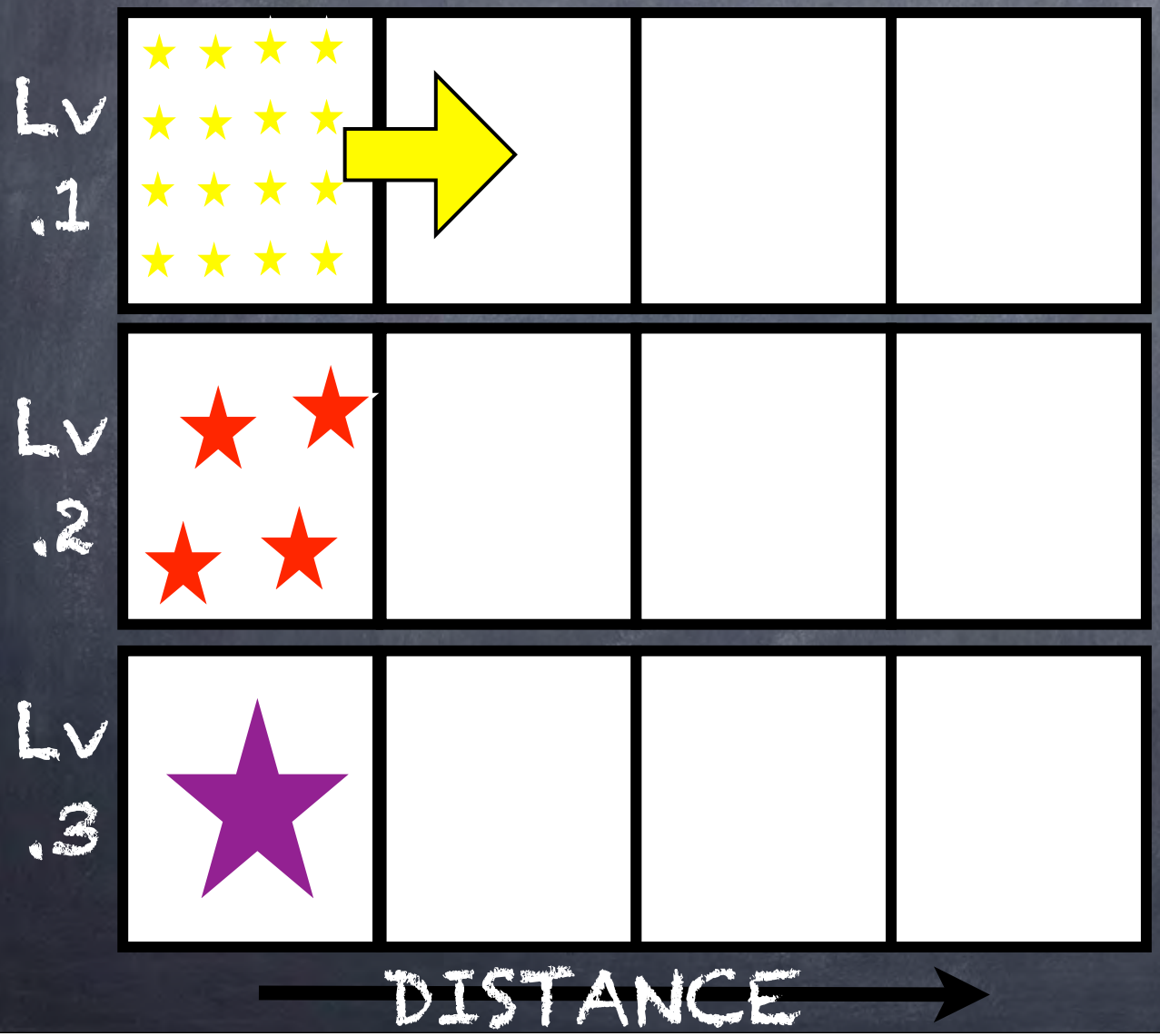


Ray-tracings are solved from all sources in all levels.

Time of MPI communications dramatically increases with increase of N_{Node}

Ray-tracing: Improved version

Point: Reuse of the information of lower level



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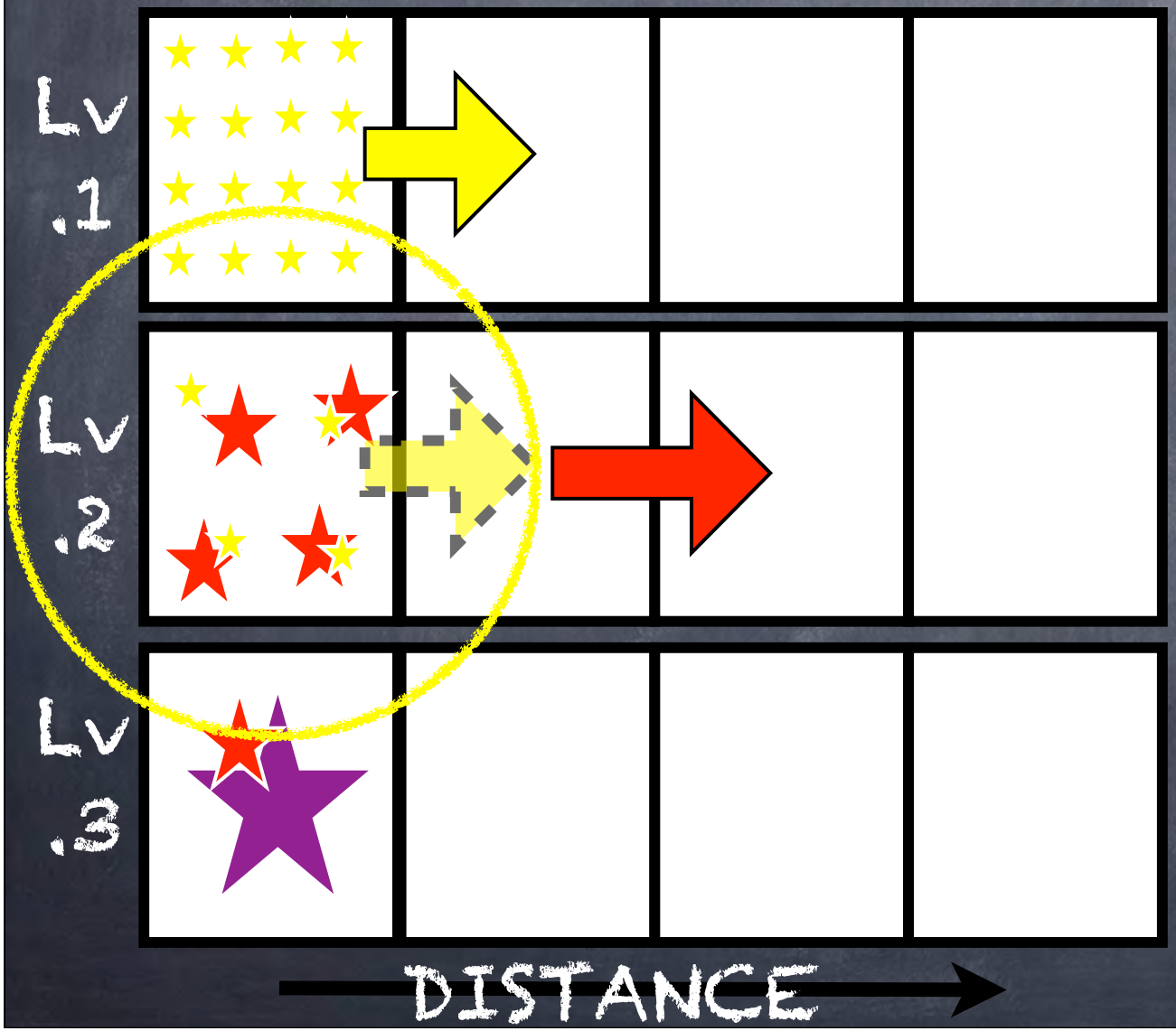

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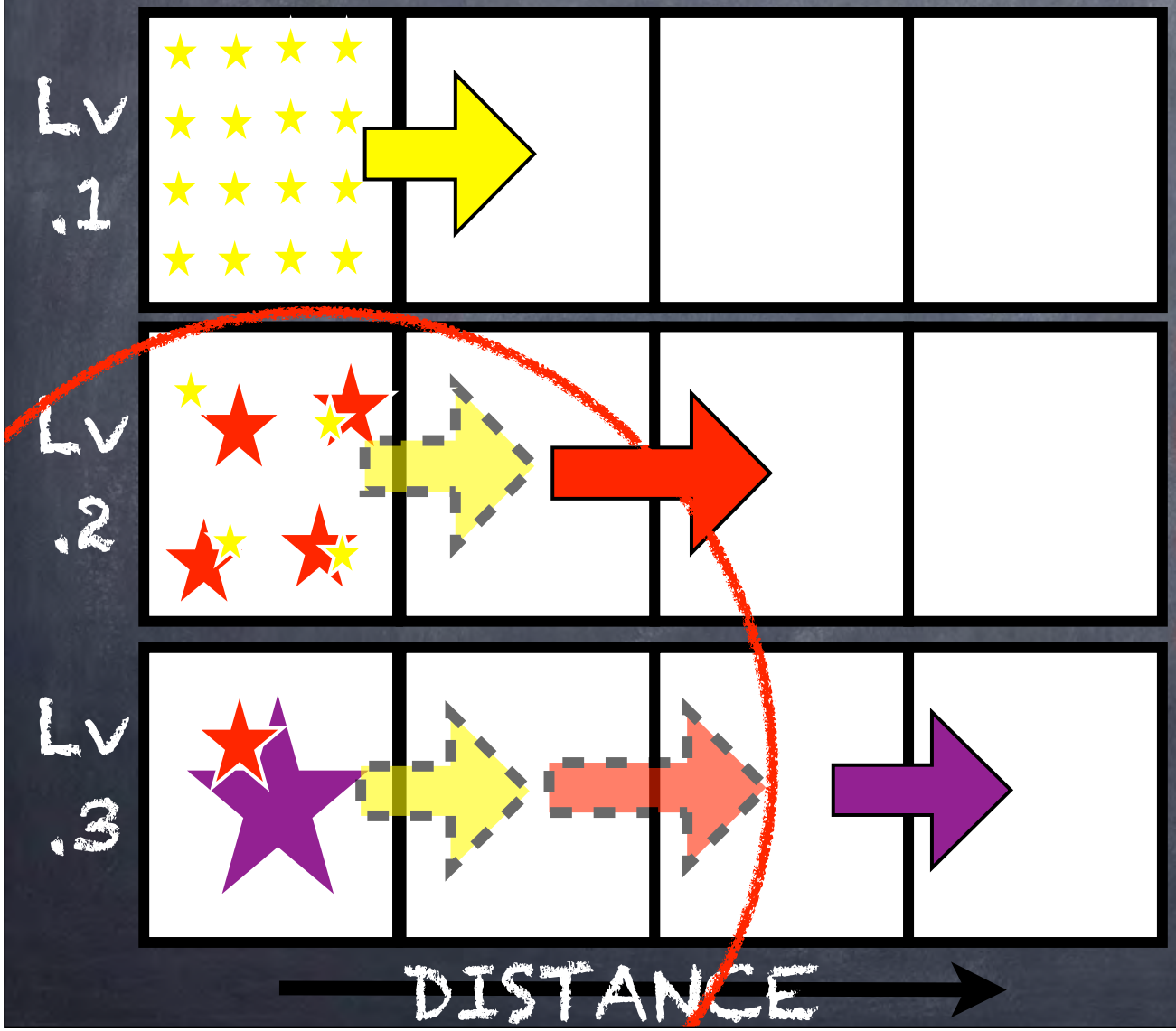

Not only MPI time but also the cost of RT calculation can be reduced.

TREE WALK

*In practice, oct-tree is utilized.

TREE WALK

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TREE WALK

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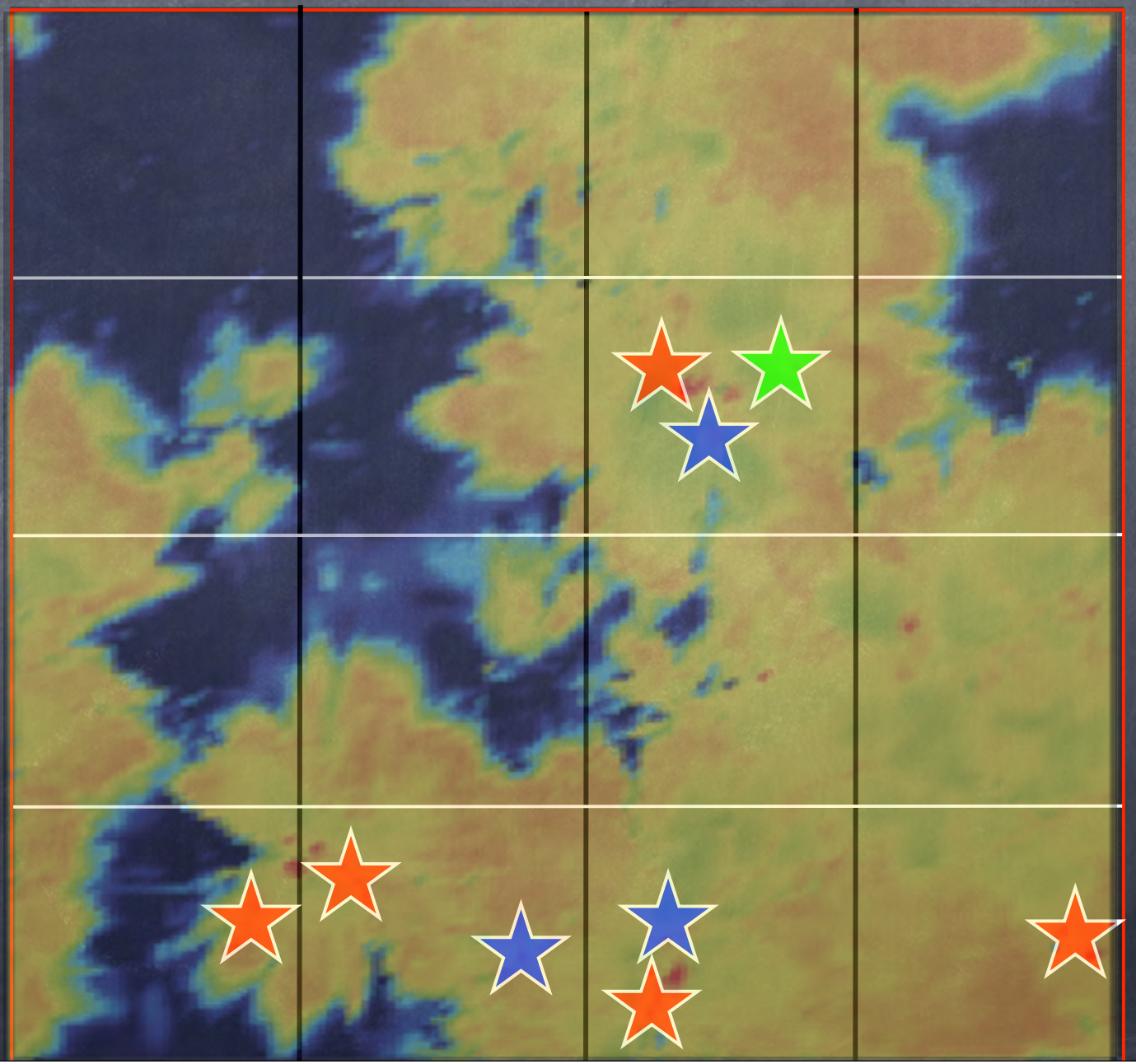
Parallelization via openmp

Parallelization: Between nodes

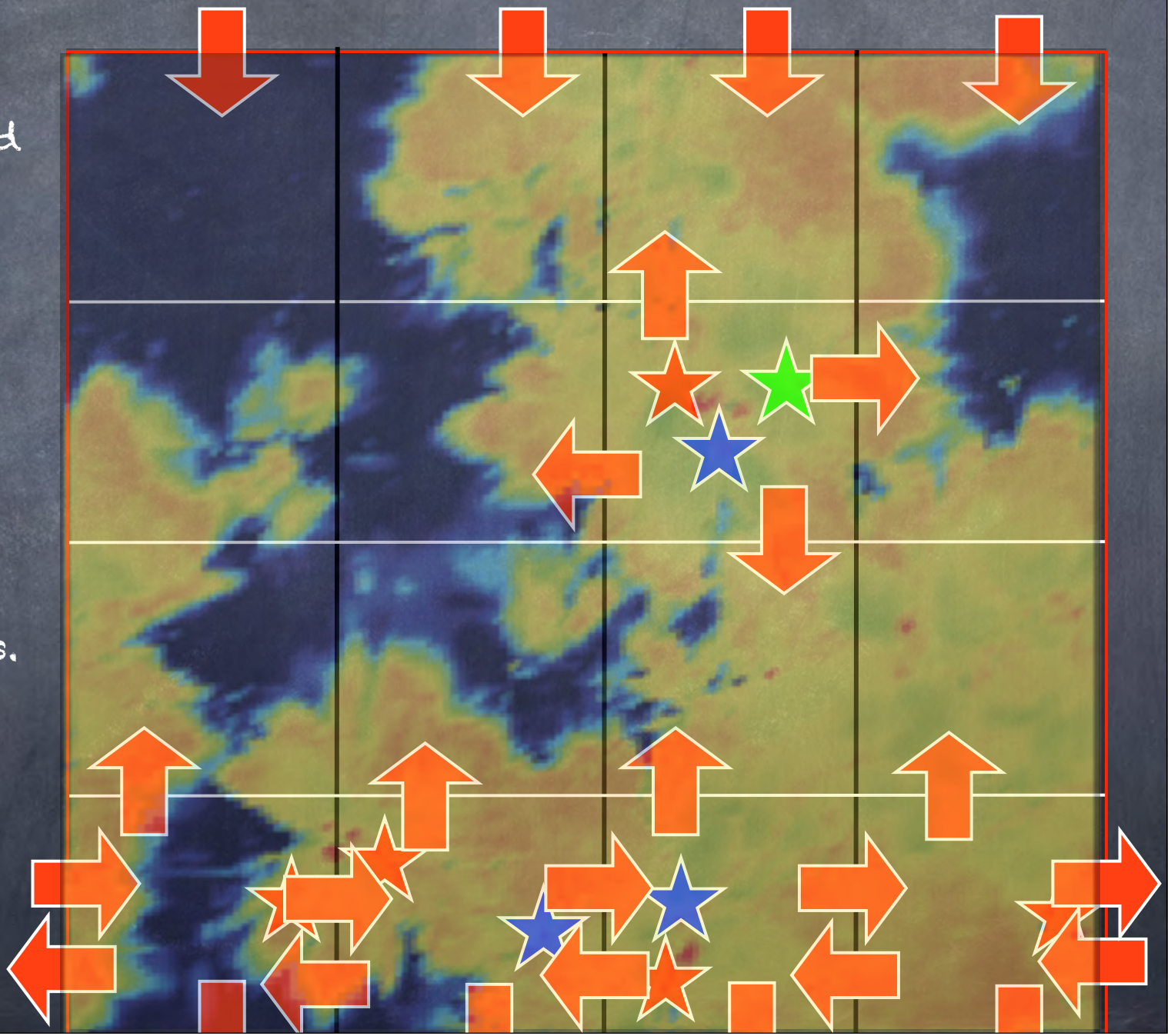
★The size of each domain is adjusted to have equivalent calculation cost every a few steps.



Parallelization: Between

★The size of each domain is adjusted to have equivalent calculation cost every a few steps.

★Each domain asynchronously sends (receives) optical depths. to downstream (from upstream) domains. (Same as RSPH by Susa 2006)



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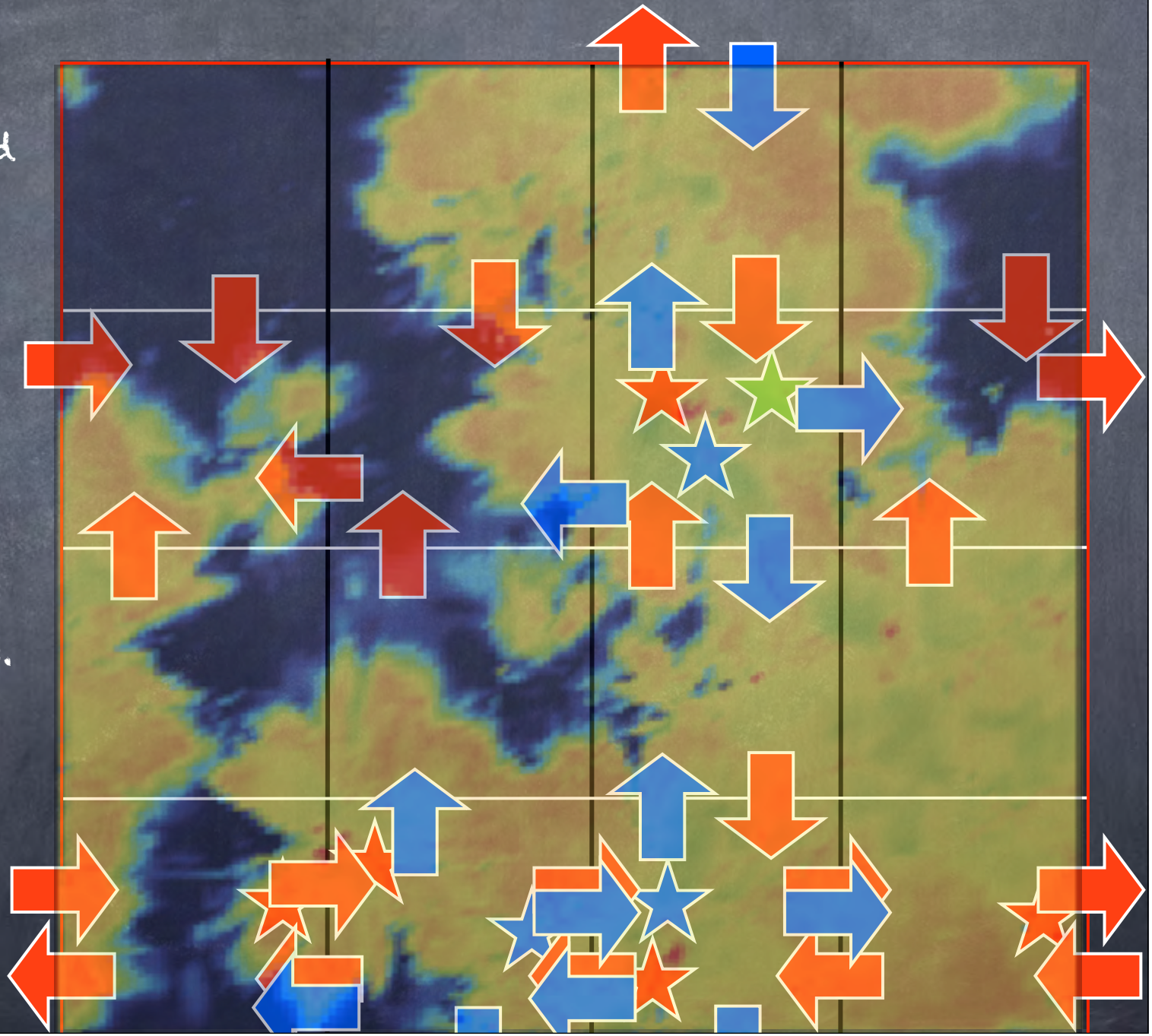

Parallelization: Between

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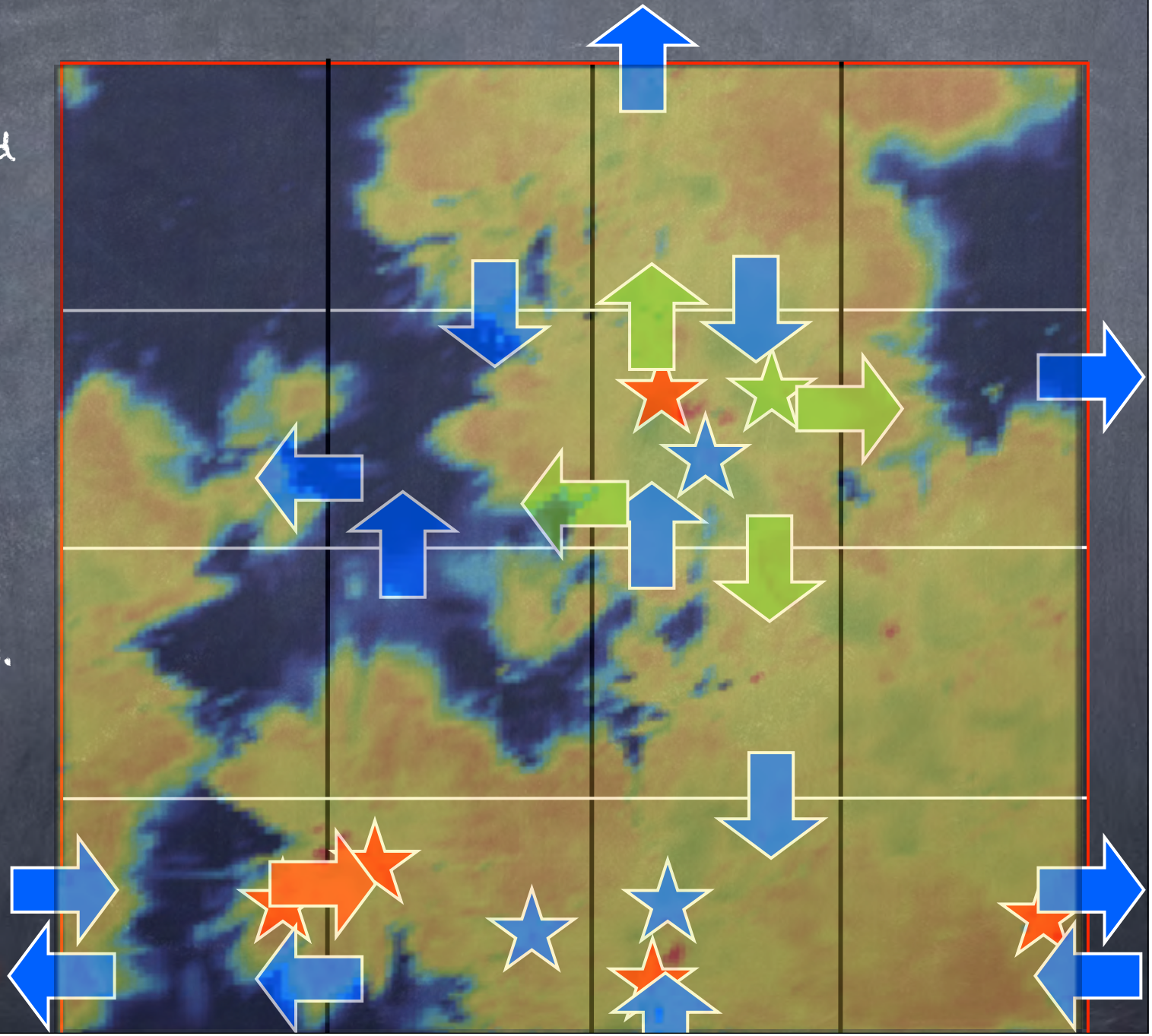
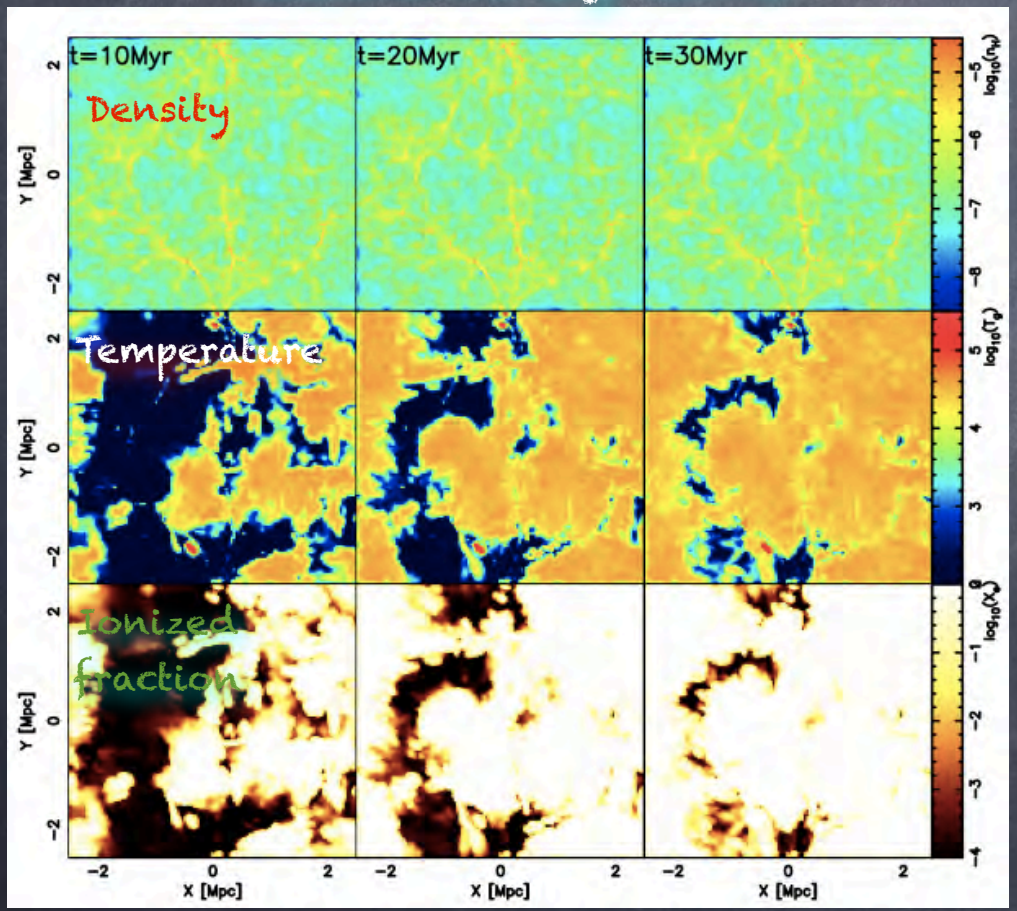
Make load balance better



Test of the new method

DATA: the distributions of the SPH and stellar particles @z=7.0 obtained by a cosmological hydrodynamic simulation. $N_{SPH} = 128^3$, $N_s \sim 300$

Reference (by RSPH)



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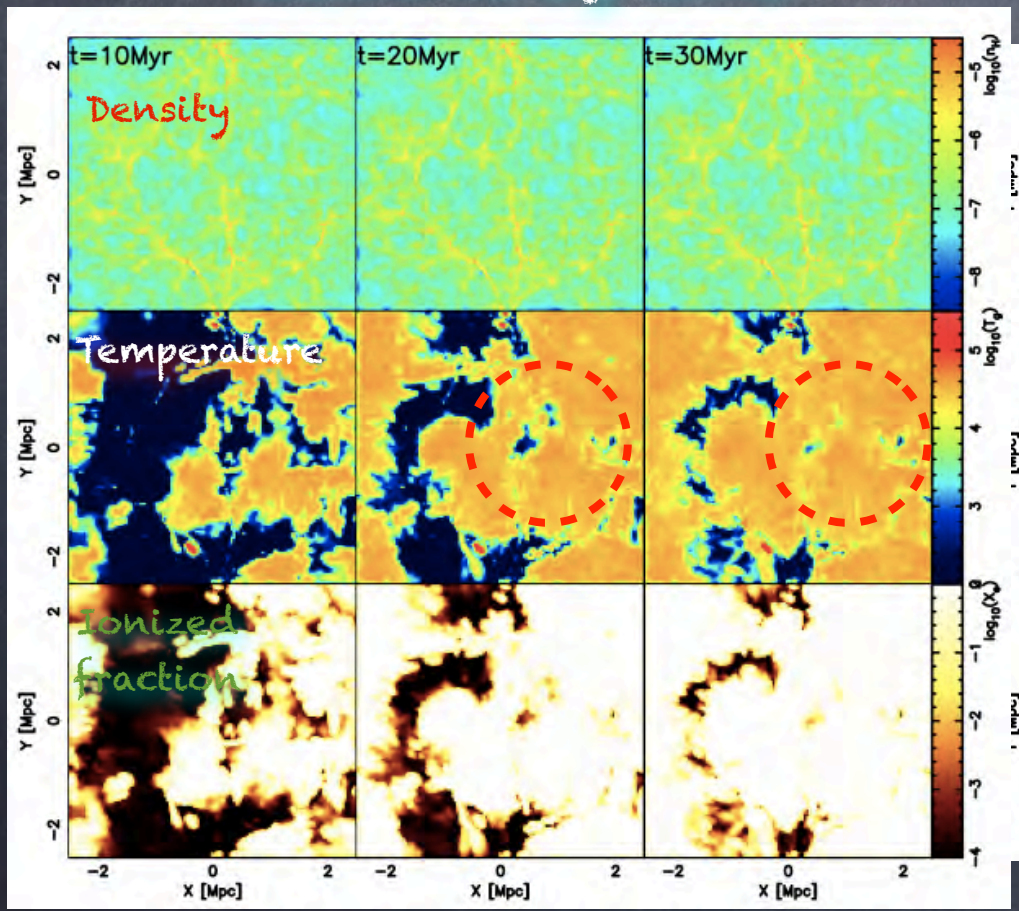
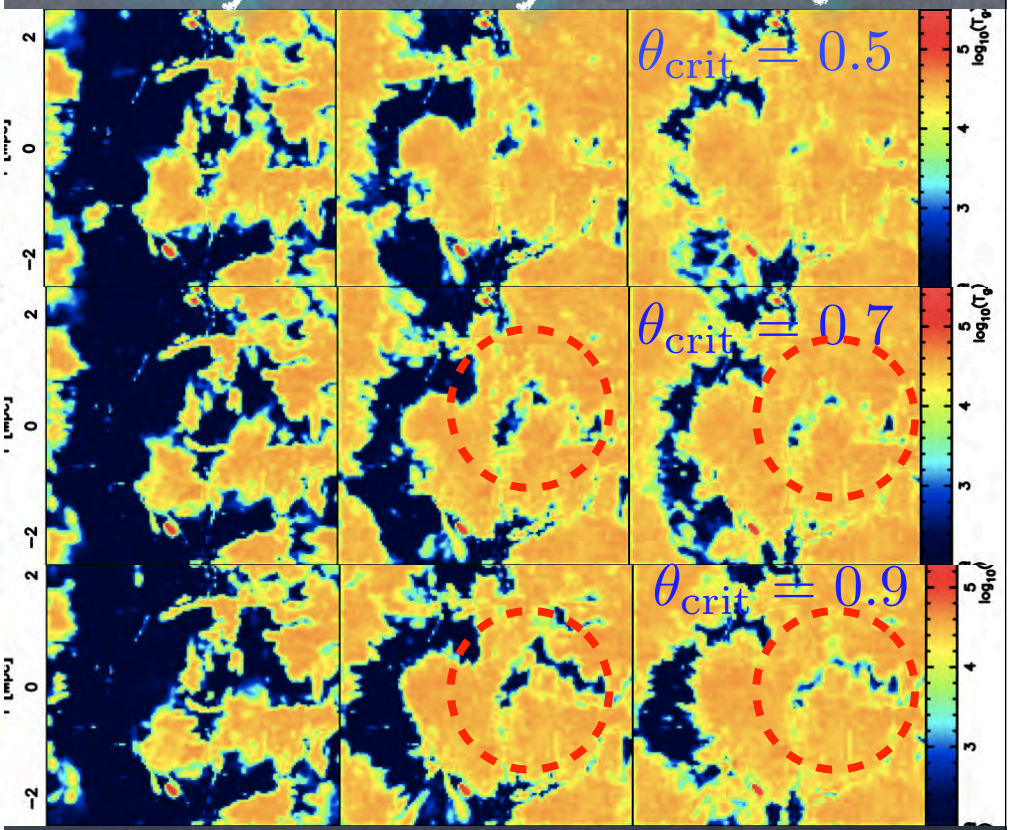


Temperature by New START

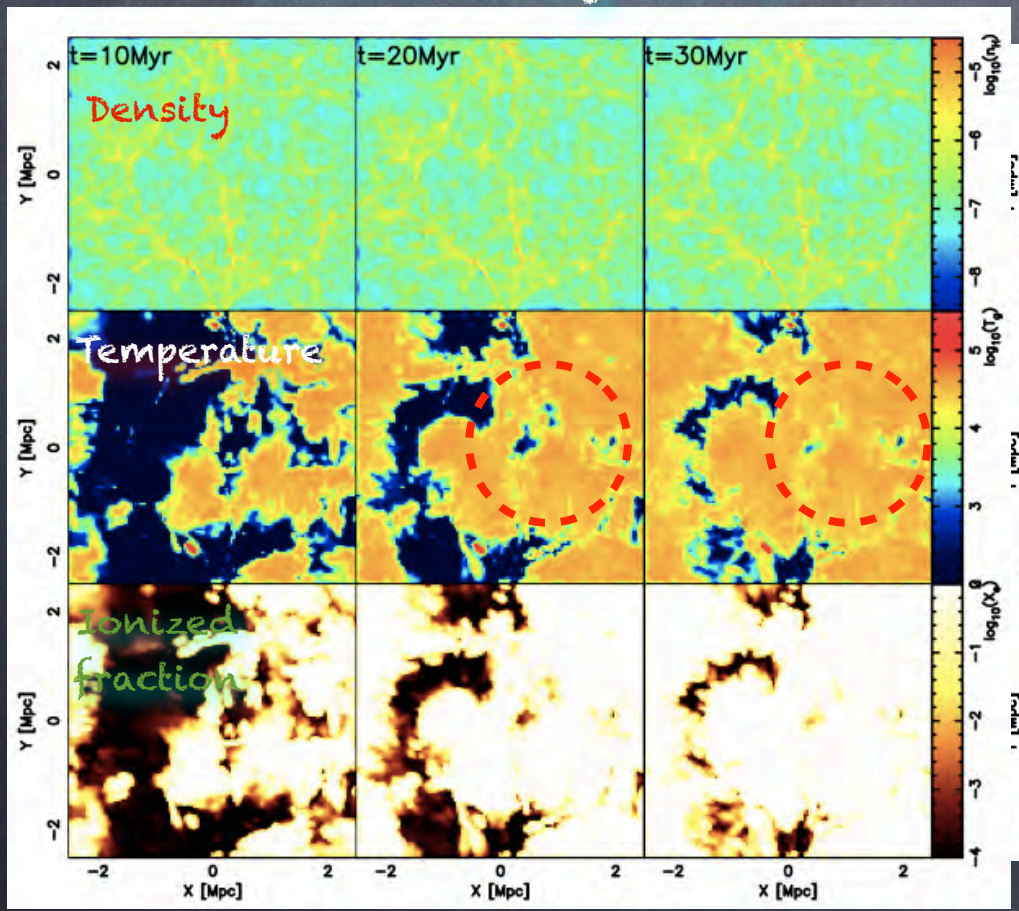
10Myr 20Myr 30Myr



Test of the new method

* If we employ an appropriate tolerance parameter, RT can be solved accurately.
* Similar method will be implemented into ARGOT by T. Oakamoto.

Reference (by RSPH)



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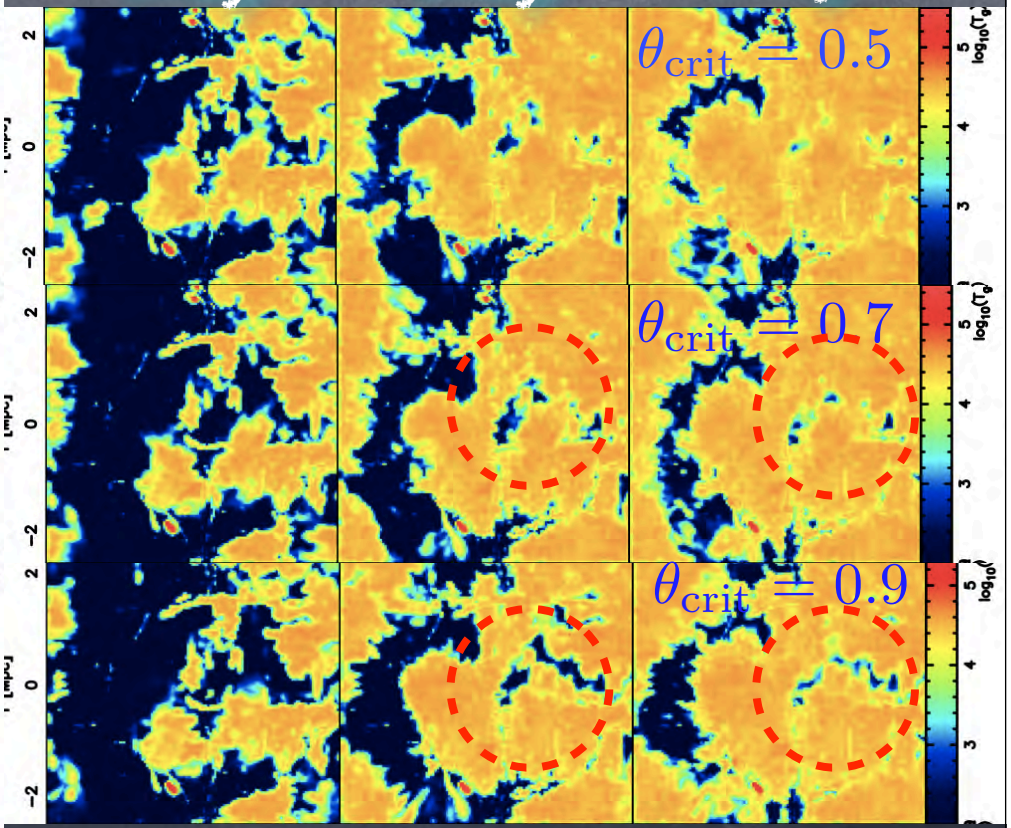
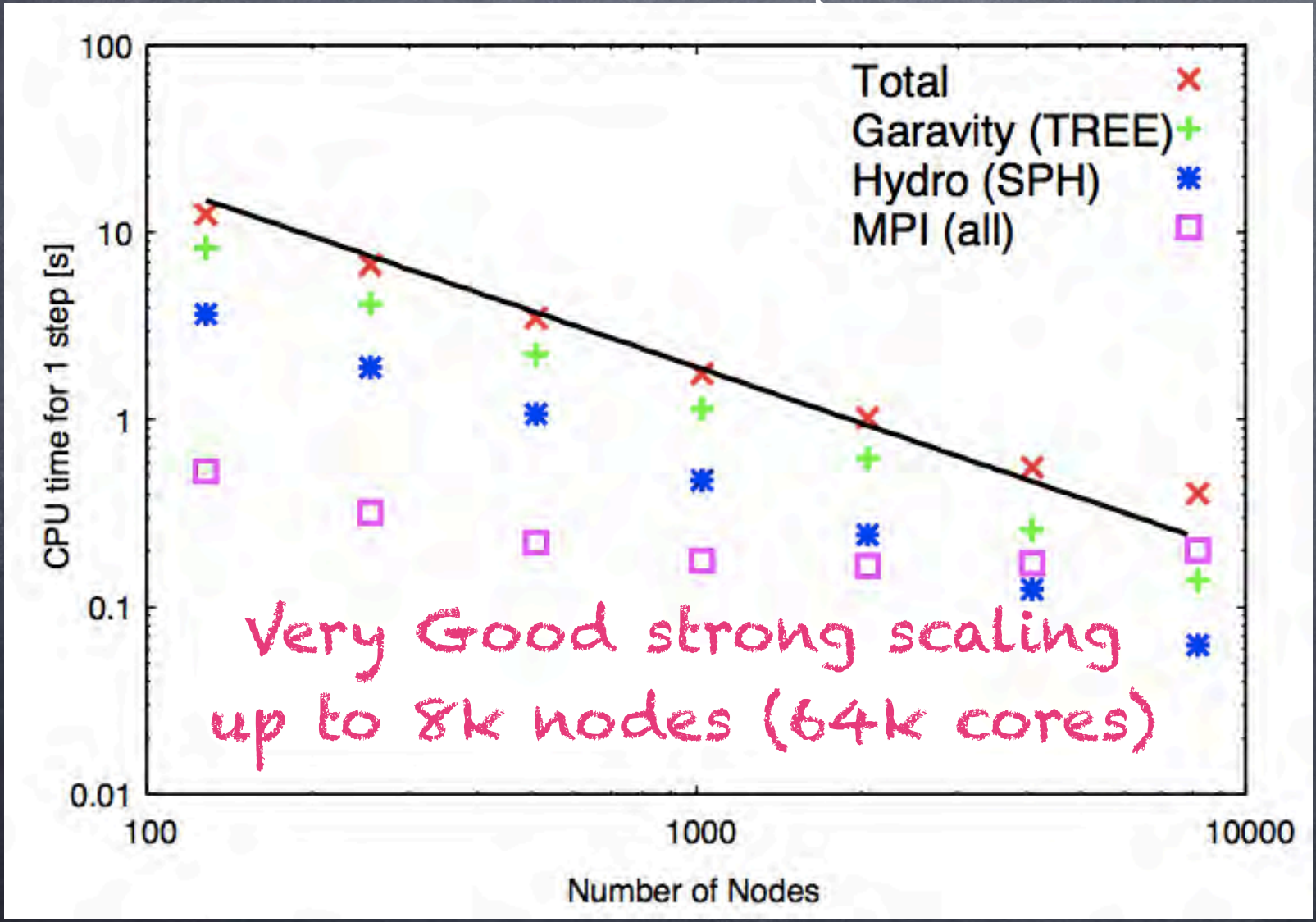


START scalability: Hydro Part

Cosmological Hydrodynamics

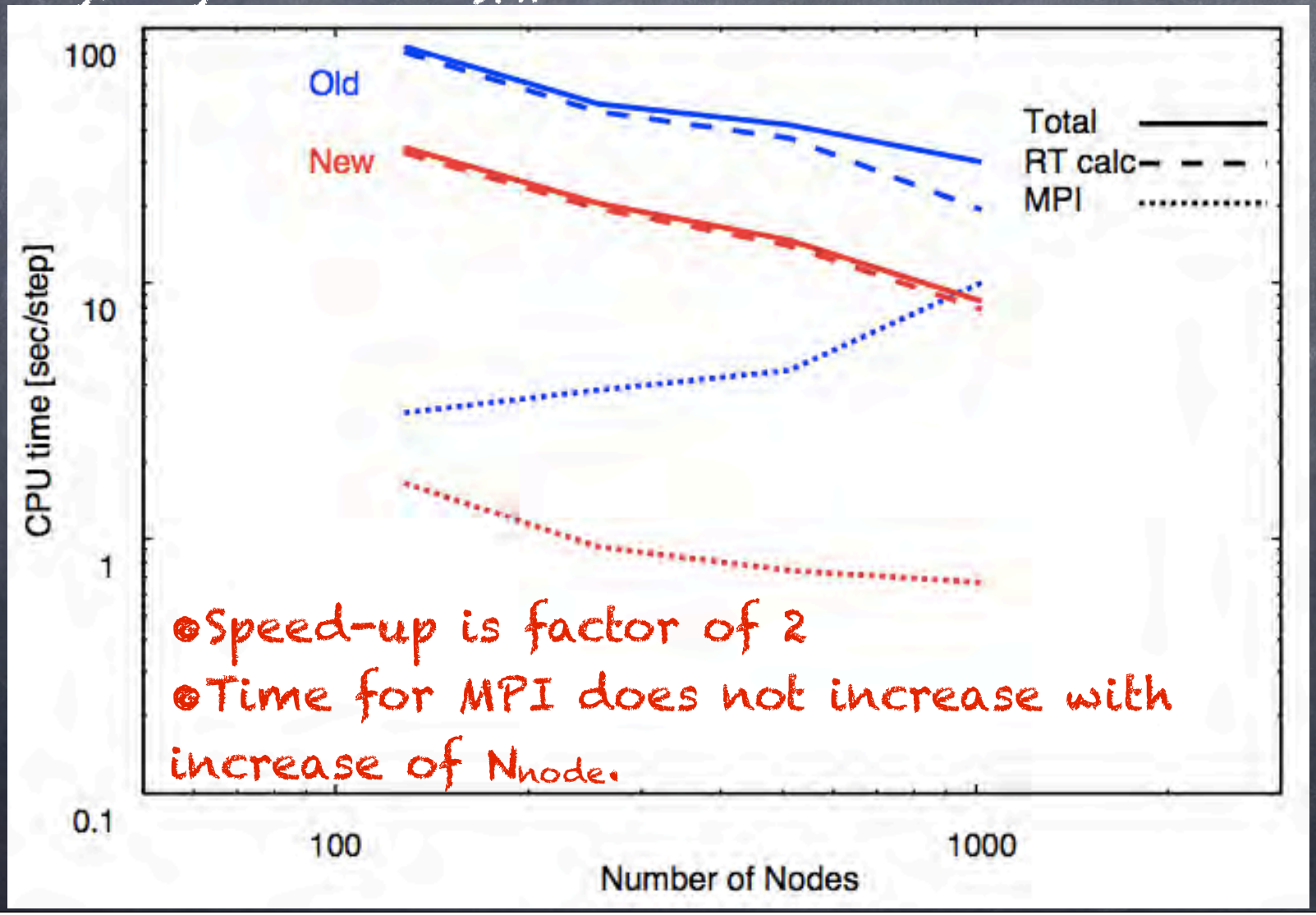
N=512^3×2: Test on K computer



START scalability: RT Part

Comparison between the improved and old versions

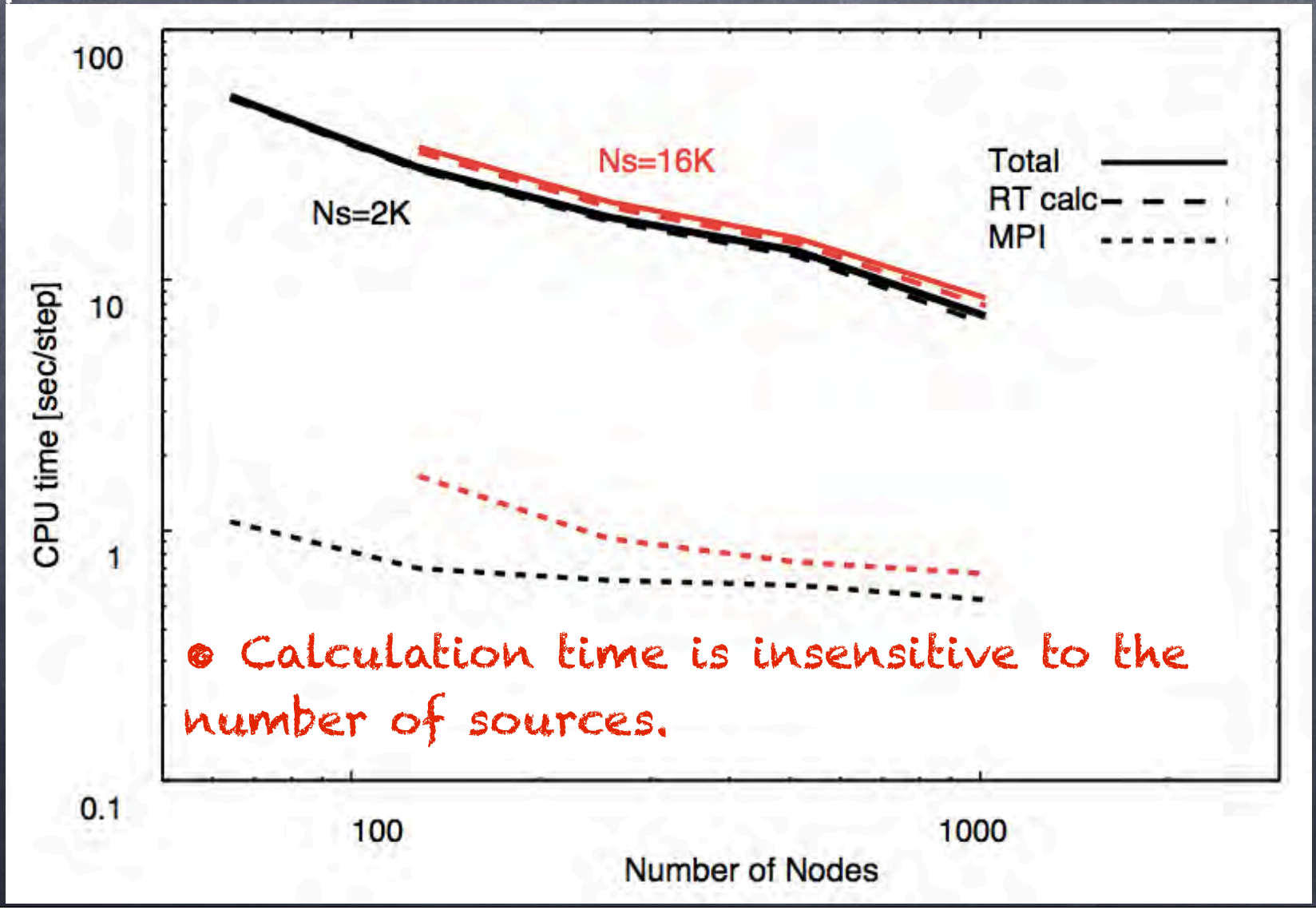
XE6(cray)@Kyoto $N_{SPH}=256^3$ $N_{source}=16k$



START scalability: RT Part

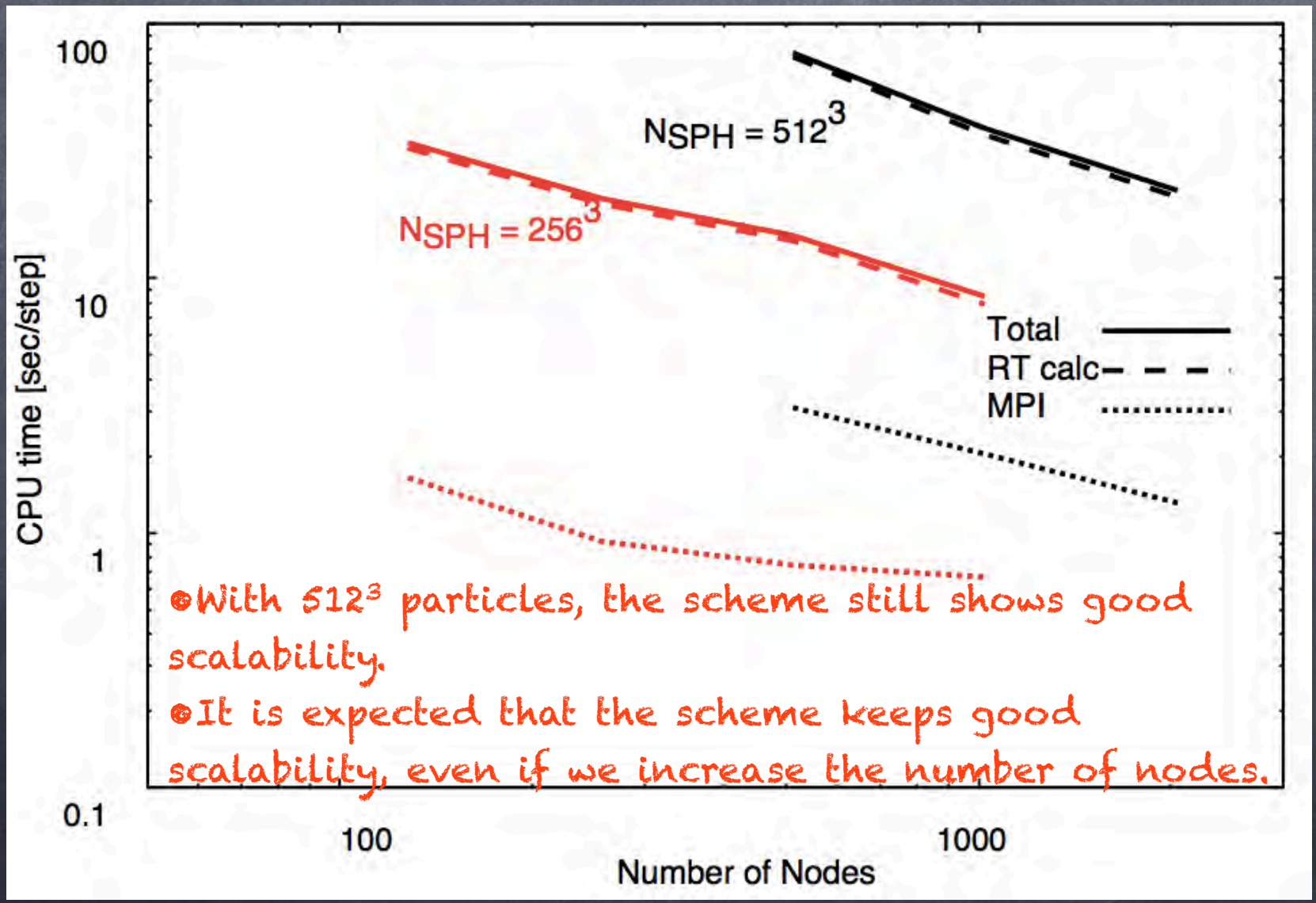
Dependence on the number of sources.

Comparison between the runs with N_s=2k and N_s=16k



START scalability: RT Part

Test with 512^3 SPH particles and 16k source particles



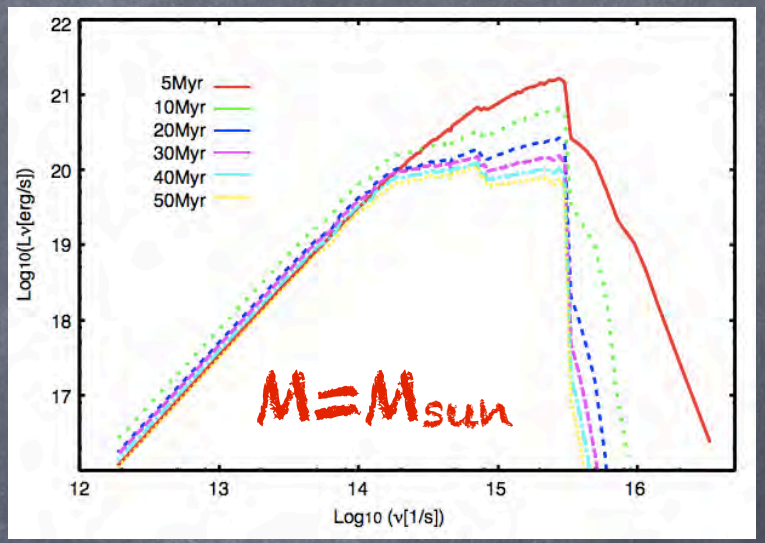
- With 512^3 particles, the scheme still shows good scalability.
- It is expected that the scheme keeps good scalability, even if we increase the number of nodes.

Additional Processes

- **Evolution of spectrum** (age, freq.) = (22, 60)

  In previous study (KH & Semelin 2012), we assumed blackbody-shape with 50,000K for stellar sources.

  High energy photons were overproduced.



Population synthesis by PEGASE

- **Metal Enrichment**
  - Metal cooling
  - Roles of Dust grain
    - Molecular formation
    - Absorption of Photons
    - Radiation Force

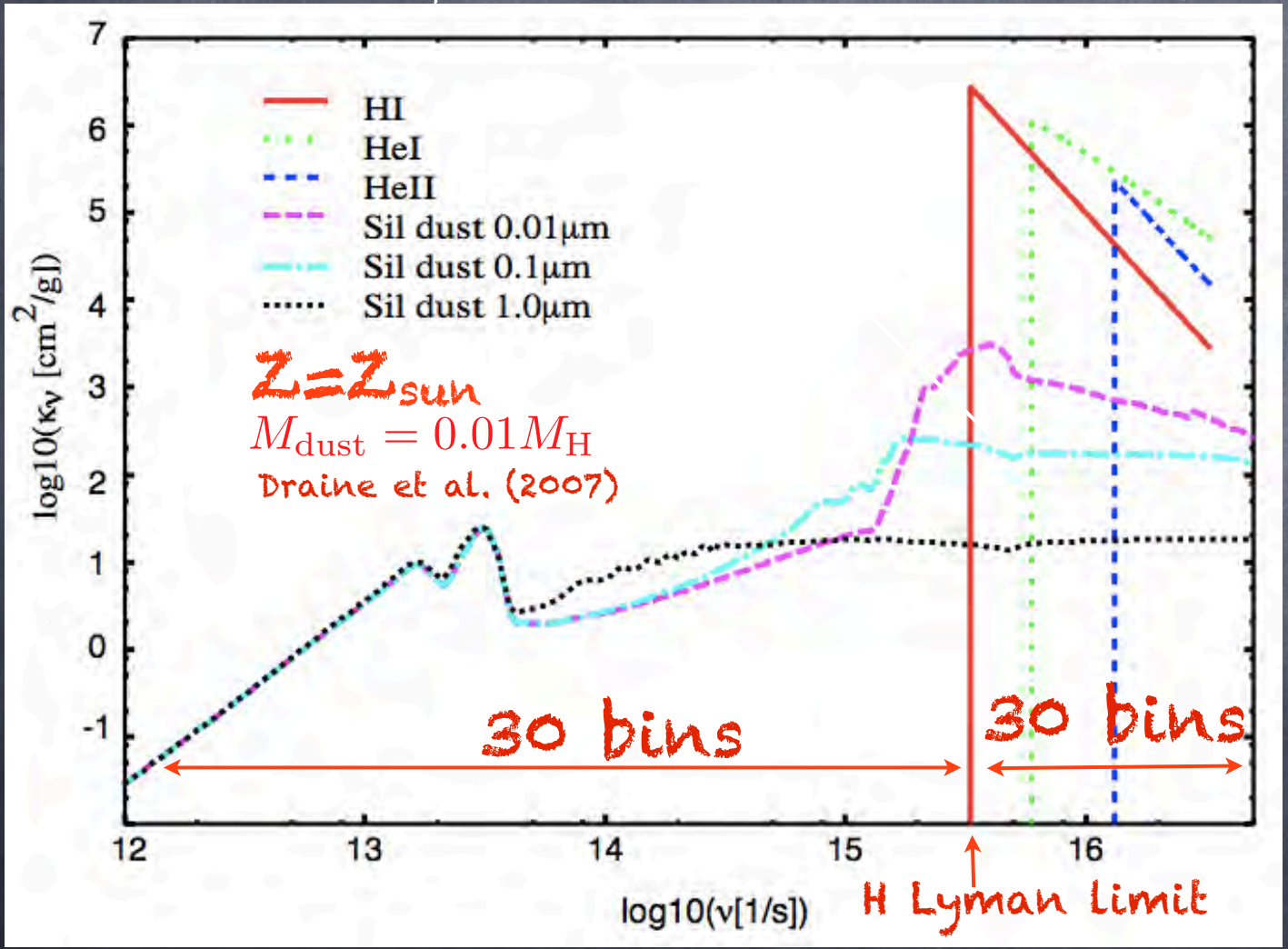
Affect

STAR FORMATION and REIONIZATION

Role of Dust

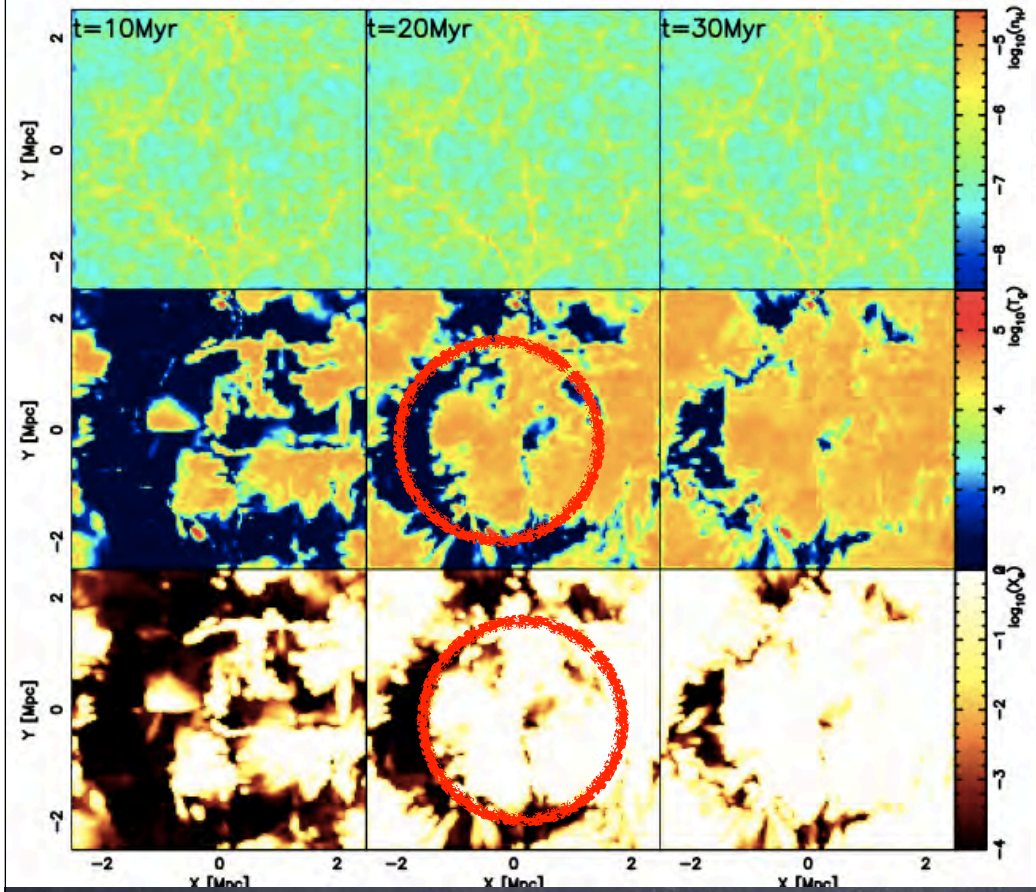
Absorption

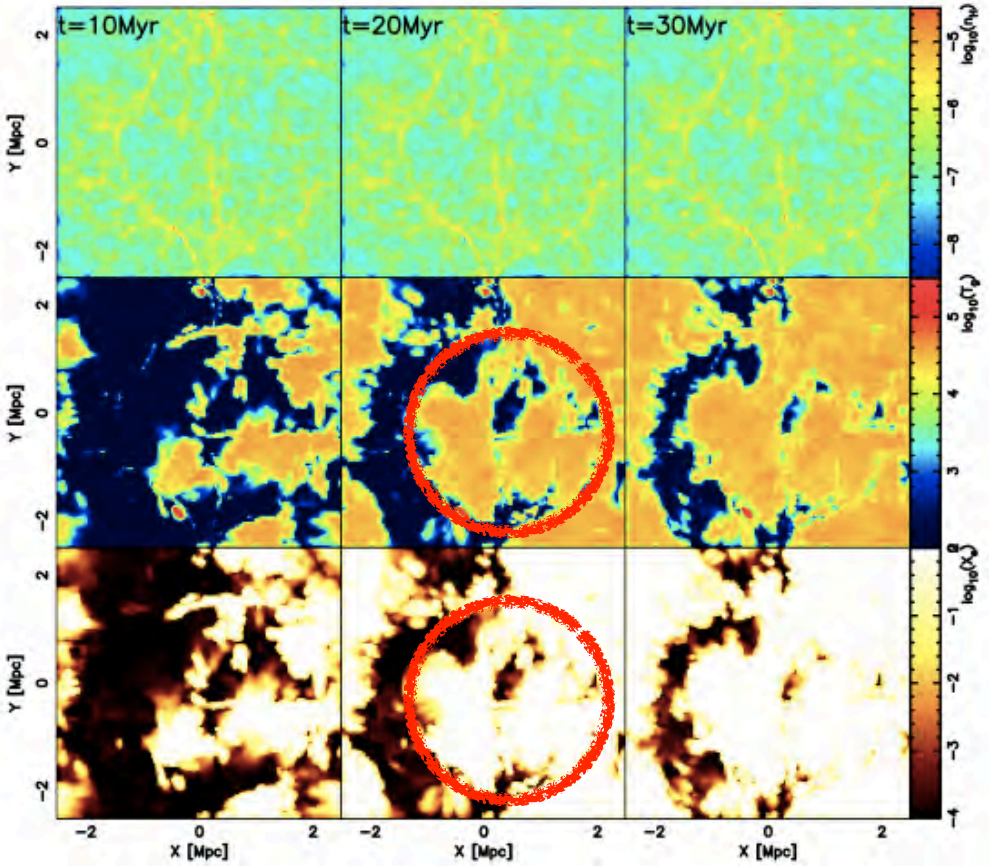
Dust date from Draine & Lee (1984)



- Even if H and He atoms are ionized, dust opacity does not change.
- Opacity is sensitive to the size of dust at frequency range above the Lyman limit.

Absorption by Dust





without dust

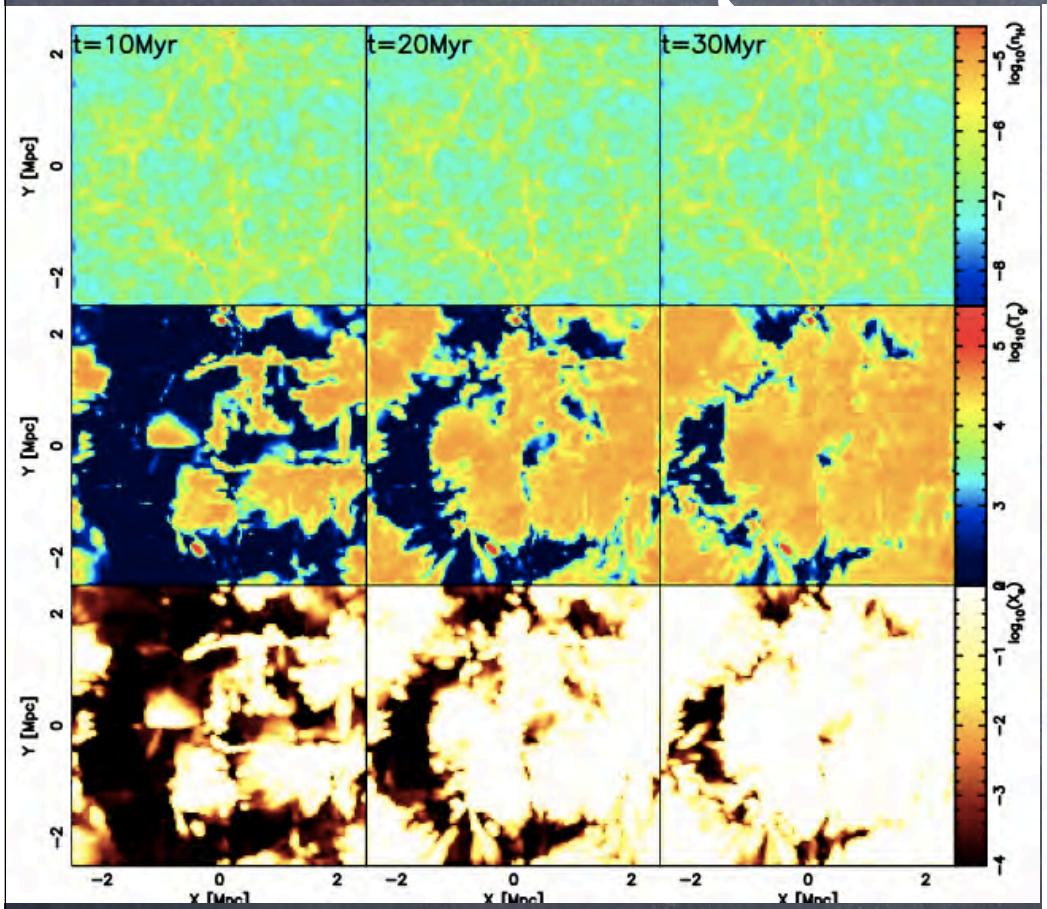
$Z=0.01Z_{sun}$

Dust size 0.1micron

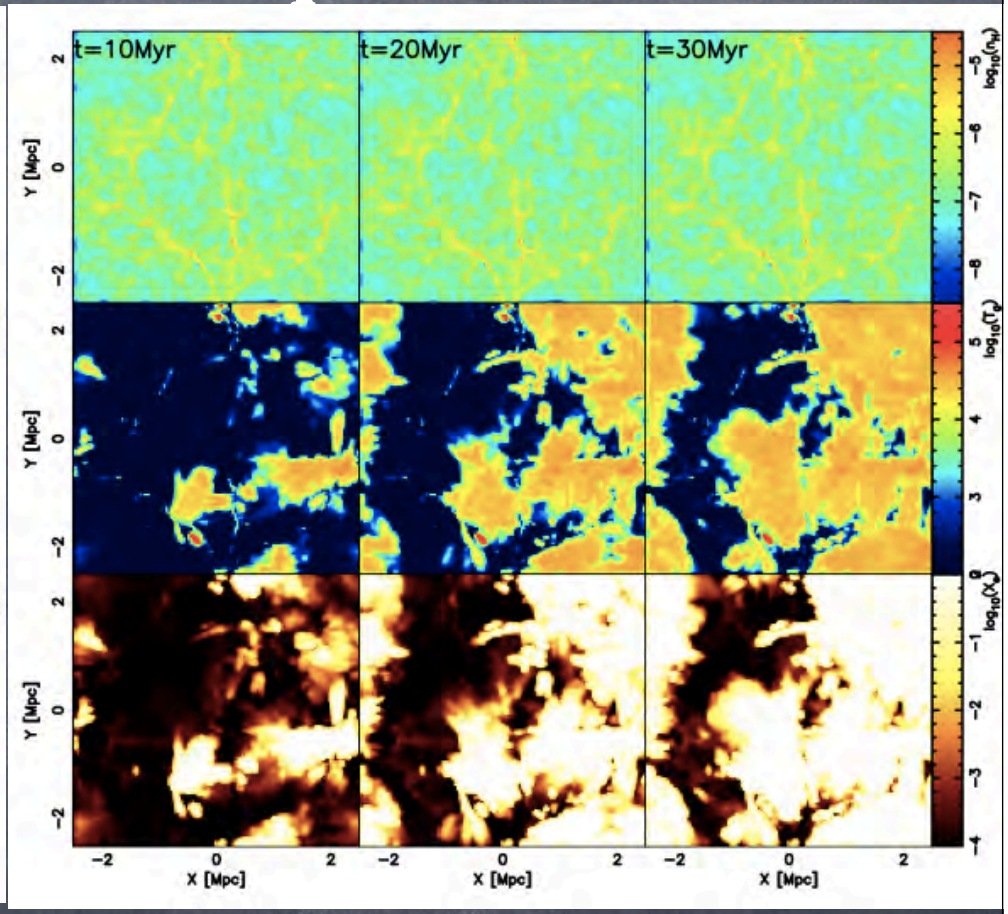
*Found in Local Group

*Proposed by Nozawa+(2007)

Absorption by Dust



without dust



$Z=0.01Z_{sun}$

Dust size 0.01micron

*Typical size of first grains, proposed by Todini & Ferrara (2001)

Summary

New method:

- Good Strong Scaling. (So far up to 2,000 nodes)

  Probably $N_{SPH}=1024^3$ run is possible, using K computer 8k-16k nodes (in 1-2 weeks?).

- Accurate (with small tolerance parameters)

Simulations including Metal Enrichment:

- The role of metal (especially dust) on the evolution of high-z galaxies and IGM.
- Compute SEDs, LF, escape fraction ... of high-z galaxies.