CoDa (COsmic DAwn) Simulation

Simulating Reionization of the Local Universe: Witnessing our own Cosmic Dawn

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Abstract

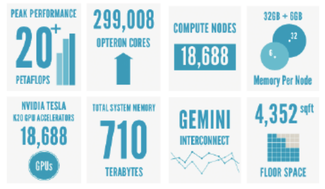
We introduce the CoDa (Cosmic Dawn) simulation, the largest ever fully coupled hydrodynamics simulation of the reionization of the local Universe. We used RAMSES-CUDATON, which computes the radiative transfer with the real speed of light, running on 8192 nodes (i.e. 8192 GPUs) on the titan supercomputer at Oak Ridge National Laboratory to simulate a 64 Mpc/h comoving box with 4096^3 dark matter particles and gas cells. In this simulation, reionization proceeds self-consistently, driven by the stars. This radiation-hydrodynamics coupled simulation demonstrates the progressive ionization and heating the Intergalactic medium. We find that gas filaments present a sheathed structure, with a hot envelope surrounding a cooler stream. It also shows a strong self-regulation and complete suppression of star formation in low mass haloes after reionization.

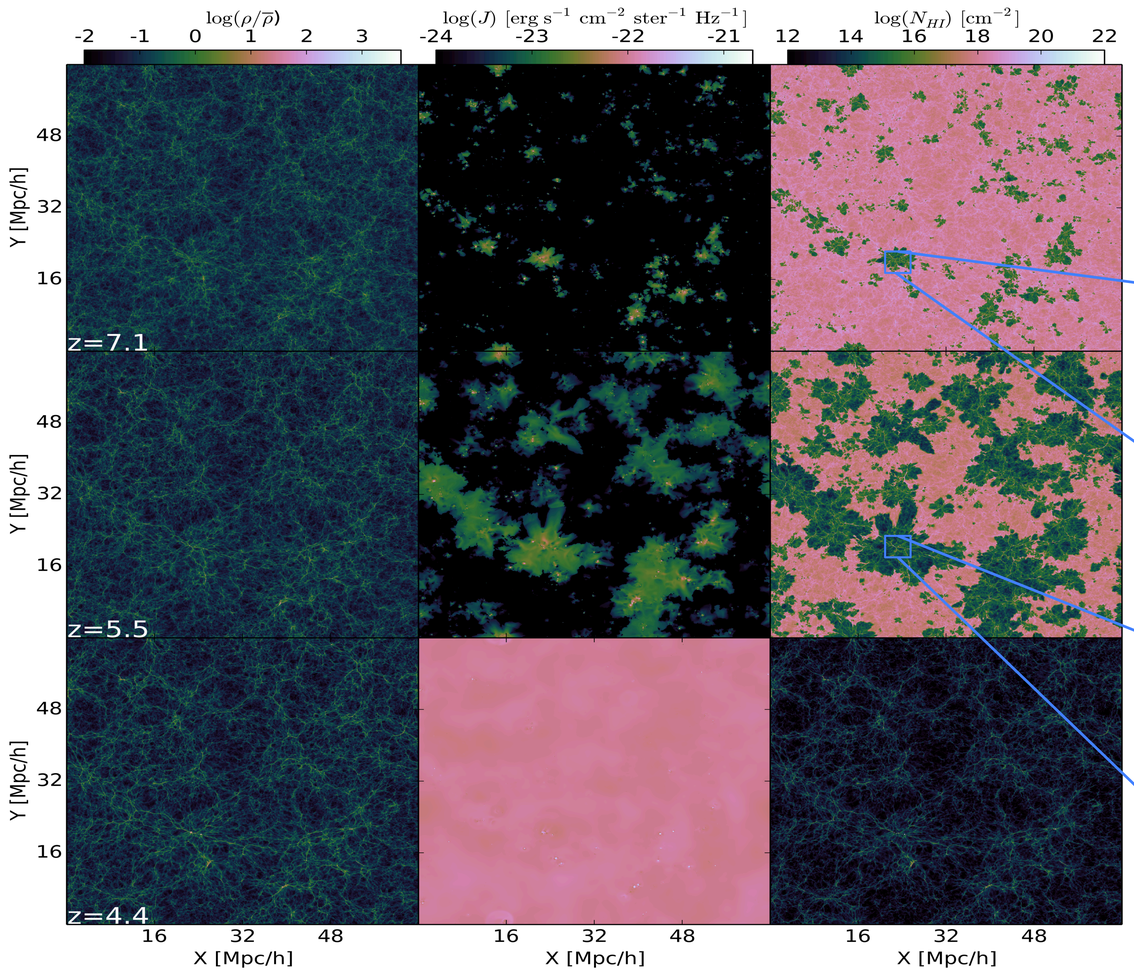
Simulation : Radiation-hydro with RAMSES-CUDATON

- RAMSES (Teyssier 2002): CPU
  - Gravity (PM) + hydrodynamics (HLLC Riemann solver)
  - Star formation + SN thermal + Kinetic feedback (Dubois & Teyssier 2008)
- ATON (Aubert & Teyssier 2008, 2010): UV Radiative Transfer, H only, Monochrome.
  - Radiative transfer on a grid : **M1 closer**, "photon soup" approximation (≠ ray-tracing)
  - Each star particle radiate ionizing photon during first 10Myrs.
  - Assuming 10^5K blackbody : effective frequency of 29.61eV
  - Cpu cost INDEPENDENT of number of sources !!!
  - EXCELLENT SCALABILITY
- CUDATON (Stranex 2010): ATON on GPU
  - speedup x80
  - **Real speed of light : c=1**
  - Uni-grid
  - Hybrid code: gravity+hydro on cpu, RT on GPU

CoDa Simulation

- On the Titan supercomputer at Oak Ridge National Laboratory
- 64 Mpc/h comoving side, 4096^3 grid, 4096^3 DM parts (M_{DM}=3.5 x 10^5 $M_\odot$)
  - Cell size : Δx ~ 15 kpc/h comoving, Δx < 3 kpc physical
  - 8192 titan nodes (16 CPU + 1GPU per node)
- **CLUES initial condition (z=300 to 4.2)**
  - **Constrained local universe IC with WMAP 7 cosmology**
- 2.15 million node hours (~11 days), 2000 (+800 000) time-steps
- 138 snapshots (every 10 million years); 2 PB data => reduced dataset: 100 TB
  - Cutouts high-res + Fullbox low-res + FoF halo catalogs (13million haloes)

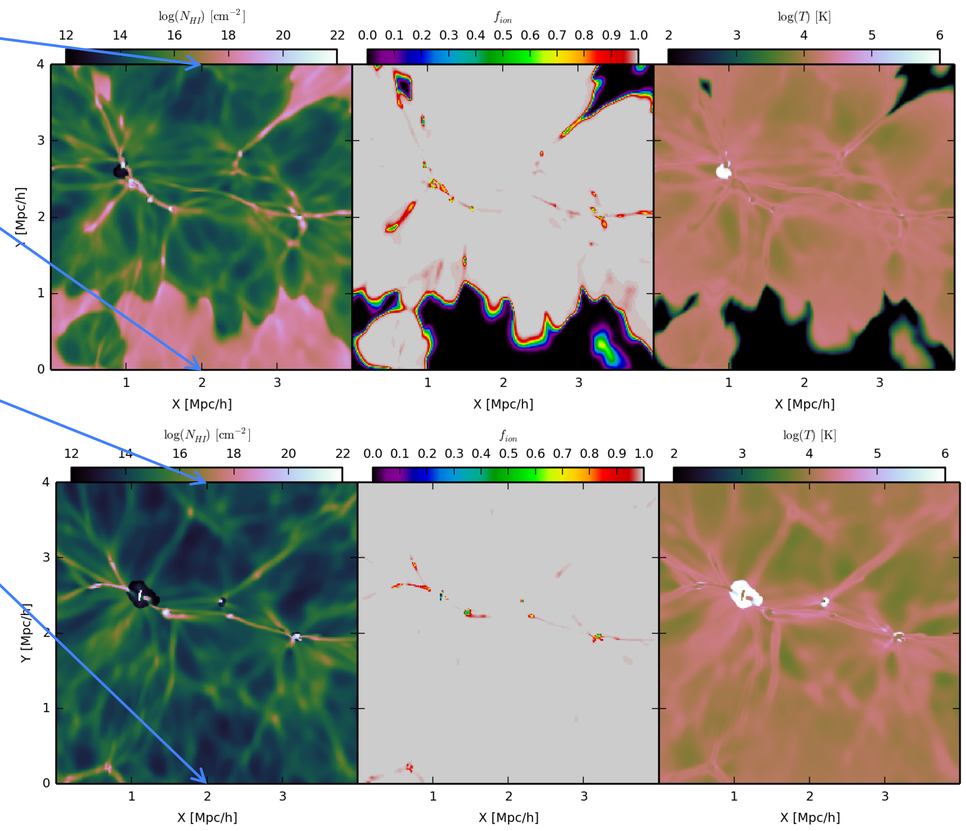




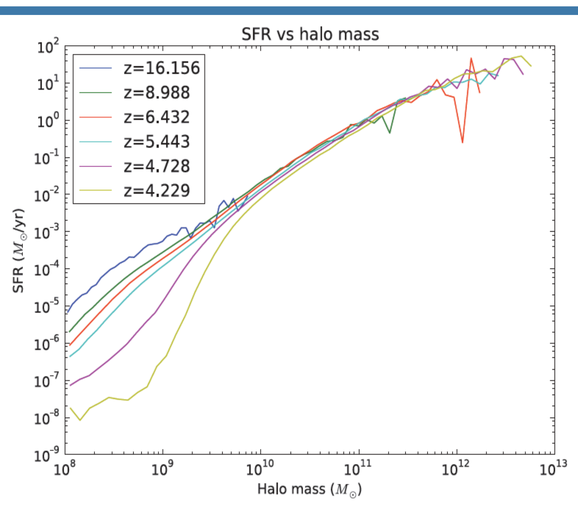
The gas over-density, photon flux density, and HI column density slice maps for the entire simulation domain (64 Mpc/h comoving), fullbox, of the CoDa simulation at z= 7.1, 5.5, and 4.4. The thickness of the slice is 31.25 comoving kpc/h.

CoDa simulation at one glance.

- Reionization finish around z~ 4.6
- Fullbox views show that reionization is driven by the stellar radiation and Reionizaition regions progressively growth.
- A single reionization region resembles a butterfly shape, the radiation sources populate follows the filaments and the radiated photons start to ionize and heat gas around filaments.
- Zoom-in views show that a sheathed structure and high HI column density region follows the filament structure.
- Zoom-in views show the existence of the shielded region inside of the ionization bubble.



4 Mpc/h cutout, zoom-in, slice maps for the HI column density, the ionization fraction, and the temperature at z= 7.1 and 5.5. The zoomed-in region is small blue box shown in the full simulation visualization, which is one of the highly clustered region at low-z. Top and bottom panels show the same region for different redshift. The figure shows the IGM heating by the ionizing radiation (~10^4K) and the supper bubble (~10^6K).



Star Formation Suppression

(Ocvirk et al 2015)

- Instantaneous SFR v.s. instantaneous M_{halo}
- Using FoF to find the dark matter halos
- Massive halos shows higher SFR
- Haloes at all masses to form less stars as time goes by.
- Suppression at low mass at later time
- Suppression starts z < 5.5
- Star formation in halos (M_{halo} < 3x10^9 $M_\odot$) are suppressed.
- Photo-heating and I-Front trapping (Shapiro et. al. 2004) could suppress the SF in low mas halos.
- **Self-Regulation**

TAKE AWAY

- ✓ CoDa simulation : the largest fully coupled self-consistent N-body + hydrodynamics + radiation transfer simulation of the reionization of the local Universe.
- ✓ Demonstrates the progressive ionization and heating the Intergalactic medium.
- ✓ Gas filaments present a sheathed structure, with a hot envelope surrounding a cooler stream
- ✓ Star Formation in low mass halos is suppressed at the epoch of reionization.

Stay tune for further studies from the CoDa simulation

References

Aubert, D., & Teyssier, R. 2008, MNRAS, 387, 295
Aubert, D., & Teyssier, R. 2010, MNRAS, 724, 244
Dubois, Y., & Teyssier, R. 2008, A&A, 477, 79
Ocvirk, P. et al 2015 in preparation
Shapiro, P. R., Iliev, I. T., & Raga, A. C. 2004, MNRAS, 348, 753
Stranex, T. 2010, "Cosmological radiative transfer at the epoch of reionization," Master's thesis, University of Zurich