Cosmic Dawn (CoDa):
Radiation-hydrodynamics of galaxy formation during the EoR

Ocvirk+2015: arxiv:1511.00011

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Cosmic Dawn (CoDa) goals: Reionization and its feedback

- **RADIATIVE FEEDBACK** on sources?
  - **INTERNAL** (inside haloes): self-regulation?
  - On IGM: filaments / cold accretion ?
  - **EXTERNAL/Environment effect?**
    - Nearby large galaxy?
    - Other nearby massive gals? (ex. council of giants)
    - Nearby galaxy cluster?
- Connexion to low mass satellites properties? (missing sats, planes of sats?)

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COUPLED RADIATION-HYDRODYNAMICS

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COUPLED RADIATION-HYDRODYNAMICS

HIGH MASS RESOLUTION

LARGE VOLUME

Coupled Radiation-hydro with RAMSES-CUDATON

- **RAMSES** (Teyssier 2002): **CPU**
  - gravity (PM) + hydrodynamics
  - star formation + SN thermal + kinetic feedback

T, x_{HI}, Λ ↑ ↓ $T, \rho, stars$

- **ATON** (Aubert 2008): UV Radiative Transfer,
  - UV photons propagation
  - Hydrogen ionization
  - Photo-heating + cooling

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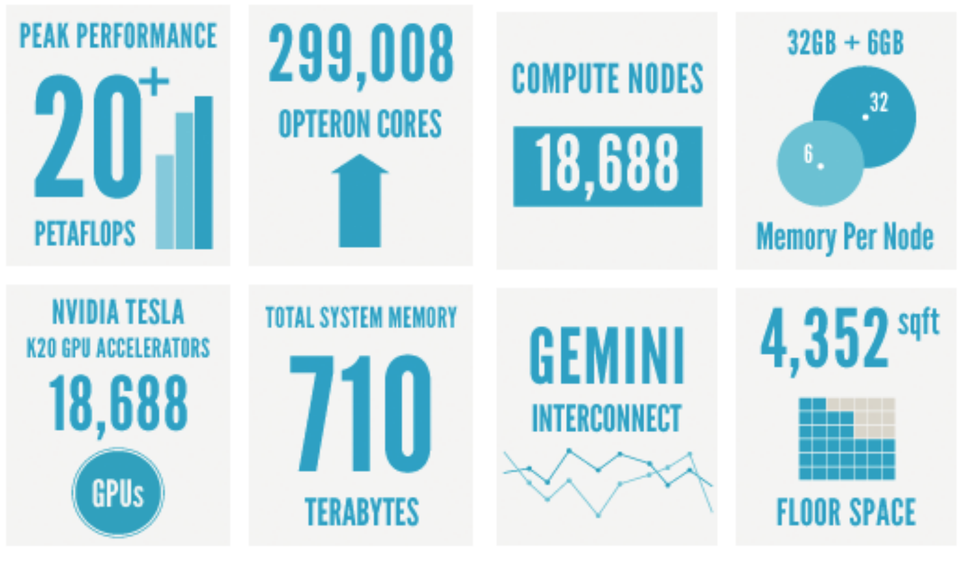
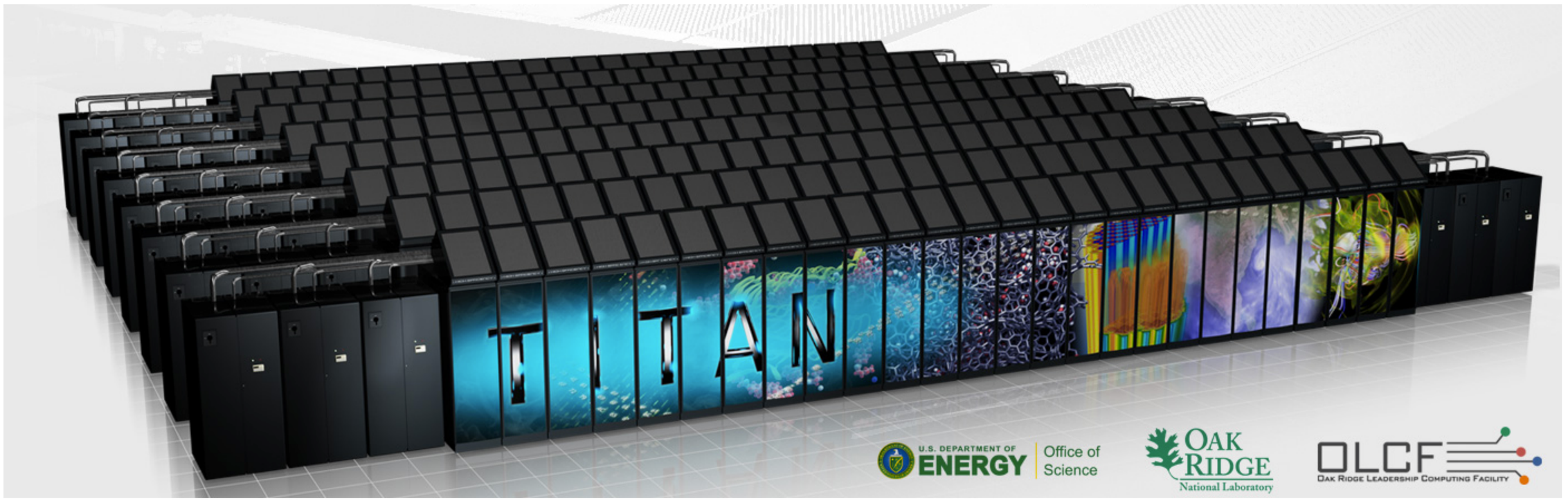
- **CUDATON** (D. Aubert, R. Teyssier): ATON on **GPU**
  - speedup x80
  - c=1
  - but no AMR => unigrid

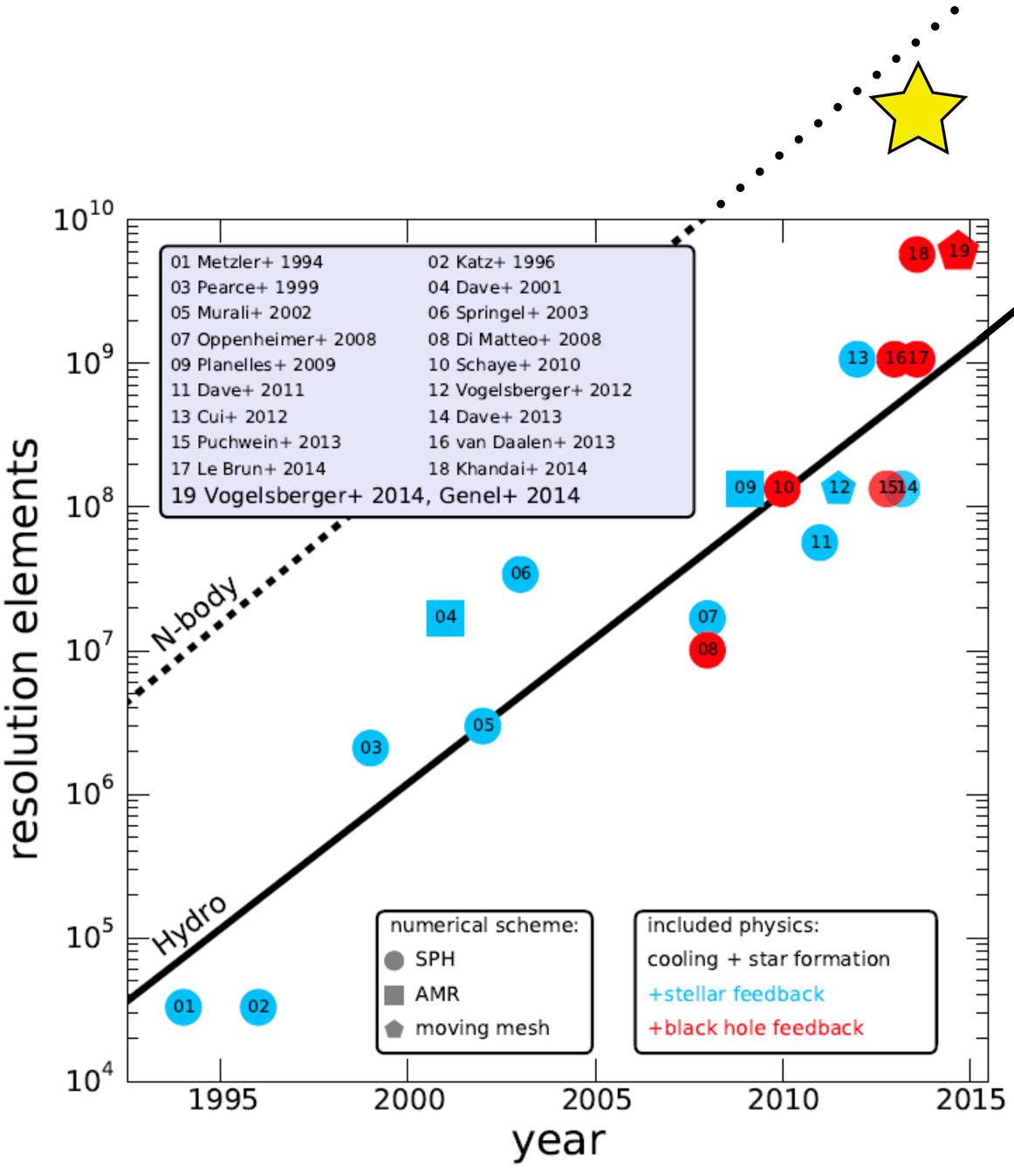
TITAN at Oak Ridge National Laboratory



- 18,688 GPUs
- 30-35 PB filesystem
- top 2 (top 1 = Tianhe)



Setup: Cosmic Dawn specs



(taken from illustris website)

- 8192 GPUs
- 64 h^{-1} Mpc side, 4096^3 grid
- $Mhalo_{min}$ ~1 x 10^8 $M_\odot$
- Δx ~ 15 h^{-1} kpc comoving (< 3 kpc physical)
- z_{end}=4.2
- ~ 11 days runtime, 2 PB data

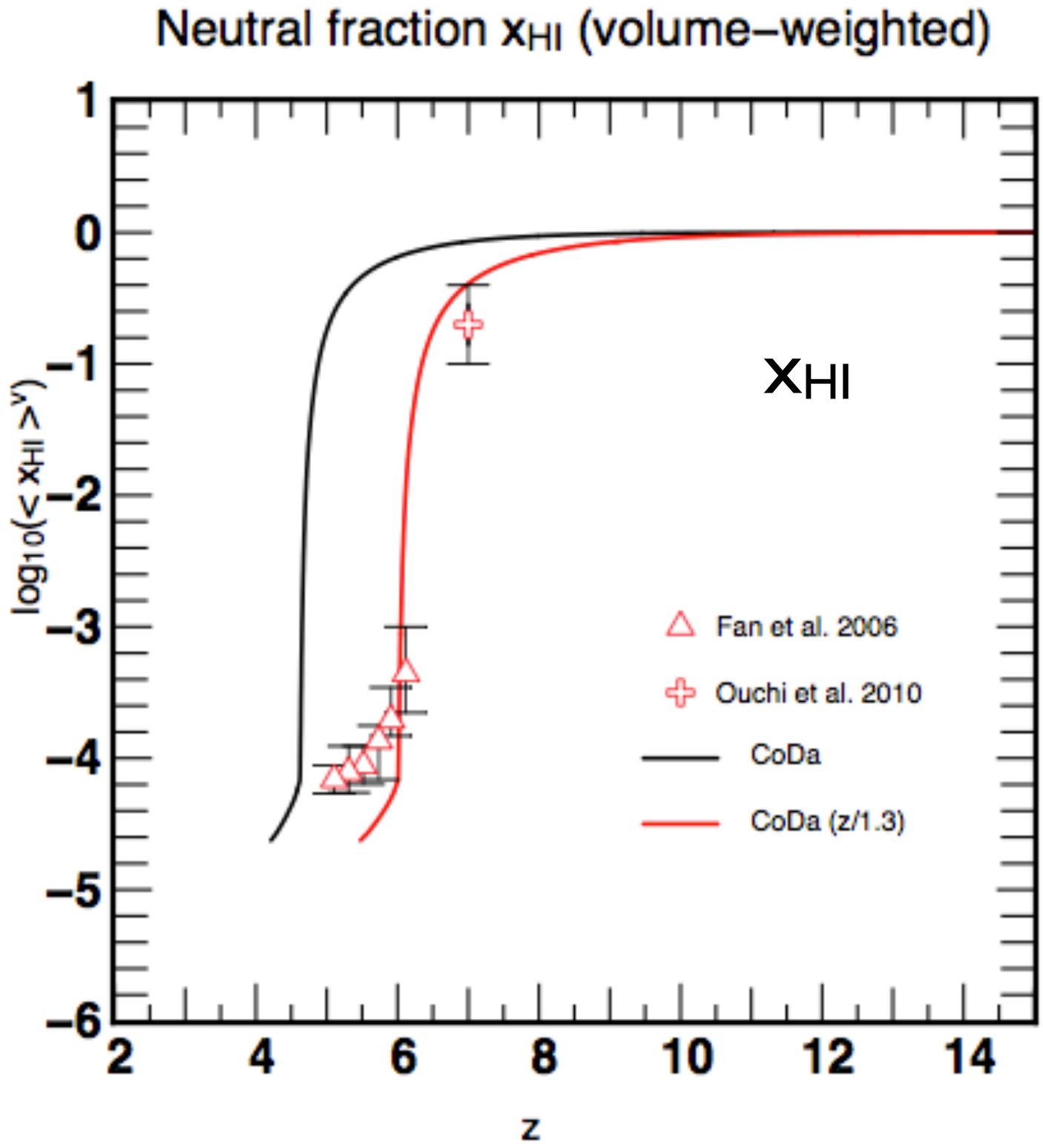
- => CoDa intermediate between large, low res (Iliev et al.) and small, very high res (Wise, Trebitsch, Rosdahl)

Cosmic Dawn calibration/rescaling

- Tuning difficult (small boxes useless)
- End of reionization
  - Fan et al.: z ~ 6
  - CoDa: z ~ 4.5-5
  - (SF efficiency too low)
  - => z rescaling (1.3)
  - => fits all 4 constraints

CoDa ——

z-rescaled CoDa ——



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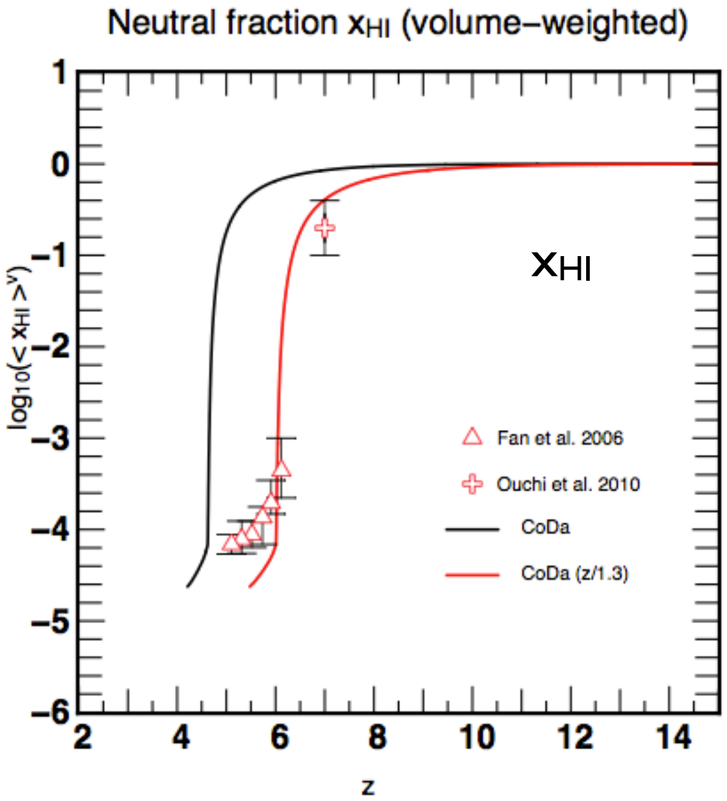
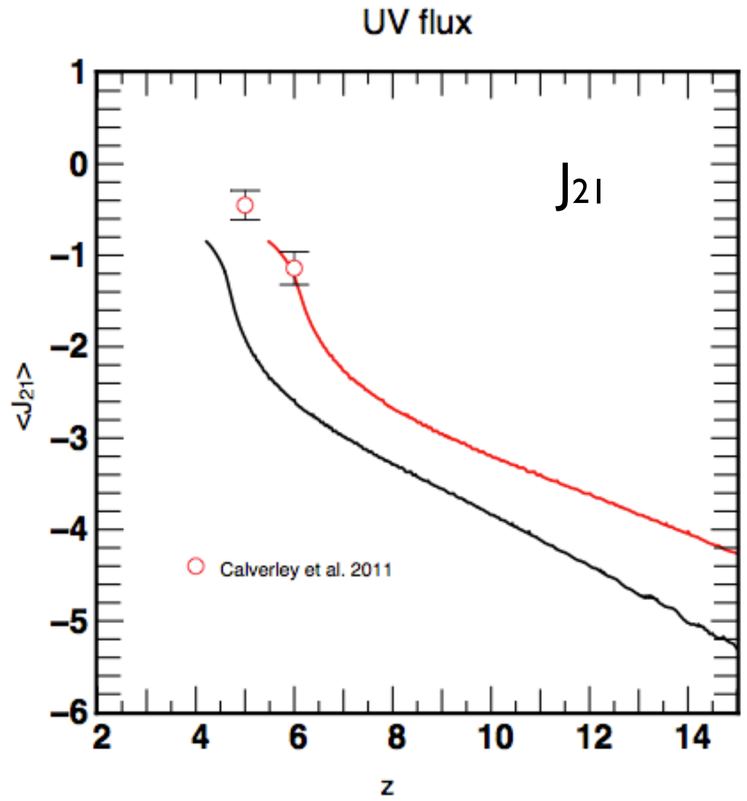
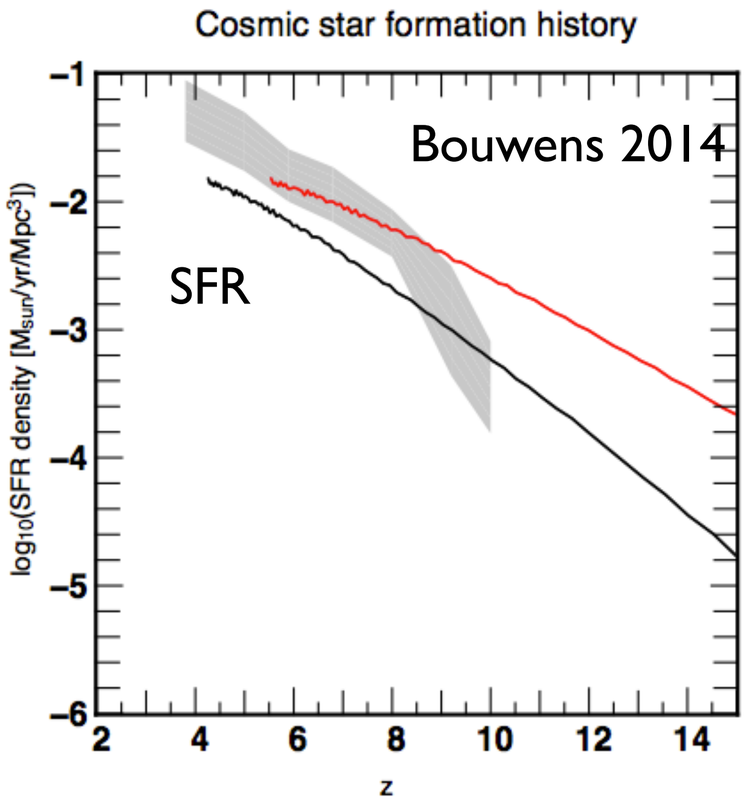
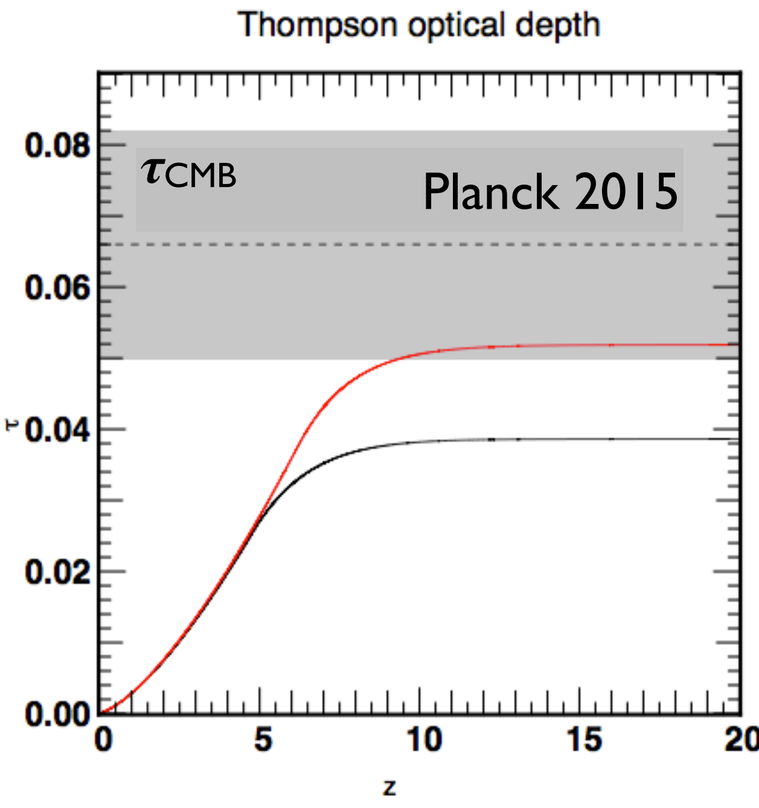
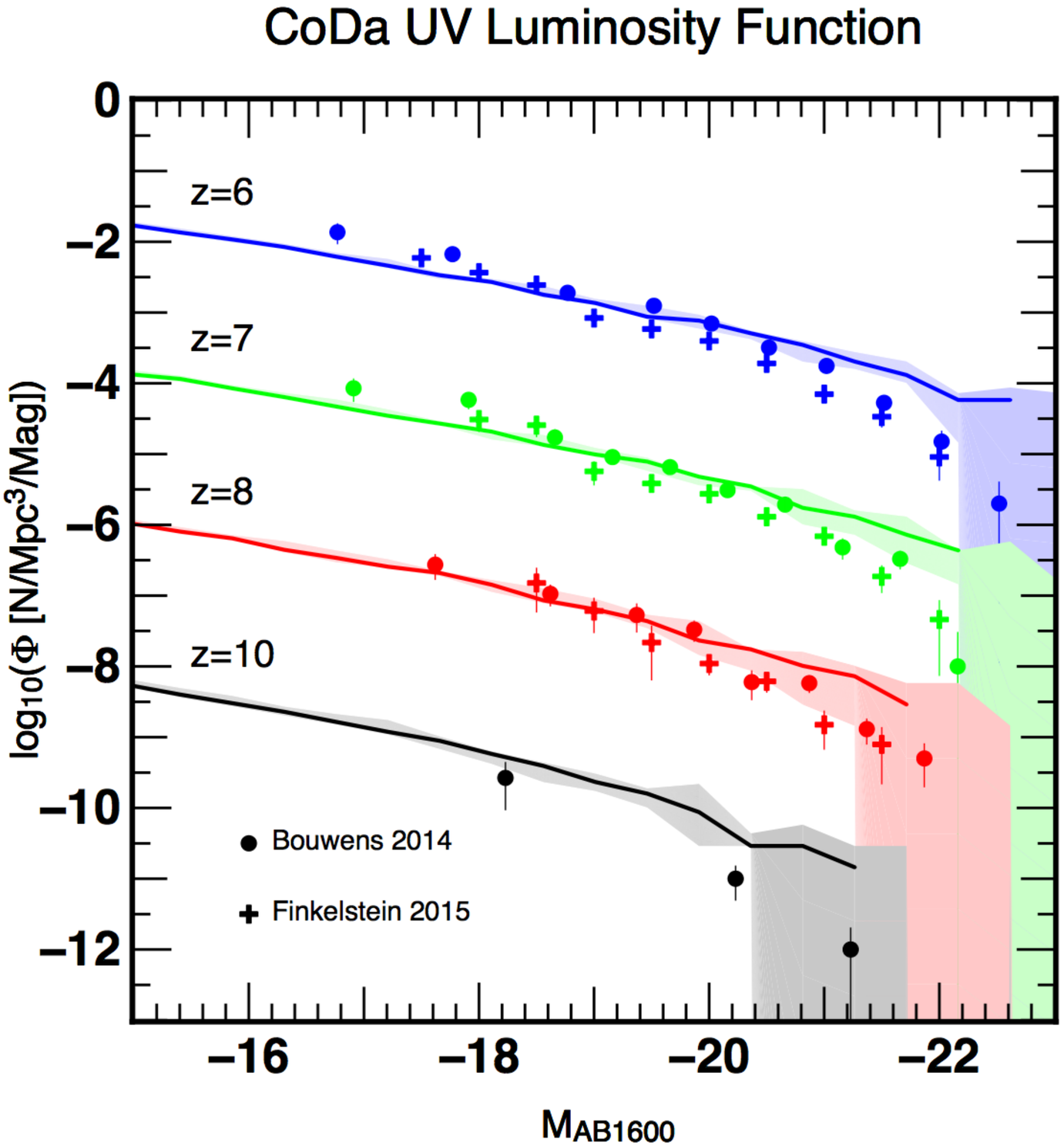








Bright end Luminosity Function



- ~agreement at $M_{1600} \sim -20$
- CoDa overabundance at high M_{1600}?
- cosmic variance?

- No Fe/H evolution
- No evolving dust content

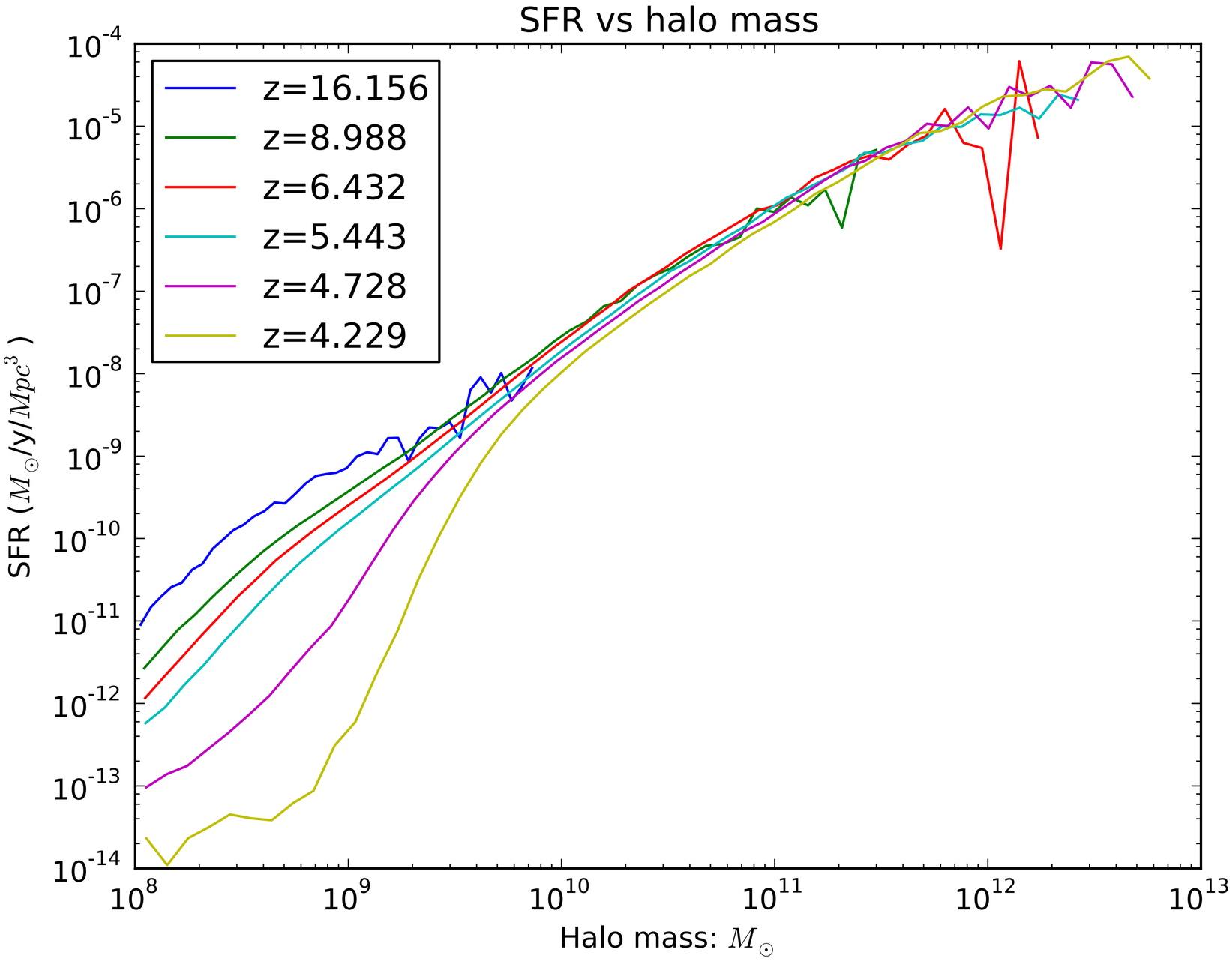
●●●● Bouwens 2015

—— CoDa

UV photon density
6 Mpc thick slice

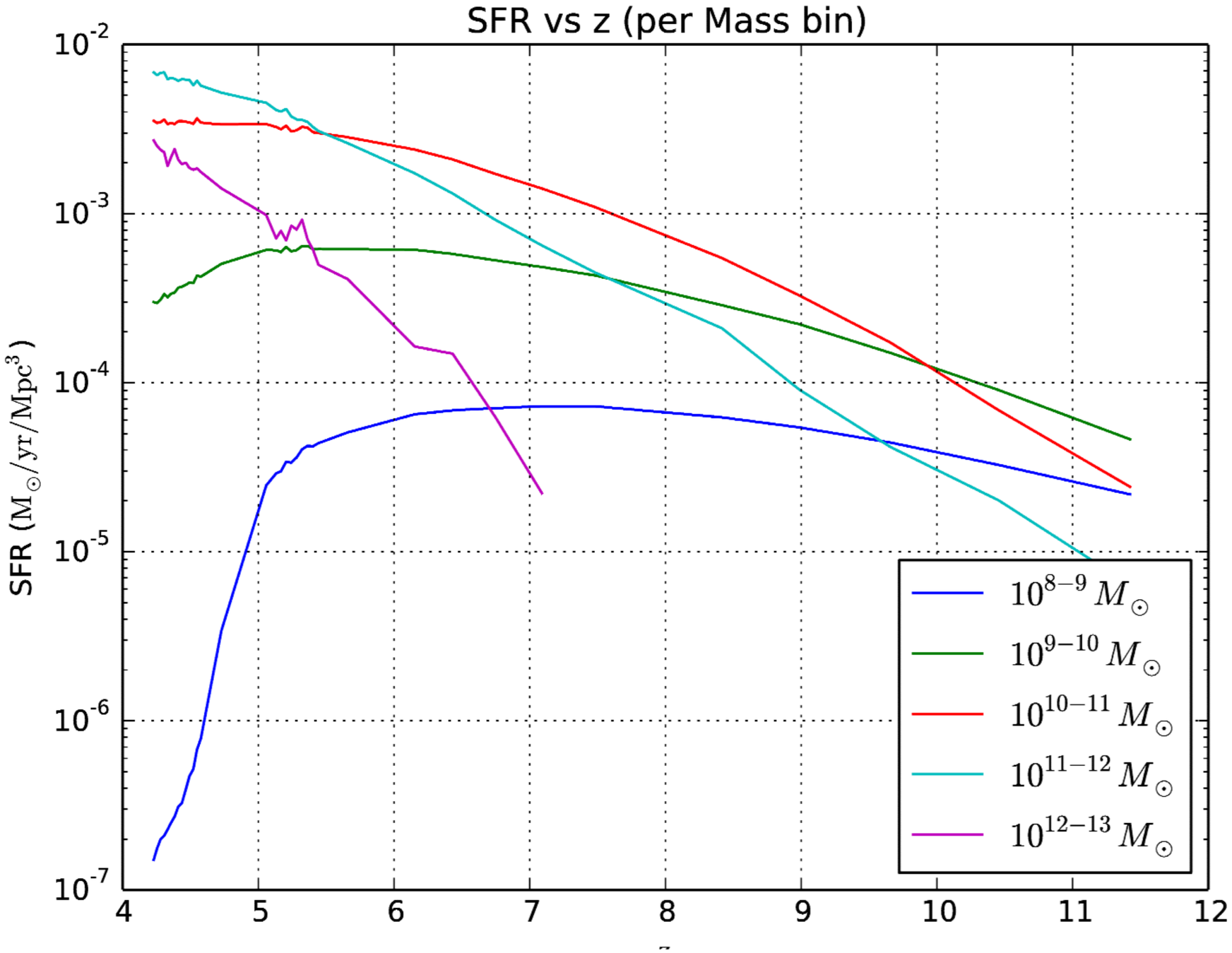
UV photon density
6 Mpc thick slice

Cosmic Dawn
Global SFR vs (M,z)



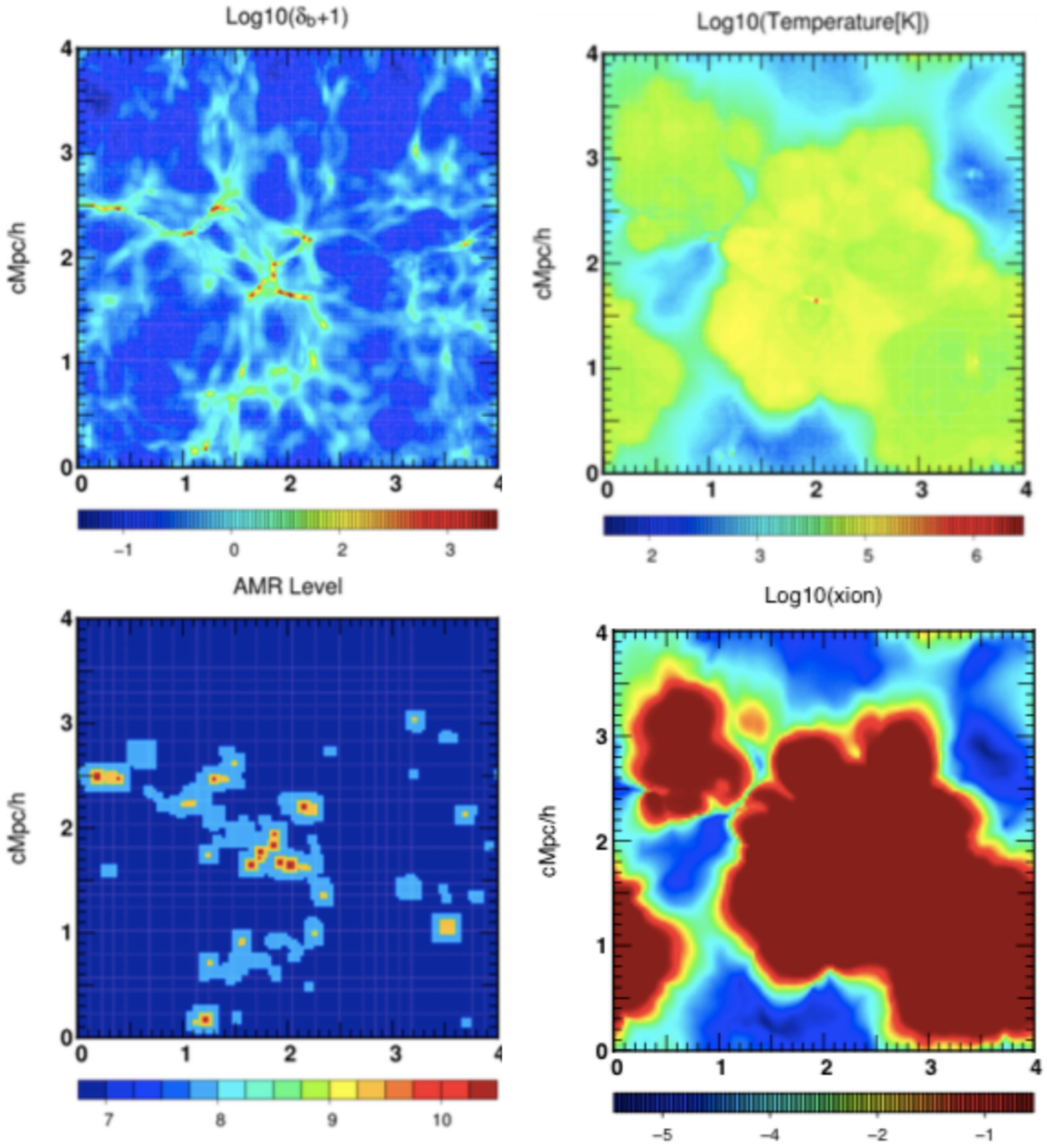
- SFR α $M^{5/3}$
- slow decrease at intermediate mass
- at z~5-4: SFR drops at low M: radiative feedback
- High mass haloes unaffected
- transition is smooth

Cosmic Dawn
Contribution to global SFR



- Low mass haloes never dominate
- very high mass haloes ramp up quickly but appear late
- $10^{10}\,M_\odot$ haloes dominate
- but what about f_{esc} ?

AMR Cosmological RT with **EMMA**



4 Mpc - 128^3 + 5 AMR levels

- **E**lectromagnétisme et **M**écanique sur **M**aille **A**daptative
- Full **standalone** cosmological code
- Collisionless Dynamics (PM)+ Hydro (MUSCL) +RT(M1)
- Full **AMR** radiative transport (like e.g. Ramses-RT (Rosdahl et al. 2013)) or restricted to the Coarse grid with thermo-chemistry on refined levels
- Star Formation + SN Feedback
- C+MPI Parallelisation (scales up to 2048 cores and 1024^3 coarse cells)
- **Optional GPU** (CUDA) acceleration for the Poisson , Hydro and RT solver

Aubert, Deparis & Ocvirk, MNRAS 2015 (in press), arXiv 1508.07888

SUMMARY

- **Cosmic Dawn (CoDa)** is the largest GPU-driven self-consistent simulation of the EoR ever made.
- CoDa reproduces current observational constraints at z>6: x_{HI}, J_{21}, SFR, τ_{CMB}, UV LF, reasonable UV f_{esc}
- Radiative feedback?
  - CoDa: M < 2.10^9 $M_\odot$ haloes have suppressed SF
  - but no convergence between groups: resolution, physics?

- Future work: CoDa II. Improved physics: chemical enrichment + dust, AGNs?
- EMMA (Aubert+2015) => CoDa with AMR
- More efficient (Cuda Proxy Server)