The Effects of X-ray Irradiation on Star Formation and Black Hole Growth

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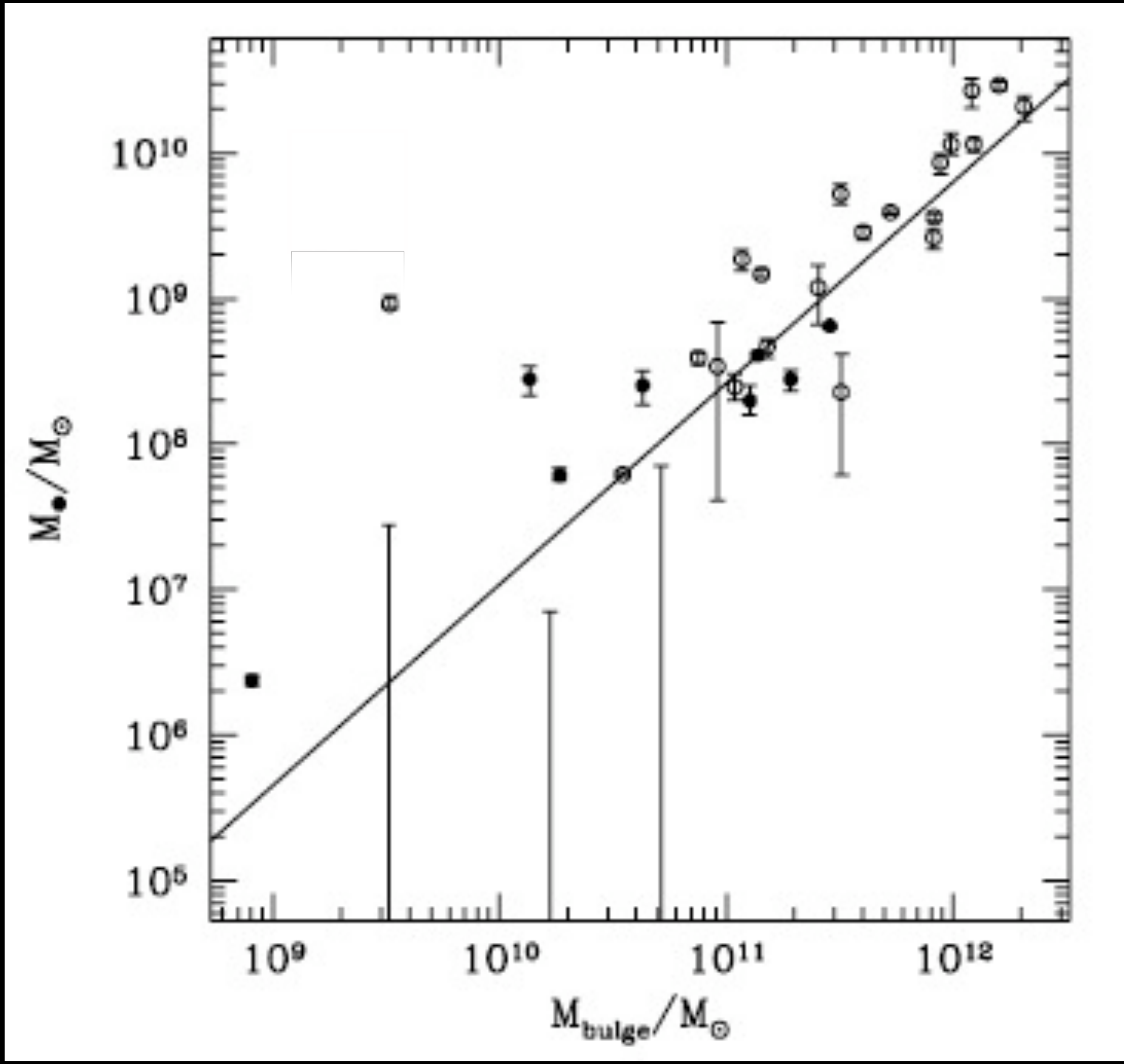
Outline

- Black holes
- X-ray Physics
- Proof of Concept
- Application
- Conclusions

Black Holes

- Many galaxies contain BHs : $M_{BH} \sim 10^{-3} M_{bulge}$ (Magorrian et al. '98), $M_{BH} \sim \sigma^4$ (Ferrarese & Meritt '00).



Magorrian et al. '98

- Possible evolution in Magorrian relation at high *z* (Walter et al. '04).

Black Holes

- SMBHs of 10^9 $M_\odot$ exist even at z ~ 6 (Fan et al. ‘03, Kurk et al. ‘07).

- Formation of the seed BHs:
  1) Stellar seed BHs(M_{BH} ~ 10^2 $M_\odot$, Volonteri et al. ‘03, Johnson & Bromm ‘07)

  2) Singular collapse (M_{BH} ~ $10^{4\text{-}6}$ $M_\odot$, Bromm & Loeb ‘03, Spaans & Silk ‘06).

- BHs produce UV (90%) and X-ray (10%) radiation.

- Thermodynamics of the gas in the inner region of an AGN is dominated by the X-ray radiation produced by the infall of gas onto the central BH (Wada et al. ‘09, Perez-Beaupuits et al. ’11).
  ➡ Important for the Magorrian relation.

X-rays

- Absorption cross-section, $\sigma \sim E^{-3}$.
  ➡ 1 keV --> 10^{22} cm^{-2} penetration

- X-rays produce fast e^- --> lose their energy through Coulomb interactions
  ➡ Secondary Ionizations Dominate --> important for H, H_2 and He

- X-rays ionize and drive the ion-molecule chemistry, hence the H_2 formation.

- X-rays couple to metals due to high cross-section.

- High opacity of metal-rich gas
  ➡ Large energy deposition rate ($\sim H_X/n_H$)

Proof of Concept

Simulations

- Include X-ray chemistry by porting XDR code (Meijerink & Spaans ‘05): dust & ion-molecule chemistry, heating, cooling (escape probability for lines); pre-computed tables in n_H, N_H, F_X, and $Z/Z_\odot$ (176 species, more than 1000 reactions).

- Employ Moray (Wise et al. ‘12): UV and X-ray radiation transport (polychromatic spectrum) around the seed BH.

- XDR (metallicity dependent) + Enzo non-equilibrium chemistry (9 species) run in parallel.

Simulations

- We perform 2 simulations for minihalos with metallicities of $Z/Z_\odot$ = 1 and 0.

- Massive black hole with a mass of $5x10^4$ $M_\odot$ at z=15.

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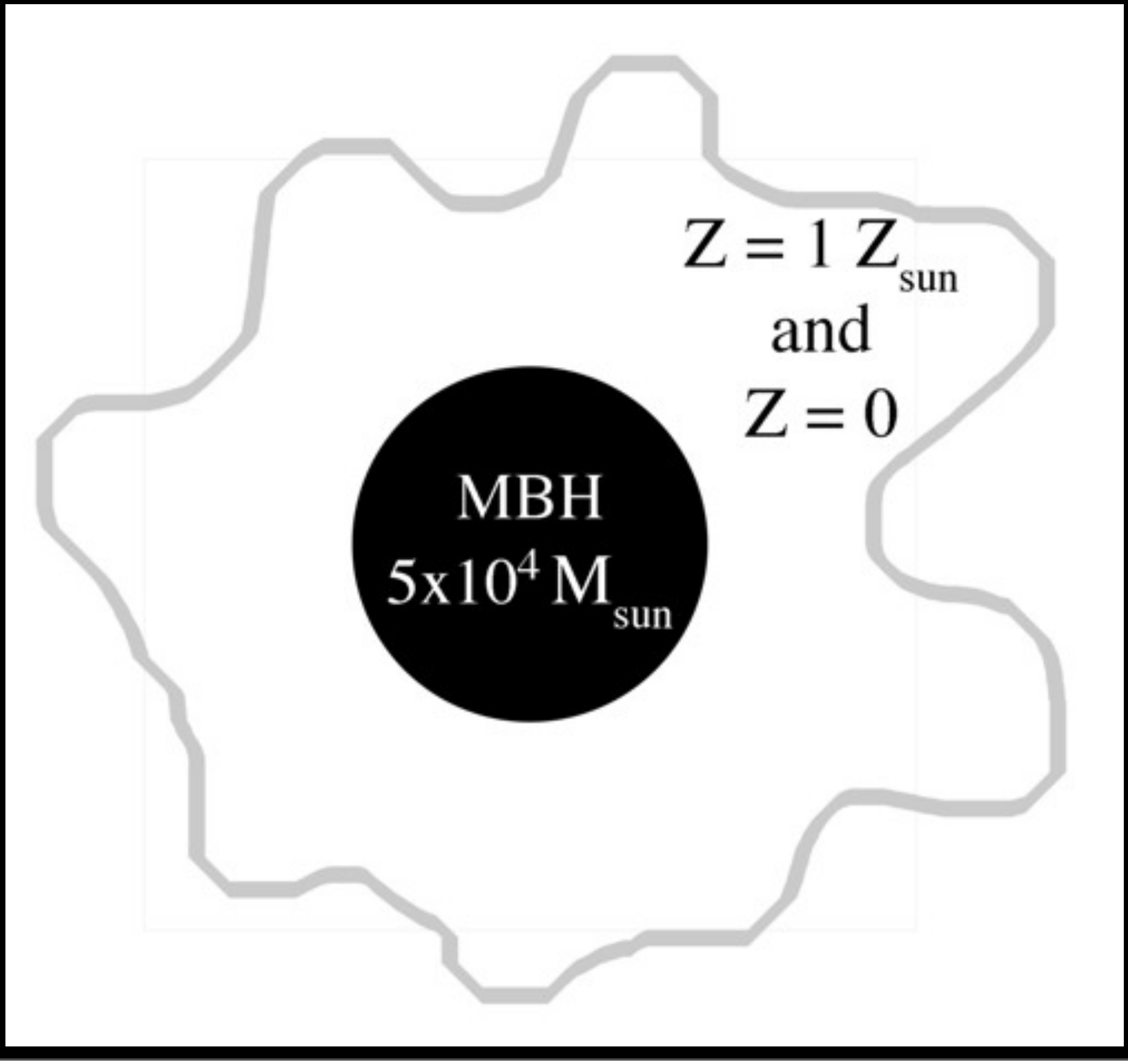
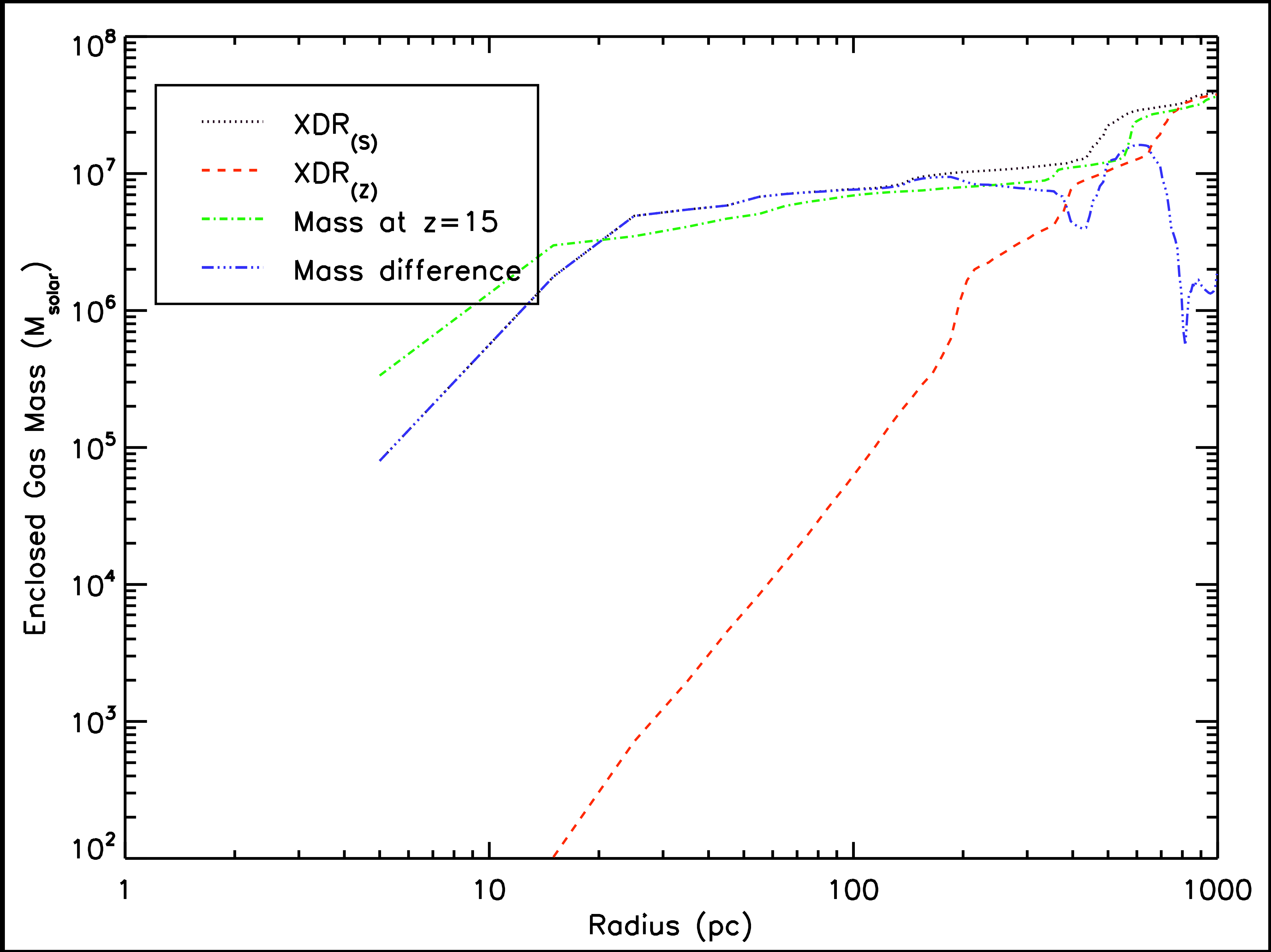
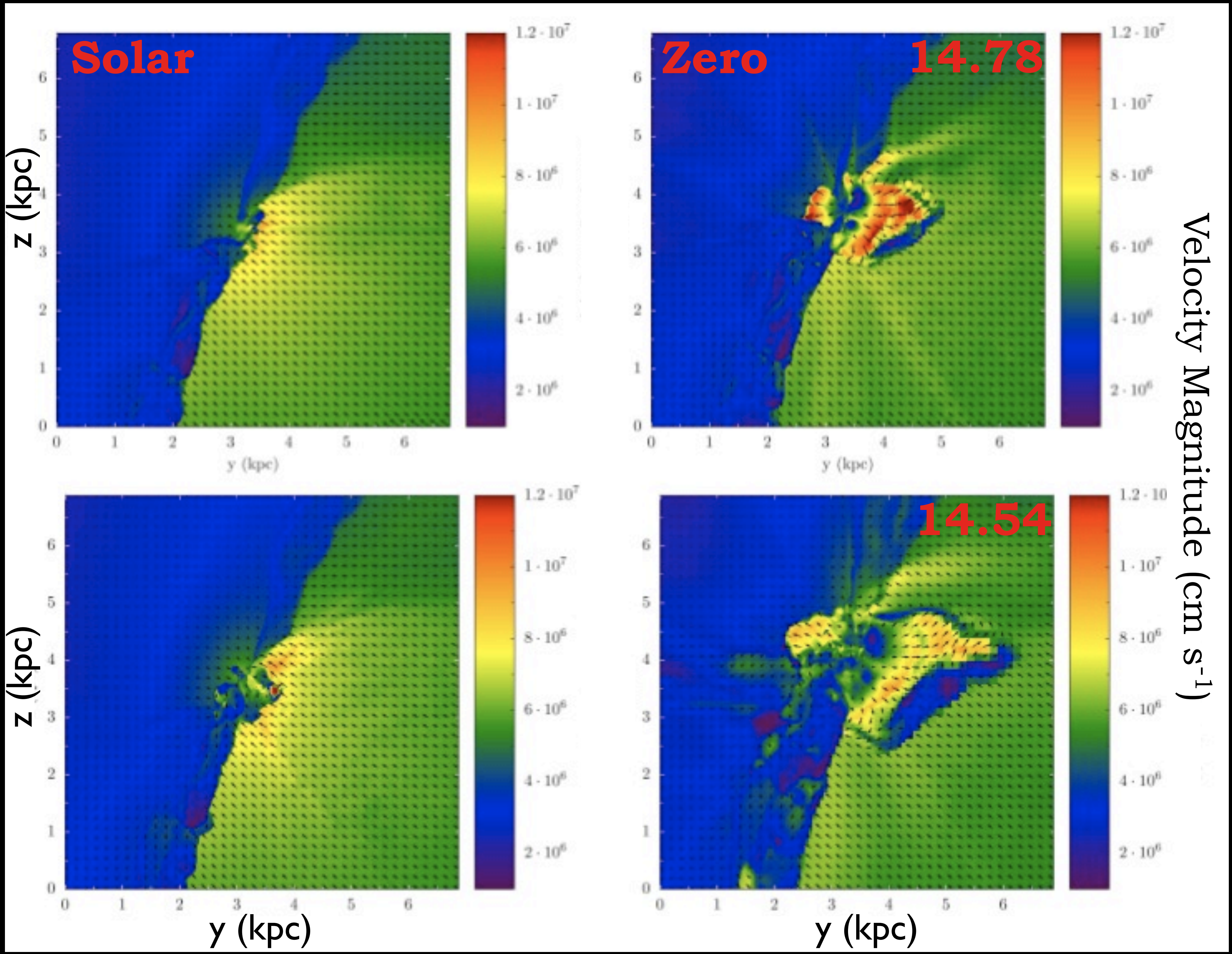


Enclosed Gas Mass



Note the missing mass in the inner 20 pc for zero metallicity case at z=14.78!

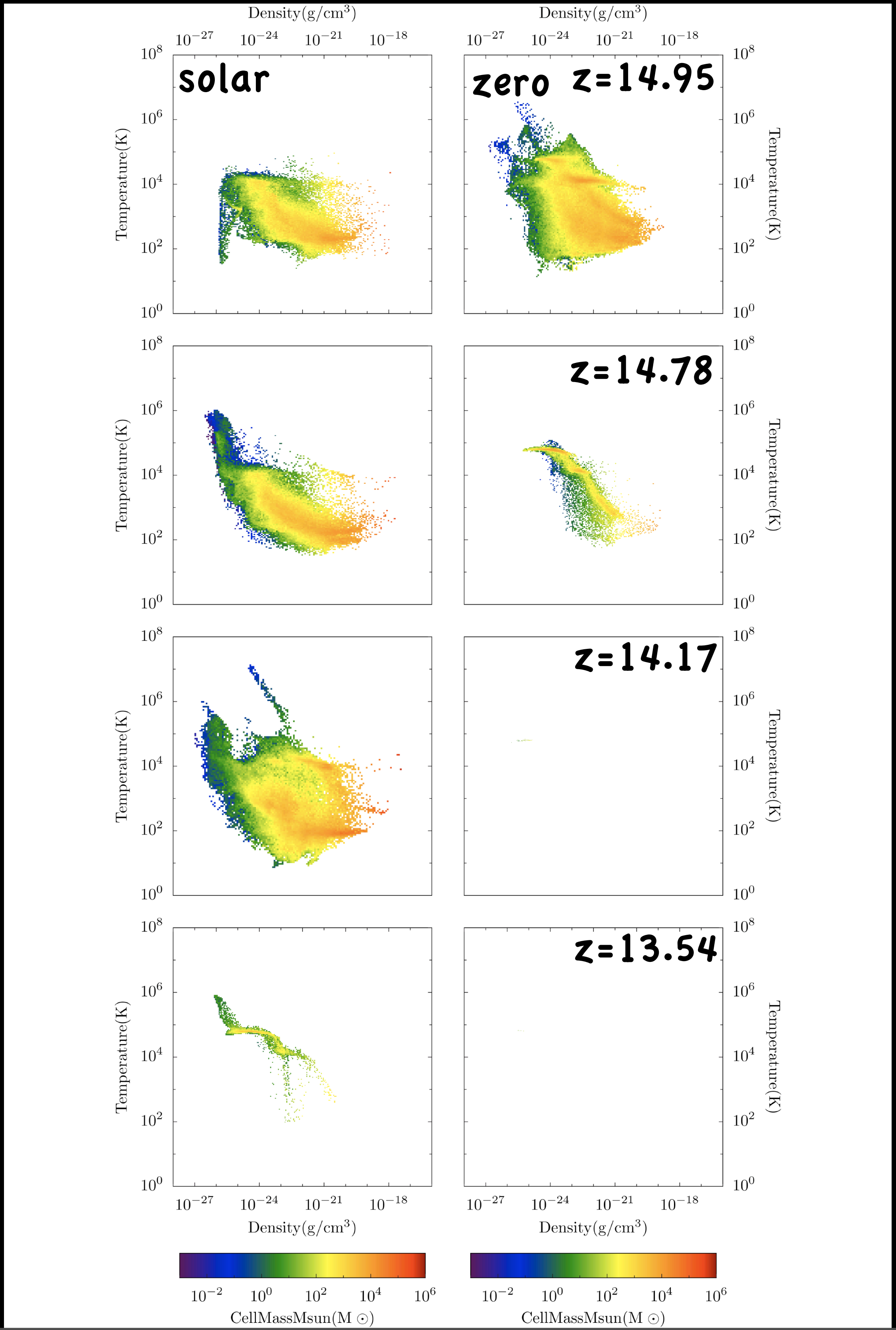
X-ray induced H II region



Velocity magnitude slices

Effects of Metals

Temperature vs density



- In solar metallicity case, lower temperatures and higher densities are reached, due to efficient cooling.
- At z=14.17, H II region is also formed in solar metallicity case but with a delay of 17 Myr.

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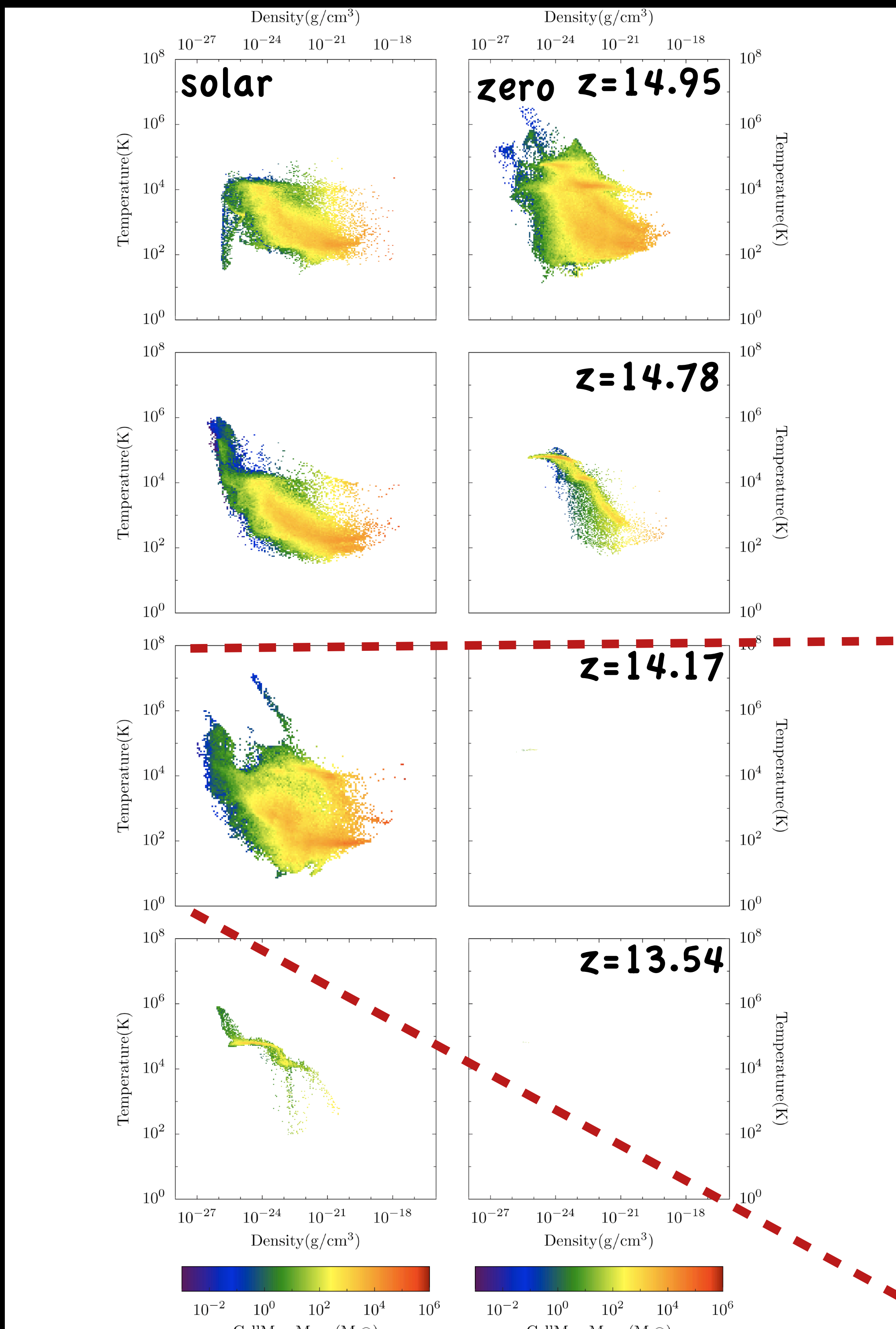

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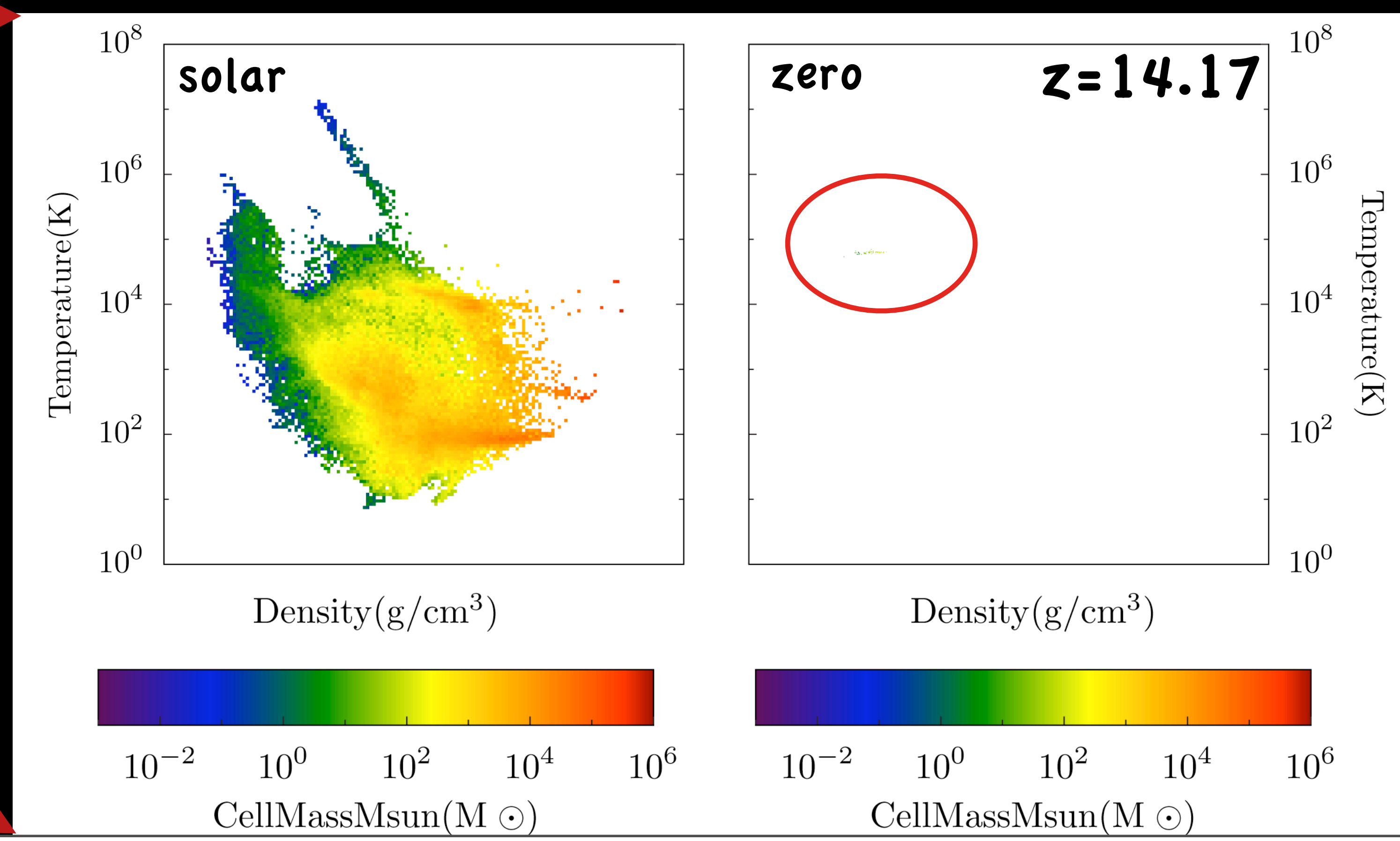
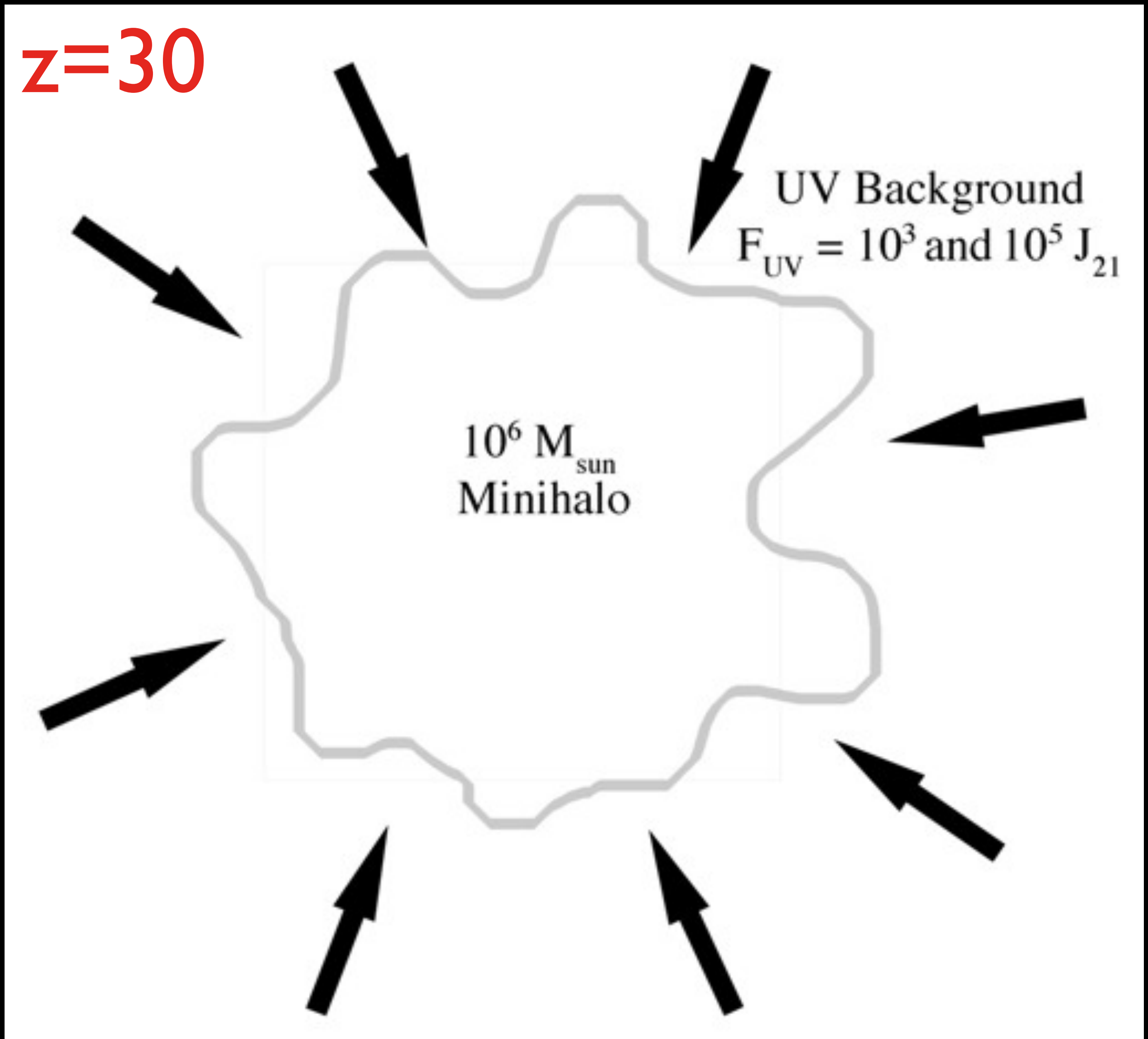


Application

Simulations

- Consider singular collapse scenario for UV backgrounds of 10^3 J_{21} (low) and 10^5 J_{21} (high), where $J_{21}=10^{-21}$ erg cm^{-2} sr^{-1} s^{-1} Hz^{-1}. Turned on at z=30.
- Introduce seed MBH M=5 x 10^4 $M_\odot$ at z=15.



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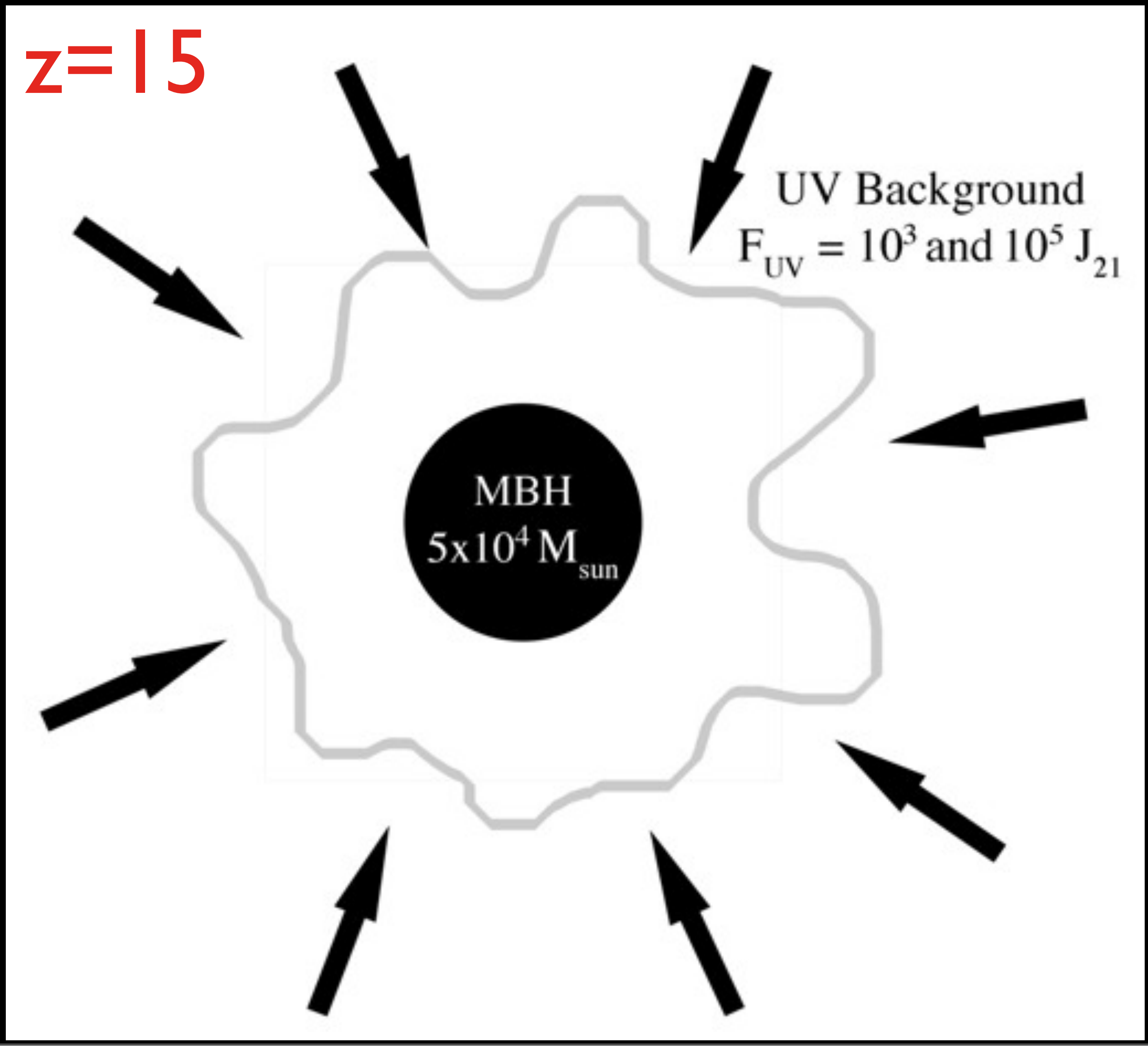
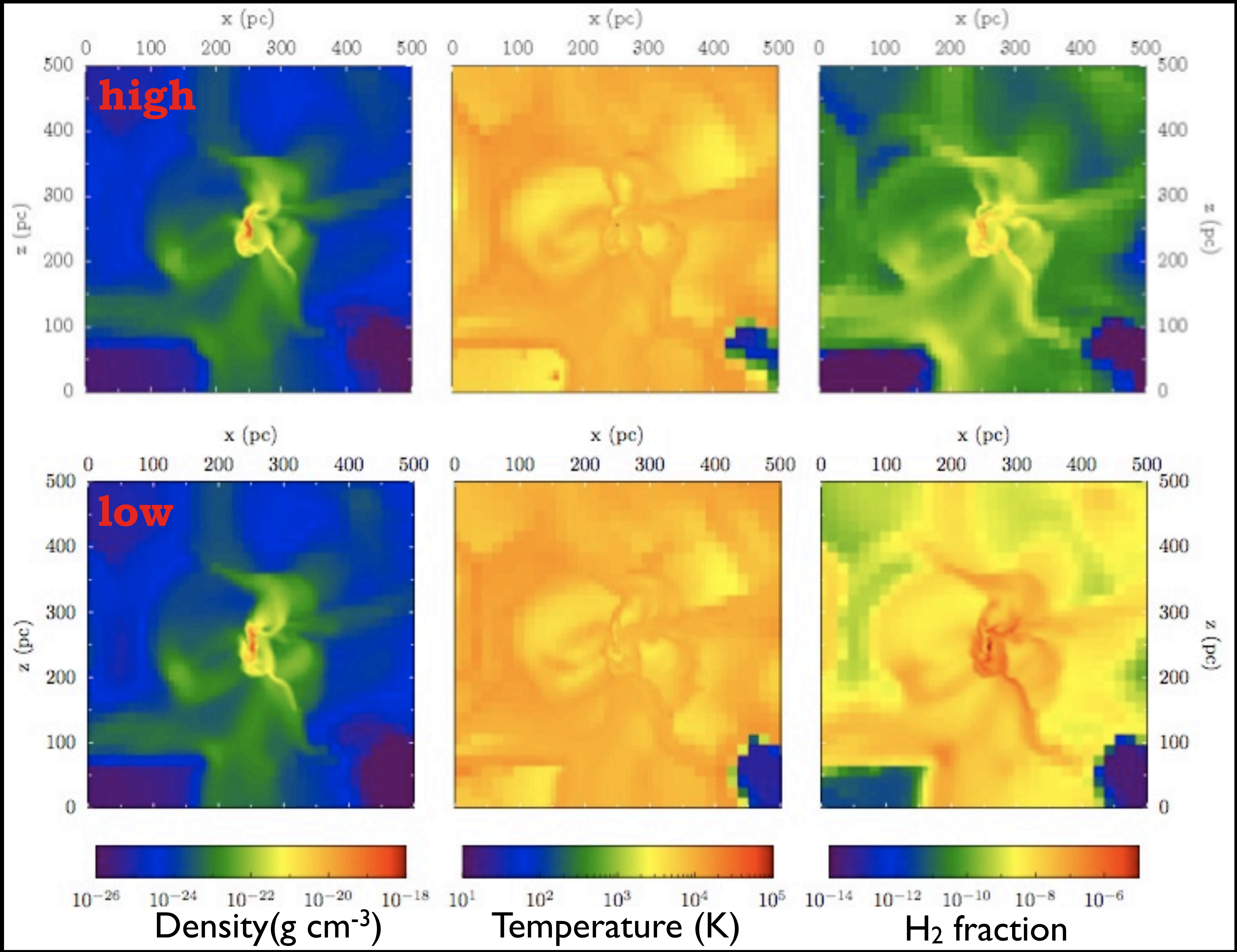


Simulations

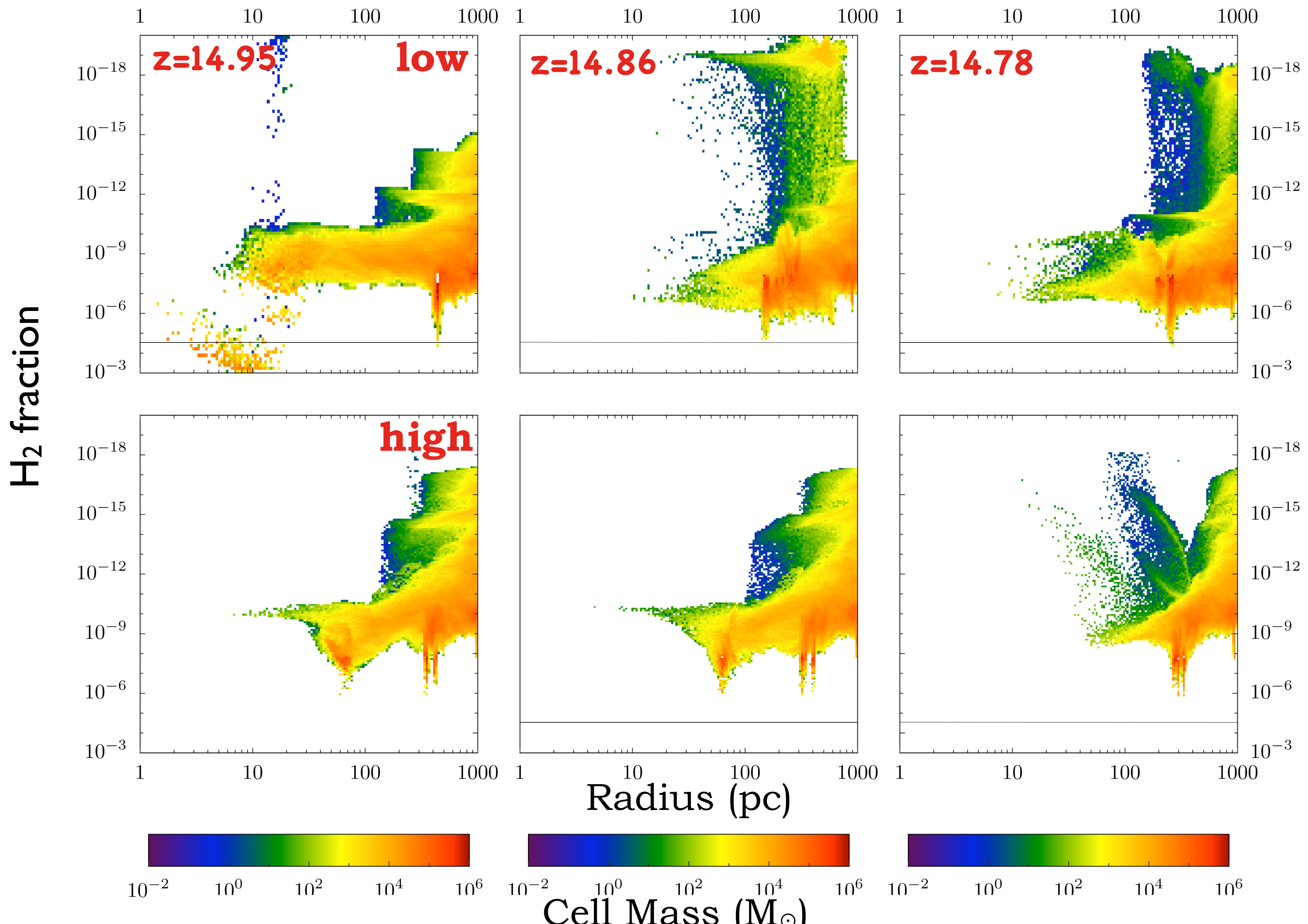
- Star formation recipe based on H_2 fraction ($> 5 \times 10^{-4}$) turned on at $z=30$ on.
- BH accretion: Eddington limited spherical Bondi-Hoyle (Kim et al. ‘11 prescription).
- SN feedback, metal enrichment followed.
- H_2 self-shielding included (Draine & Bertoldi ‘96 prescription).

Application



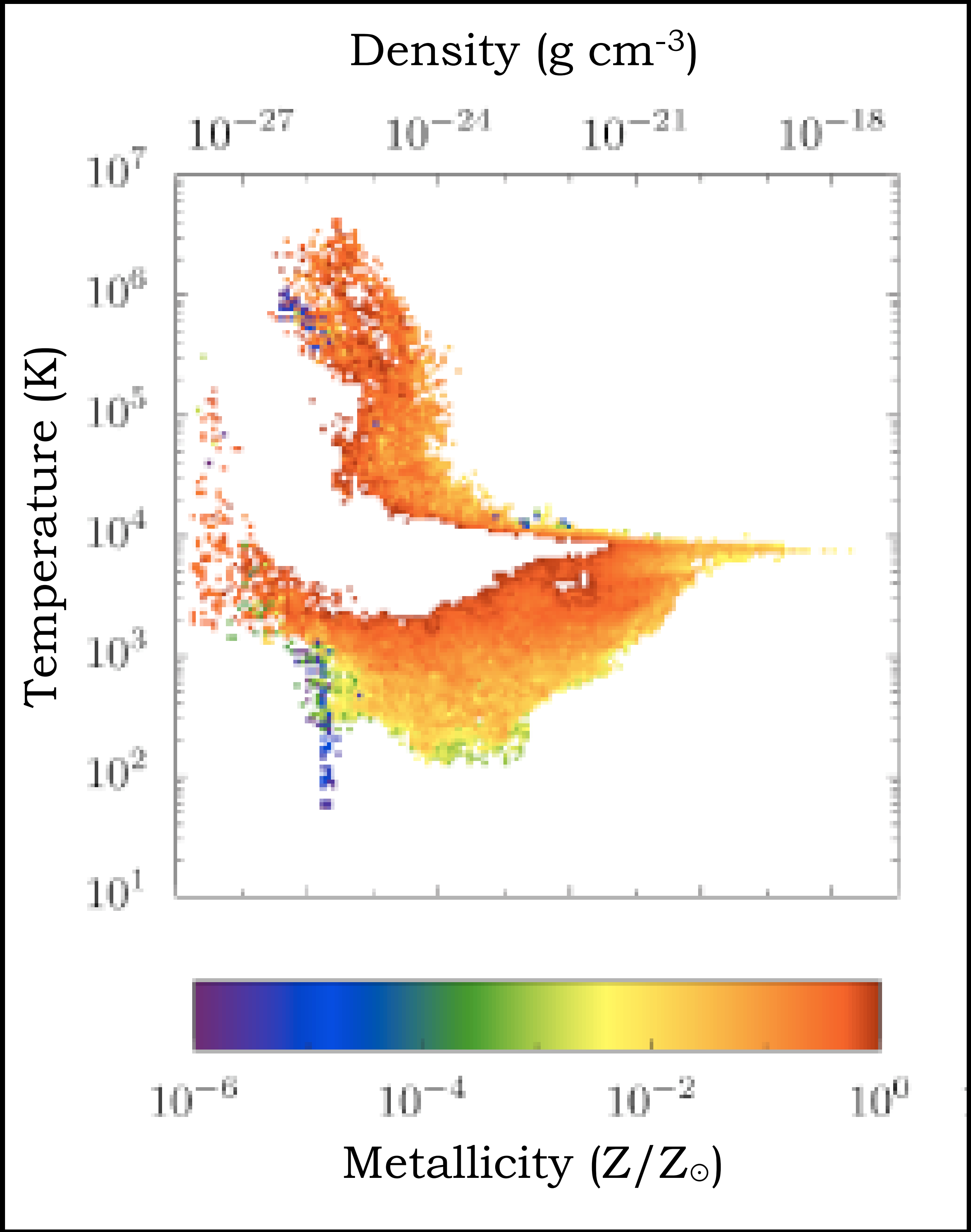
Density (left), temperature (middle), and H_2 fraction (right).

H_2 fraction

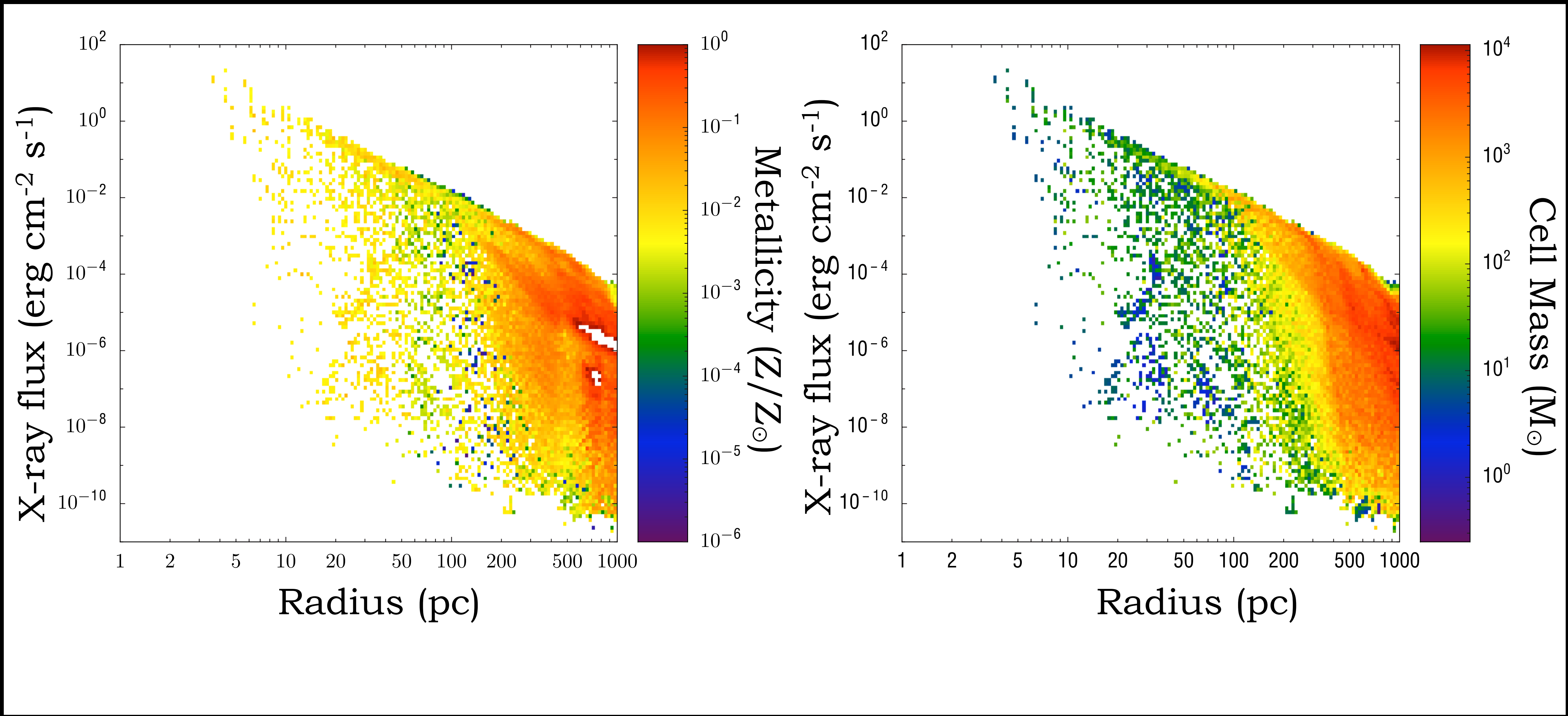


H_2 fraction vs radius

Metal enrichment



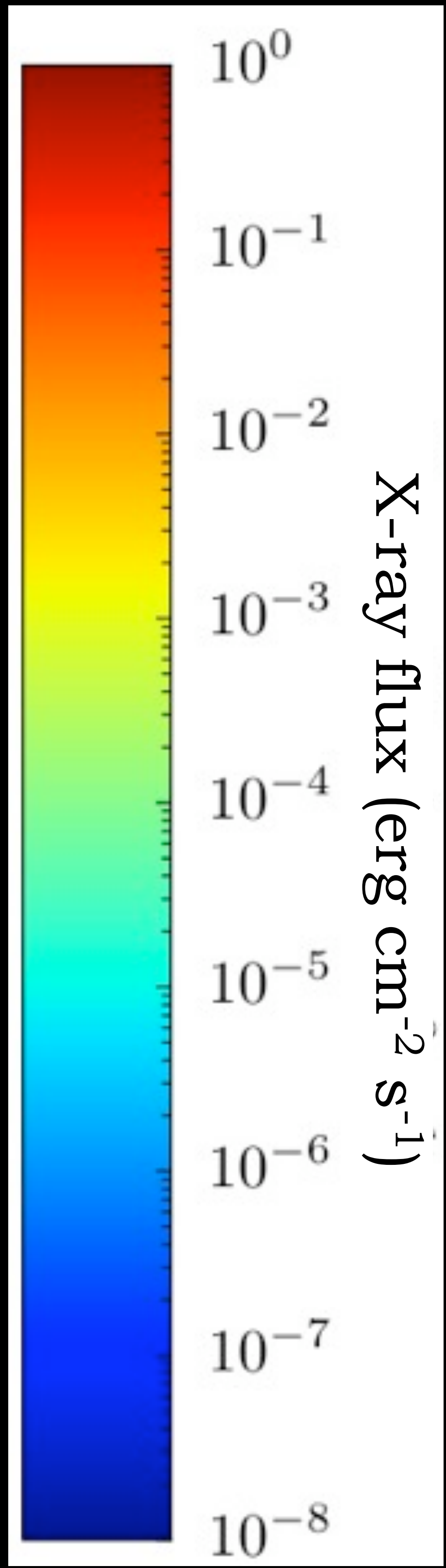
X-ray flux



X-ray vs radius color coded for metallicity

X-ray vs radius color coded for mass

X-ray flickering



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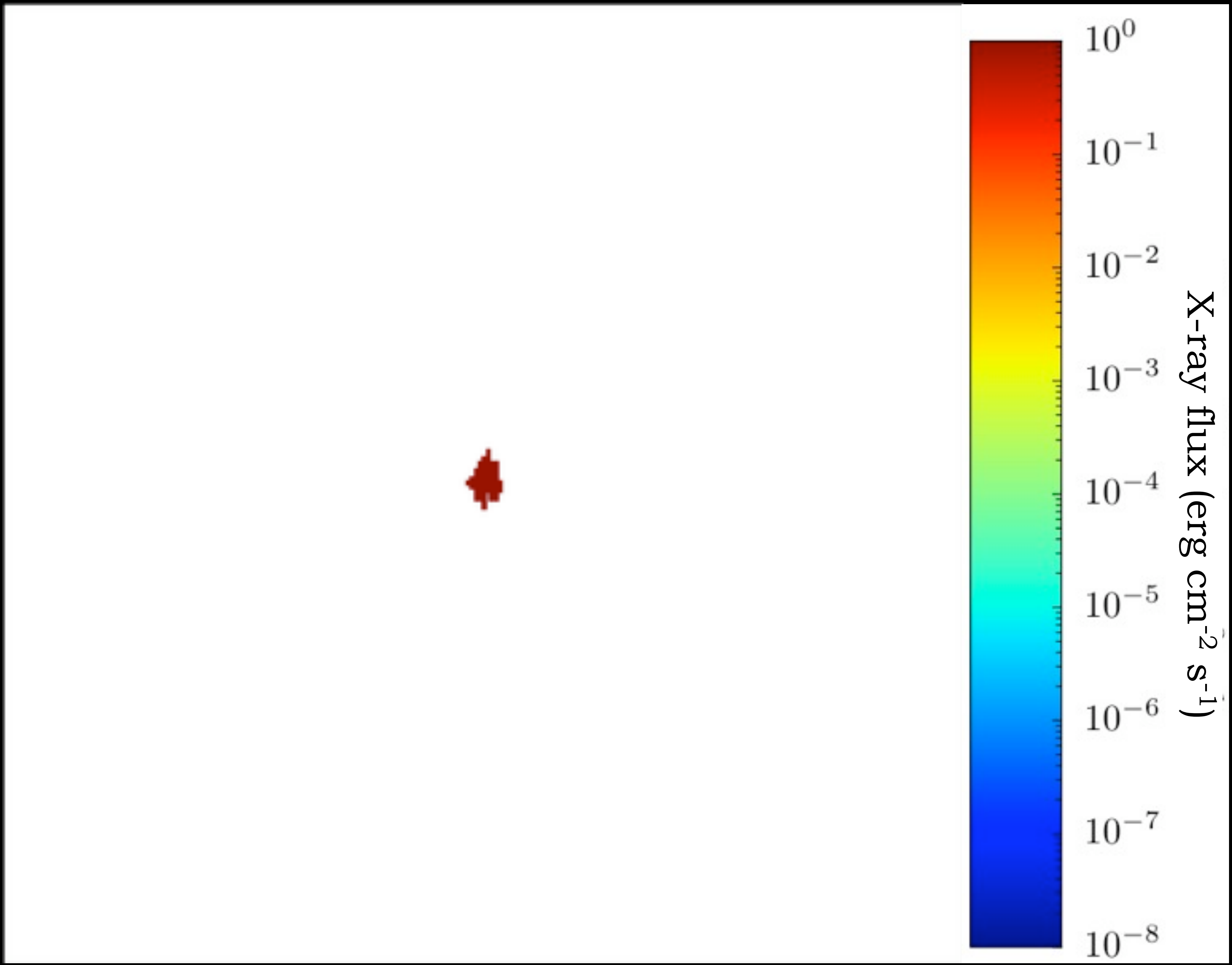
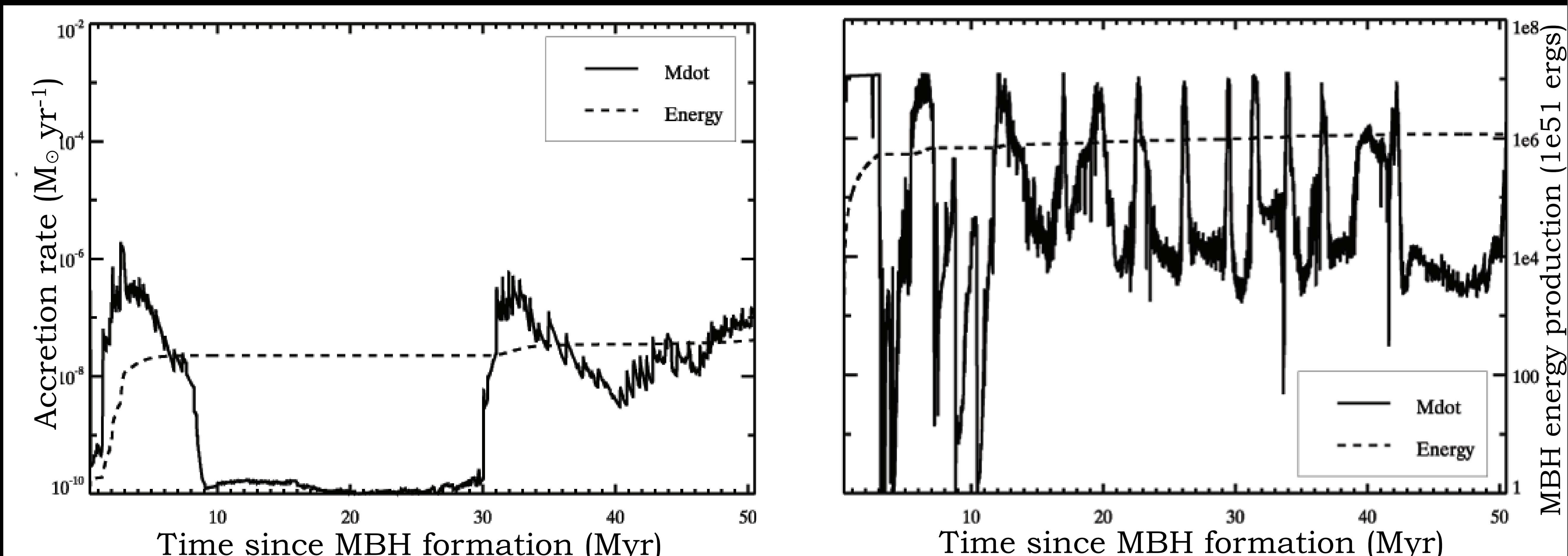


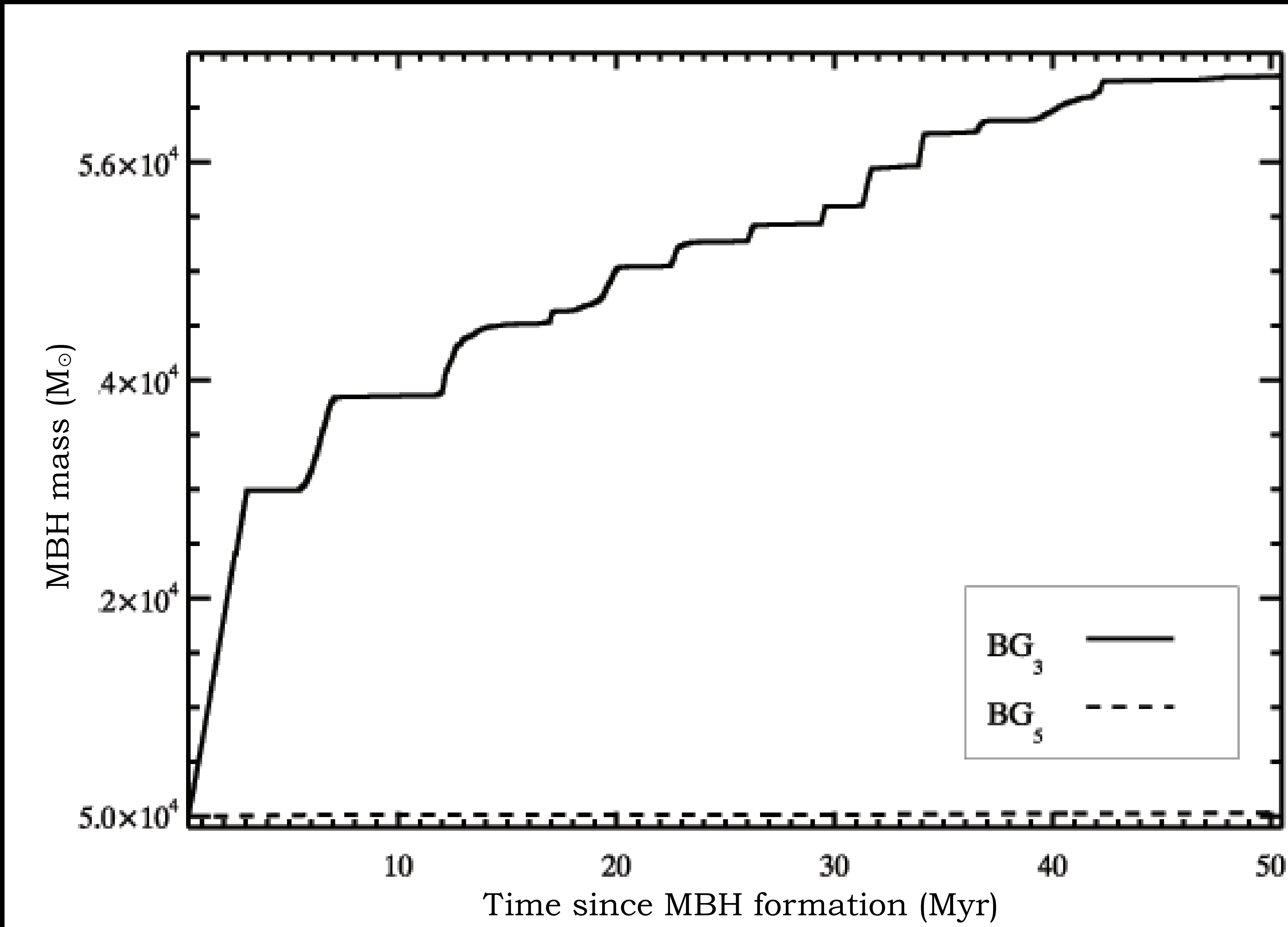
Accretion rate



High UV bg case: 10^5 J_{21}

Low UV bg case: 10^3 J_{21}

Black hole growth



- X-ray feedback/BH growth self-regulating.
- Strong UV background prevents growth to a SMBH!

Conclusions

- X-rays important & metals boost X-ray opacity --> heating.
- X-ray feedback/BH growth is self-regulating.
- Weaker 10^3 J_{21} UV background allows Pop III star formation and subsequent enrichment of the medium.
- For low UV bg, 10^5 $M_\odot$ MBH grows at 10^{-3} $M_\odot$/yr, doubles in mass in Edd. time (usual suspects for SMBHs at z=6).
- Singular collapse scenario does not yield SMBHs at z=6 for 10^5 J_{21} UV background.
- Interesting for slowly evolving dwarfs today, unless there is later time UV weakening and/or metal enrichment.