Kimm et al. (2018, MNRAS, 475, 4617)

Impact of Lyman Alpha Pressure on Metal-Poor Dwarf Galaxies

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in collaboration with

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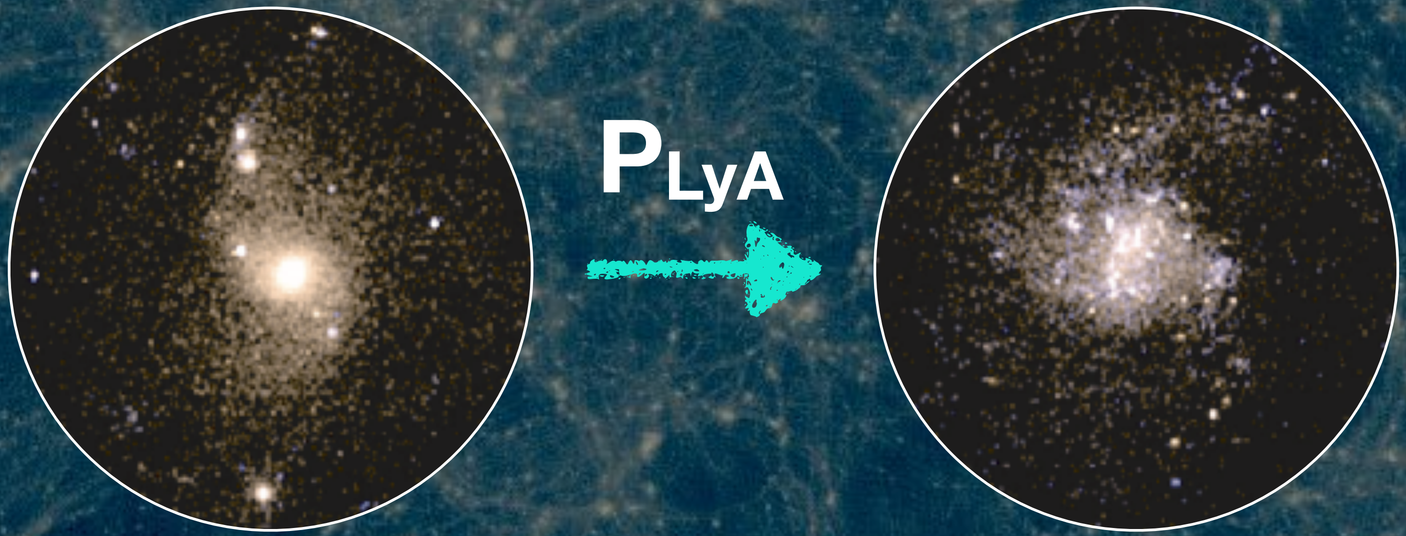
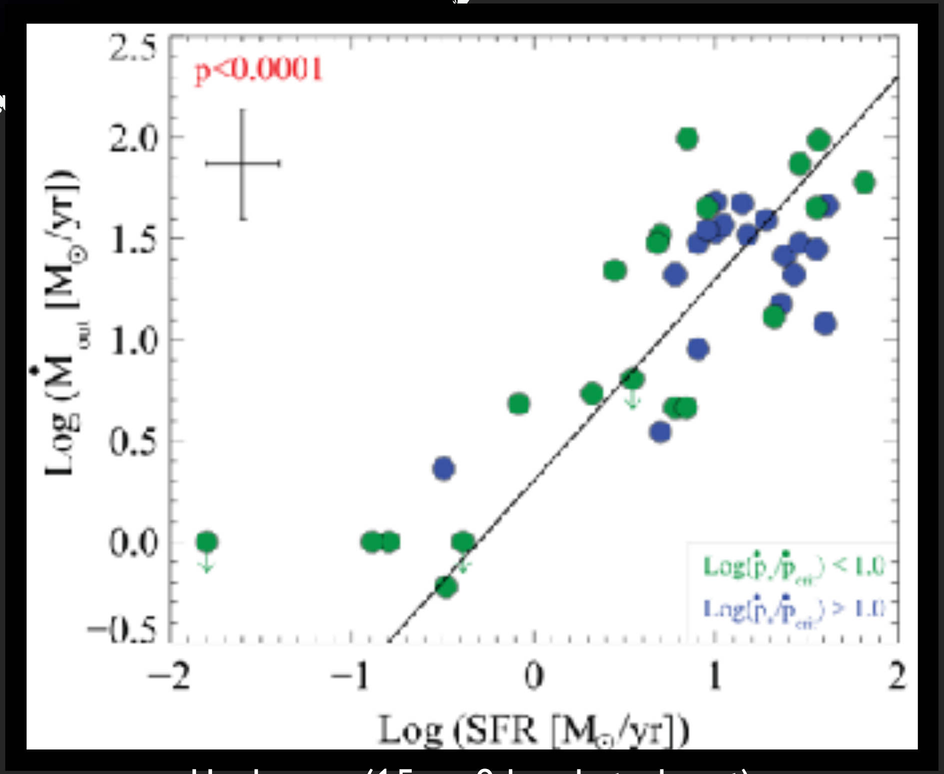
Leo **Michel-Dansac** (Lyon)
Harley **Katz** (Oxford)
Romain **Teyssier** (Zurich)



Common feature of SFRs – Outflows

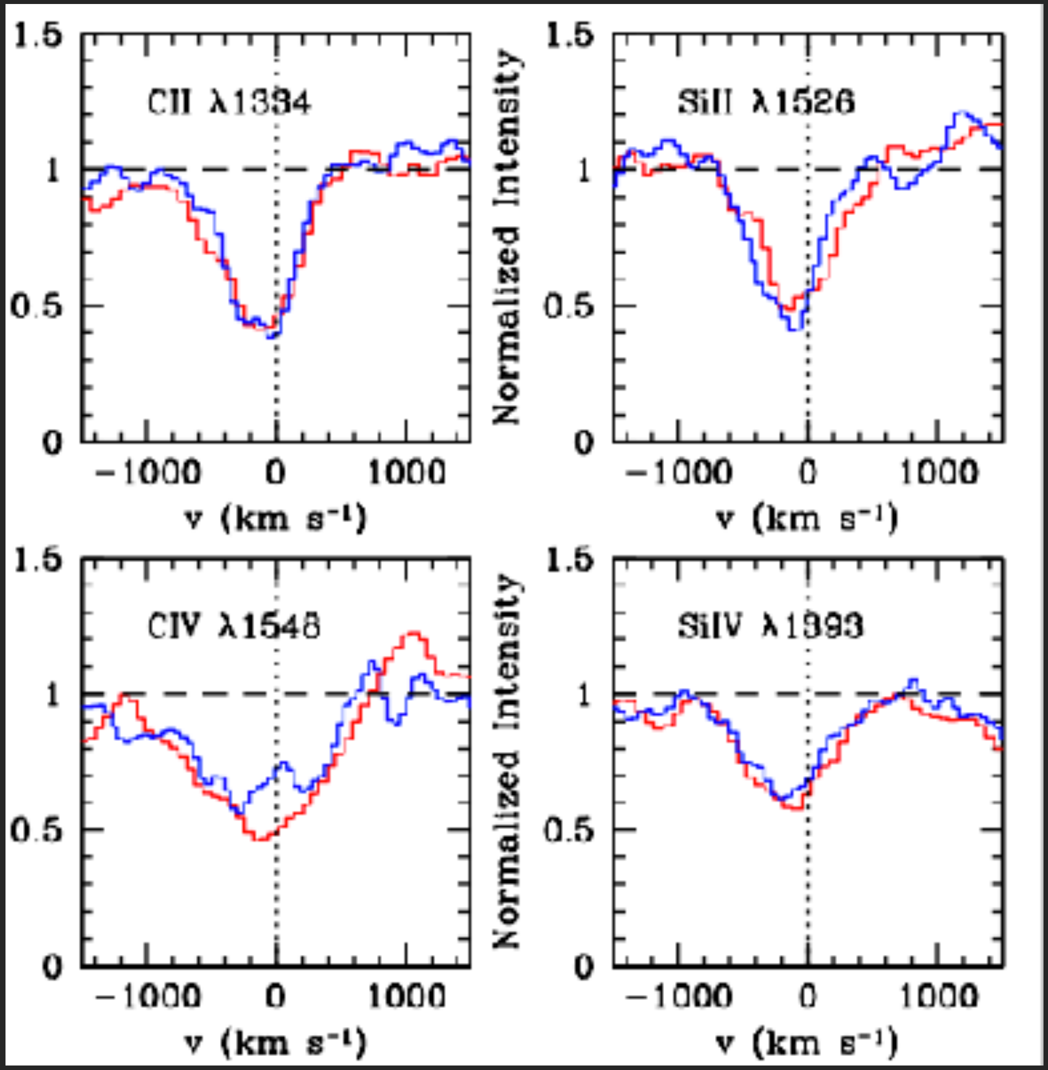
M82: local starburst

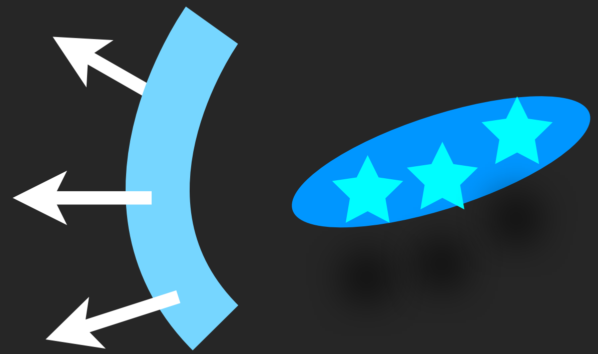
Red (0.3-1.1 keV); 3×10^{6}-10^{7}K
Green (0.7-2.2 keV); 7×10^{6}-2×10^{7}K
Blue (2.2-6 kev); 2×10^{7}-6×10^{7}K
(Credit: Chandra)



Heckman+(15; z~0 local starburst)

Ubiquitous **Outflows** in LBGs at z~2 (Steidel+10)



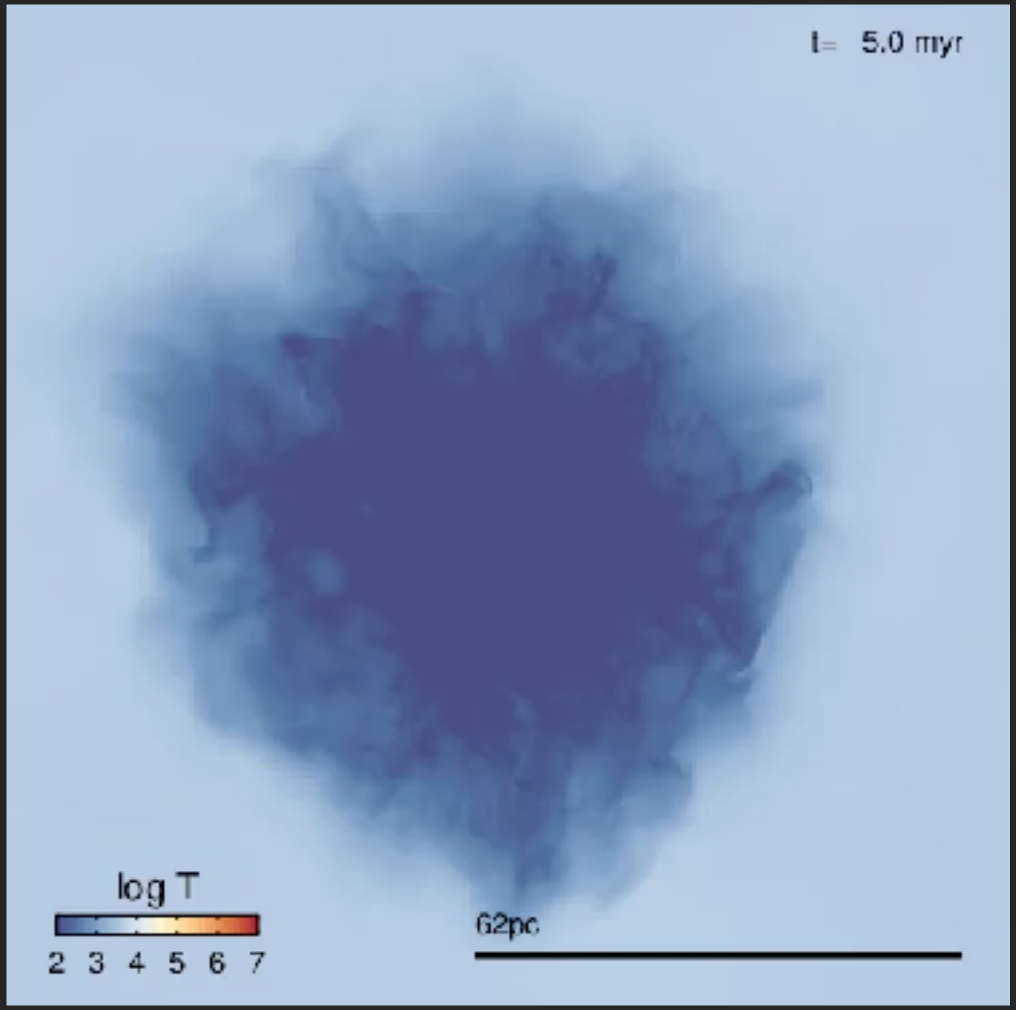


observer

Introduction

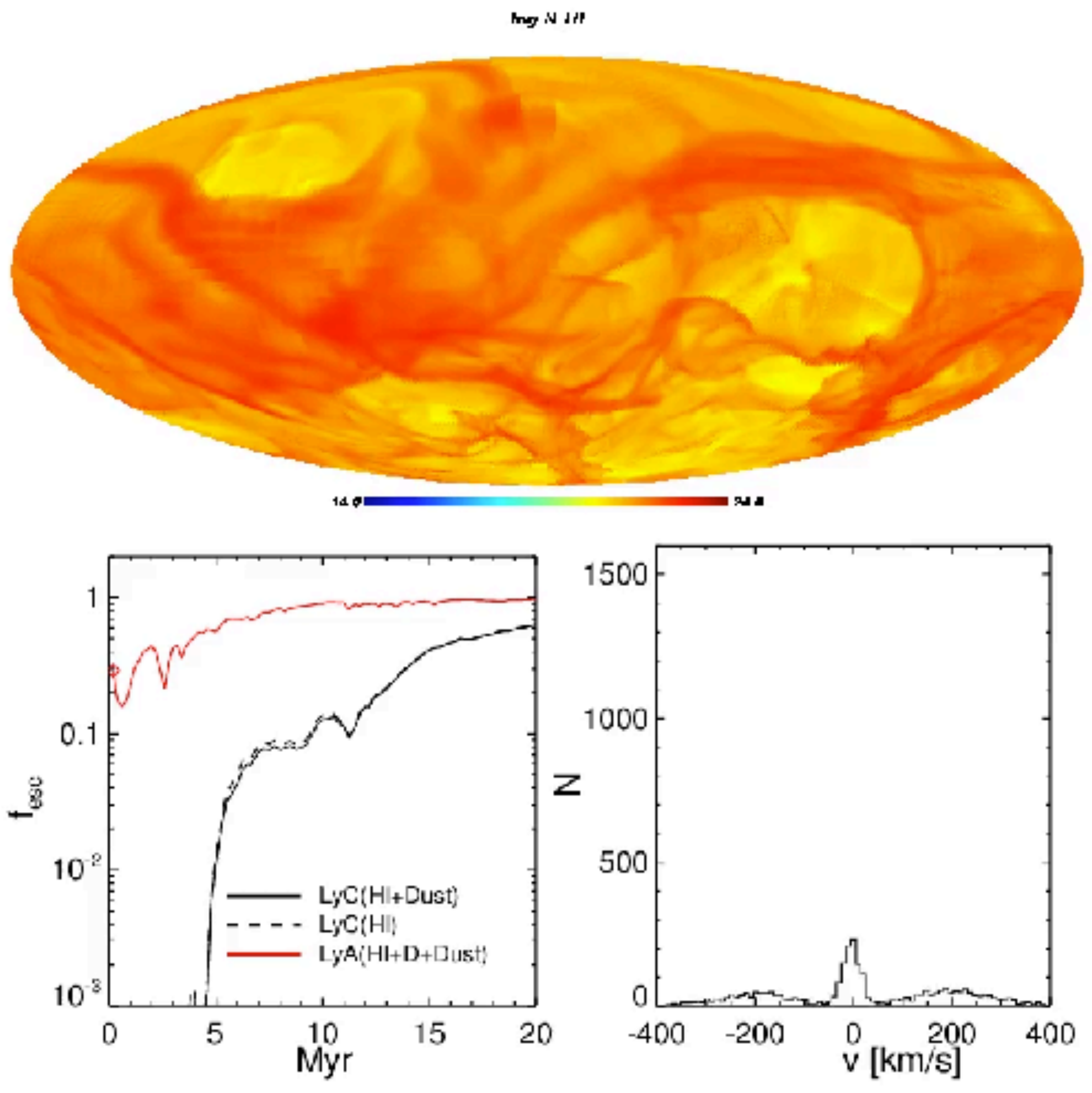
Lyman alpha profile on cloud scales

c.f. Neufeld (90;91); Zheng+(02); Verhamme et al. (06,12); Dijkstra et al. (06); Gronke & Dijkstra (15)



Radiation-Hydrodynamic simulations of a turbulent cloud with $M_{cloud}=10^6 M_{sun}$, SFE=1%

Post-processing with **RASCAS** (Jeremy Blaizot's talk)

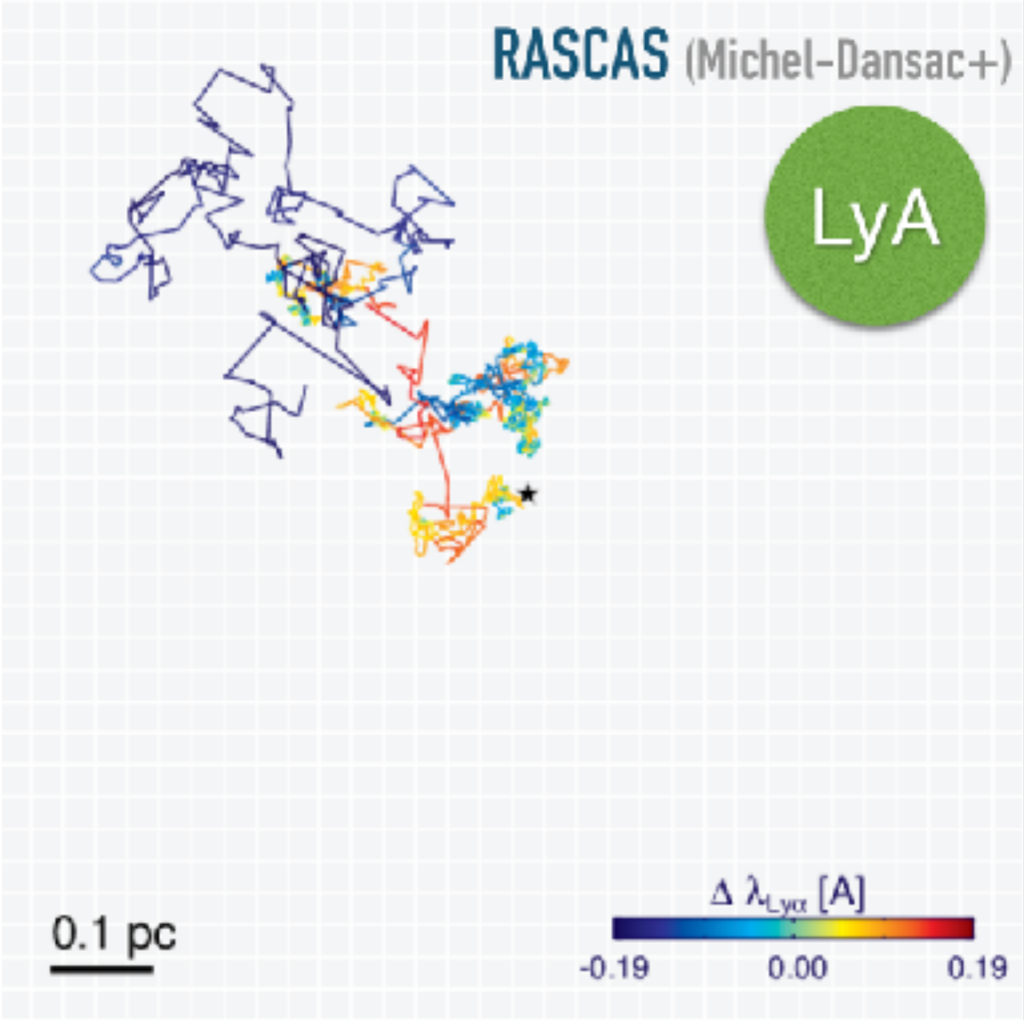


recombination+collisional radiation

Kimm, Blaizot et al. (in prep)

Lya pressure

Scattering of LyA photons transfers momentum to the surroundings



Momentum transfer

$$\Delta\vec{p} = \frac{h_p}{c}\left(\nu_{\rm in}\hat{n}_{\rm in} - \nu_{\rm out}\hat{n}_{\rm out}\right)$$

Multiplication factor

$$F_{Ly\alpha} = M_{\rm F}\frac{L_{Ly\alpha}}{c}$$

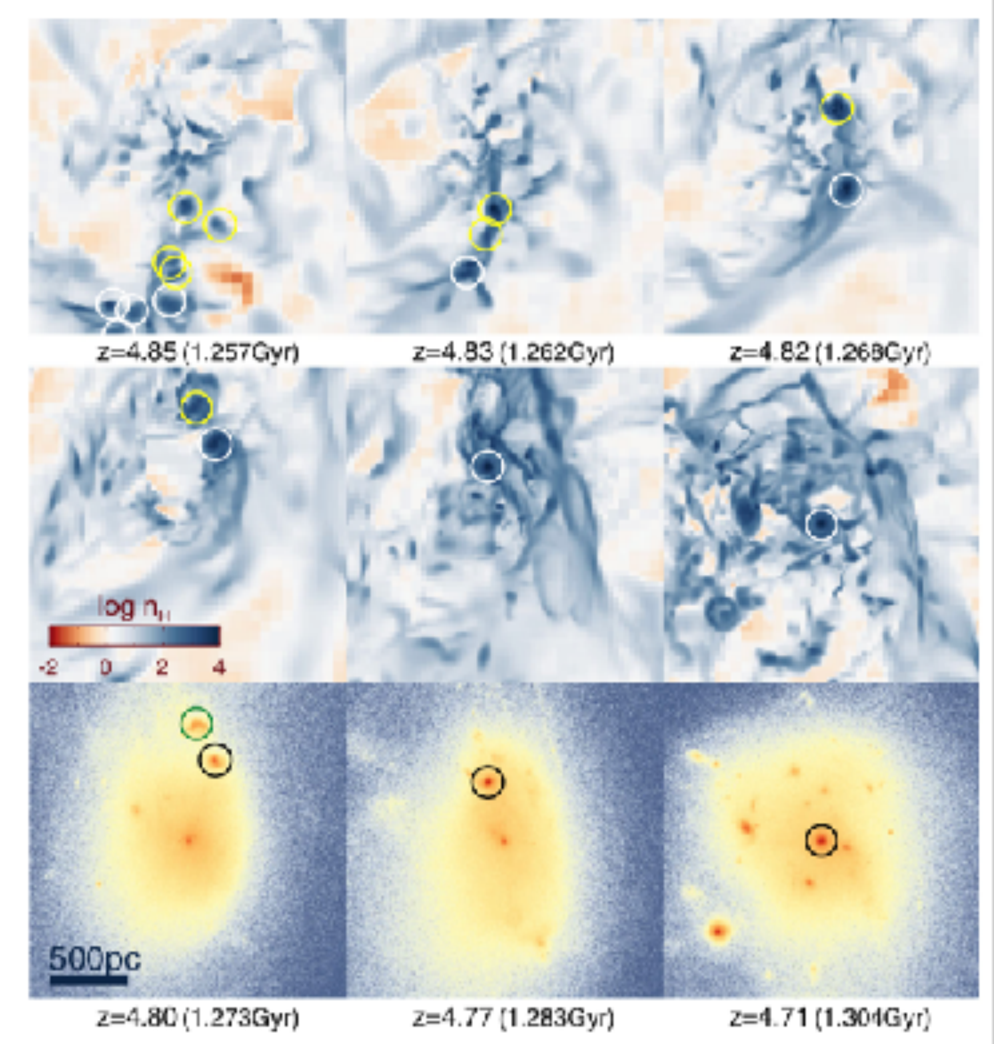
See also Dijkstra & Loeb (08), Smith et al. (16)

WHY DO WE CARE?

Optical depth to LyA is huge!

$$\tau_{Ly\alpha} = \left(\frac{N_{\rm HI}}{2\times10^{13}\ {\rm cm}^{-2}}\right)\left(\frac{T}{10^4\ {\rm K}}\right)^{-1/2}$$

Solution to the Over-cooling problem at high z?

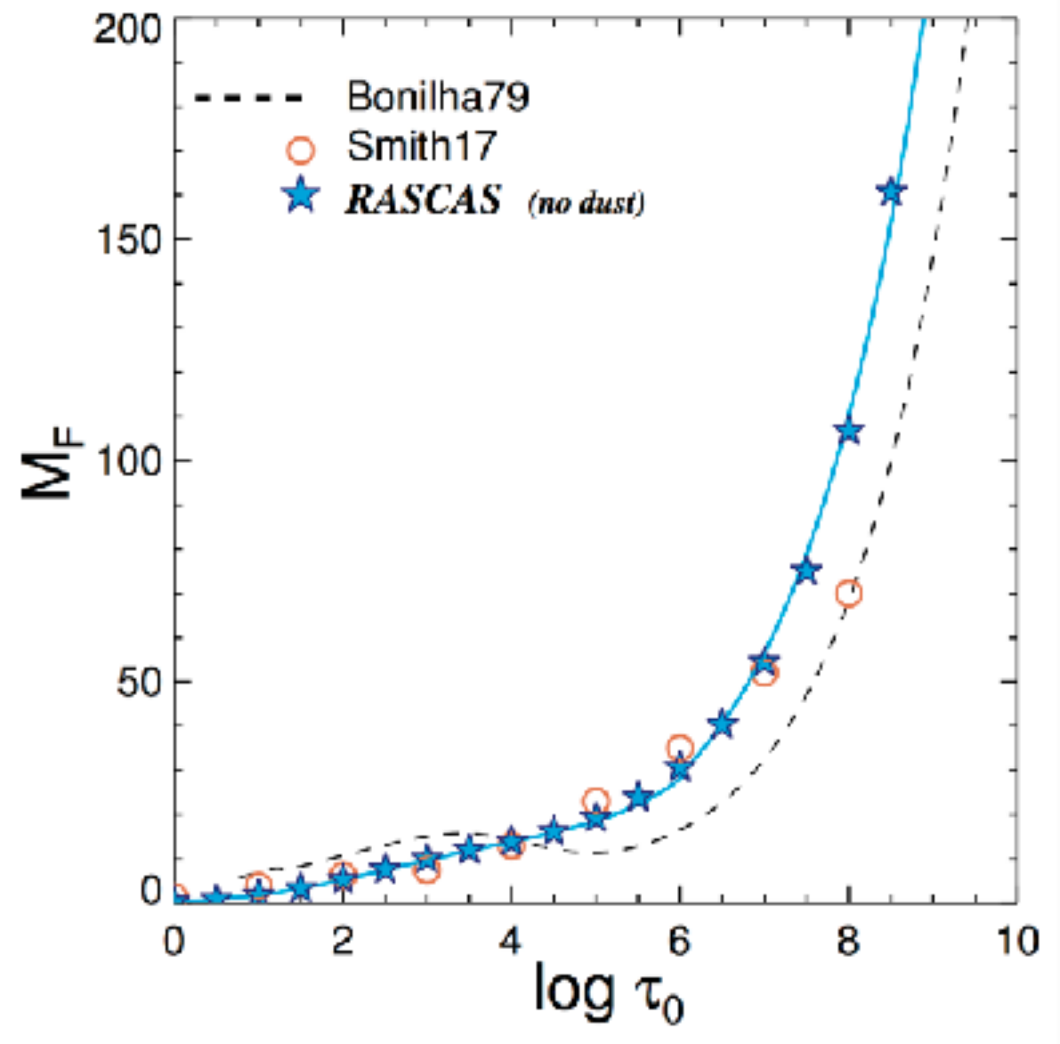


Kimm, Cen, Devriendt+(15)

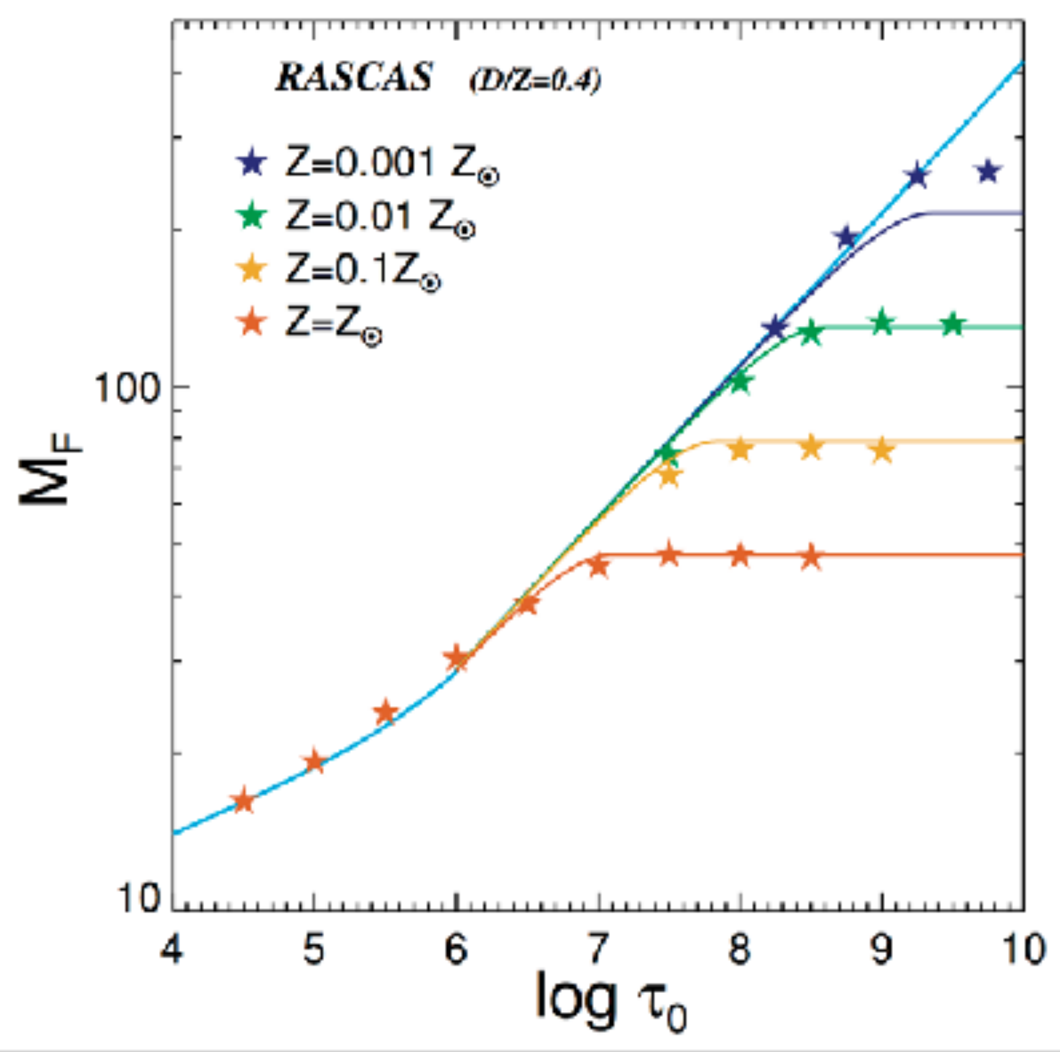
Scattering of LyA photons transfers momentum to the surroundings

See also Dijkstra & Loeb (08), Smith et al. (17)

Dust-free



Dusty



Multiplication factor

$$F_{Ly\alpha} = M_{\rm F} \frac{L_{Ly\alpha}}{c}$$

Dust-to-metal ratio: Remy-Ruyer+(14)

$$\begin{aligned} \log f_{\rm d/m} &= 0 & (x > 8.10), \\ &= 1.25 - 2.10 \times (x_\odot - x) & (x \leq 8.10), \end{aligned}$$

$x = 12 + \log(O/H)$ and $x_\odot = 8.69$

Momentum budget from Lya pressure

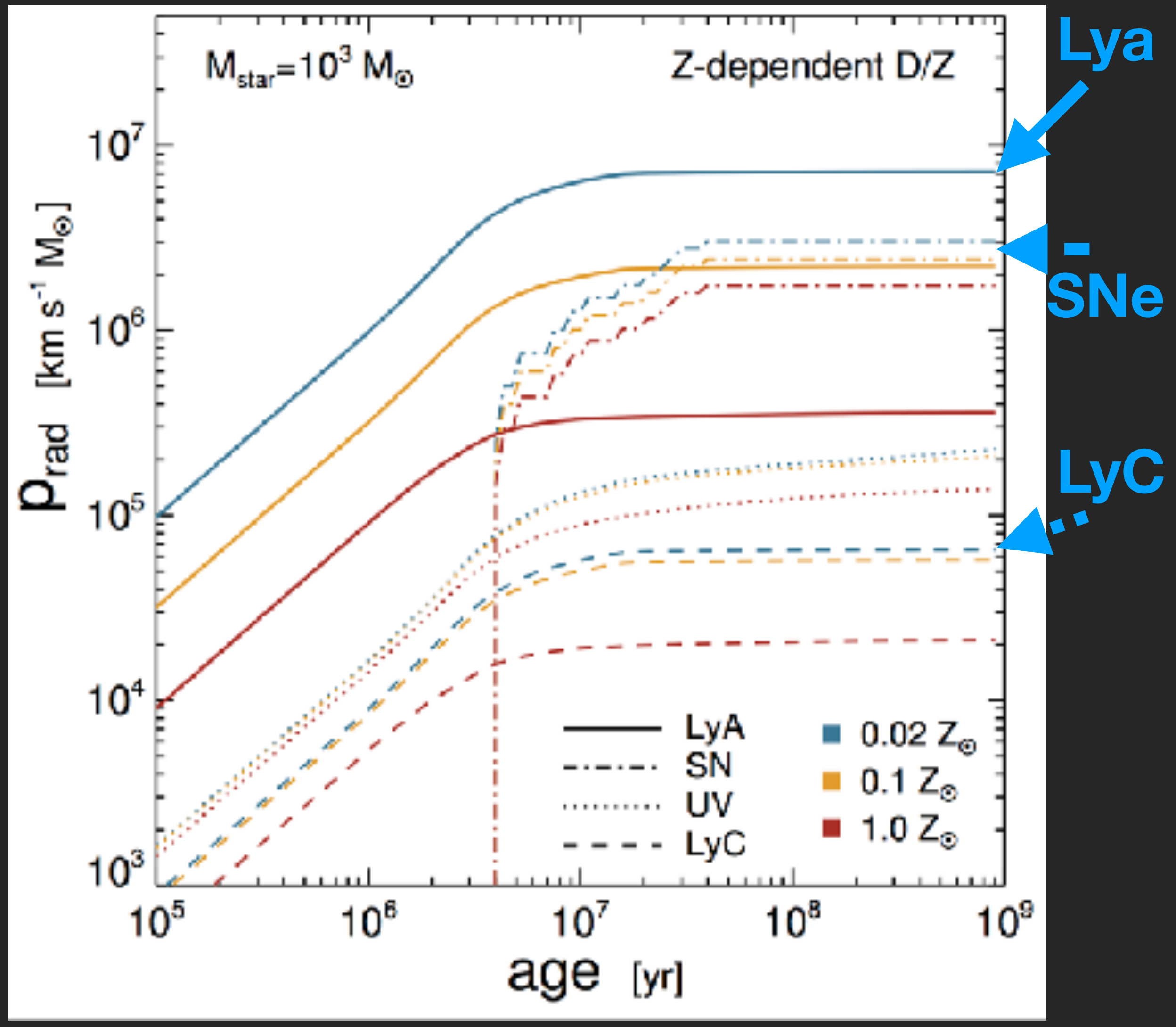


Photo-ionization heating

$$n_{\rm H,ion} T_{\rm ion} = n_{\rm H,0} T_0$$

$$r_{\rm PH} \approx 26\,{\rm pc} \left(\frac{m_{\rm star}}{10^3\,{\rm M_\odot}}\right)^{1/3} \left(\frac{P/k_{\rm B}}{10^5\,{\rm cm^{-3}\,K}}\right)^{-3/2} \left(\frac{T_{\rm ion}}{10^4\,{\rm K}}\right)^{2/3}$$

Lyman alpha pressure

$$n_{\rm H} k_B T = \frac{M_F L_\alpha}{4\pi r_\alpha^2 c}$$

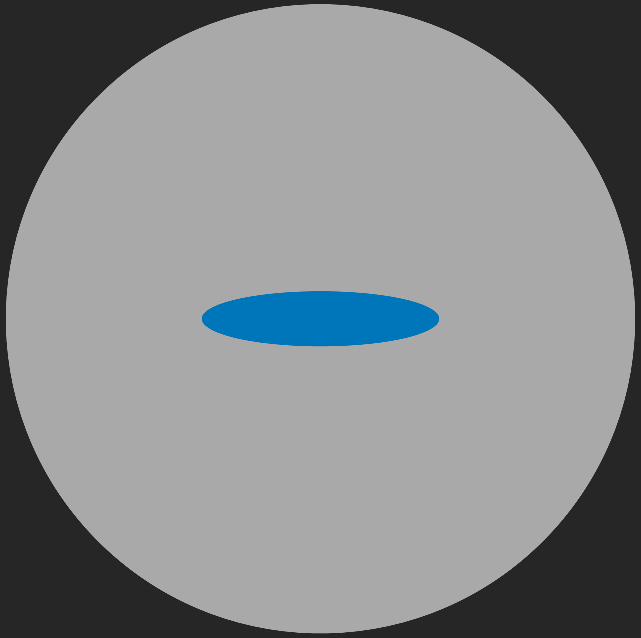
$$r_\alpha = 37\,{\rm pc} \left(\frac{M_{\rm F}}{100}\right)^{1/2} \left(\frac{m_{\rm star}}{10^3\,{\rm M_\odot}}\right)^{1/2} \left(\frac{P/k_{\rm B}}{10^5\,{\rm cm^{-3}\,K}}\right)^{-1/2}$$

- The momentum from Lya is comparable or more significant than that of SNe
- Lya pressure is advantageous from a computational viewpoint as well

Radiation-hydrodynamic simulations of an isolated disk

Simulation set-up

M_{DMH}~10^{10} M_{sun}



Z=0.02 Z_{sun}

M_{star}= 2×10^{8} M_{sun}

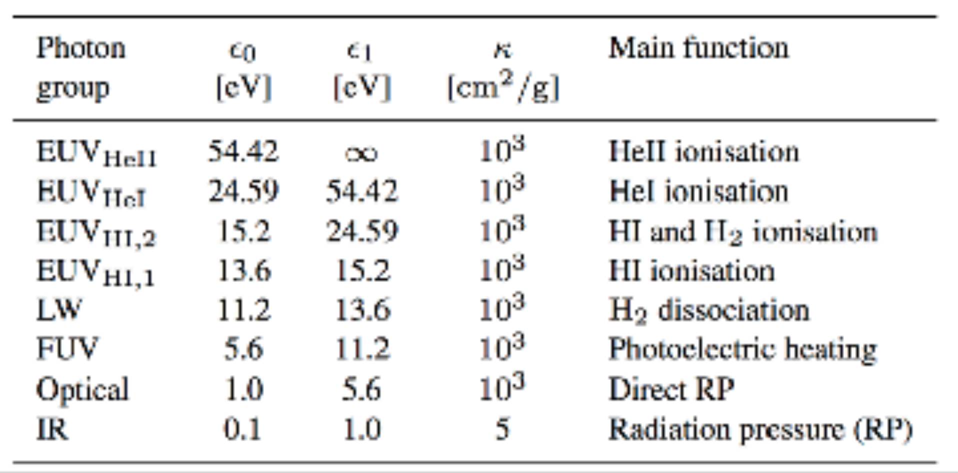
M_{gas}=1.7×10^{8} M_{sun}

Max Resolution: 2 - 5 pc

Input physics

RAMSES-RT (Teyssier 02; Rosdahl+13)

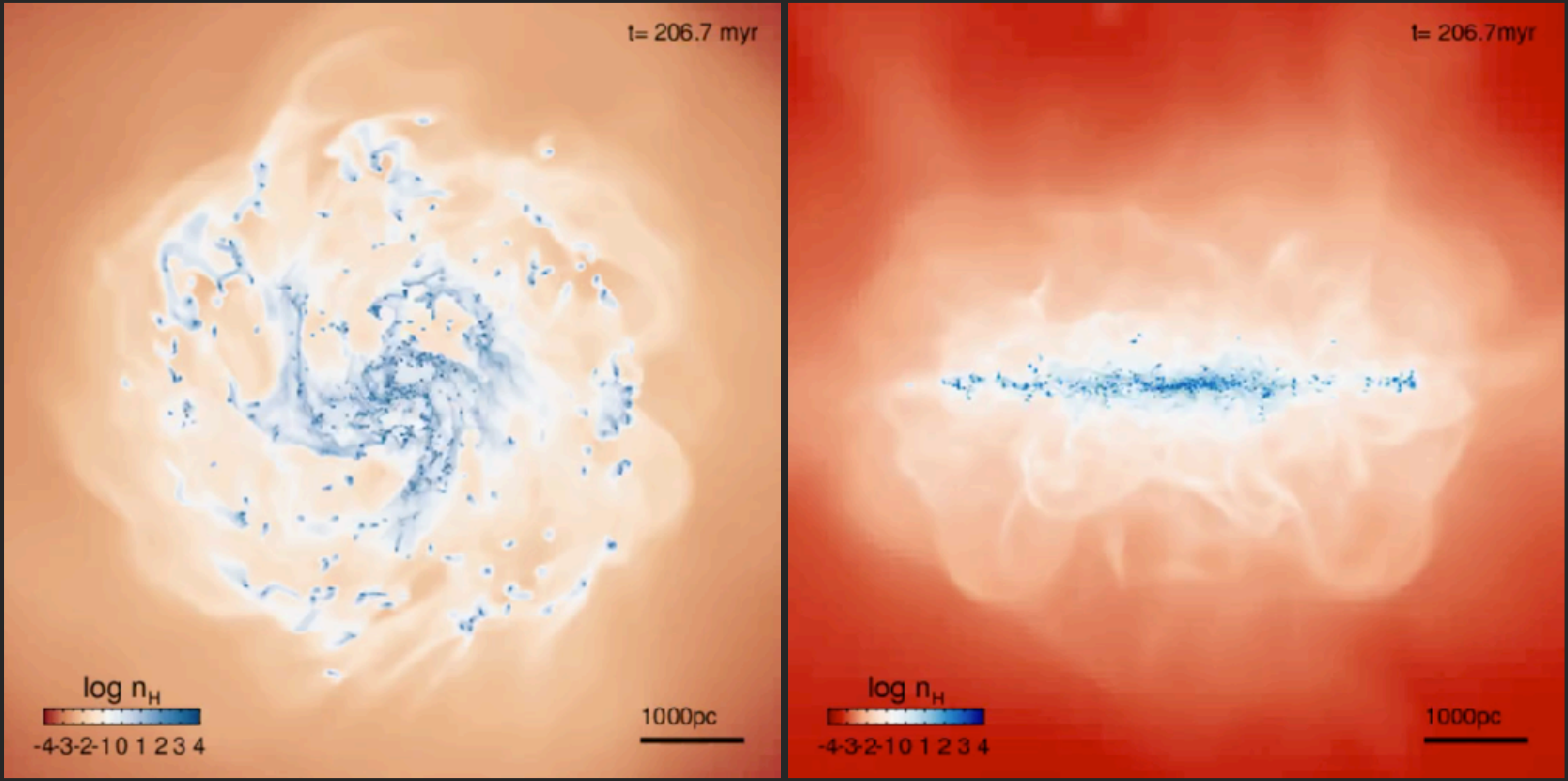
- **Thermo-turbulent star formation scheme** (Kimm+17)
- **Momentum-conserving SNe** (Kimm & Cen 14, Kimm+15)
- **Non-equilibrium photo-chemistry with H_2** (Katz,Kimm+17)
- **Photo-ionisation heating** (Rosdahl+13)
- **Direct radiation pressure** (Rosdahl+13)
- **RP by reprocessed IR photons** (Rosdahl & Teyssier 15)
- **Photoelectric heating on dust** (Kimm+17)
- **Lya pressure** (Kimm+18)



Photon group	ϵ_0 [eV]	ϵ_1 [eV]	κ [cm^2/g]	Main function
EUV_{HeII}	54.42	∞	10^3	HeII ionisation
EUV_{HeI}	24.59	54.42	10^3	HeI ionisation
$EUV_{HI,2}$	15.2	24.59	10^3	HI and H_2 ionisation
$EUV_{HI,1}$	13.6	15.2	10^3	HI ionisation
LW	11.2	13.6	10^3	H_2 dissociation
FUV	5.6	11.2	10^3	Photoelectric heating
Optical	1.0	5.6	10^3	Direct RP
IR	0.1	1.0	5	Radiation pressure (RP)

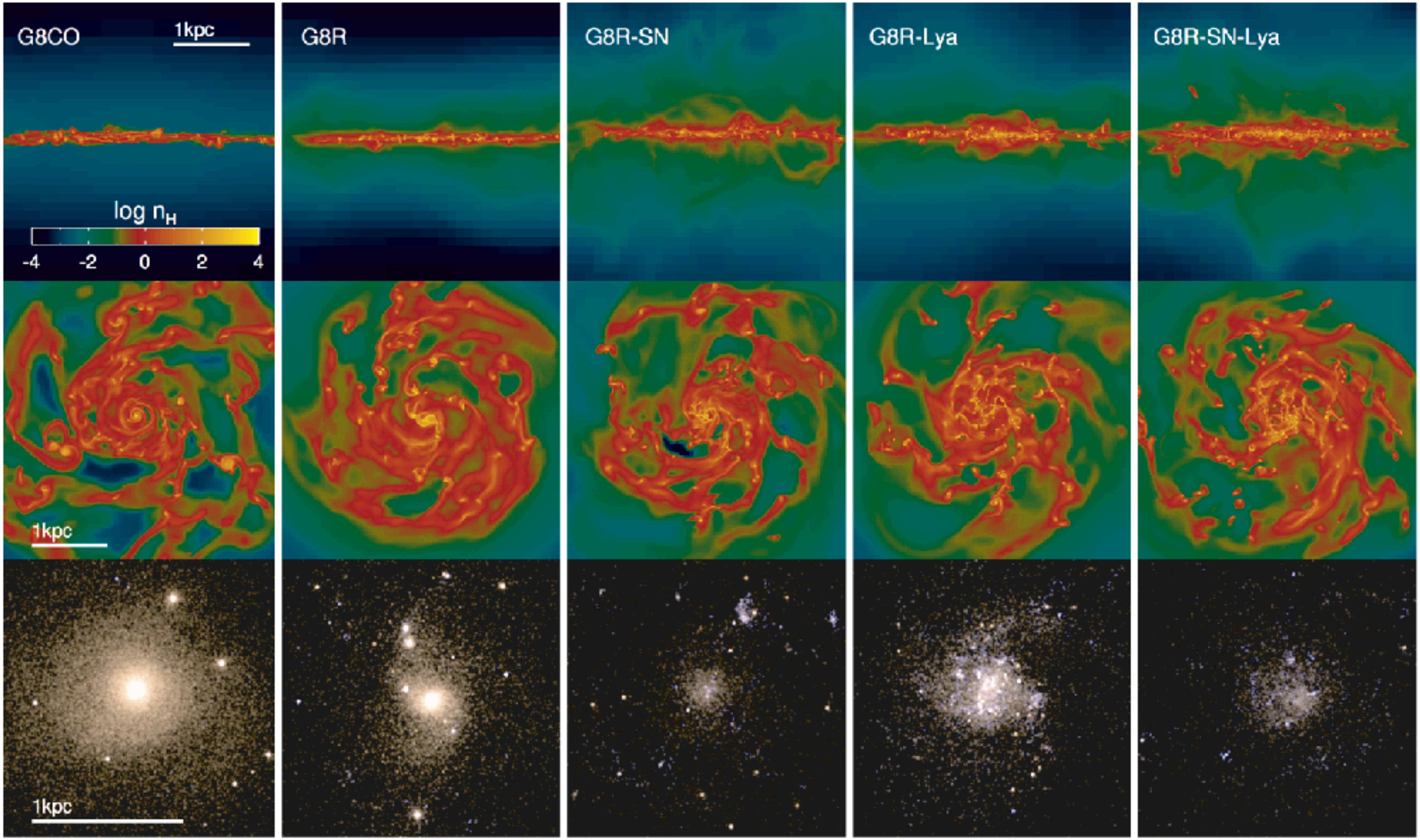
Radiation-hydrodynamic simulations of an isolated disk

PHOTOHEATING+DIRECT RADIATION PRESSURE +IR PRESSURE
+SN EXPLOSIONS + LYA PRESSURE



Lya pressure

Radiation-hydrodynamic simulations of an isolated disk



Lya pressure

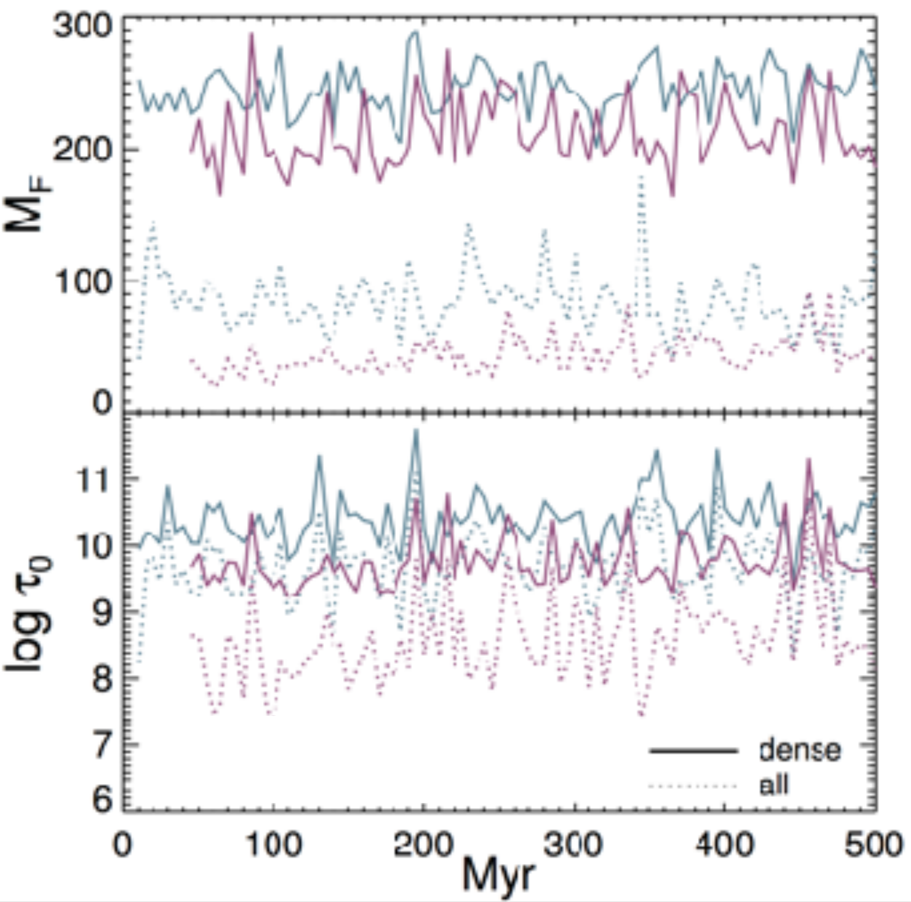
Where does Lya operate?

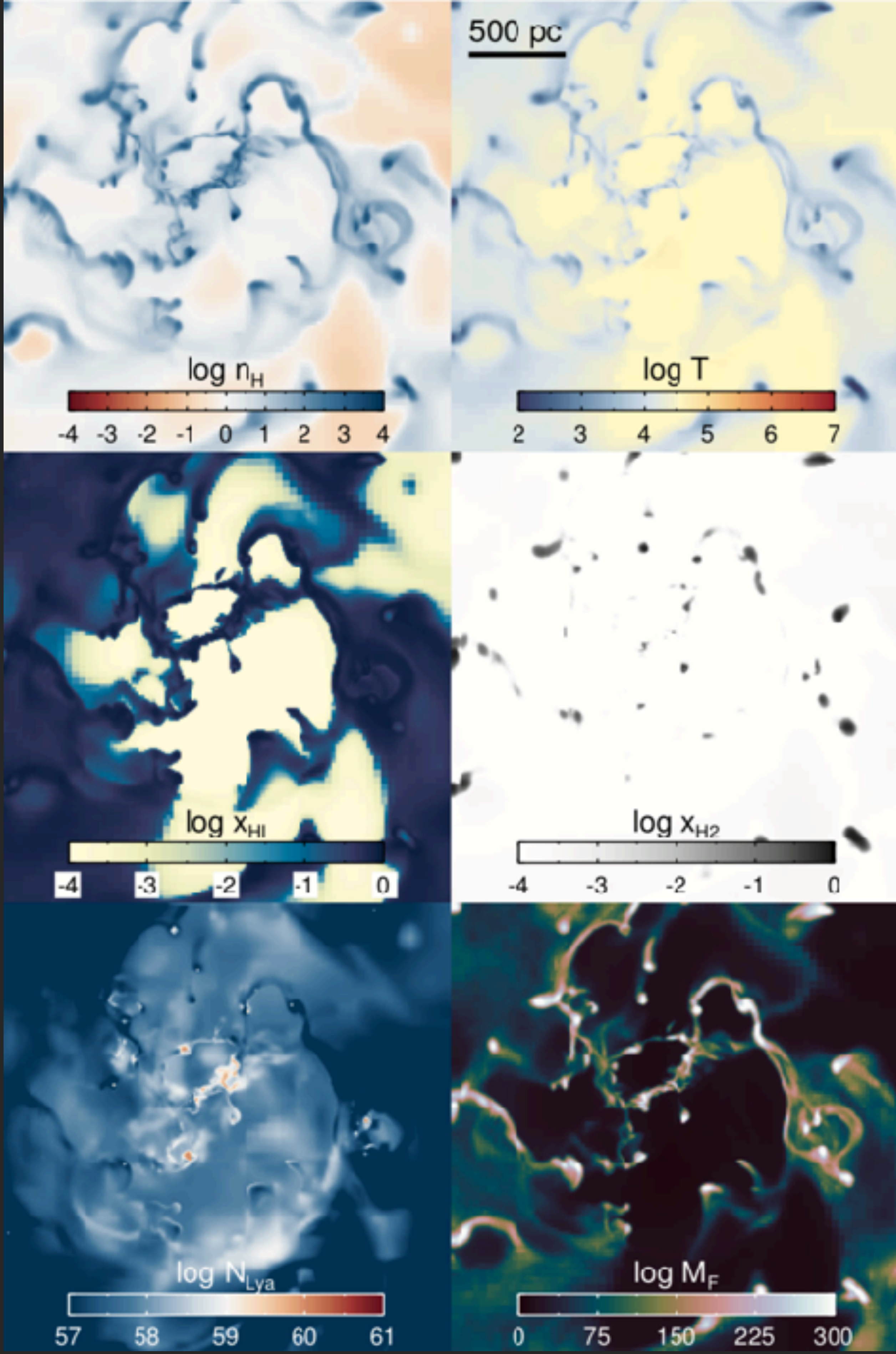
- Requirement for strong Lya pressure
  - Luminous ionizing source
  - Large N_{HI} density

→ **AROUND YOUNG STARS**

→ **INTERRUPT SF QUICKLY (<5MYR)**

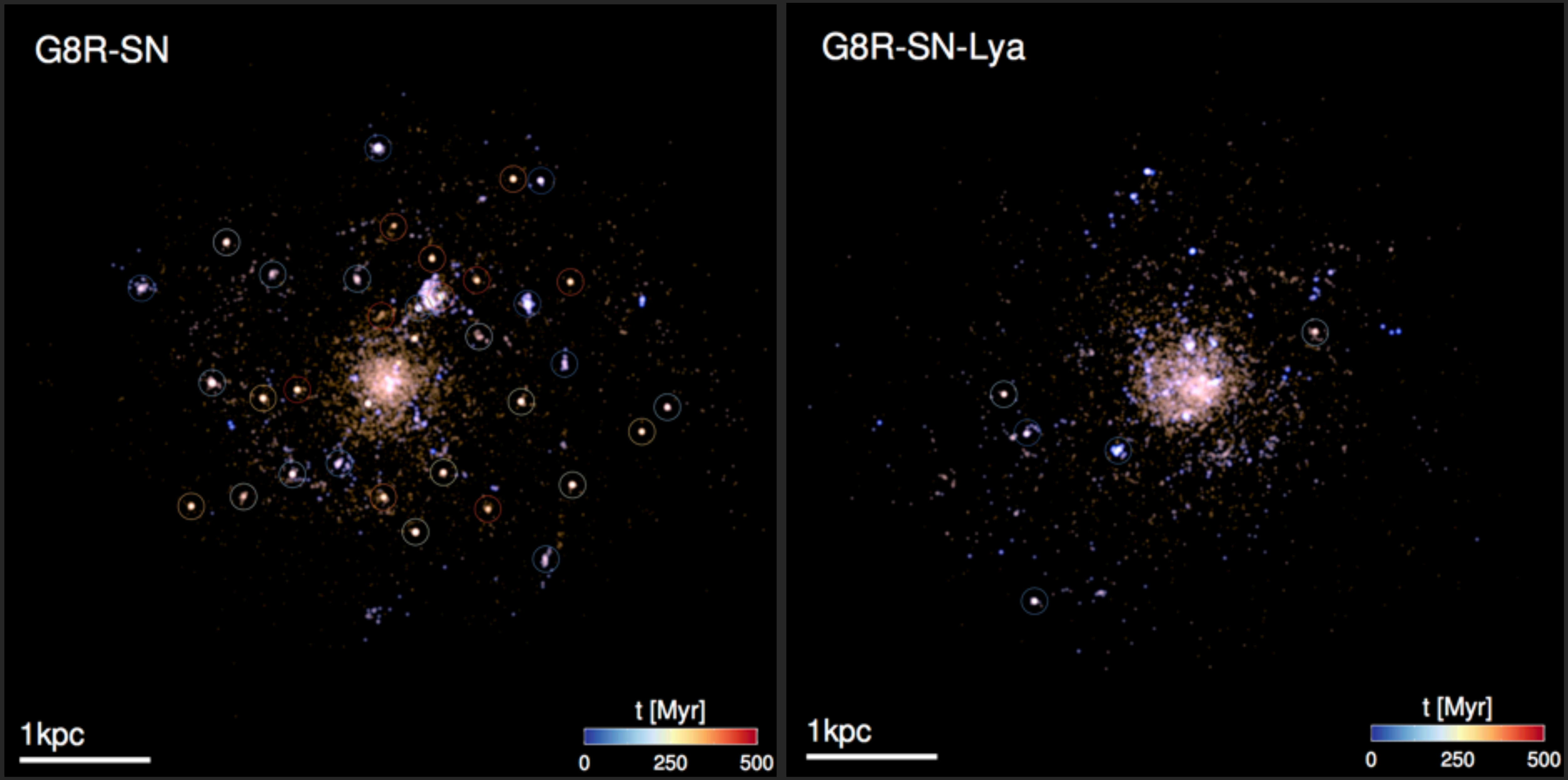
- Effective M_F ~ 200-300 in dense regions





Lya pressure

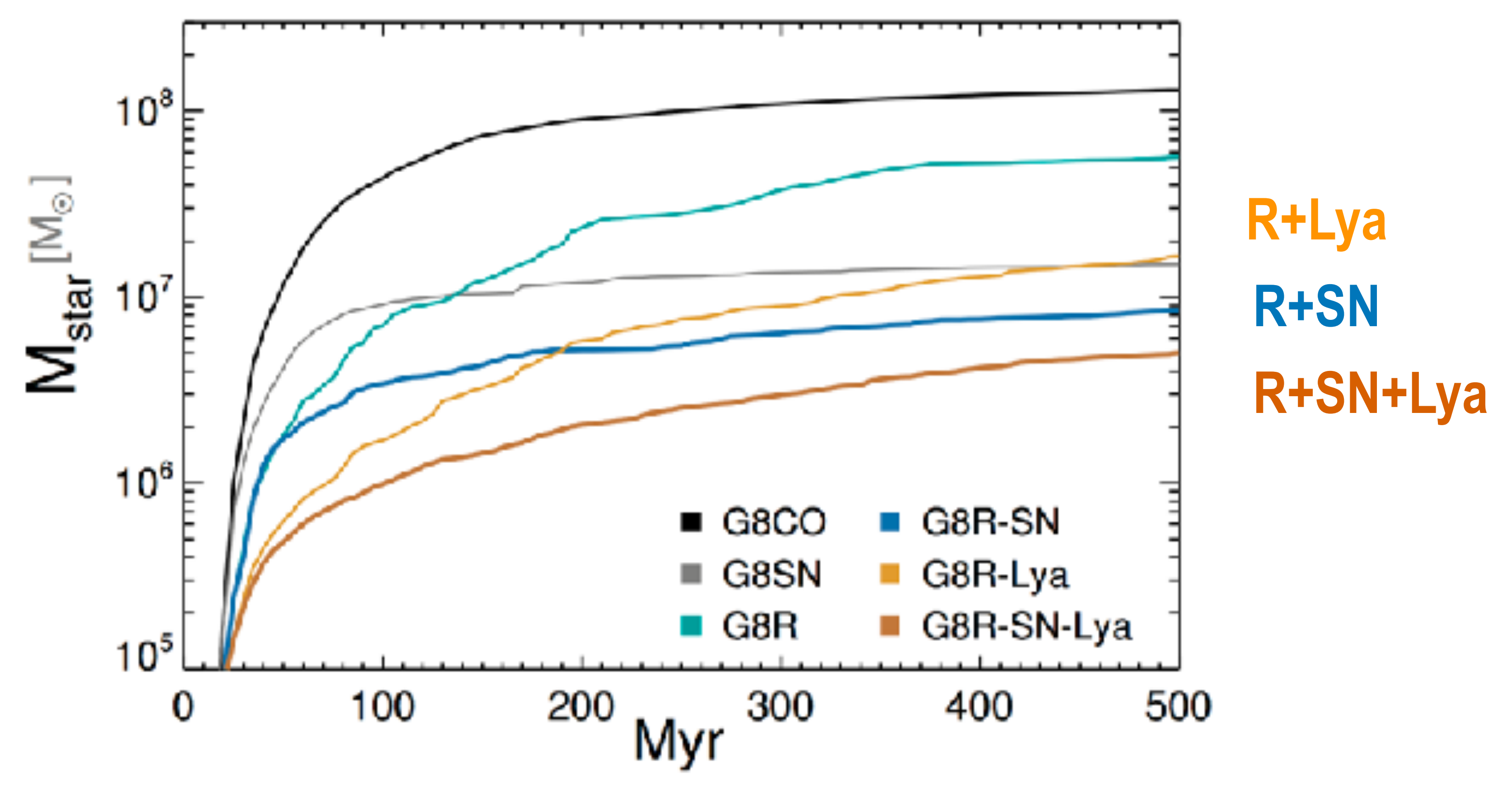
Cluster Formation with LyA Feedback



- Fewer clusters form and survive when strong radiation feedback is present
  (caution: cluster formation in HD simulations…)

[see also Abe & Yajima 18]

Star formation histories of a gas-rich, metal-poor dwarf



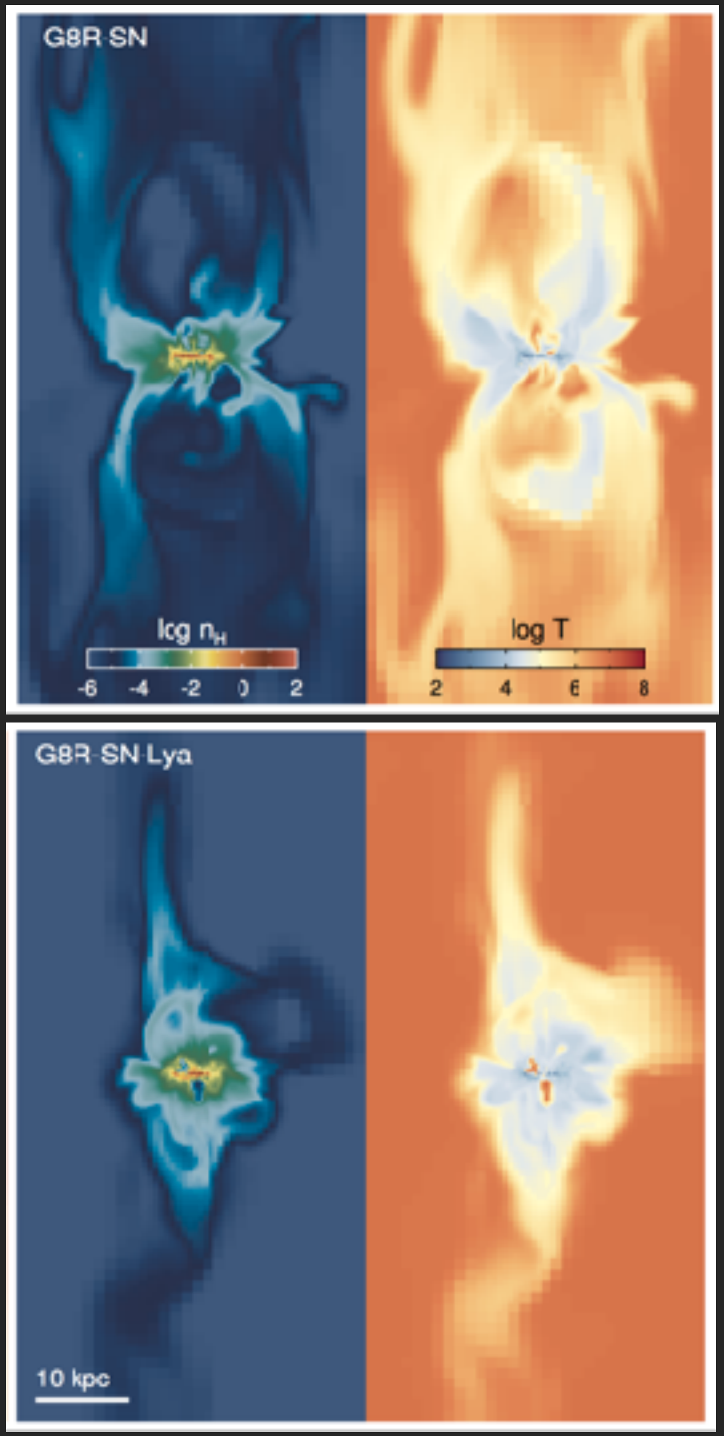
- Suppression of Star formation

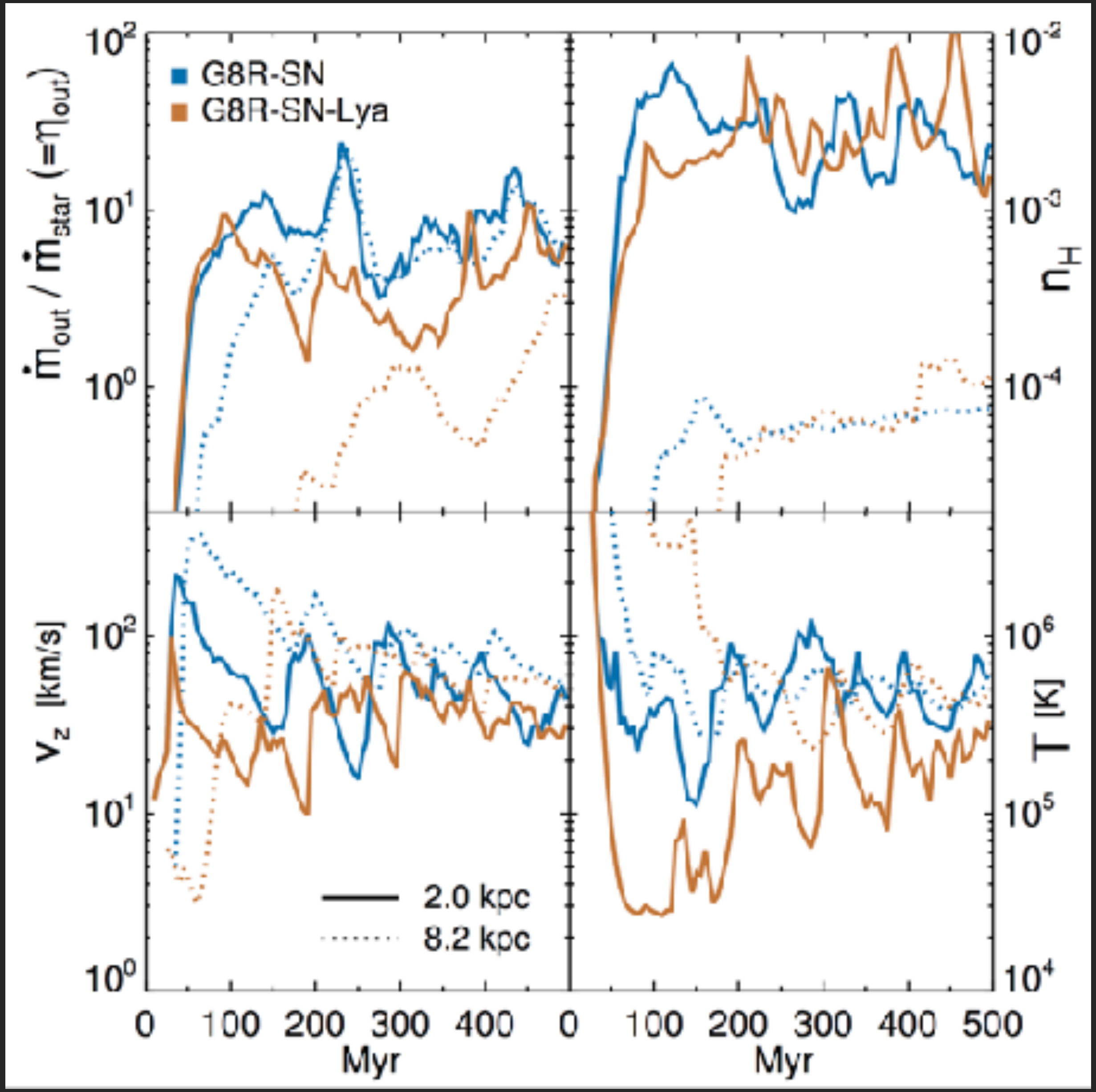
LYA < SN < SN+LYA

Weaker outflows with Lya pressure

w/o Lya

w/ Lya



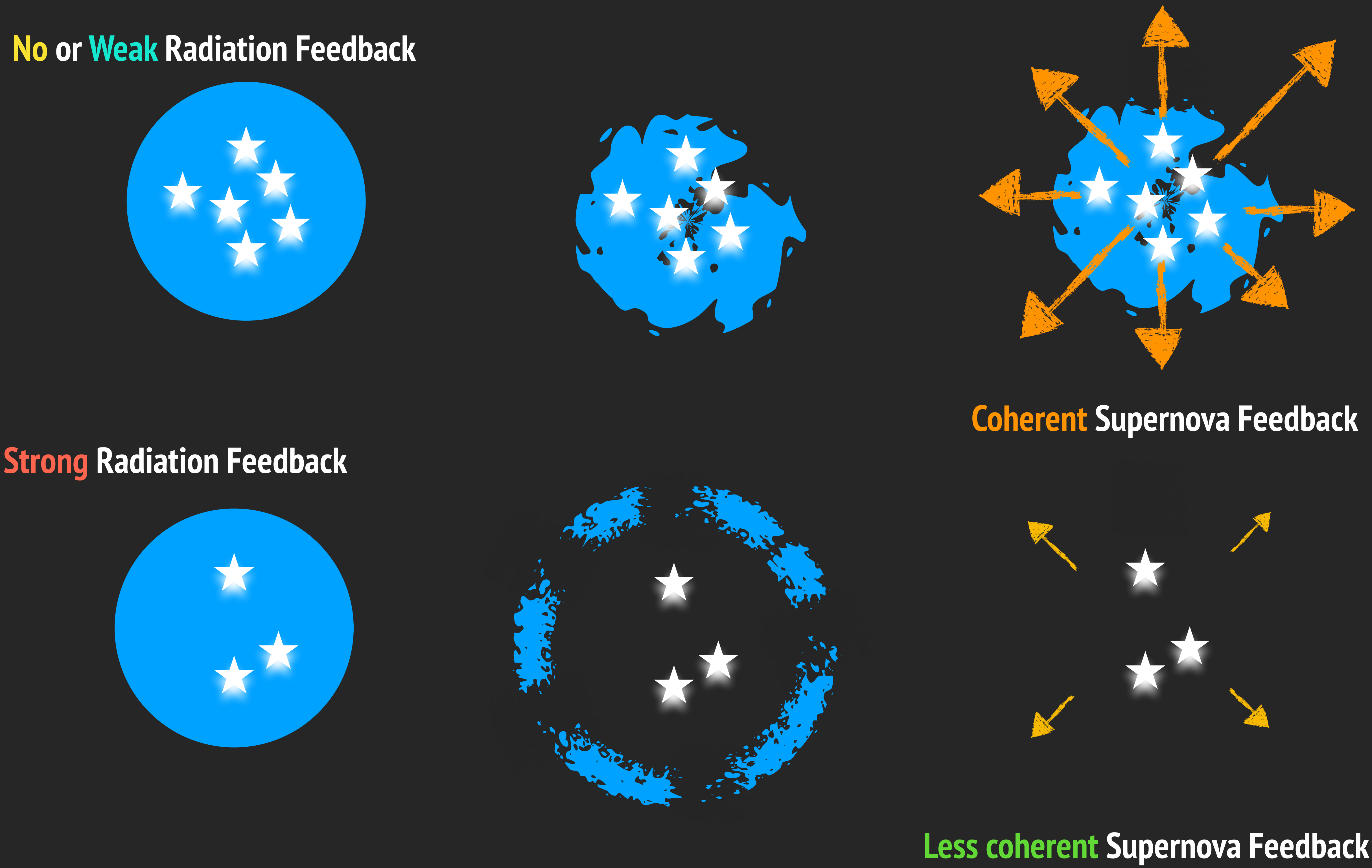


With Lya pressure

- Mass-loading factor is decreased
- Outflows become cooler and slower

Lya pressure

A picture with strong radiation feedback



No or Weak Radiation Feedback

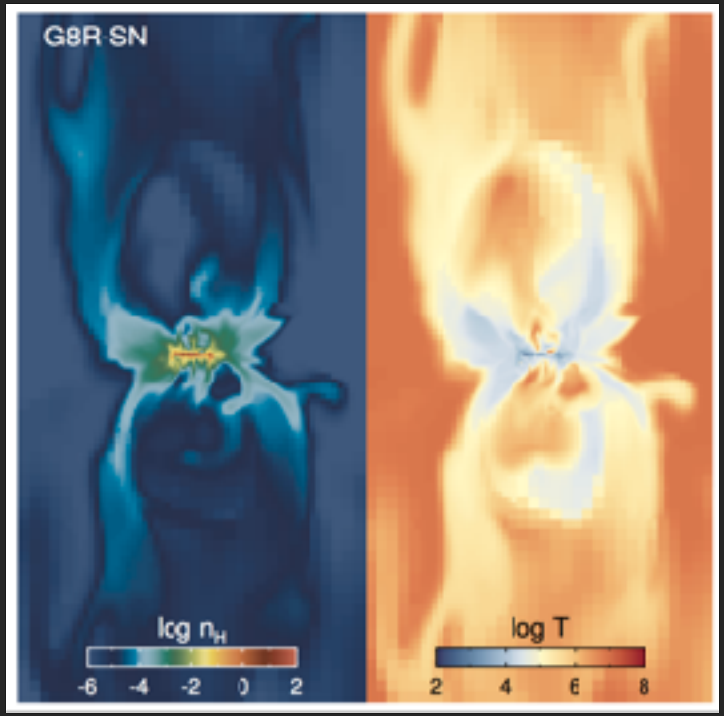
Coherent Supernova Feedback

Strong Radiation Feedback

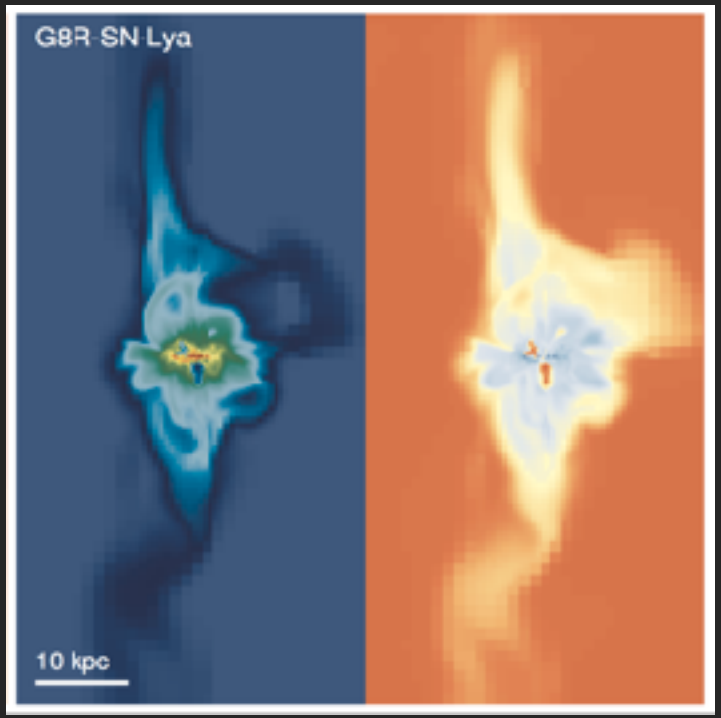
Less coherent Supernova Feedback

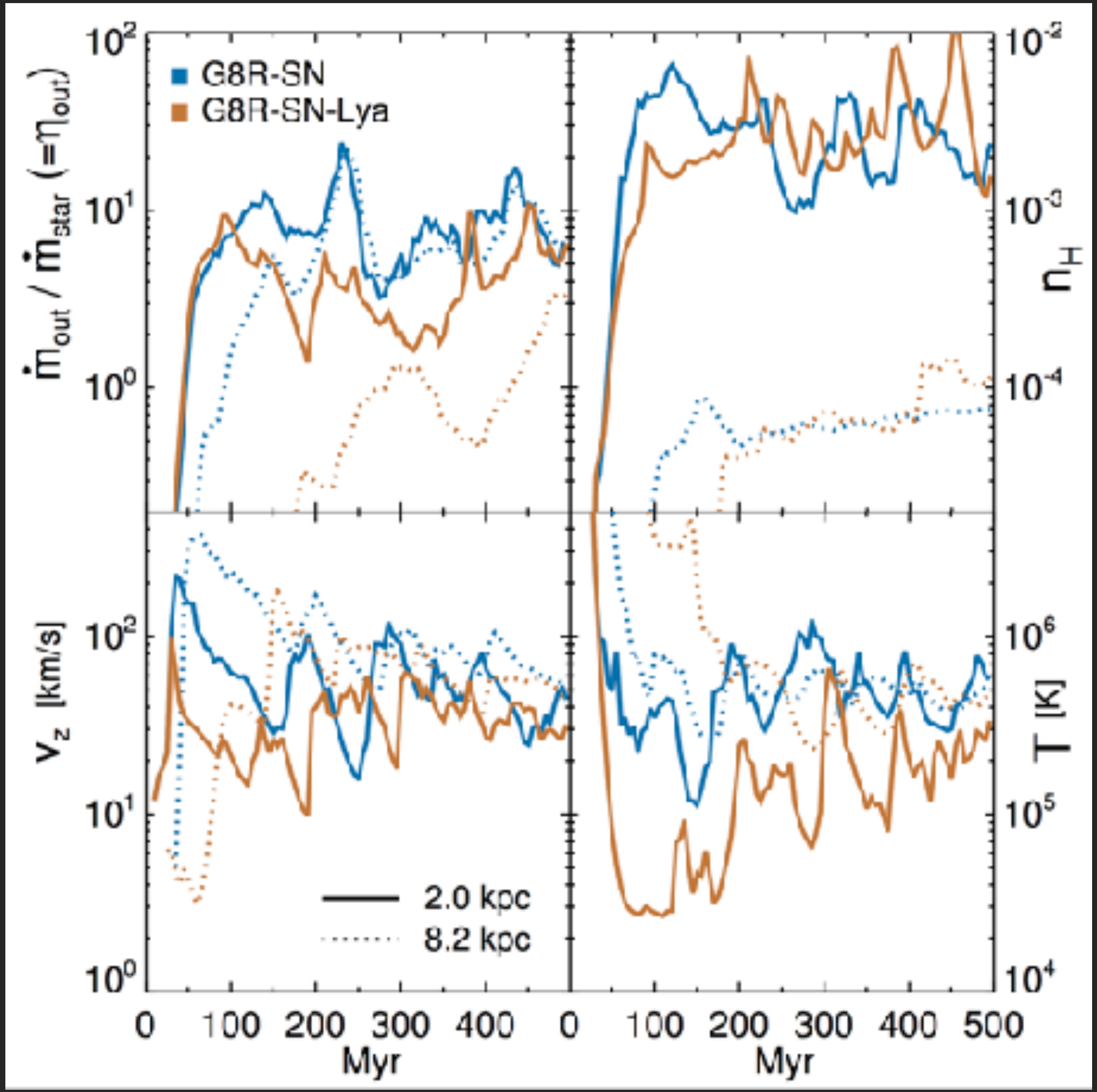
Weaker outflows with Lya pressure

w/o Lya



w/ Lya





WITH LYA PRESSURE

- Mass-loading factor is decreased
- Outflows become cooler and slower

Summary

- LyA photons resonantly scatter with HI, and impart 100-300 times more momentum than the single-scattering case (L_{Lya}/c) in the metal-poor regime

- Isolated gas-rich, metal-poor dwarf galaxy test:
  - Total stellar mass : suppressed by a factor of ~2
  - weaker outflows (mass loading~a few at 0.2 Rvir)
  - Star clusters are more difficult to form and survive -> important for GC formation

  - Strong RP does not necessarily lead to stronger outflows (due to self-regulated SF)

- (Partial) Solution to the over-cooling problem in galaxy formation simulations