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

Impact of Lyman Alpha Pressure on Metal-Poor Dwarf Galaxies

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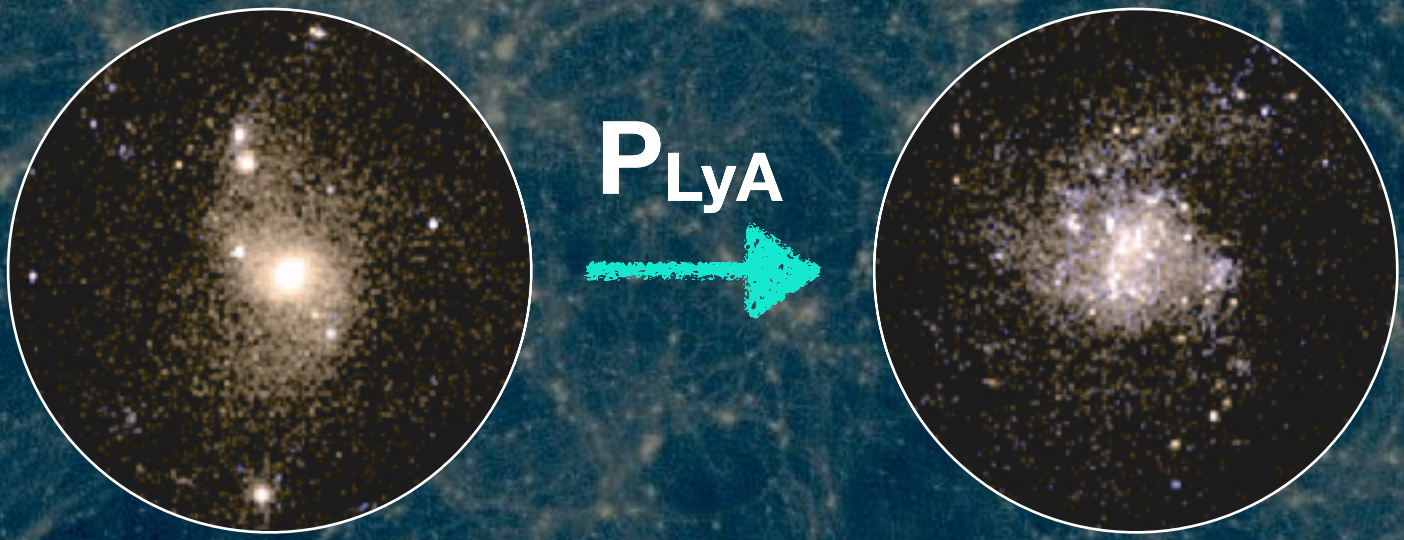
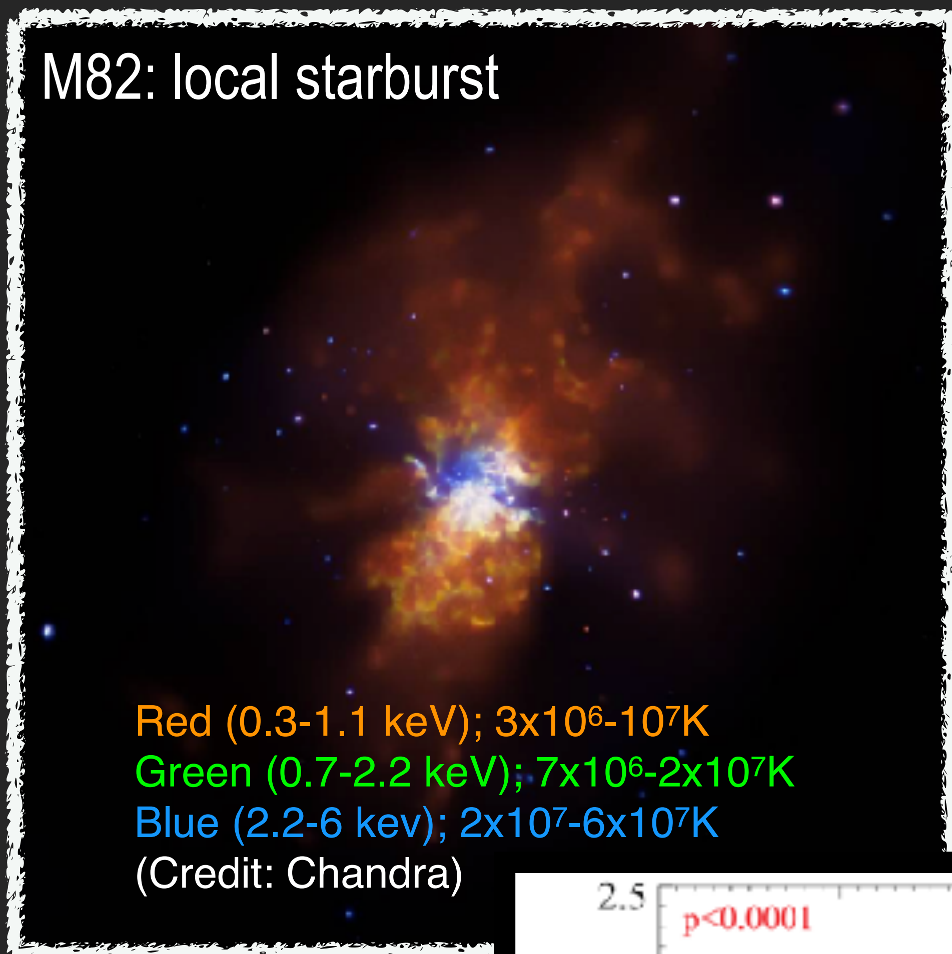


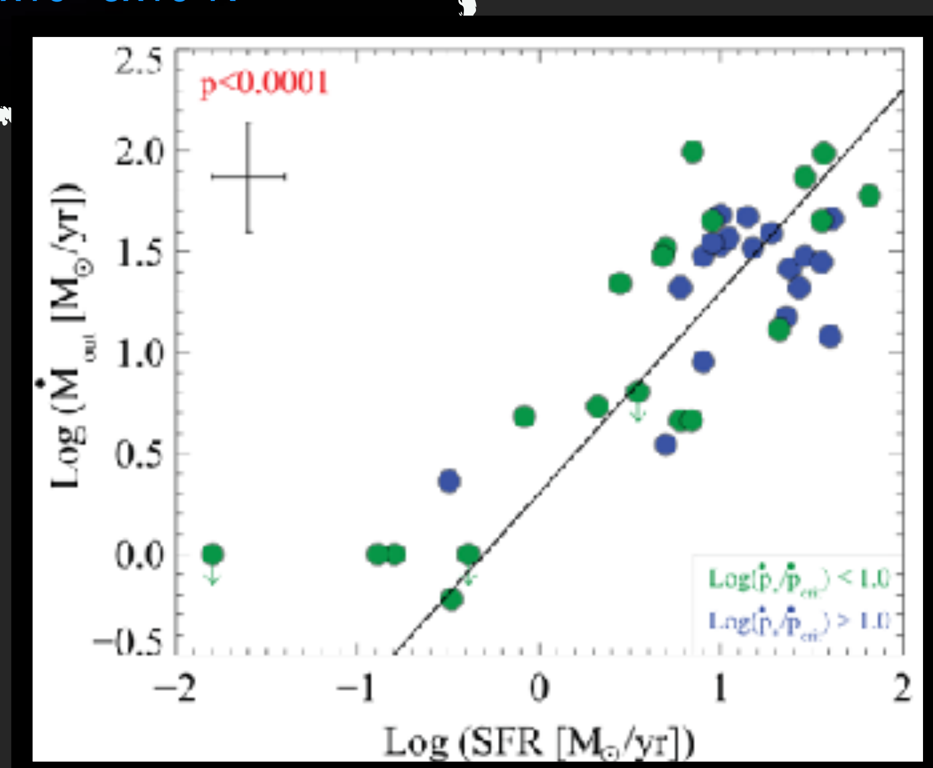






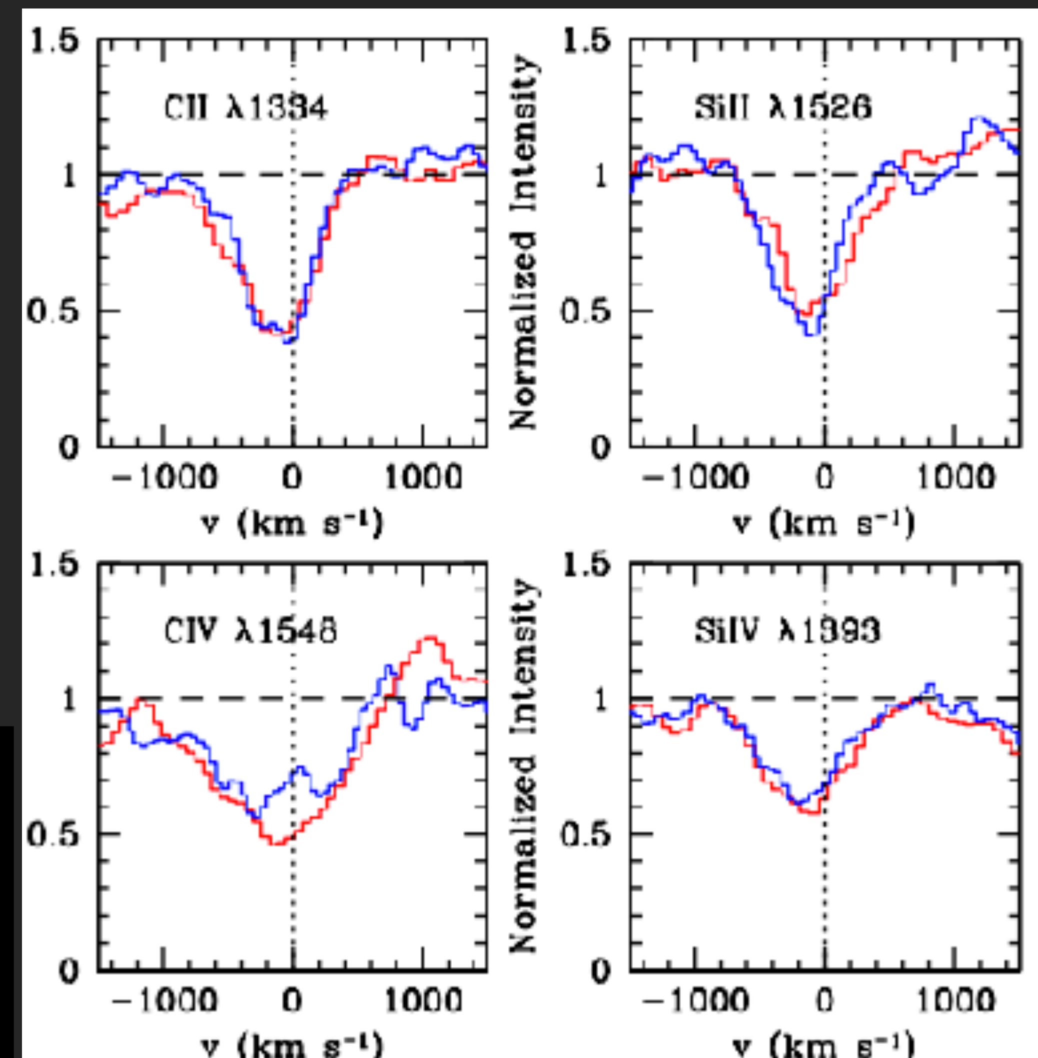
Common feature of SFRs – Outflows

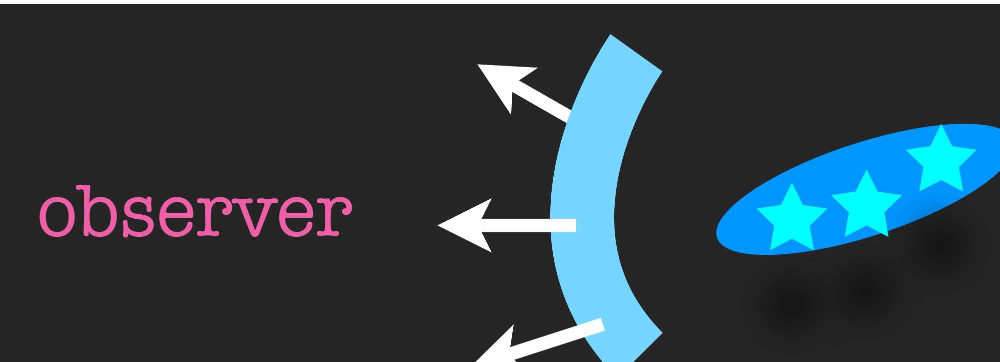




Heckman+(15; z~0 local starburst)

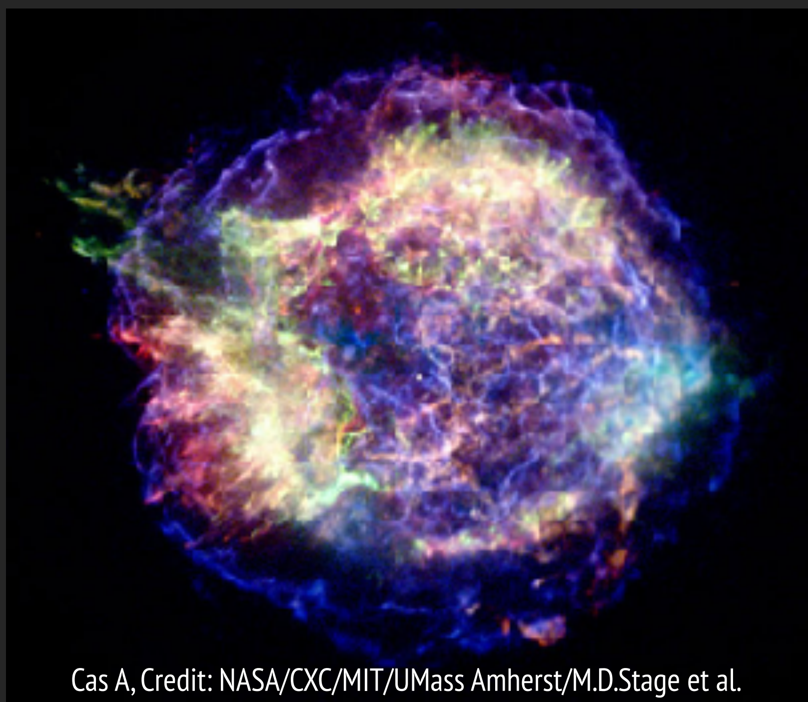
Ubiquitous **Outflows** in LBGs at z~2 (Steidel+10)





Feedback processes

Supernova explosions

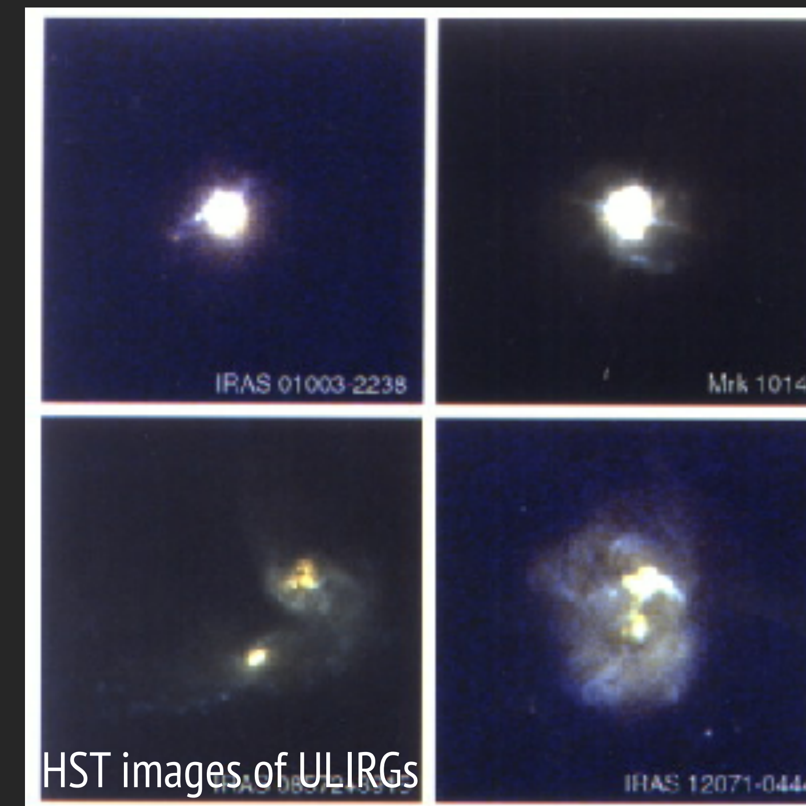


Cas A, Credit: NASA/CXC/MIT/UMass Amherst/M.D.Stage et al.

Photoionization Heating / Direct Radiation Pressure

Image Credit: Lori Allen, Xavier Koenig (Harvard-Smithsonian CfA) et al., JPL-Caltech, NASA

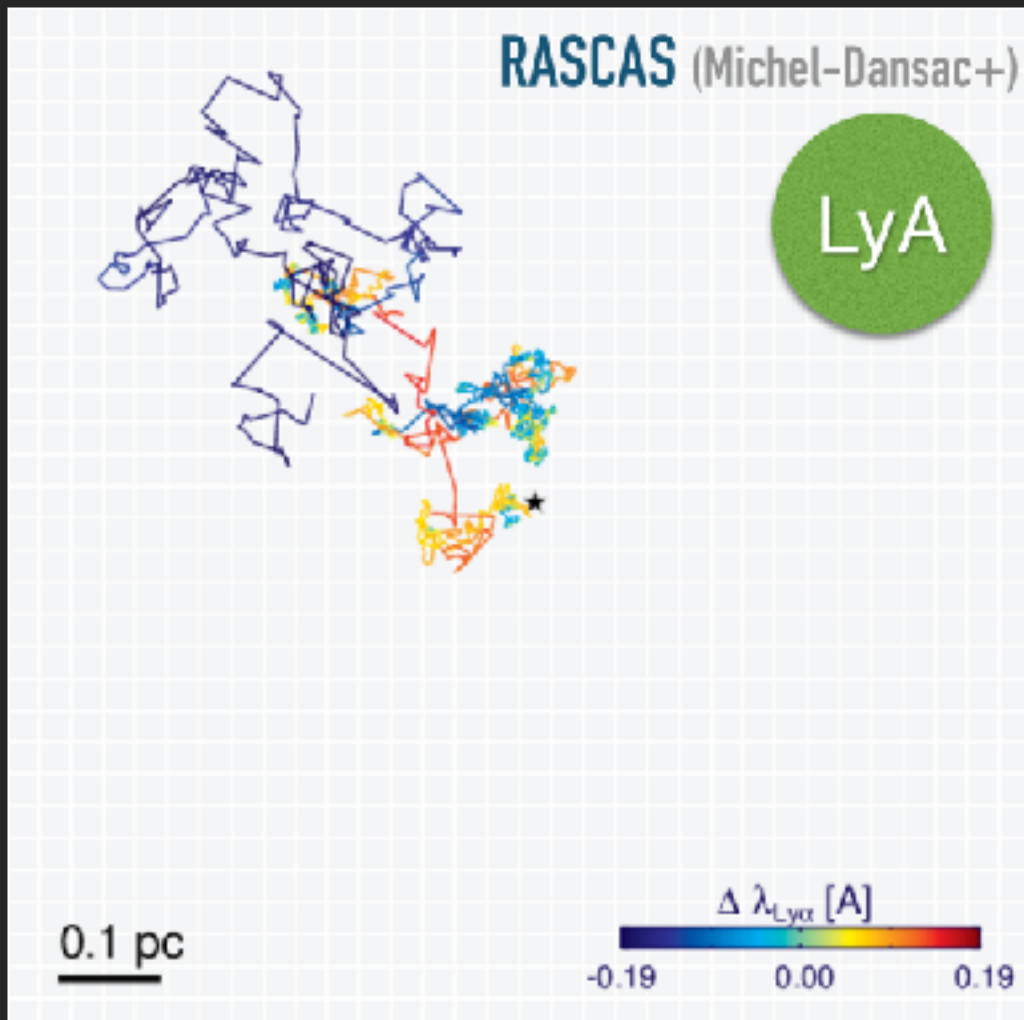
Pressure due to reprocessed IR photons



HST images of ULIRGs

a large amount of dust is required

Scattering of LyA photons transfers momentum to the surroundings



Momentum transfer

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

Multiplication factor

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

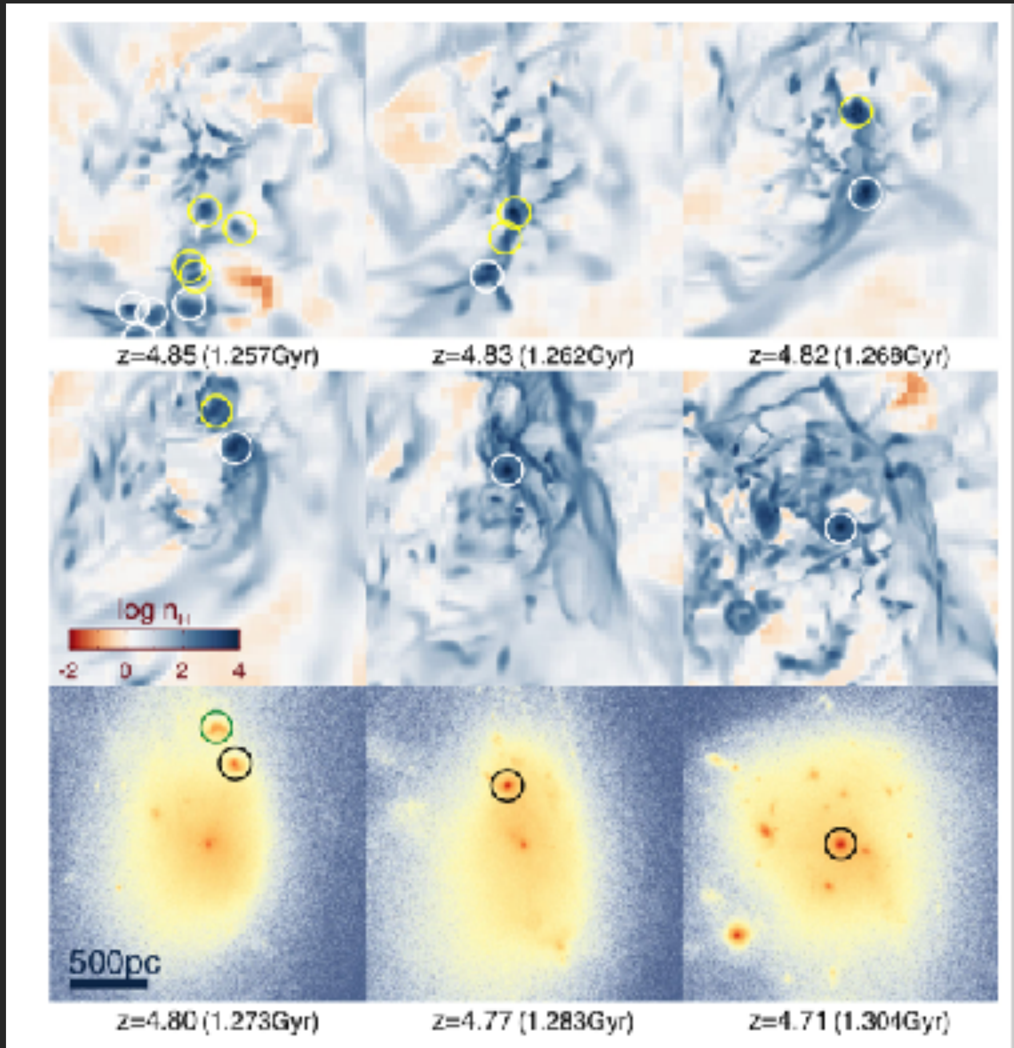
See also Dijkstra & Loeb (08), Smith et al. (16)

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?

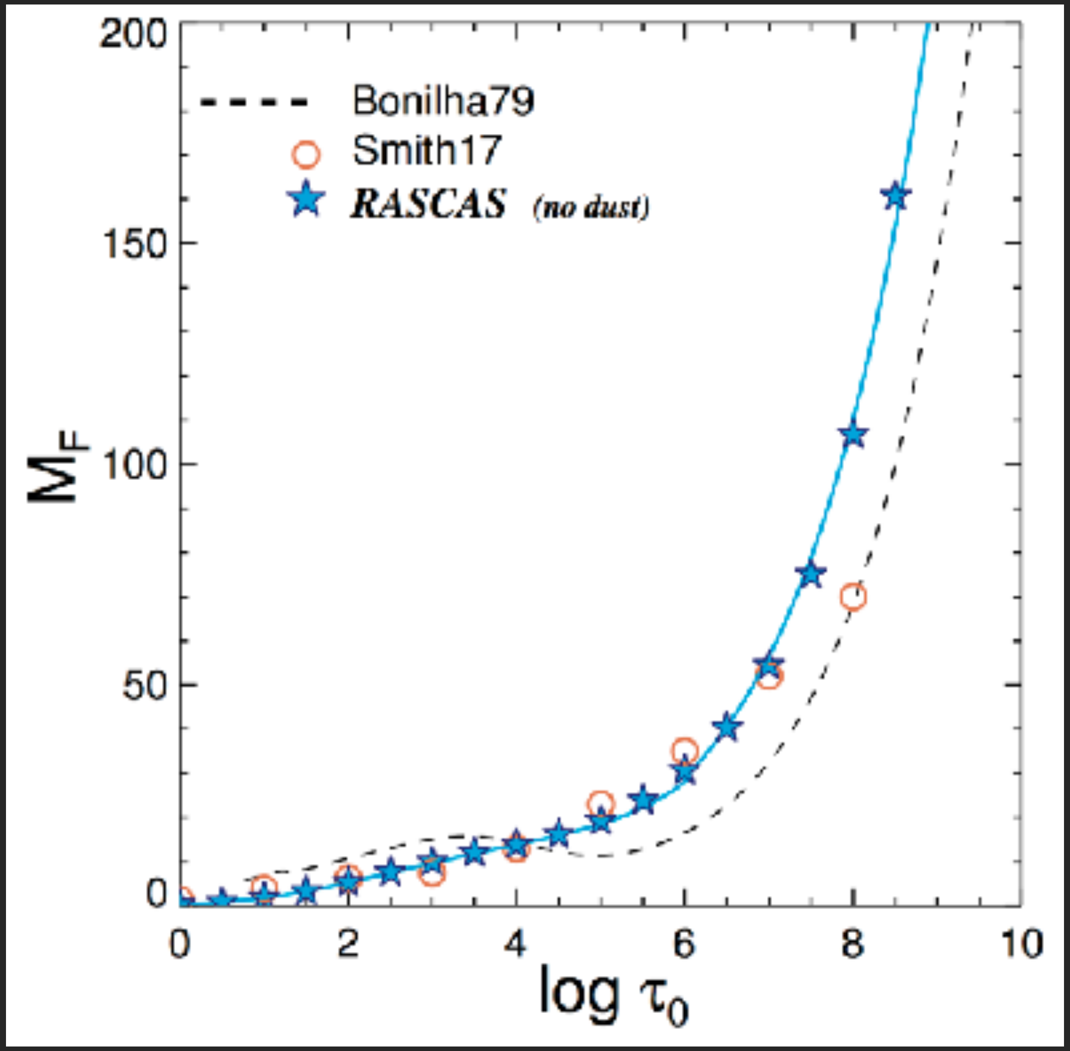


Kimm, Cen, Devriendt+(15)

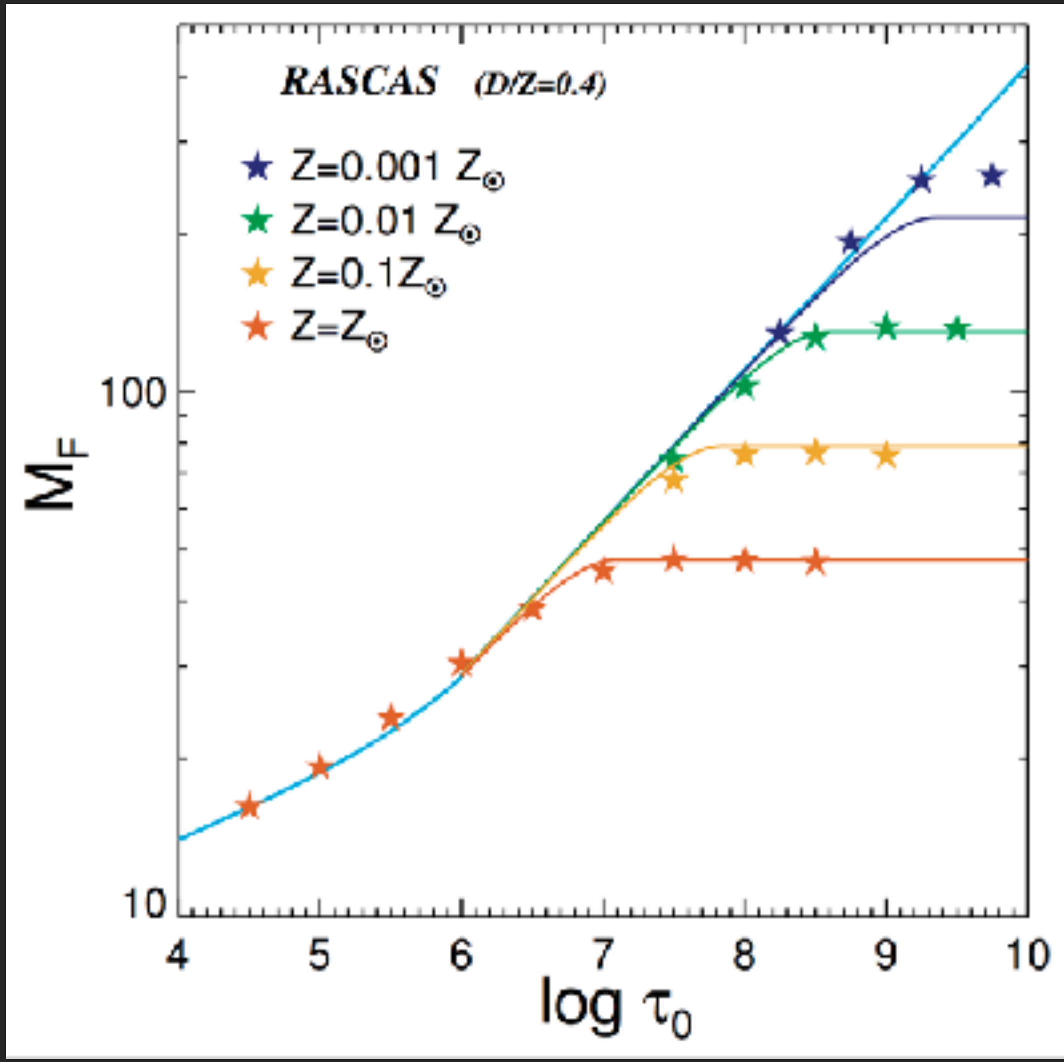
Scattering of LyA photons transfers momentum to the surroundings

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)

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

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

Momentum budget from Lya pressure

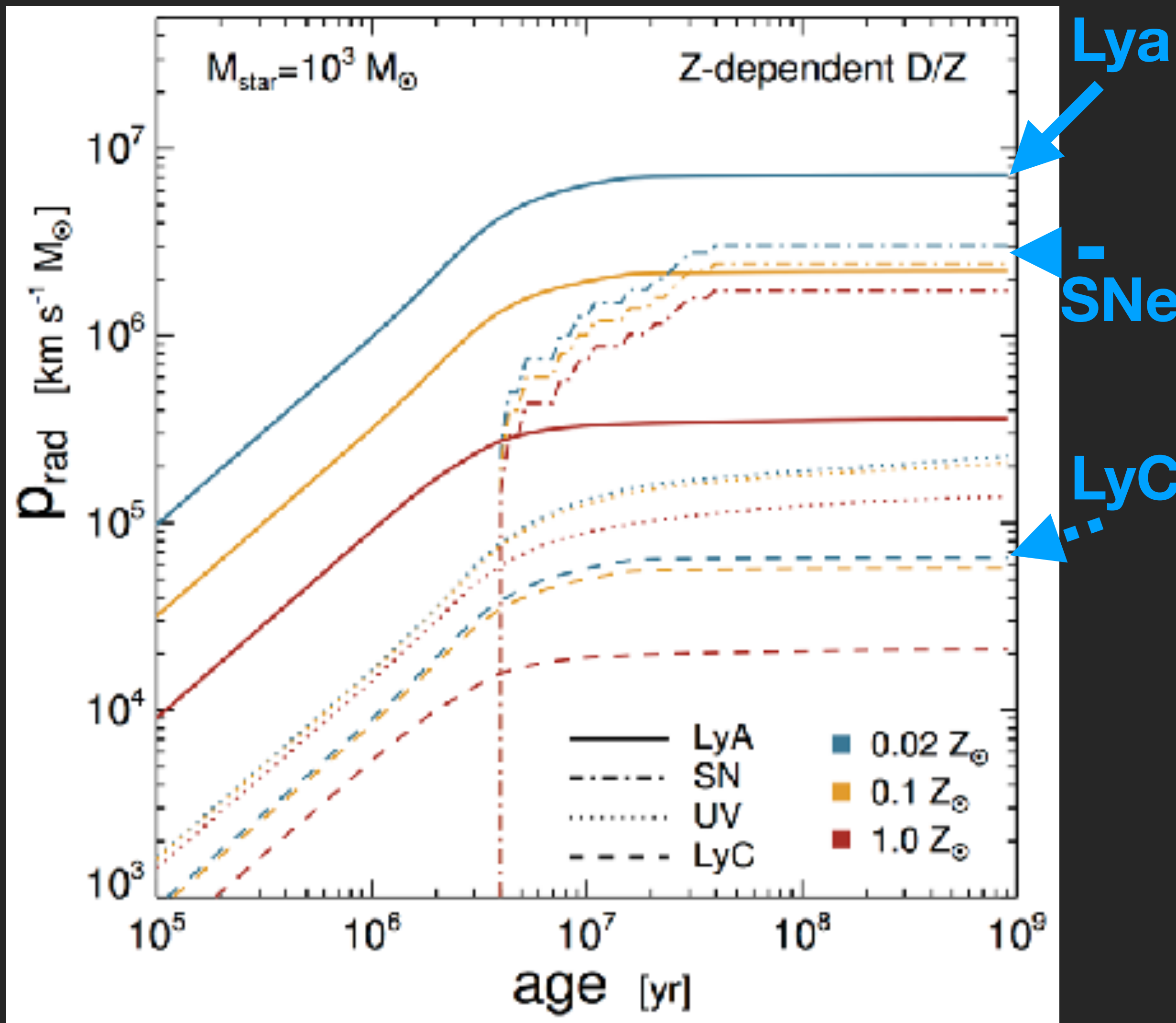


Photo-ionization heating

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

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

Lyman alpha pressure

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

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

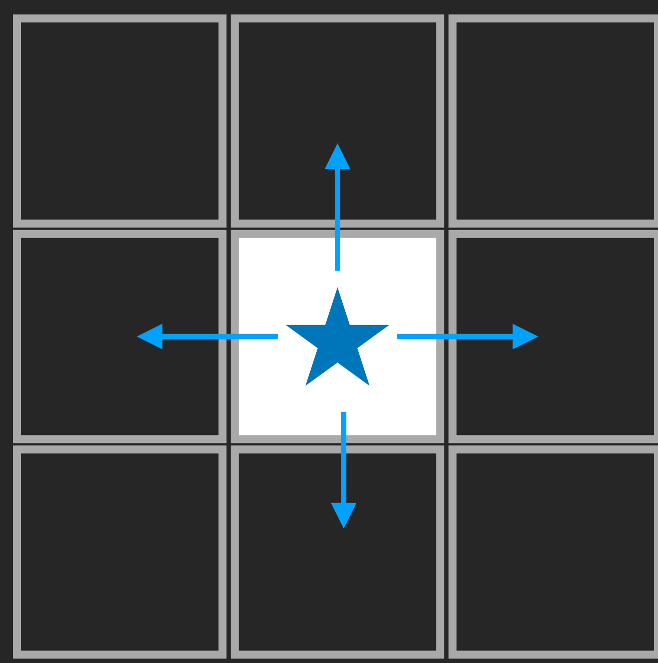
- The momentum from Lya is comparable or more significant than that of SNe
- Lya pressure is advantageous from a computational viewpoint as well

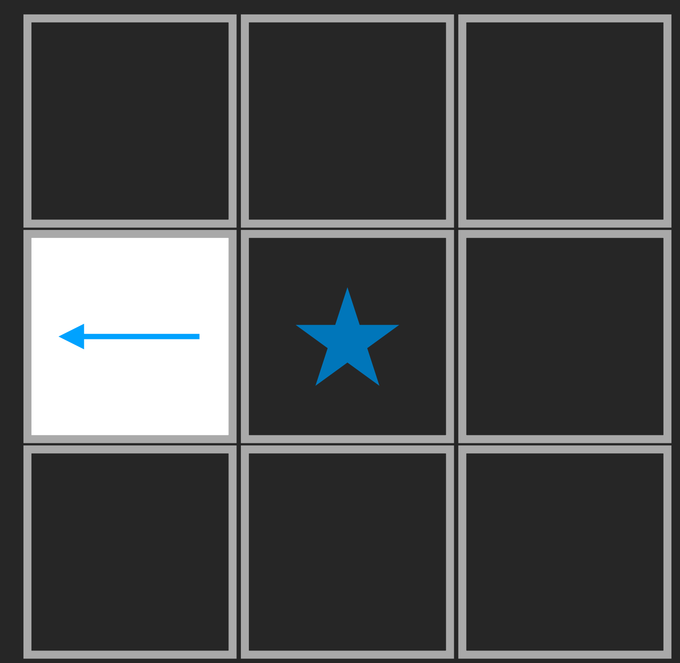
Implementation

$N_{LyC,abs} \rightarrow N_{Lya}$

N_{HI} (Sobolev approx.) $\rightarrow M_F$

$v \rightarrow v + dv$



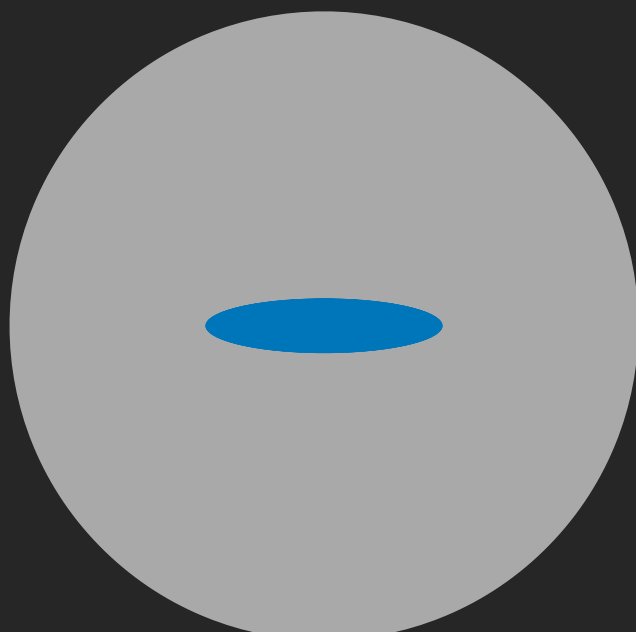


N.B: our method is likely to under-estimate the impact due to Lya photons that escape from their birth cells when M_F is smaller than $M_{F,max}$

Radiation-hydrodynamic simulations of an isolated disk

Simulation set-up

$M_{DMH} \sim 10^{10} M_{sun}$



$Z = 0.02 Z_{sun}$

$M_{star} = 2 \times 10^8 M_{sun}$

$M_{gas} = 1.7 \times 10^8 M_{sun}$

Max Resolution: 2 - 5 pc

Input physics

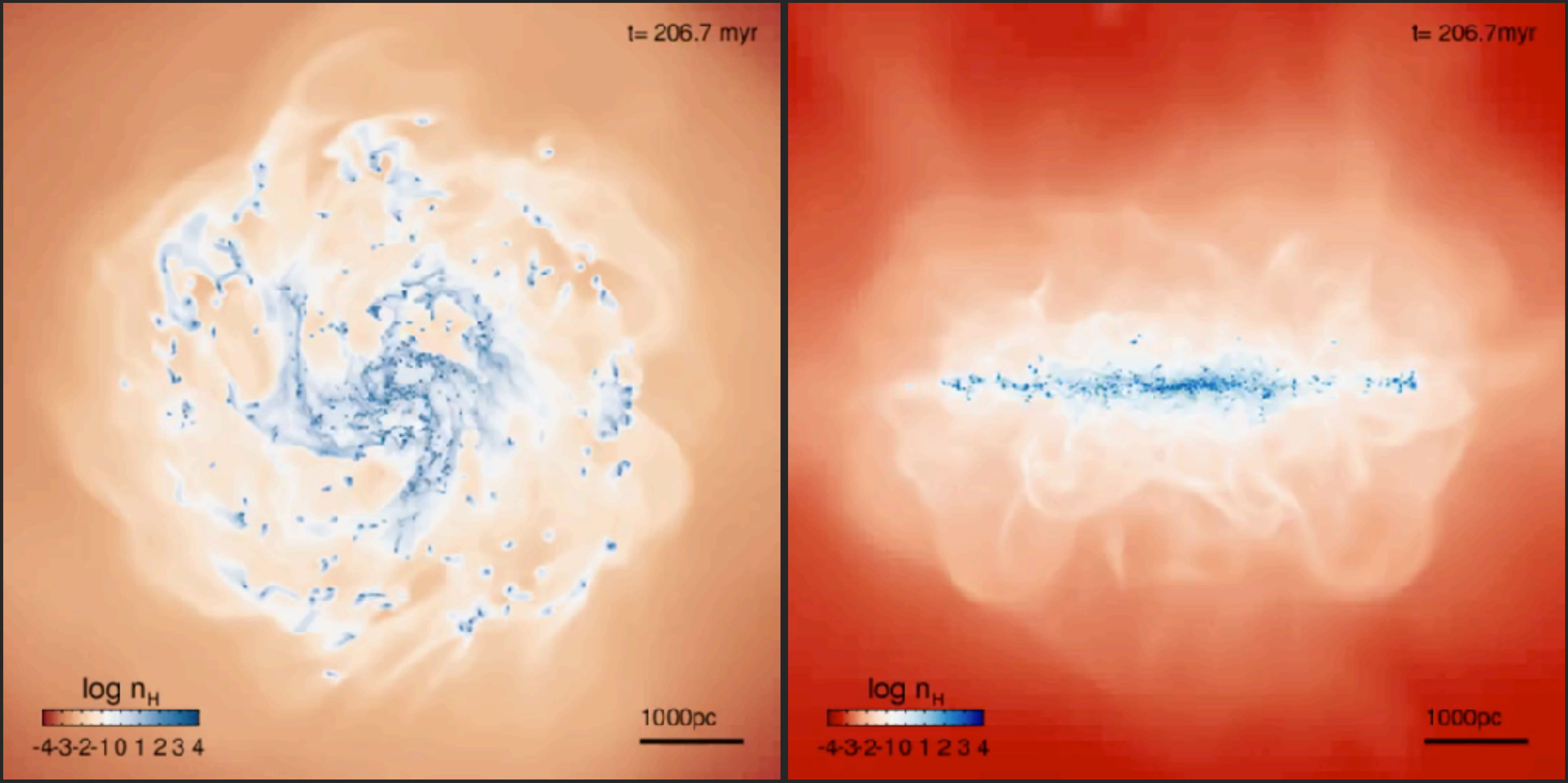
RAMSES-RT (Teyssier 02; Rosdahl+13)

- **Thermo-turbulent star formation scheme** (Devriendt+, Kimm+17)
- **Momentum-conserving SNe** (Kimm & Cen 14, Kimm+15)
- **Non-equilibrium photo-chemistry with H_2** (Katz+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



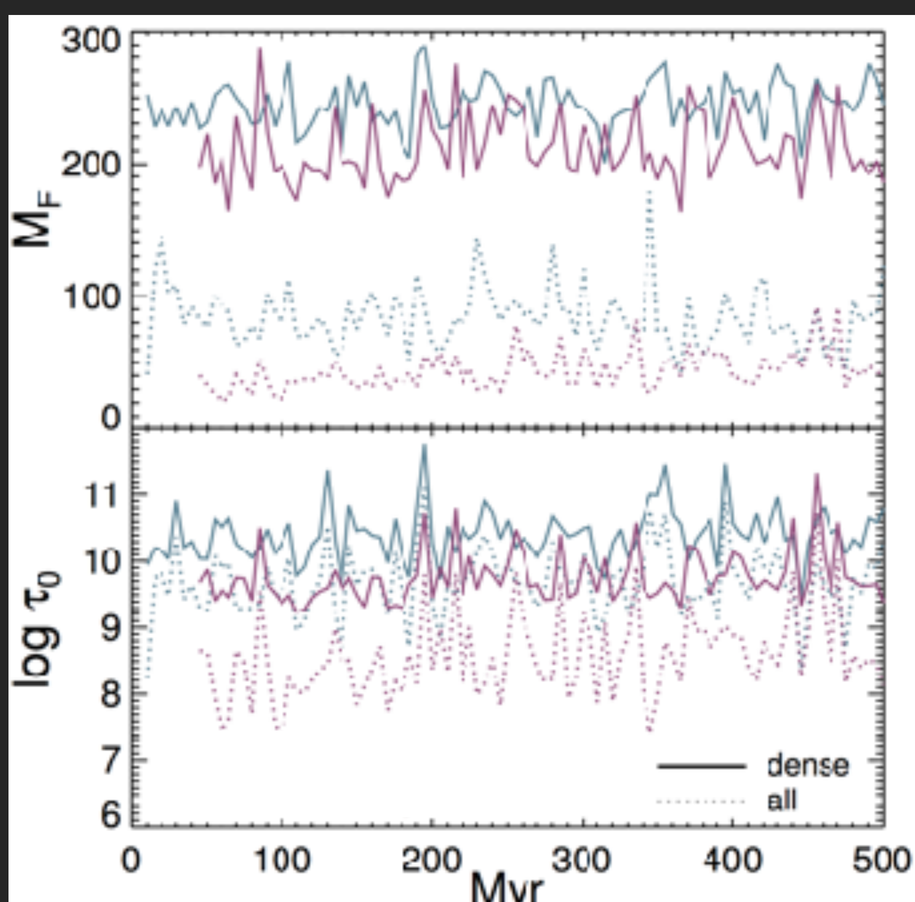
Where does Lya operate?

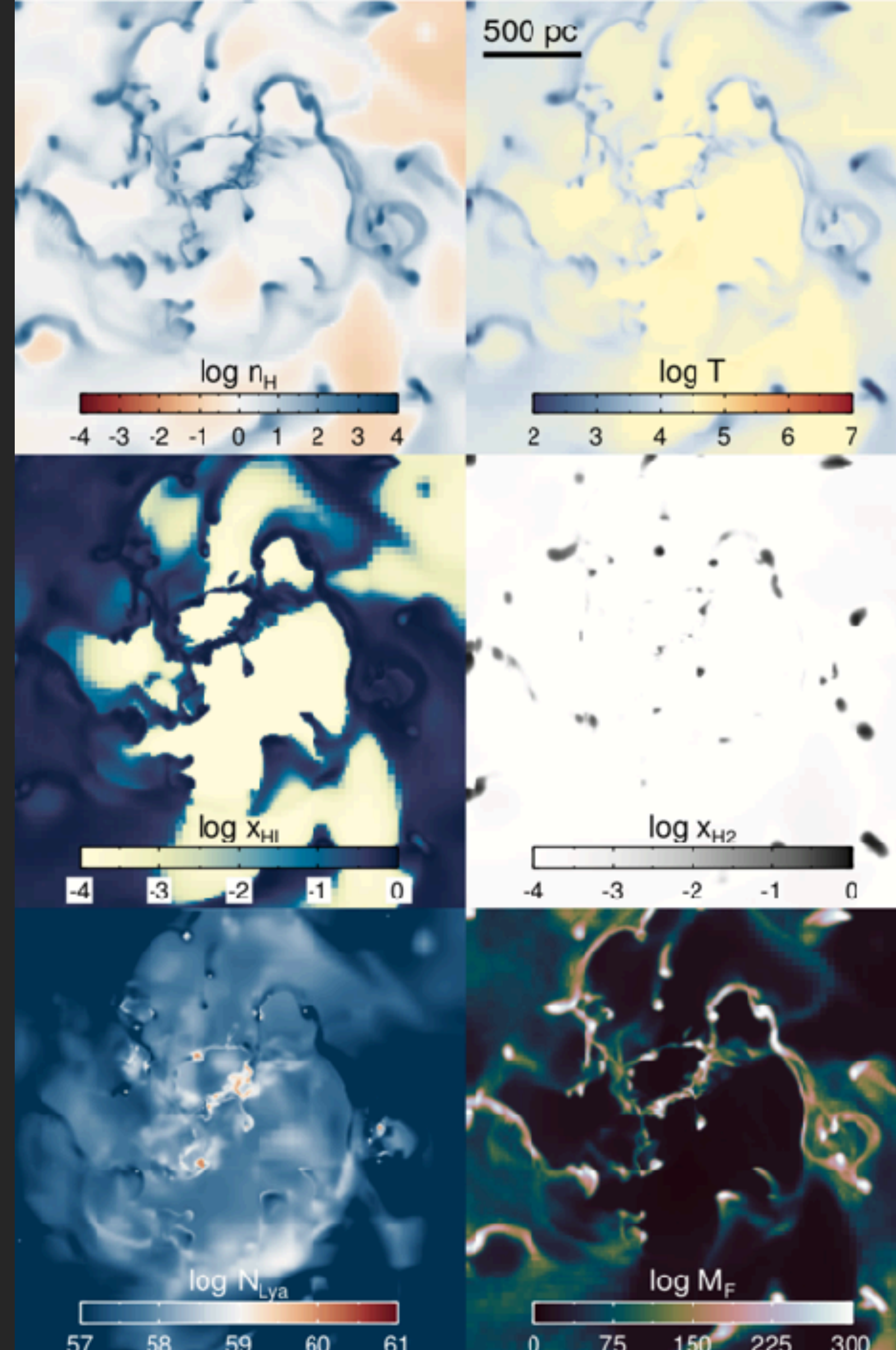
- Requirement for strong Lya pressure
  - Luminous ionizing source
  - Large N_{HI} density

→ **AROUND YOUNG STARS**

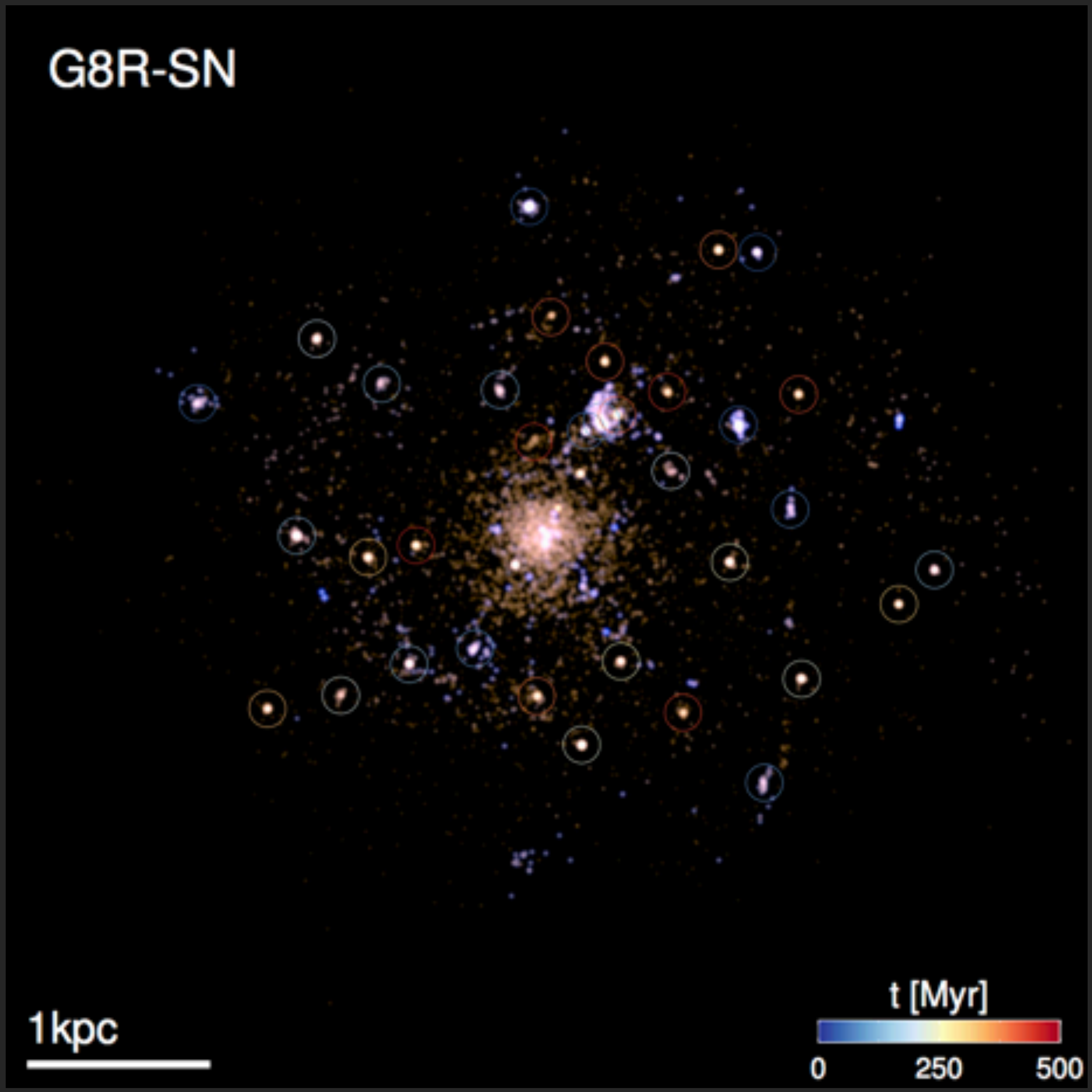
→ **INTERRUPT SF QUICKLY (<5Myr)**

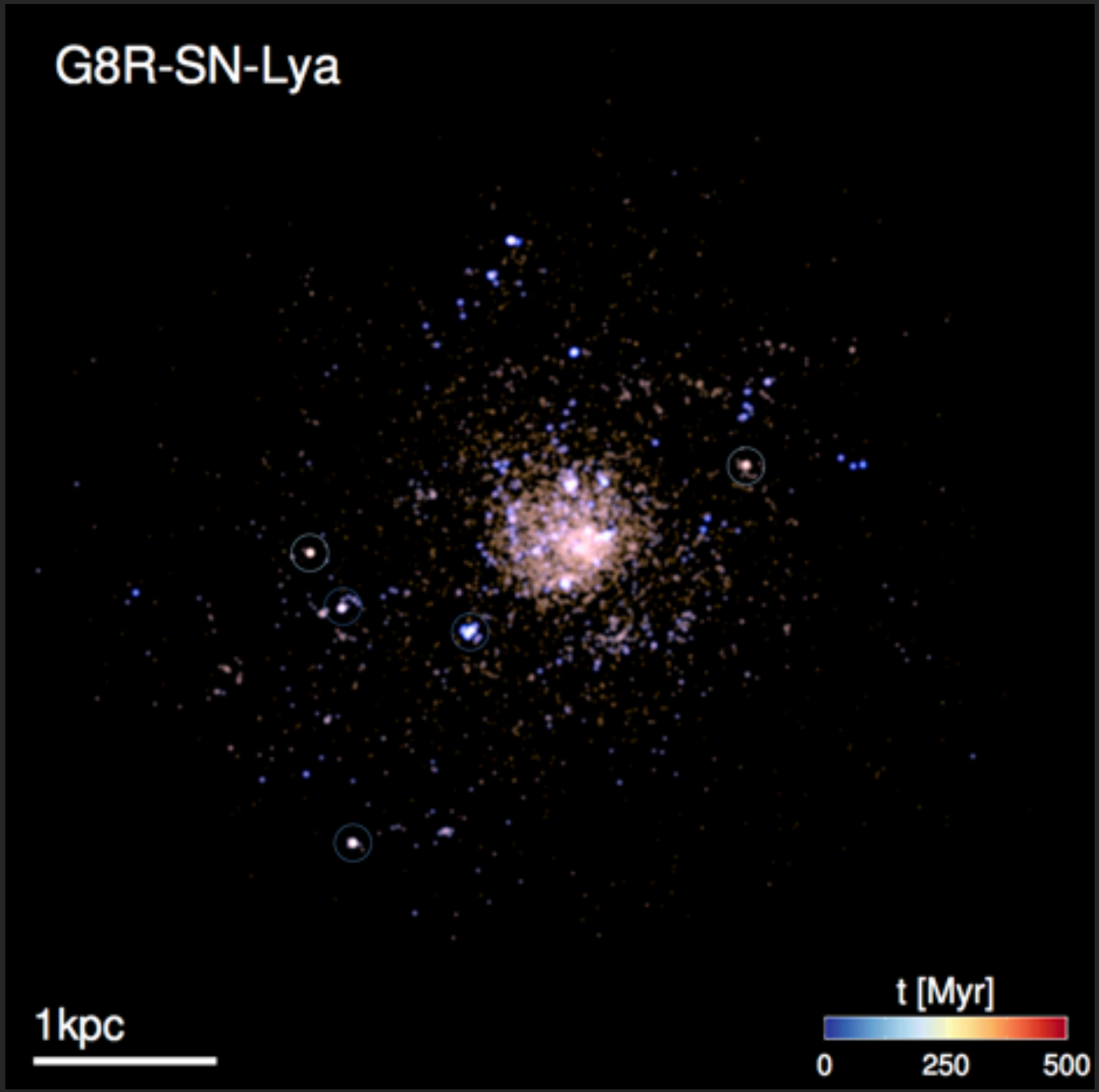
- Effective M_F ~ 200-300 in dense regions





Cluster Formation with LyA Feedback





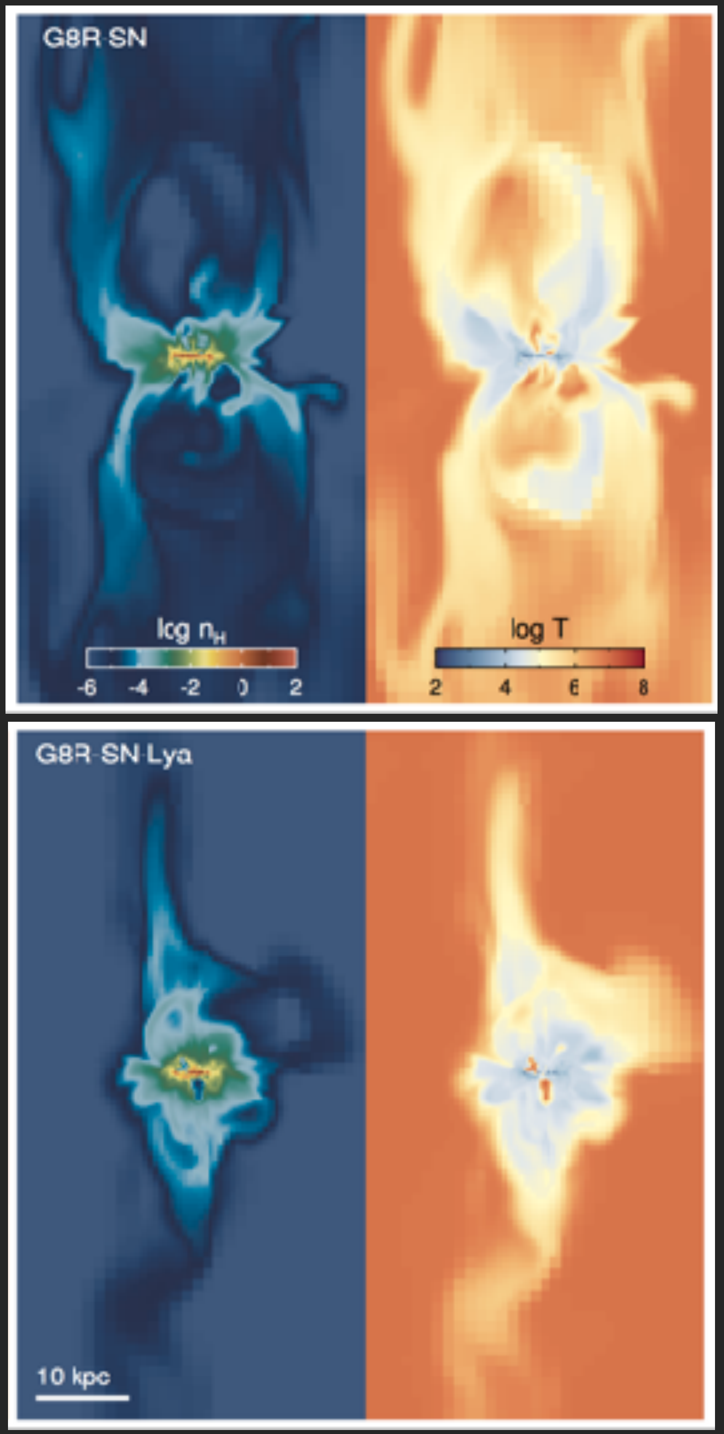
- Fewer clusters form and survive when strong radiation feedback is present
  (caution: cluster formation in HD simulations…)

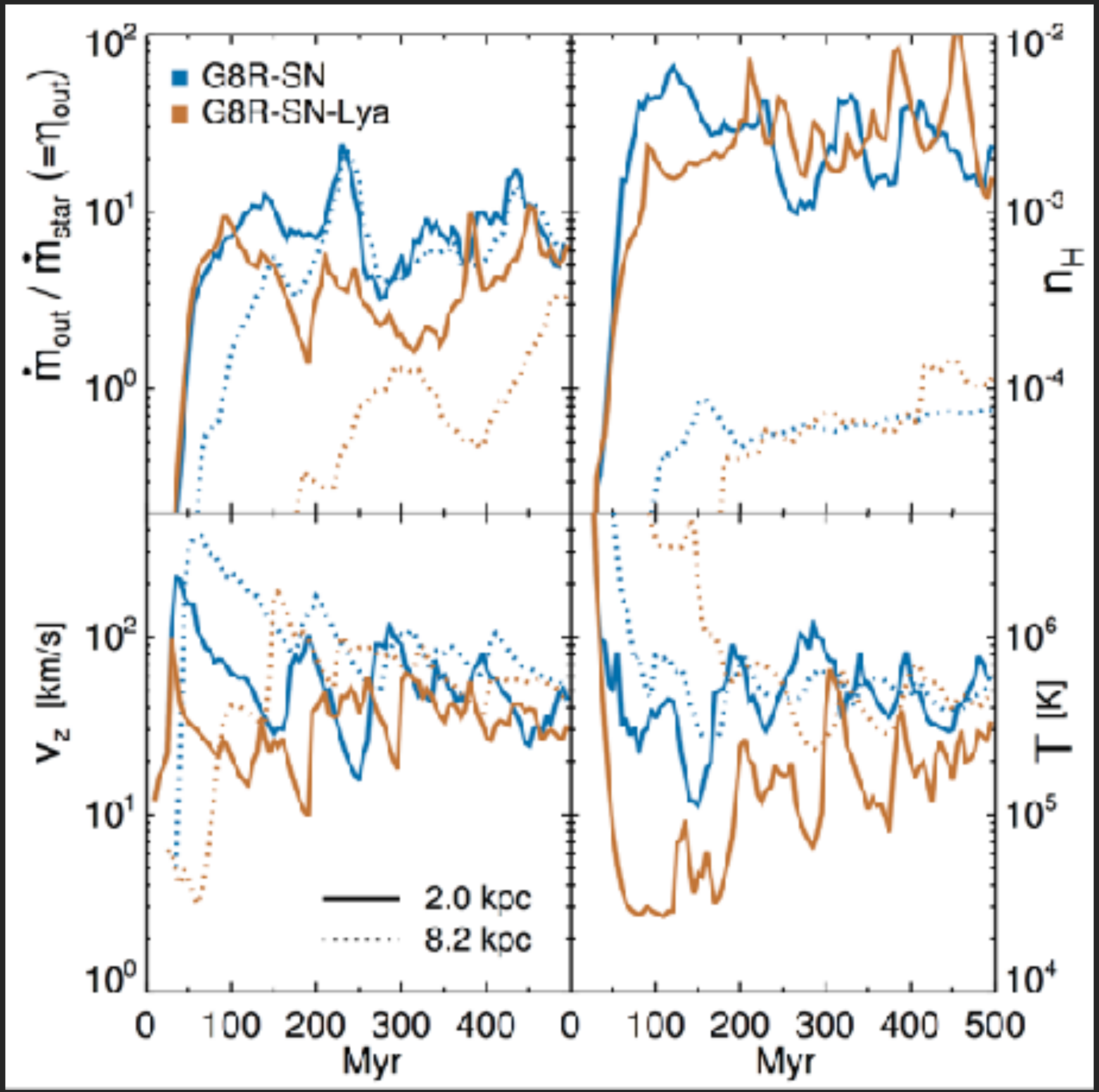
[see also Abe & Yajima 18]

Weaker outflows with Lya pressure

w/o Lya

w/ Lya

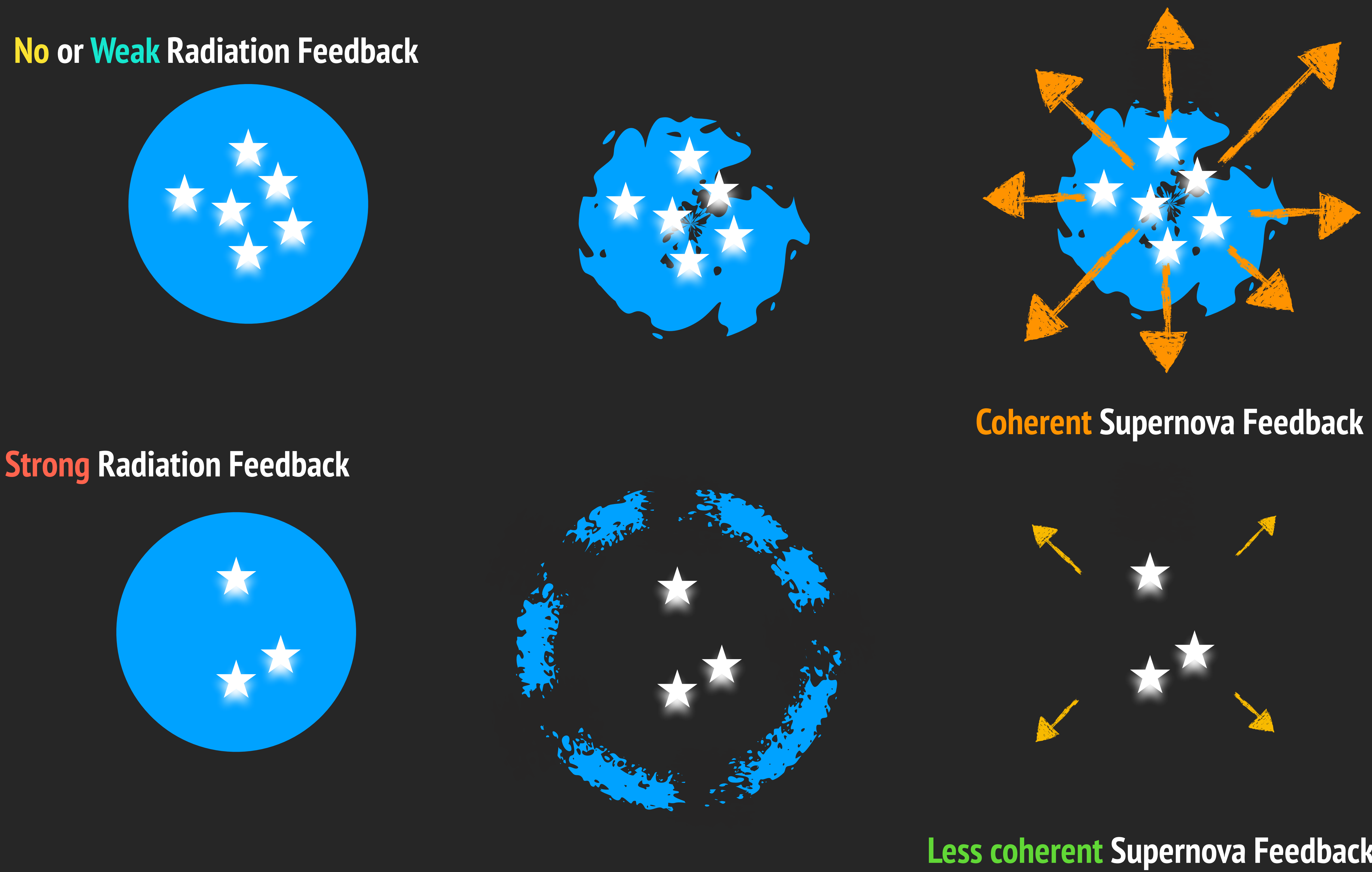




WITH LYA PRESSURE

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

A picture with strong radiation feedback



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)

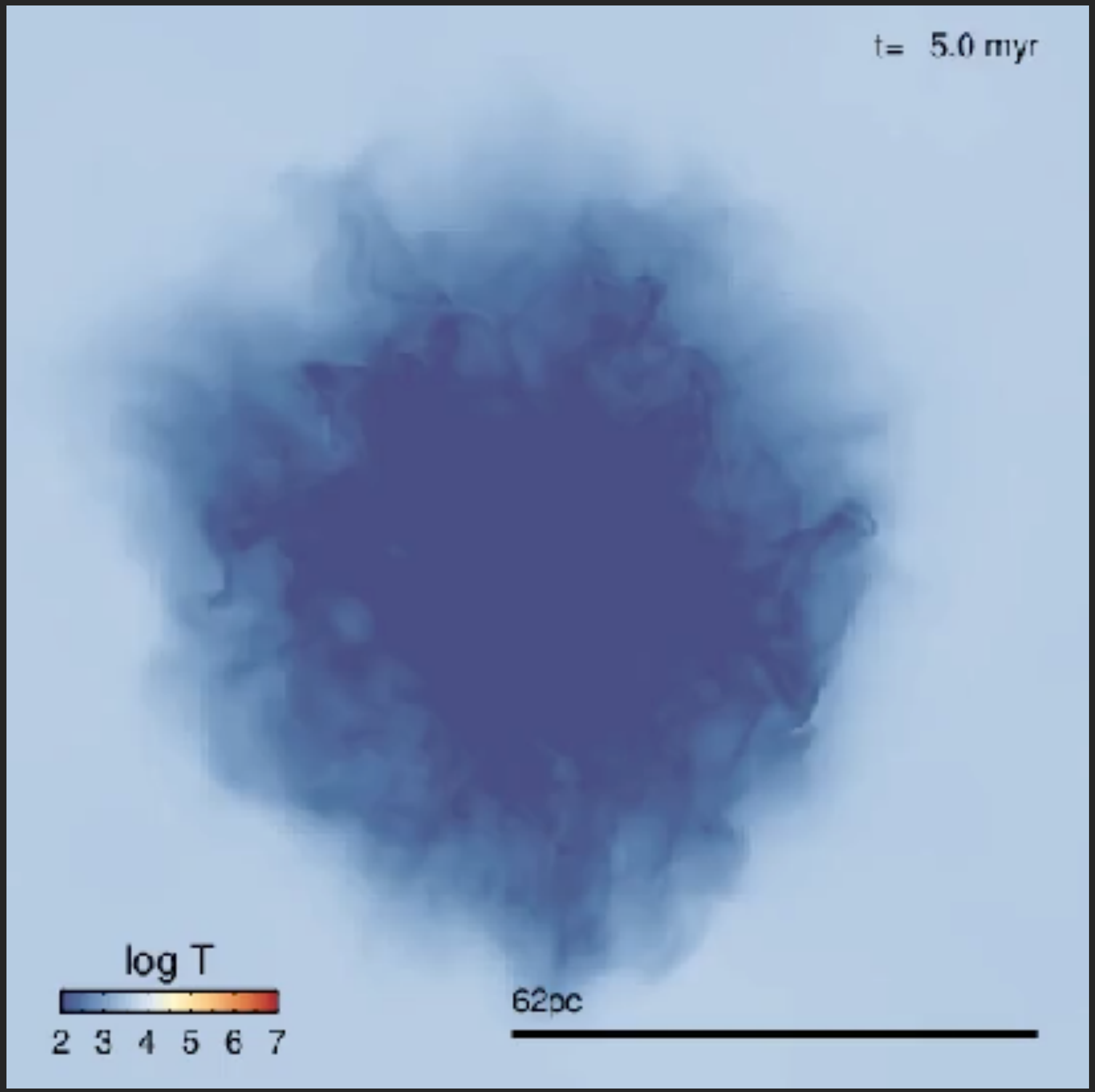
- (Partial) Solution to the over-cooling problem in galaxy formation simulations

What about Lya pressure in clouds?

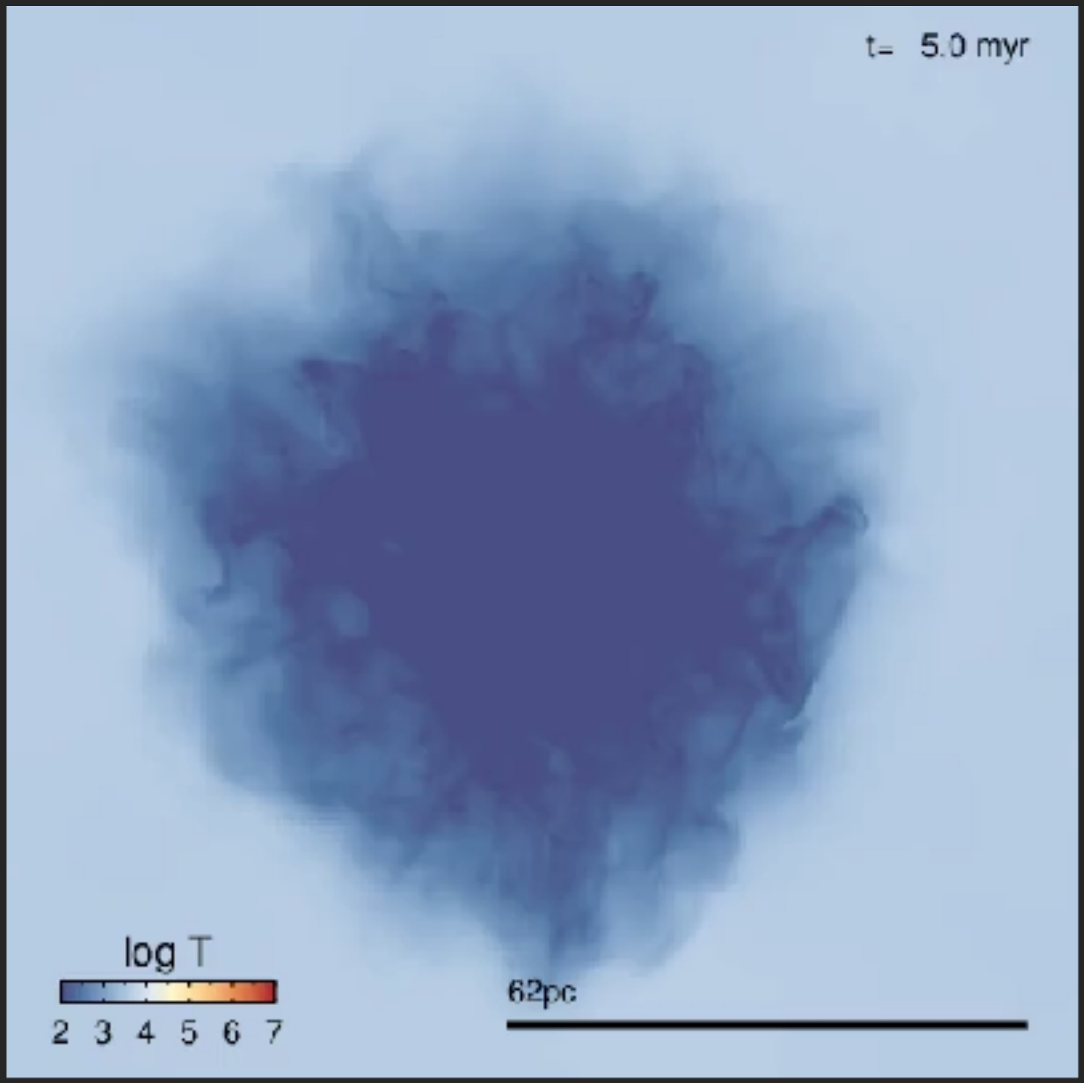
$M_{cloud}=10^6\,M_{sun}$ / $M_{star}=10^4\,M_{sun}$

* Star particles are placed in the dense clumps

box size = 512pc



PH+RP+IR+SN



PH+RP+IR+SN+Lya

Stay tuned...