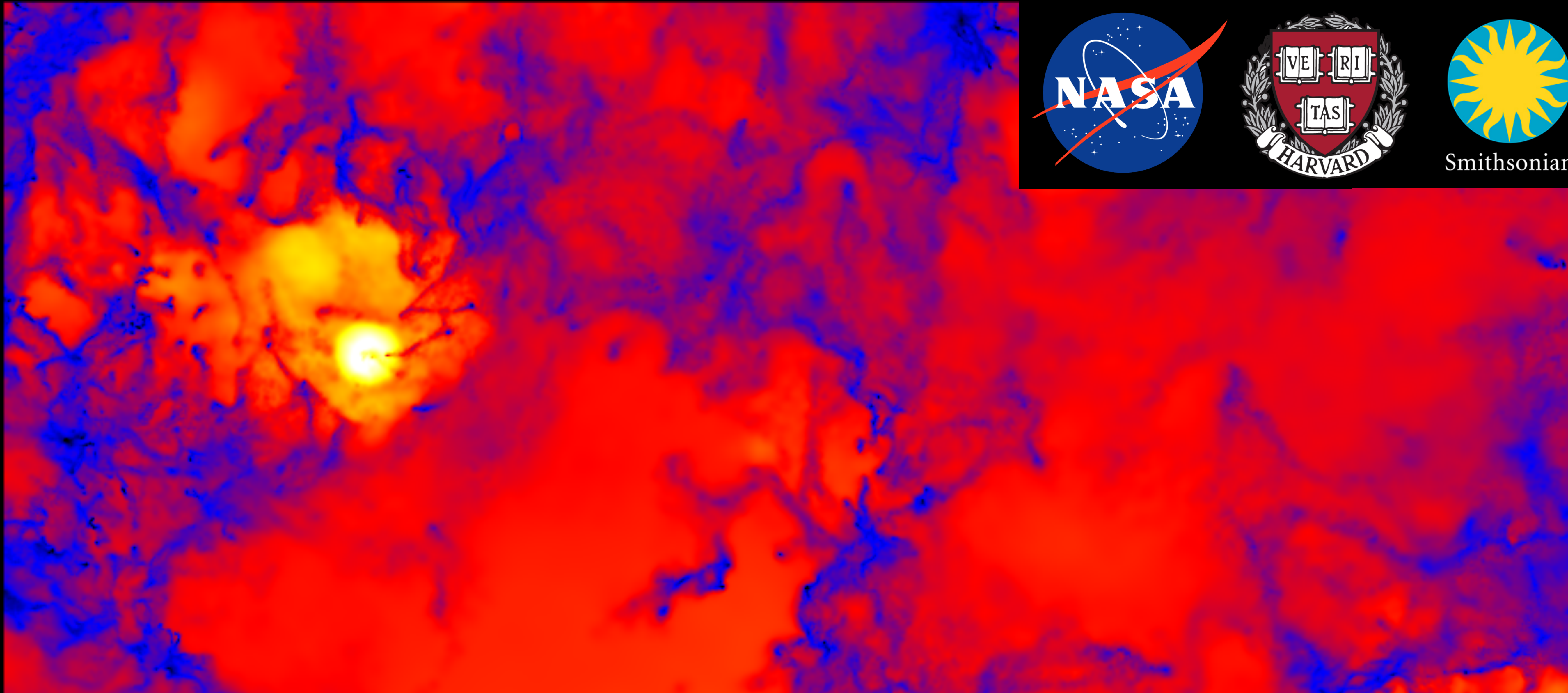

Impact of radiation fields in galaxies

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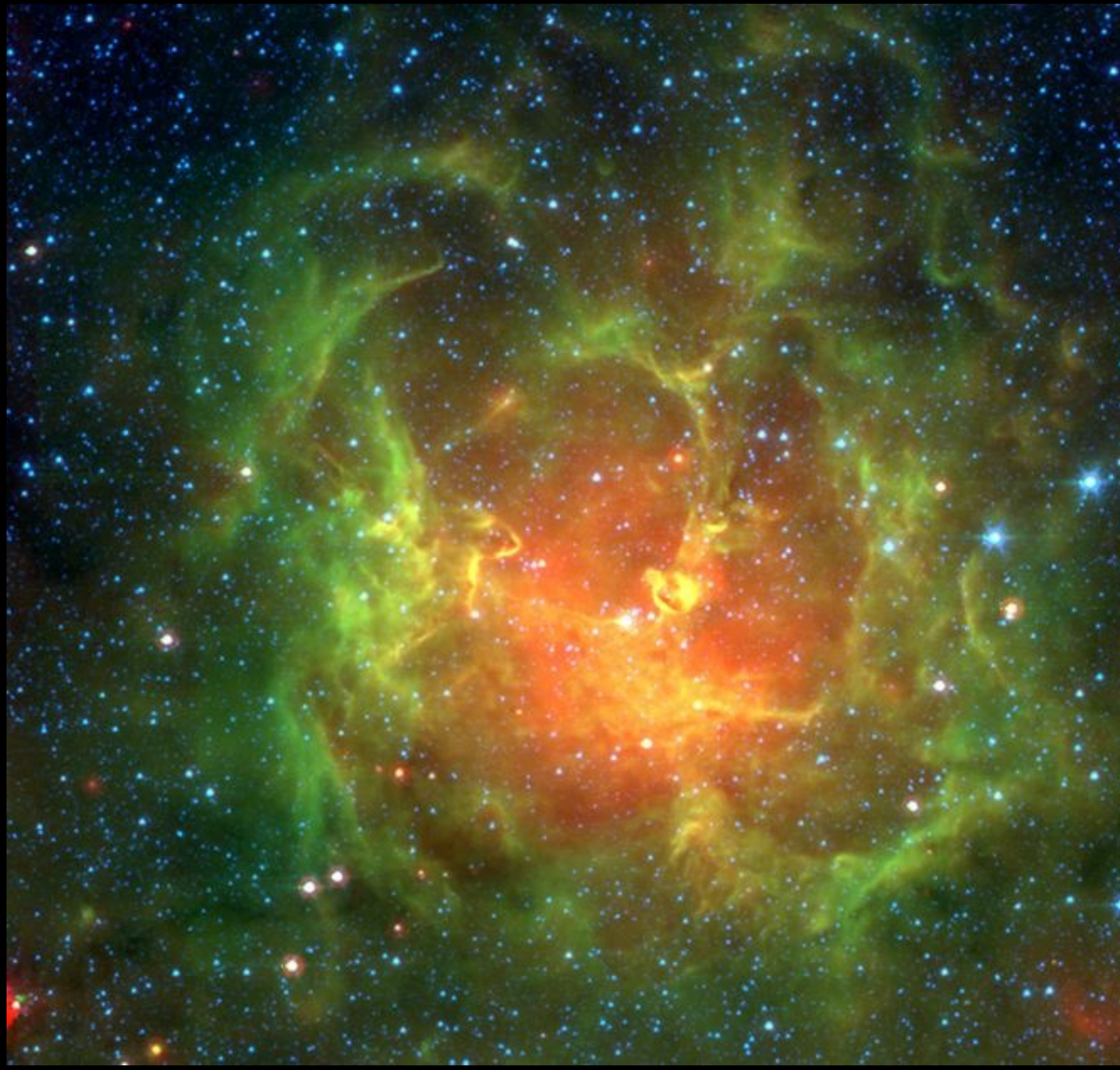
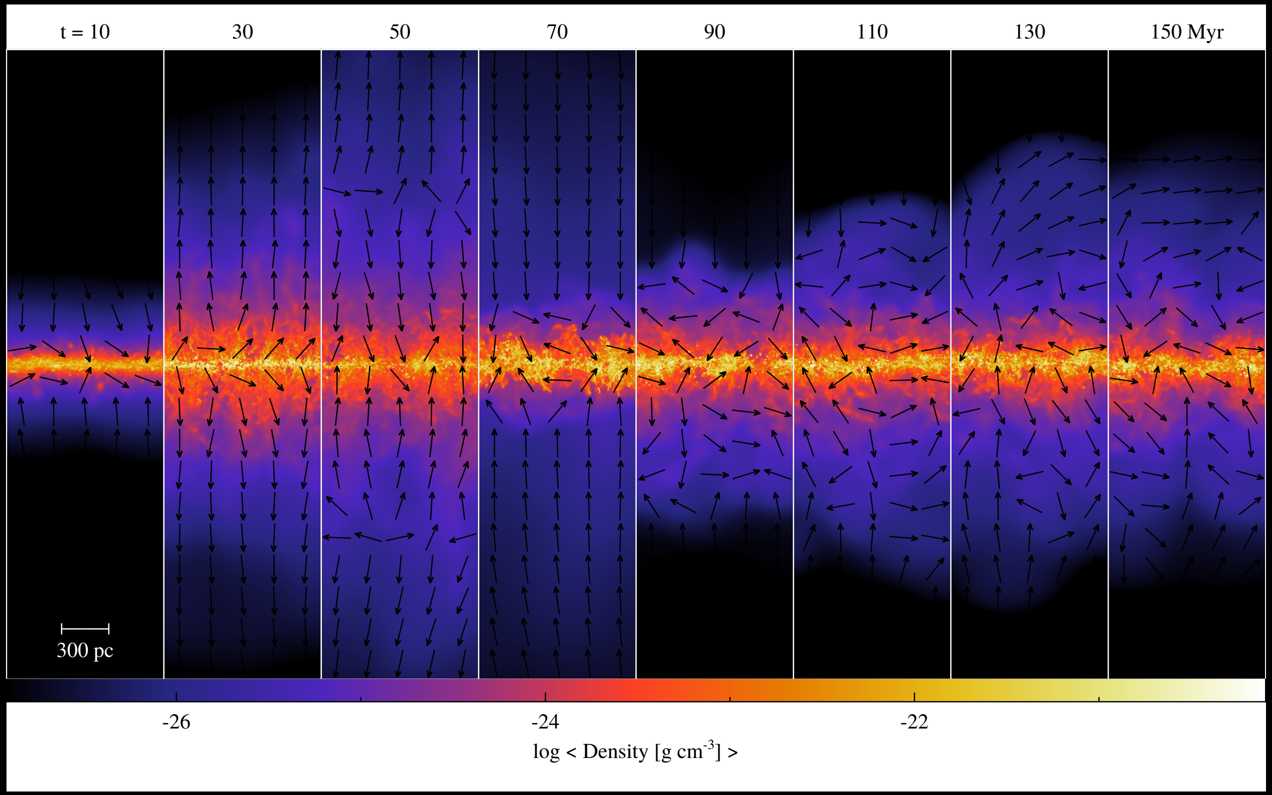
Radiation fields in the Universe

- Radiation fields are ubiquitous in Nature.
- Important diagnostic tool - Until recently EM radiation was the only window into observing the Universe.
- They also have important dynamical effects in many Astrophysical systems.

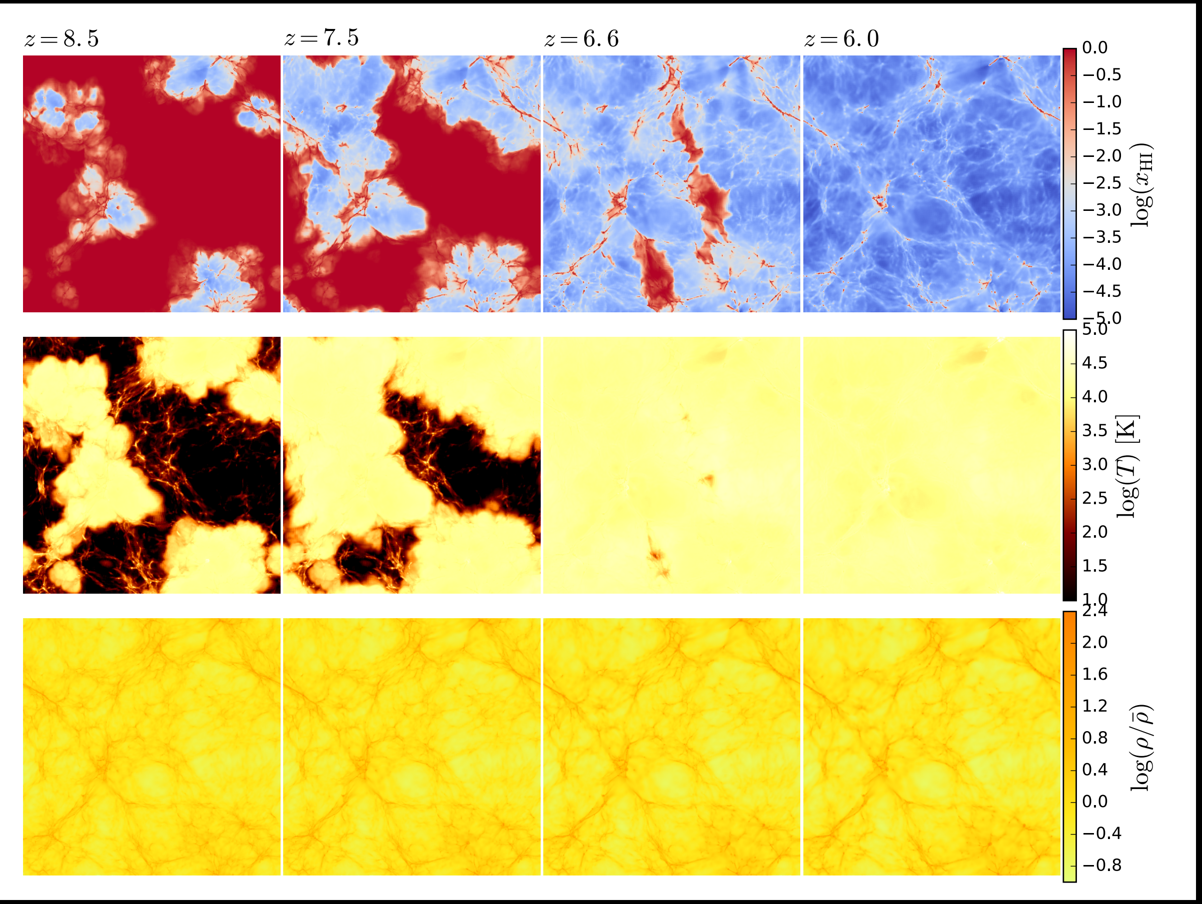


Radiation fields in the Universe

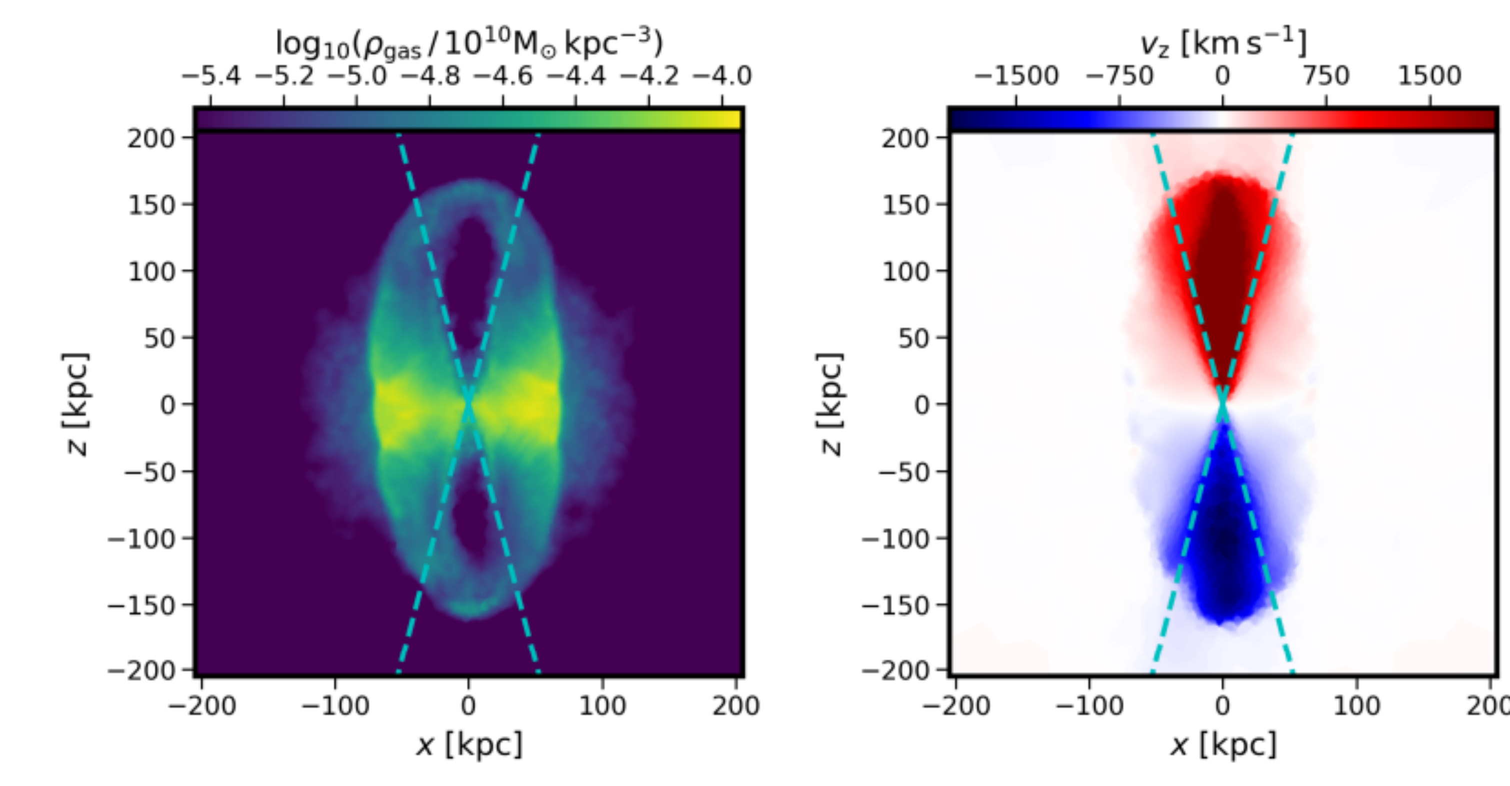
- The impact of stellar radiation fields in regulating the SFR of sub L_* galaxies.
- Radiation pressure driven outflows in high luminosity quasars and their role in quenching high mass galaxies.
- Investigating the sources that reionise the Universe and its impact on low mass haloes.



RK+ in prep.

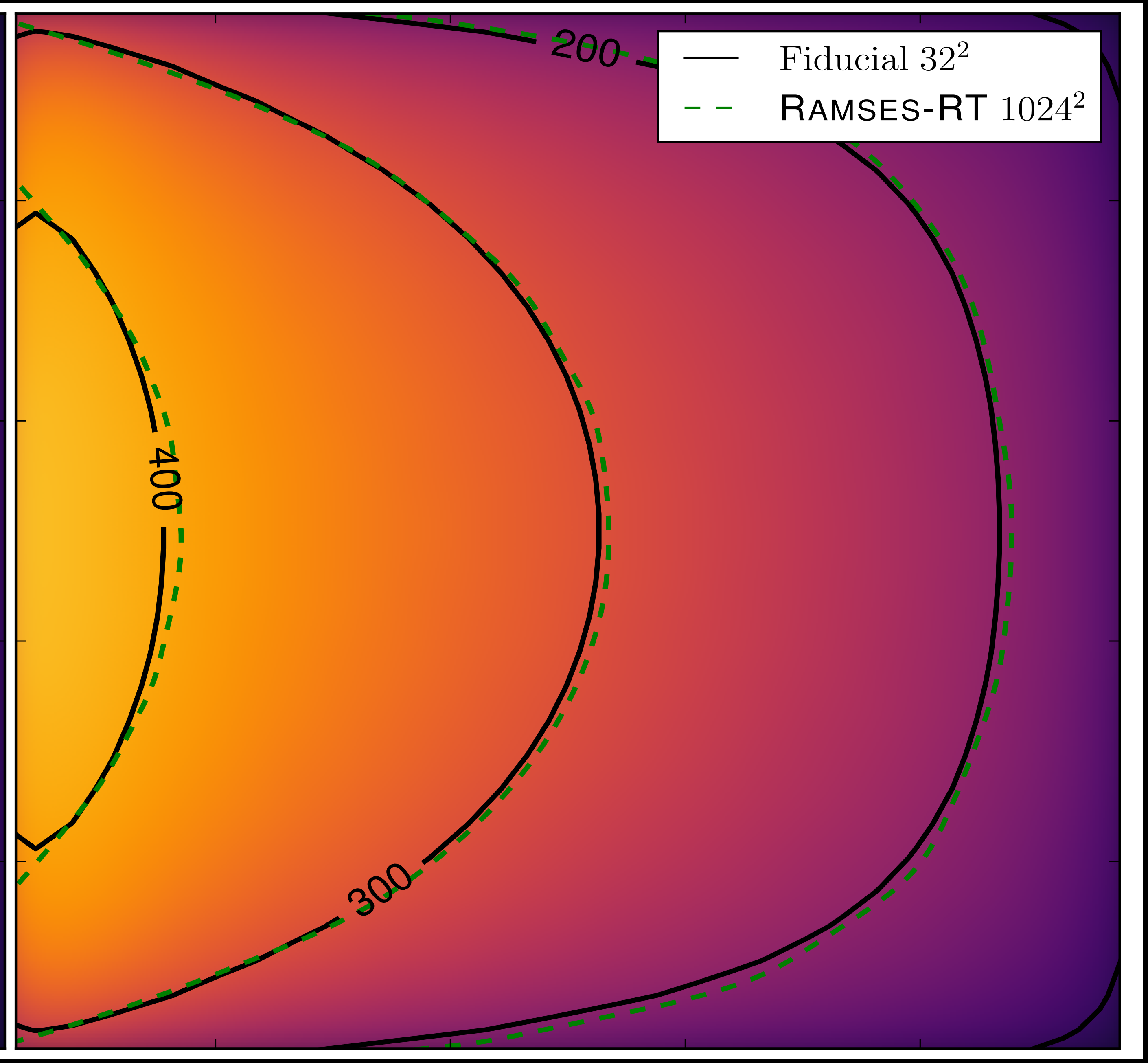


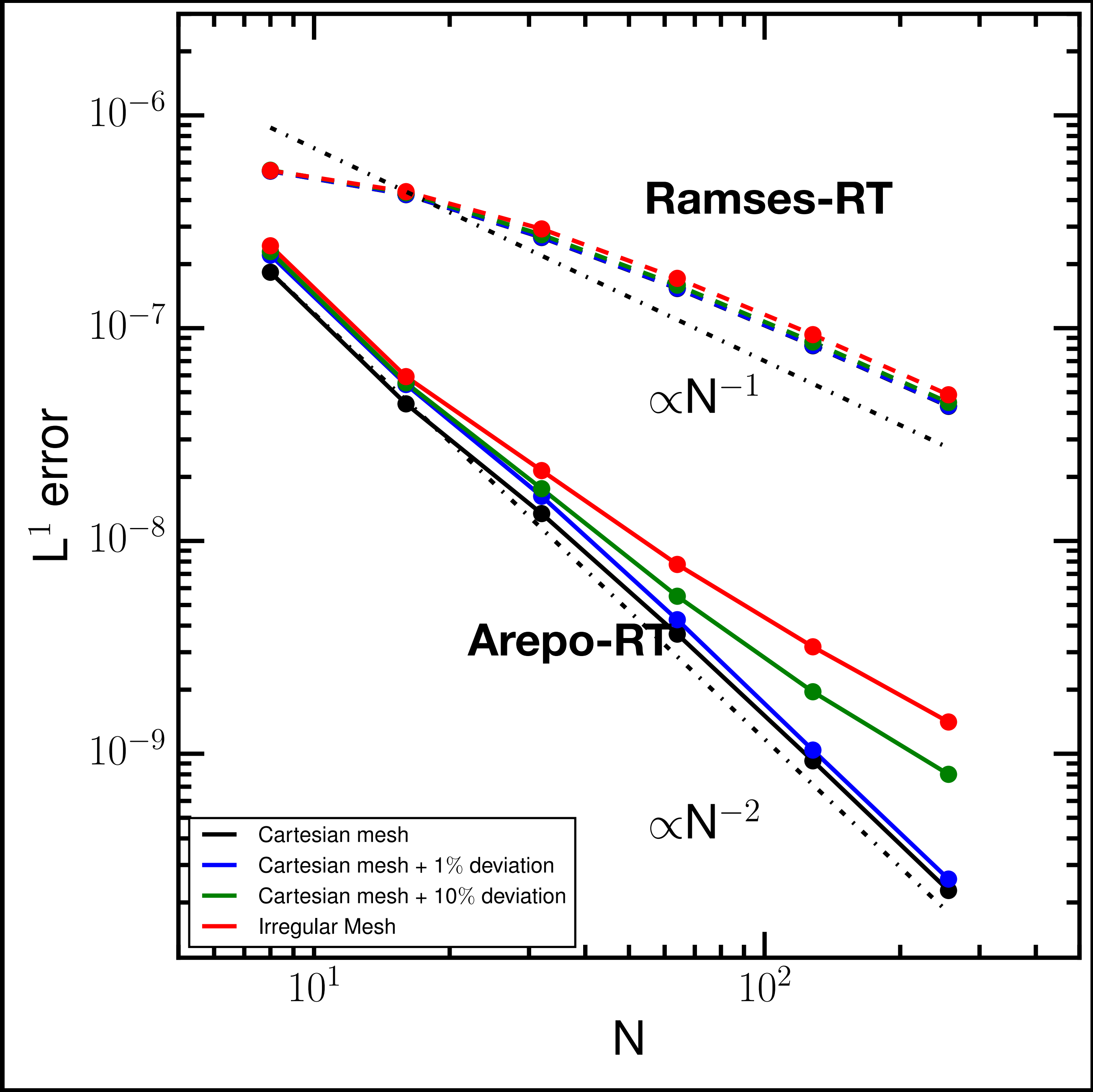
Wu, RK + in prep.



Barnes, RK + in prep.

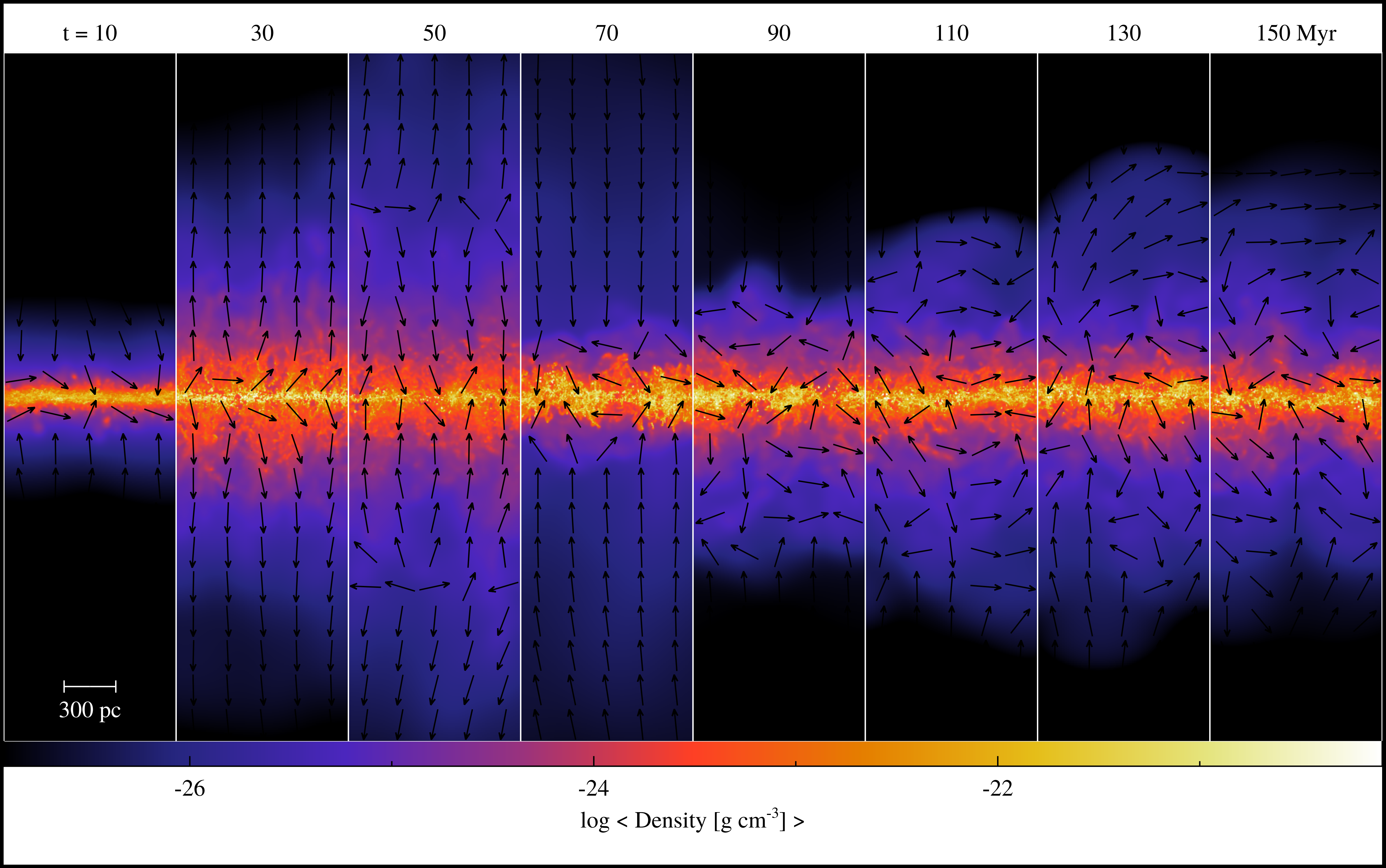
Arepo-RT (Kannan+2018)





- RHD extension to Arepo
- Full second order convergence even in the presence of source therms
- Excellent diffusivity control
- A 32^2 simulation done with Arepo-RT can match the results obtained by a 1024^2 simulation performed by Ramses-RT

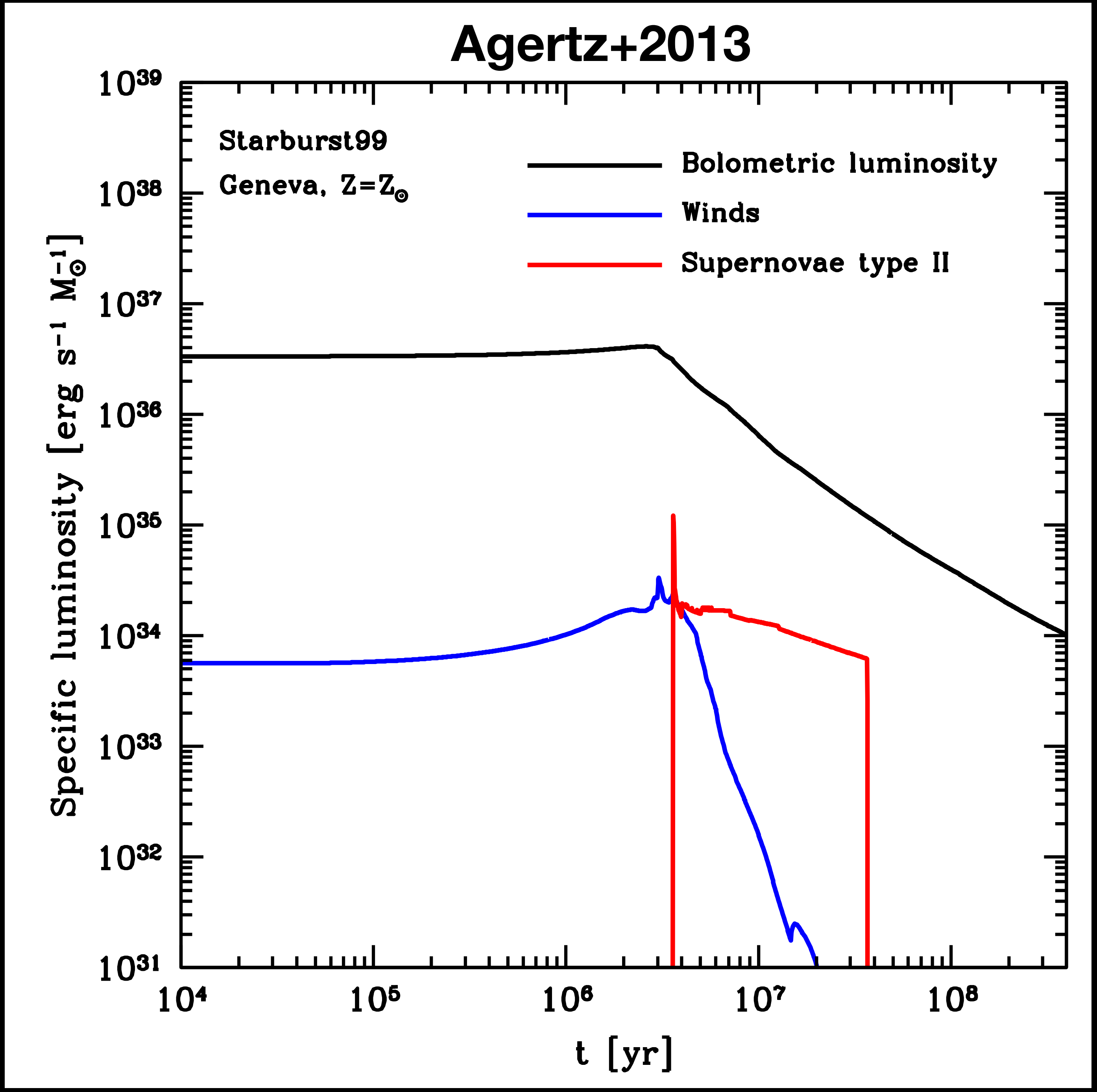
The impact of stellar radiation fields in regulating the SFR of sub L* galaxies.



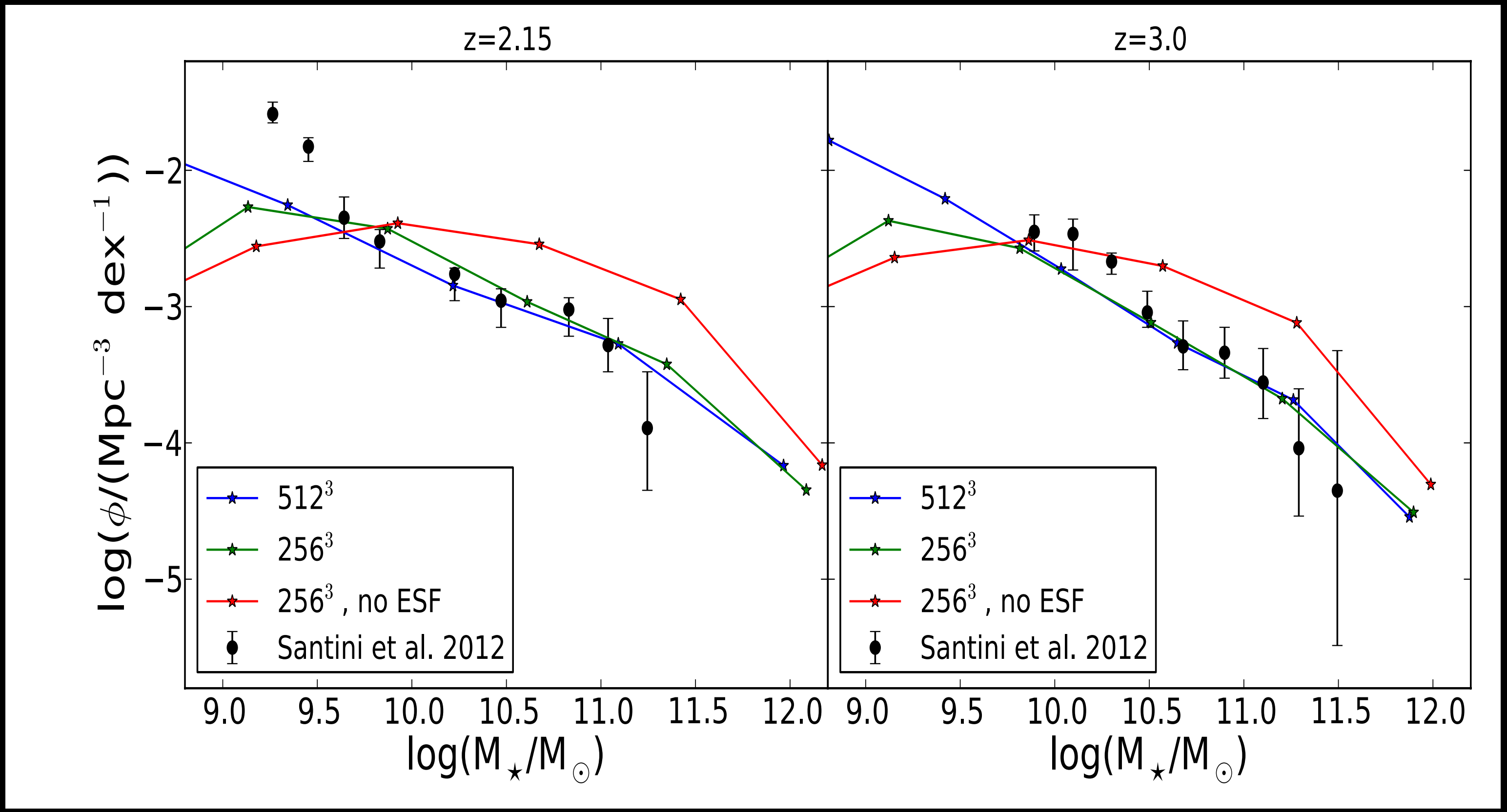
RK+ in prep.

Radiation fields from Massive stars

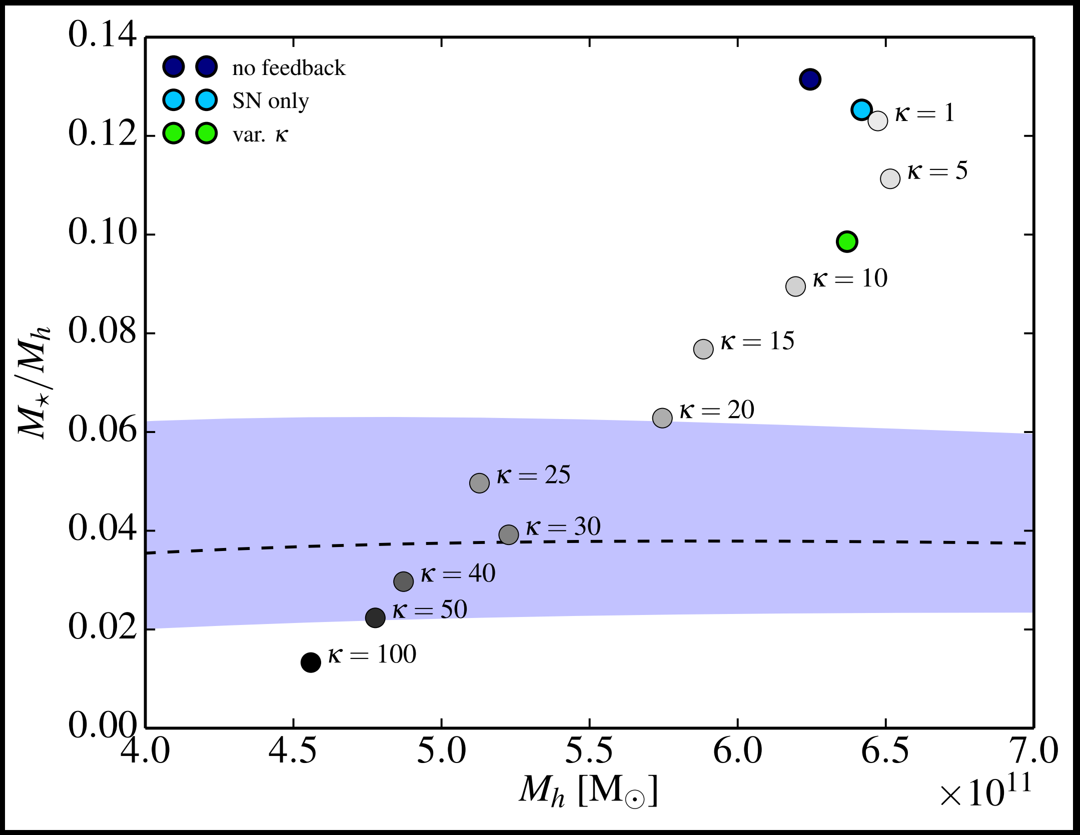
- Stellar radiation fields and winds can also inject large amounts of energy into the ISM
- The radiation energy input is much larger than that of SNe
- They can significantly alter the regions around stars and can make the SNe more efficient (Hokins+2011, Stinson+2013, Agertz+2013)

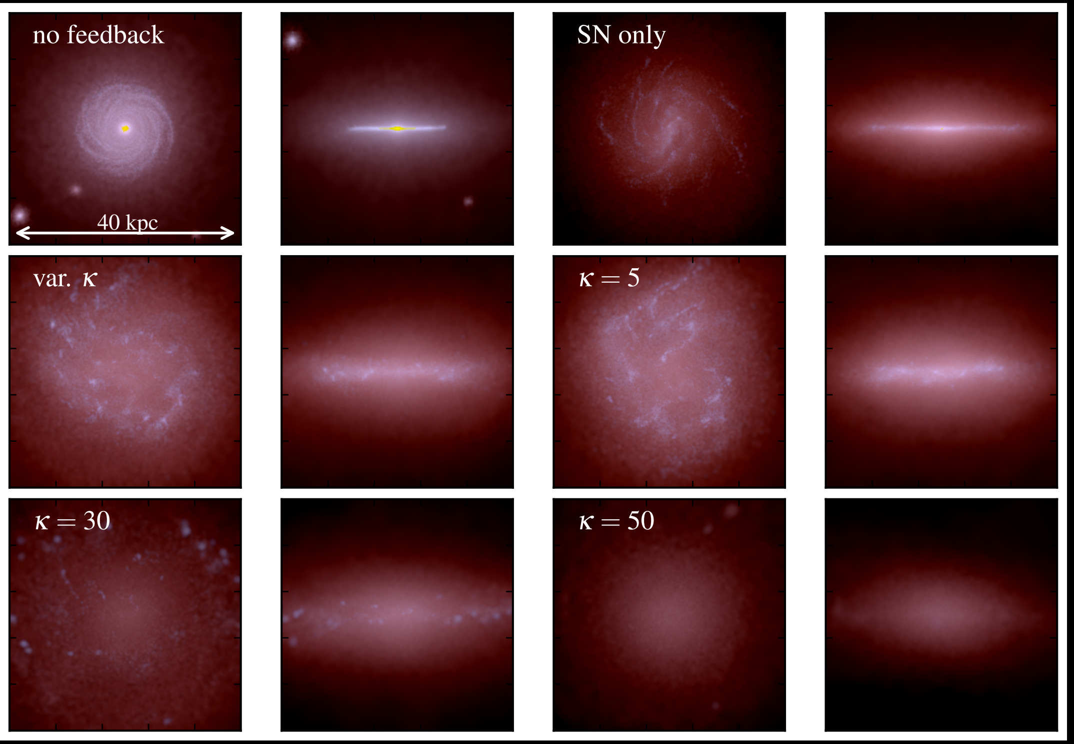


Sub-grid models for radiation feedback



Kannan+2014





Roskar+2014

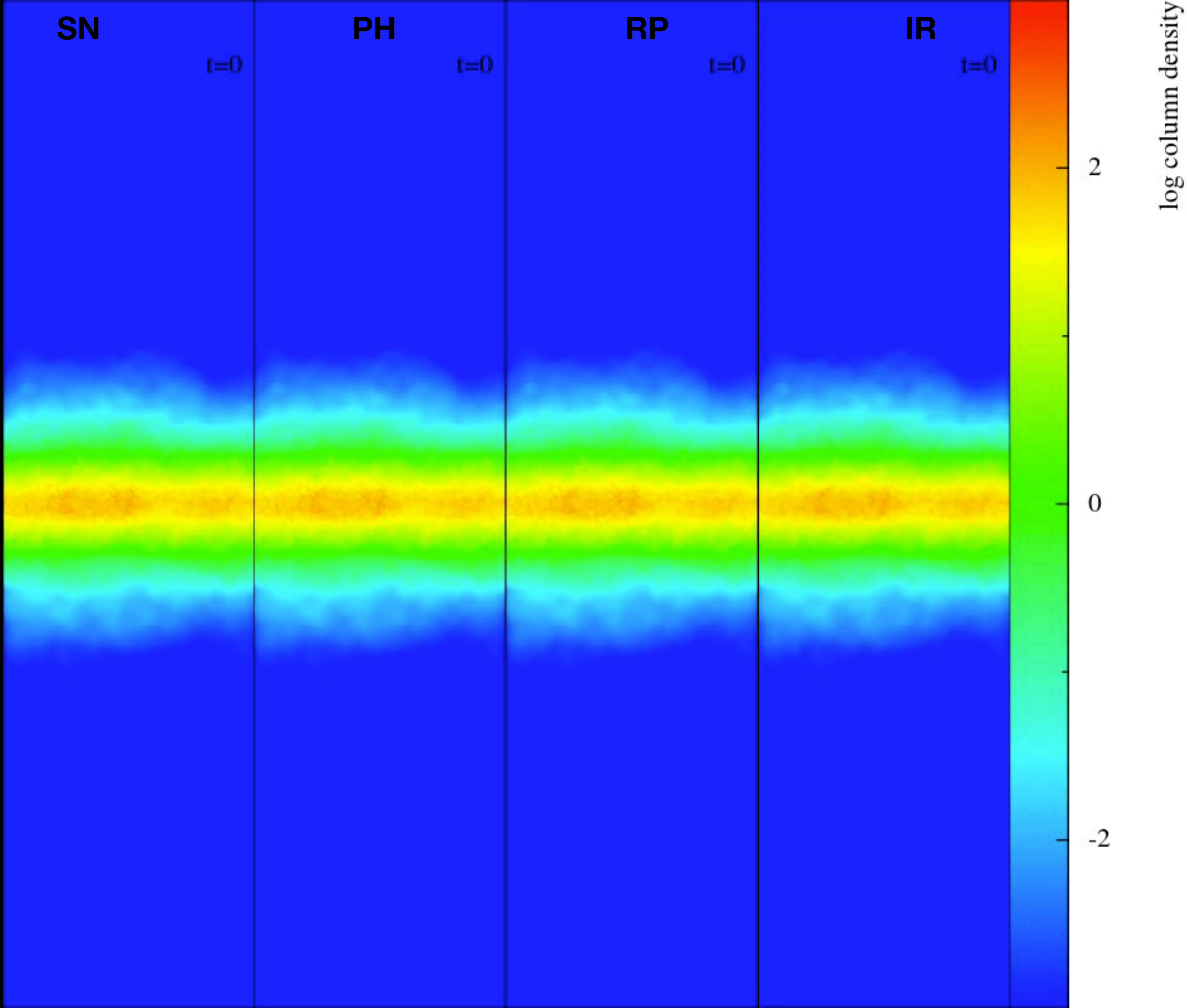
- Stinson+2013 : Subgrid model for photoheating, assume that *10% of the bolometric luminosity of stars thermalizes around stars* and heats the surrounding gas

- IR radiation pressure - Invokes trapped radiation pressure

$$\dot{p} = \frac{L}{c}(1 + \tau_{IR})$$

High resolution simulations of radiation feedback

- Tallbox simulations - 1 x 1 x 10 kpc box - solar neighborhood initial conditions ($5\ \mathrm{M_\odot/pc^2}$, $10\ \mathrm{M_\odot/pc^2}$, $20\ \mathrm{M_\odot/pc^2}$)
- Mass resolution - 10 Msun
- Spatial resolution - Softening 0.13 pc (resolves strongmen radius)
- RT coupled to chemistry network of Smith,Glover+2013 ; follows H2,H, He and a minimal model for CO and dust
- 6 radiation bins - IR, optical/FUV, Lyman-Werner, HI, HI/H2, HeI ionization
- 4 simulations to gauge the effectiveness of each process
    - SN - Supernova thermal dump of energy
    - PH - SN + Photoheating
    - RP - PH + UV radiation pressure
    - IR - RP + IR radiation pressure


SN
PH
RP
IR
t=0
t=0
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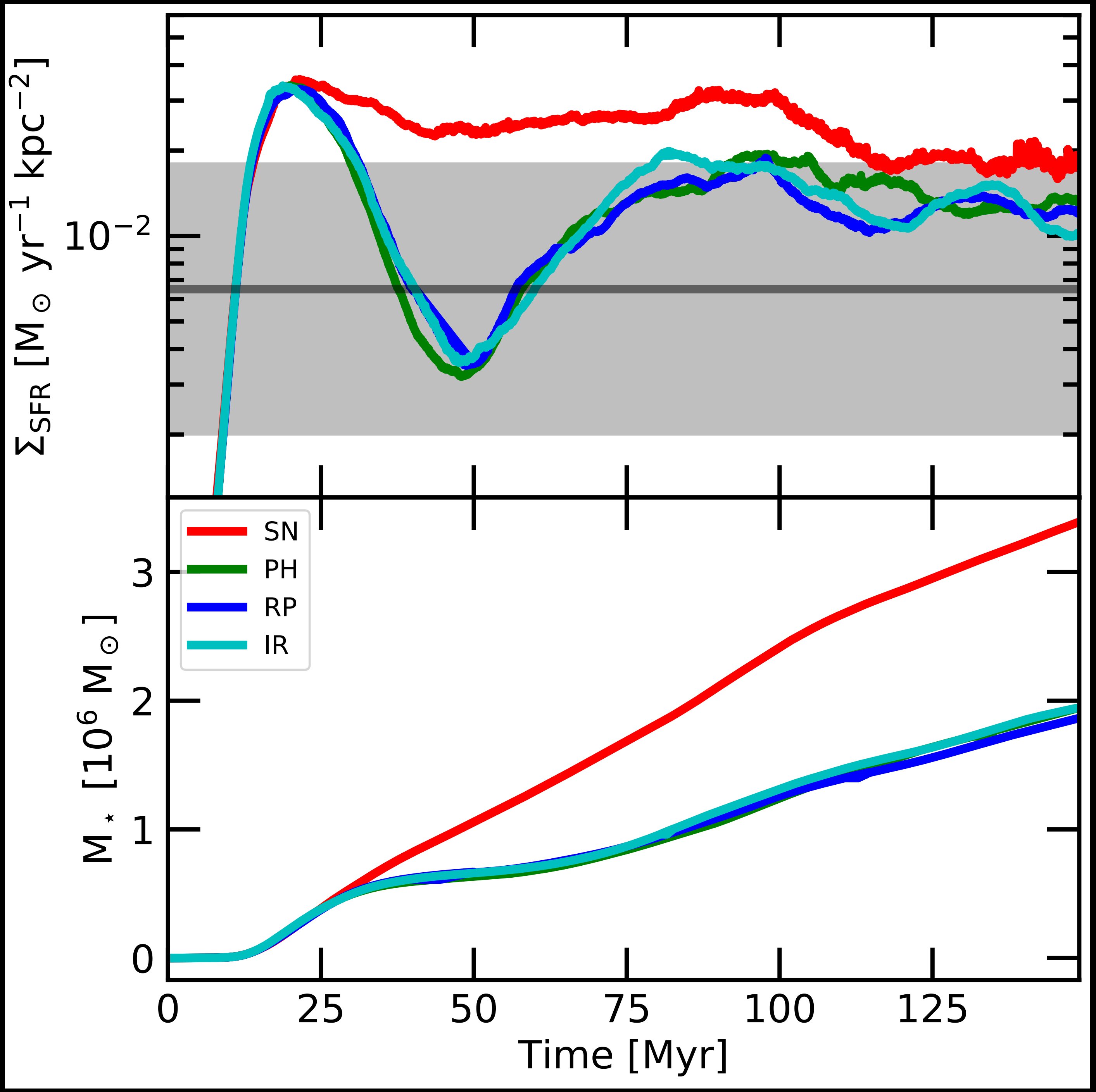
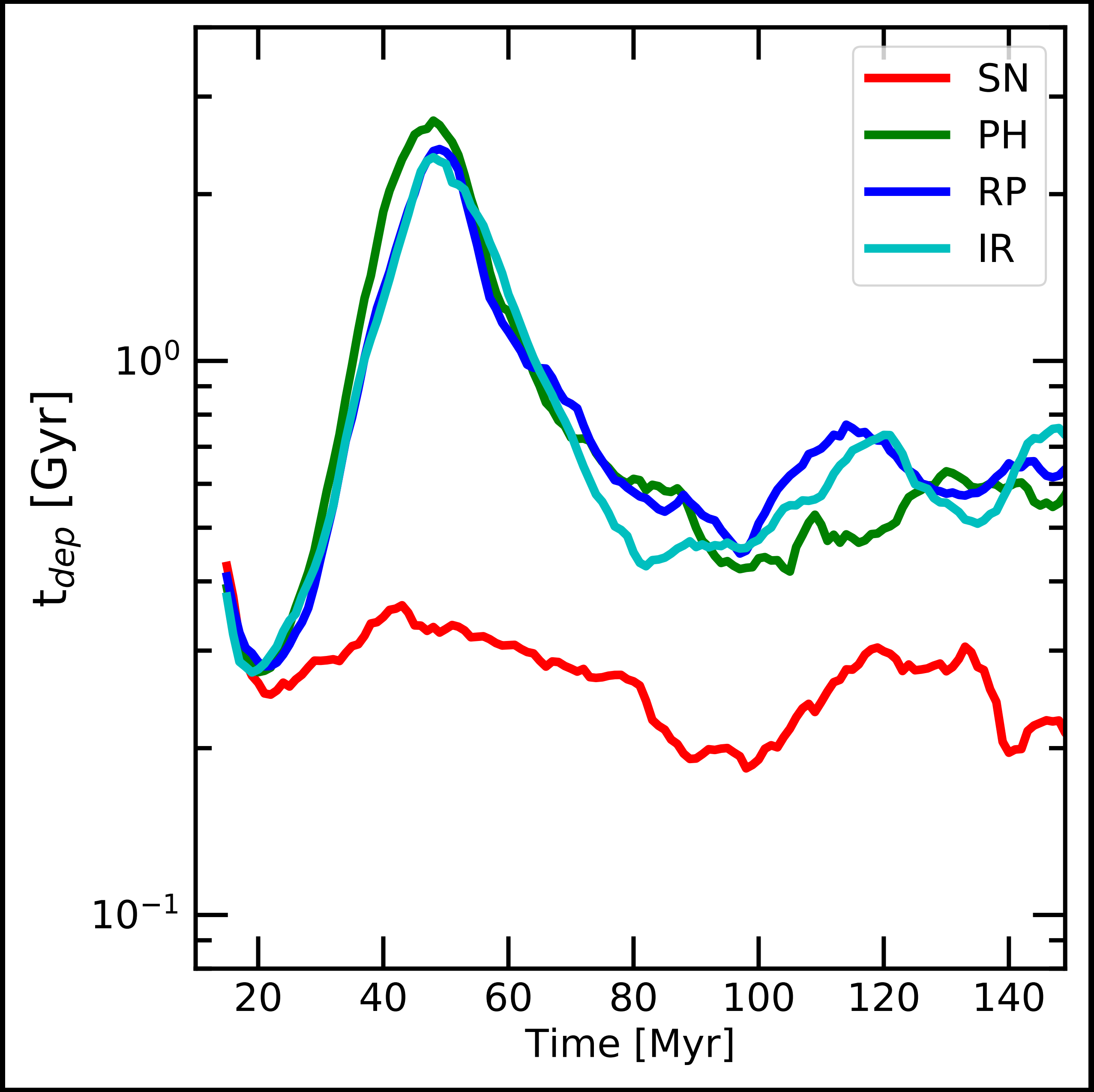
t=0
2
0
-2
log column density

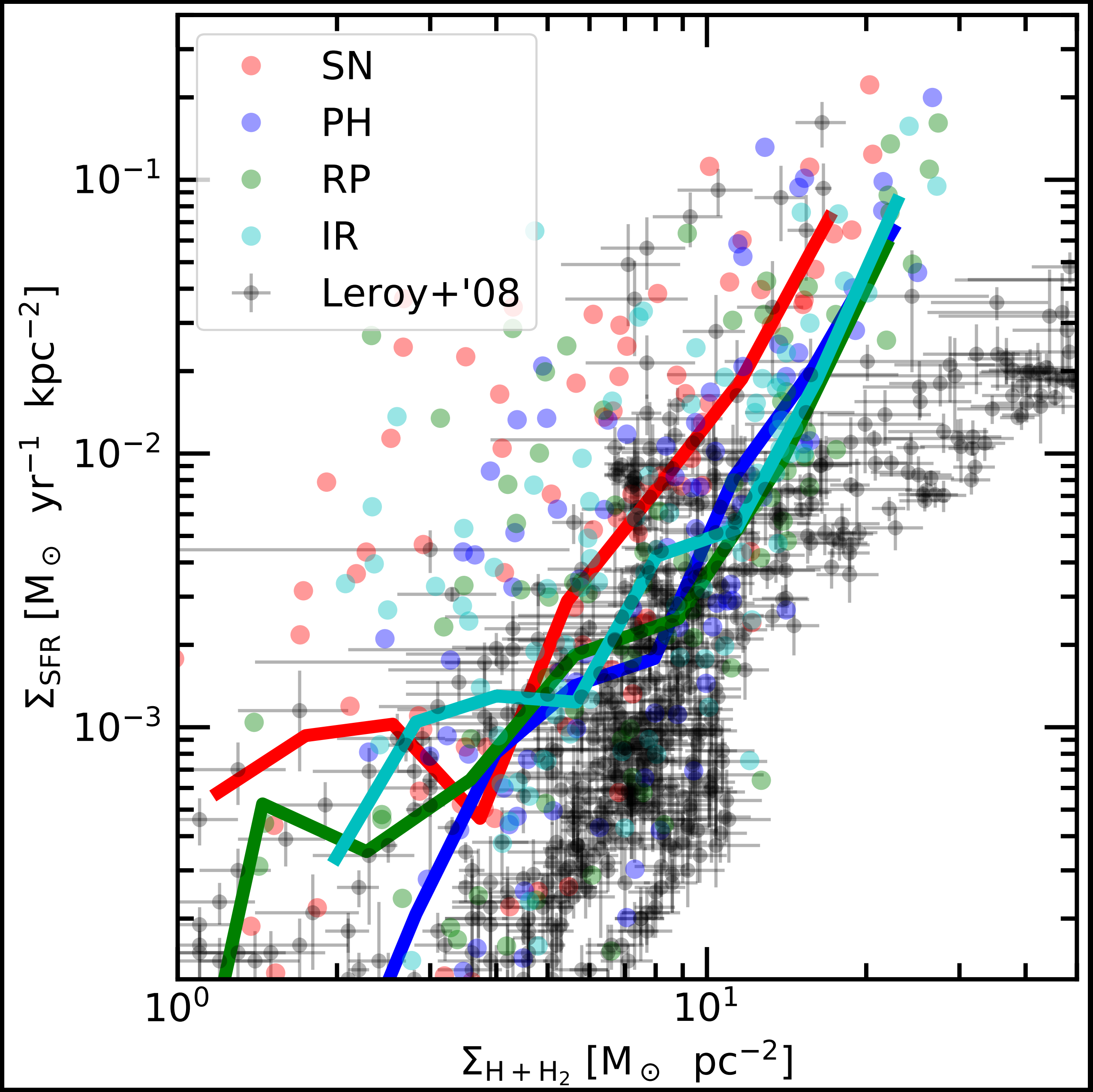
SFRs and depletion times

- The average SFR is lowered by about 50% if the radiation fields are included, brings it within the observational limits.
- The total stellar mass of the disk is also reduced by about 50% (consistent with Rosdahl+2015).
- Radiation pressure (both direct and trapped IR) does not seem to have a large affect on the SFRs.



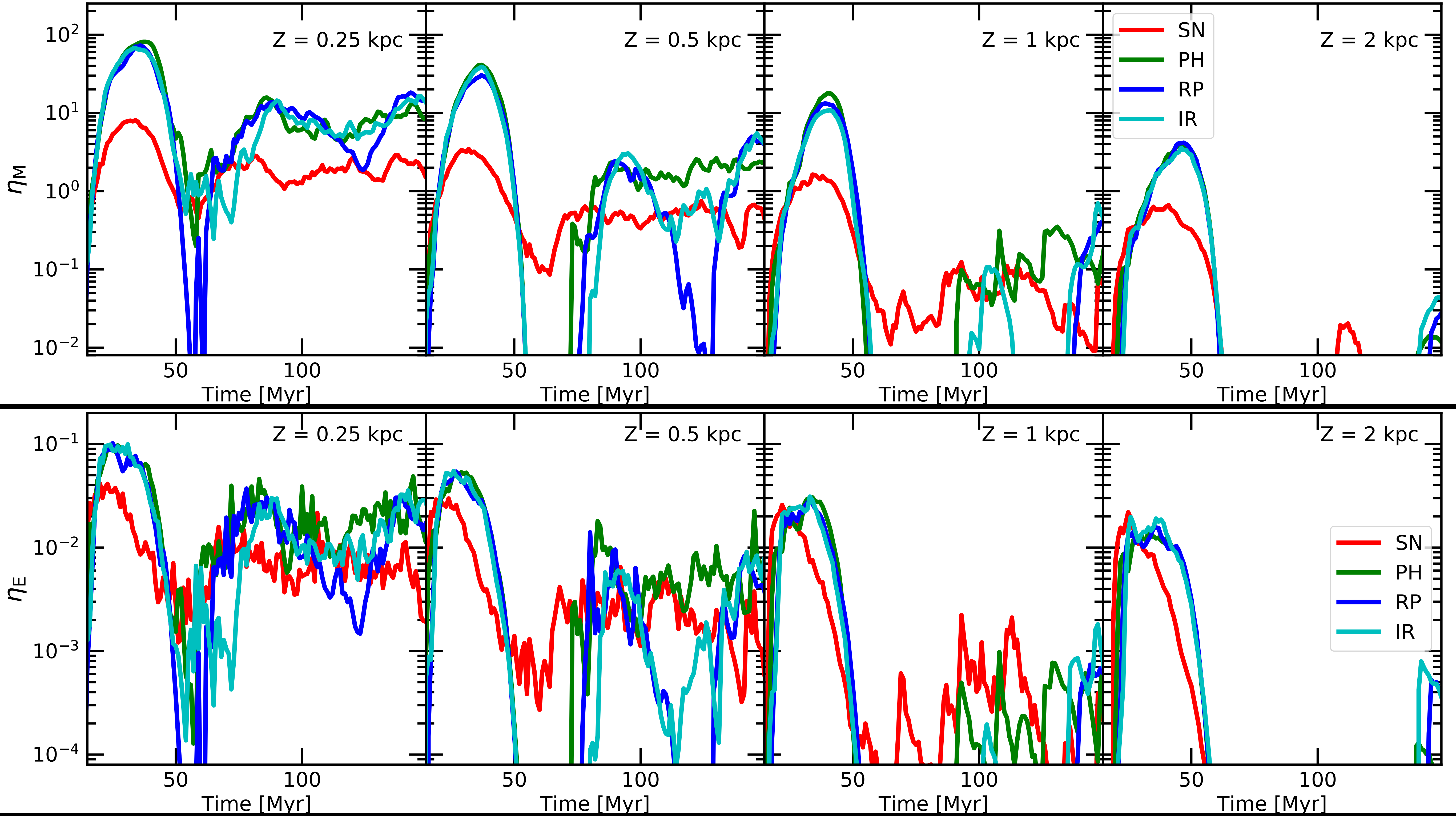
KS relation and depletion timescales





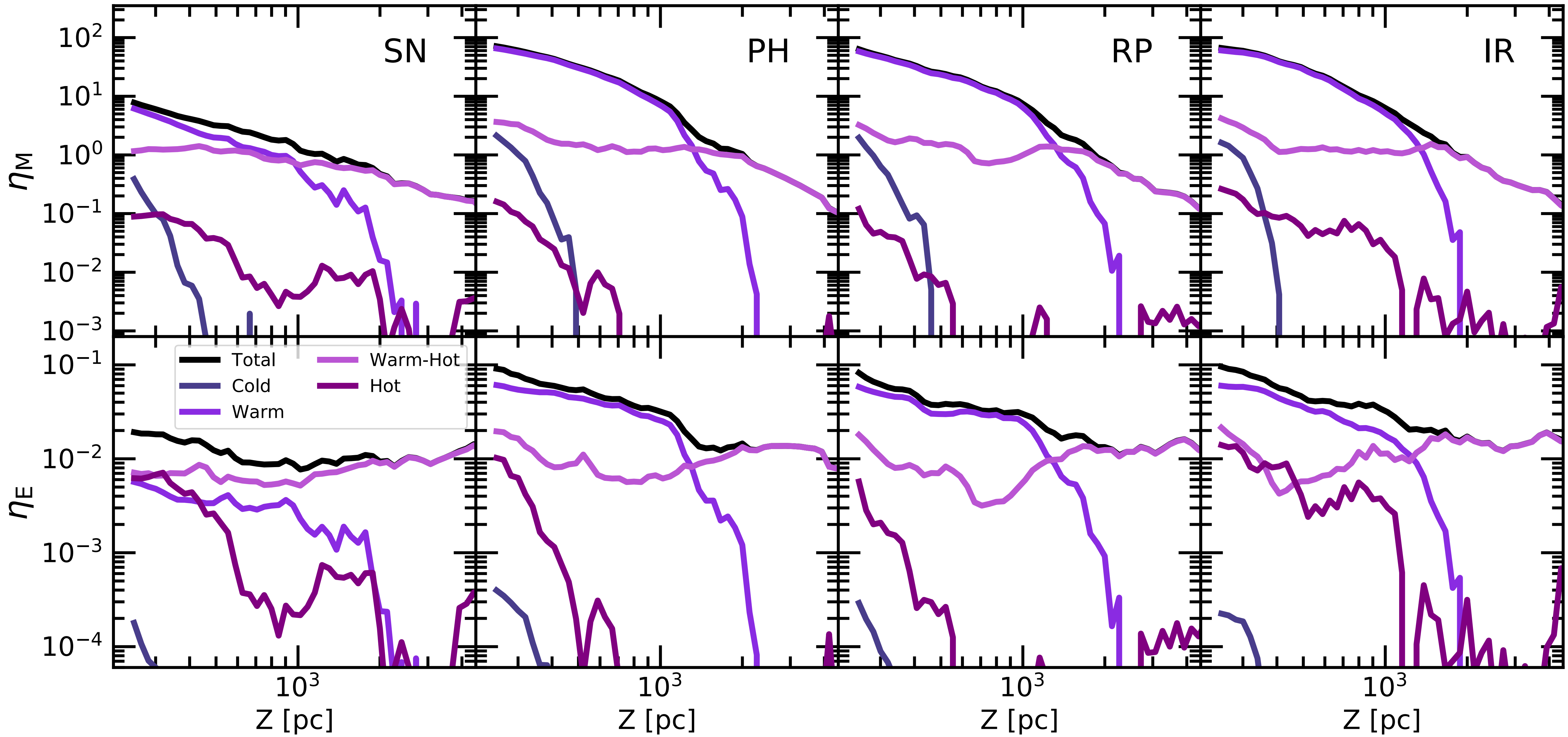
- The depletion timescales increase by a factor of 3-5, bringing it closer to canonical 1 Gyr value
- This lower the SFR per unit mass of gas bringing the simulation results closer to the observed KS relation

Mass & Energy loading factors



- Mass loading - ($dM_{outflow}/dt$) / SFR - mass ejected by unit star formation
- Energy loading - $E_{outflow}/E_{SNe}$ - fraction energy return

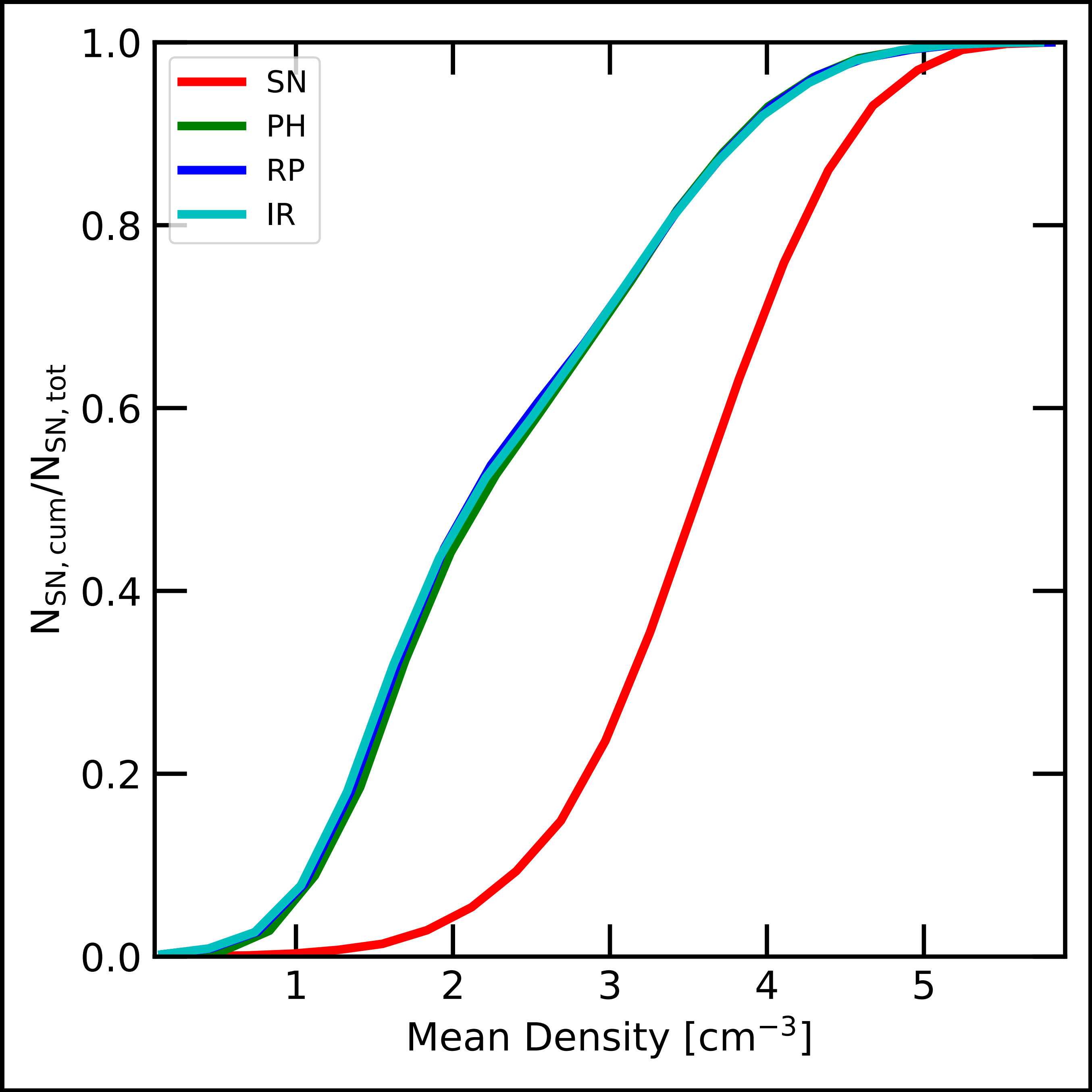
Mass & Energy loading factors



- The increase in mass and energy loading is mainly driven by the increase in the outflow of the warm gas (300-8000 K).
- There is very little differences in the other phases of the outflow.
- The outflows in runs with radiation fields are also shown to entrain more dense material.

Mean environment density of a SNe explosion

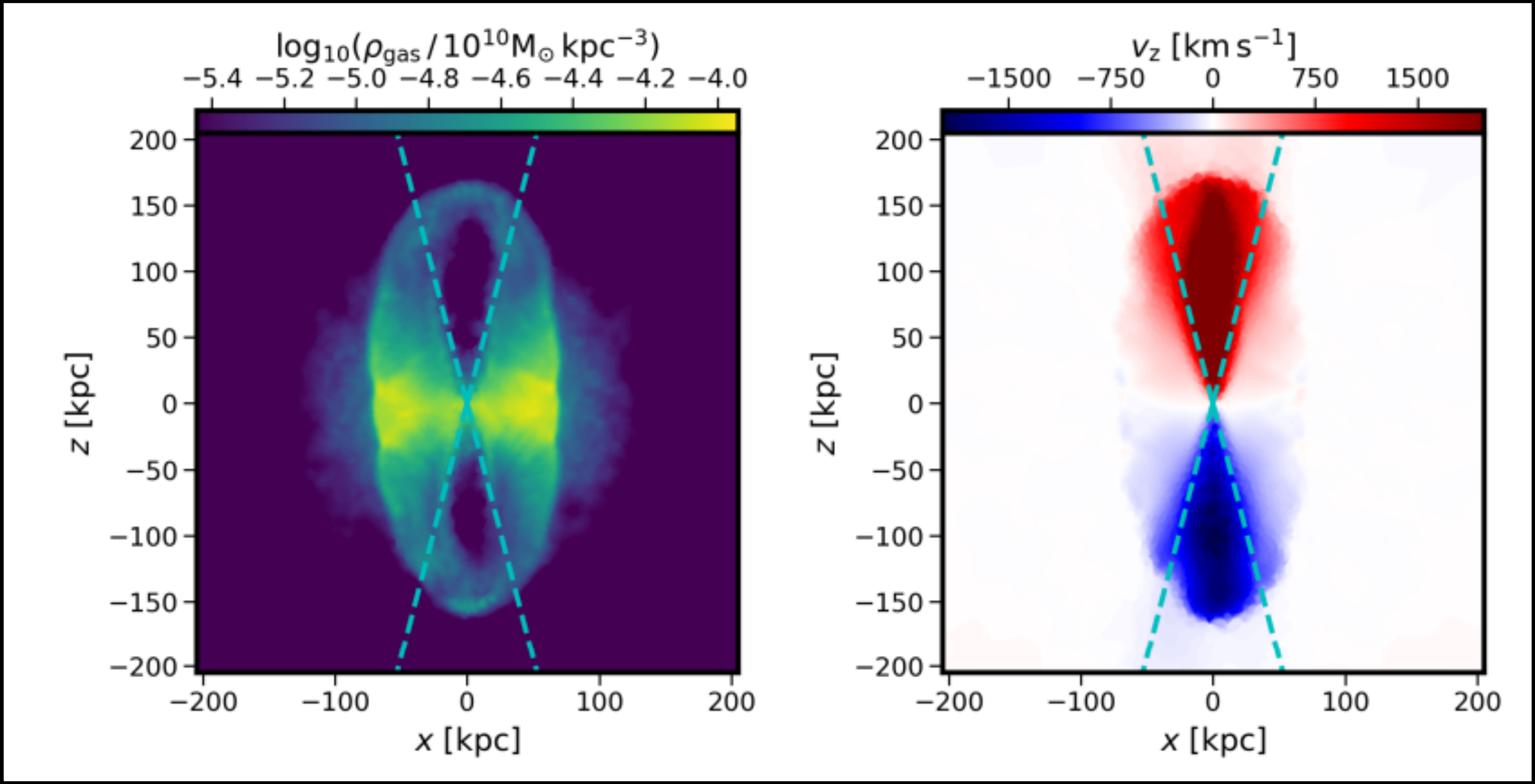
- The mean environmental density of a SNe explosion is reduced by 1-2 orders of magnitude.
- Increase the efficiency of the coupling between the feedback energy and the ISM.
- This means that the SNe momentum boost is increased by a factor of 2.



Conclusion - I

- Radiation fields play an important role in regulating star formation in sub L* galaxies.
- Radiation pressure is unimportant in these low gas surface density regimes, phtoheating is the most important effect
- The SFRs and the stellar mass formed are reduced by almost a factor of 2.
- The mass and energy loading factors are increased by more than an order of magnitude.
- The energy coupling between the SNe and the ISM is enhanced in the presence of radiation fields.

Radiation pressure driven outflows in high luminosity quasars

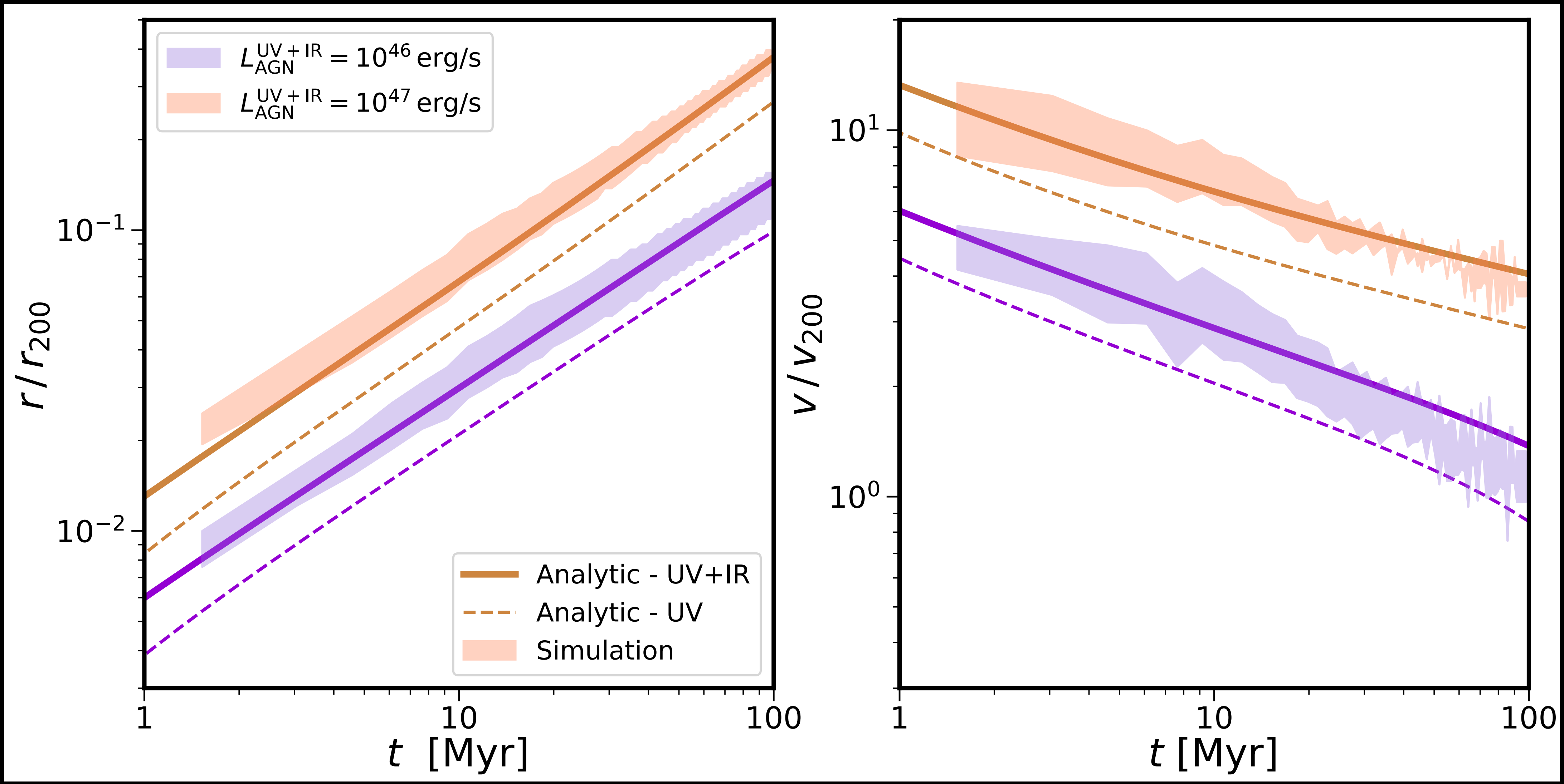


Barnes, RK + in prep.

Quasar outflows

- Luminous quasars output large amounts of radiation energy into the surrounding media.
- The outflow velocities can reach up to 0.1c
- There are generally multiphase and can be very dusty
- The momentum loading factors are of the order of 10 and energy loading of about 5%.
- We investigate the idea that these outflows can be driven by radiation pressure on dust (Dust model - McKinnon+2015)

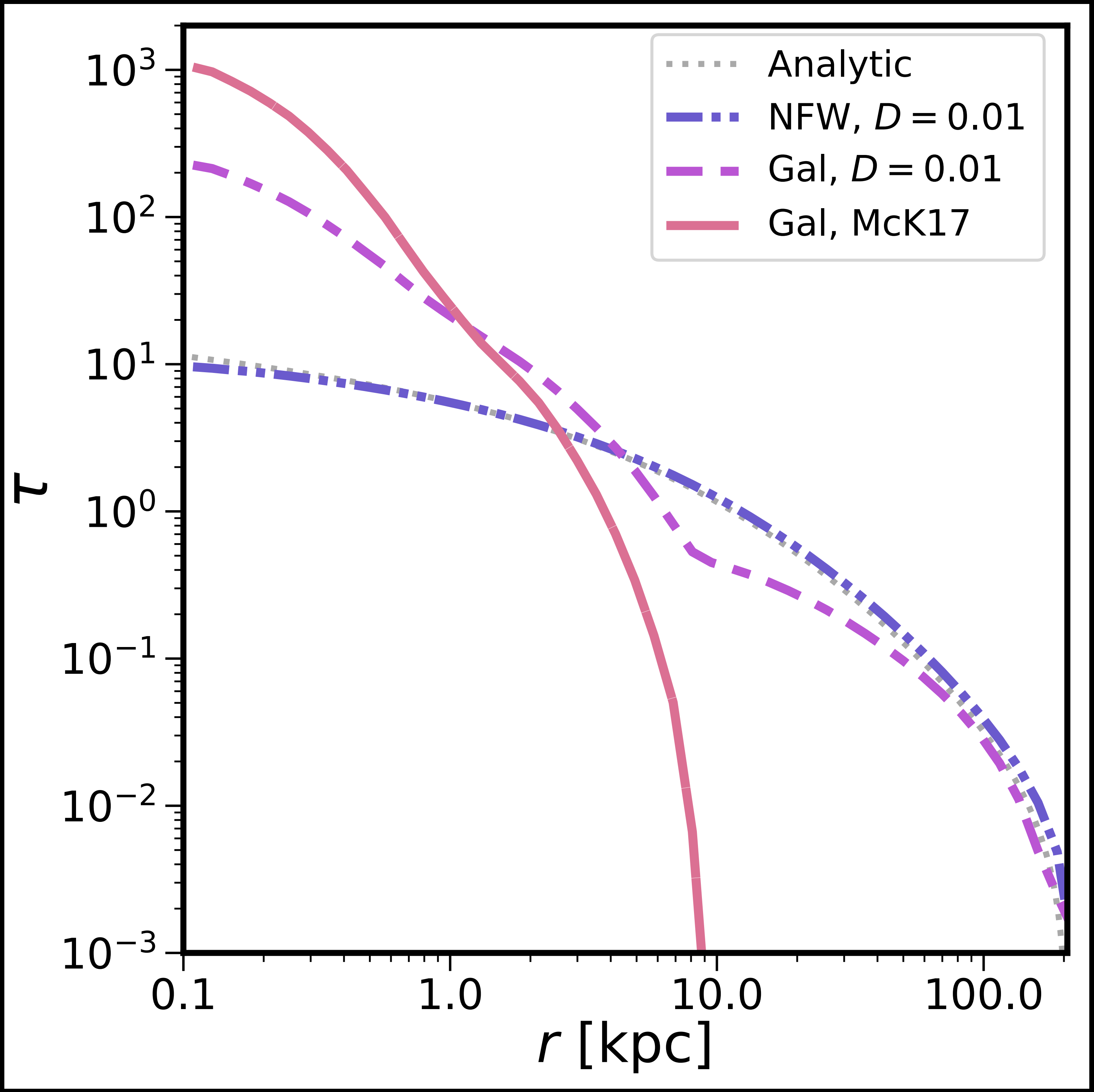
Analytic expectations



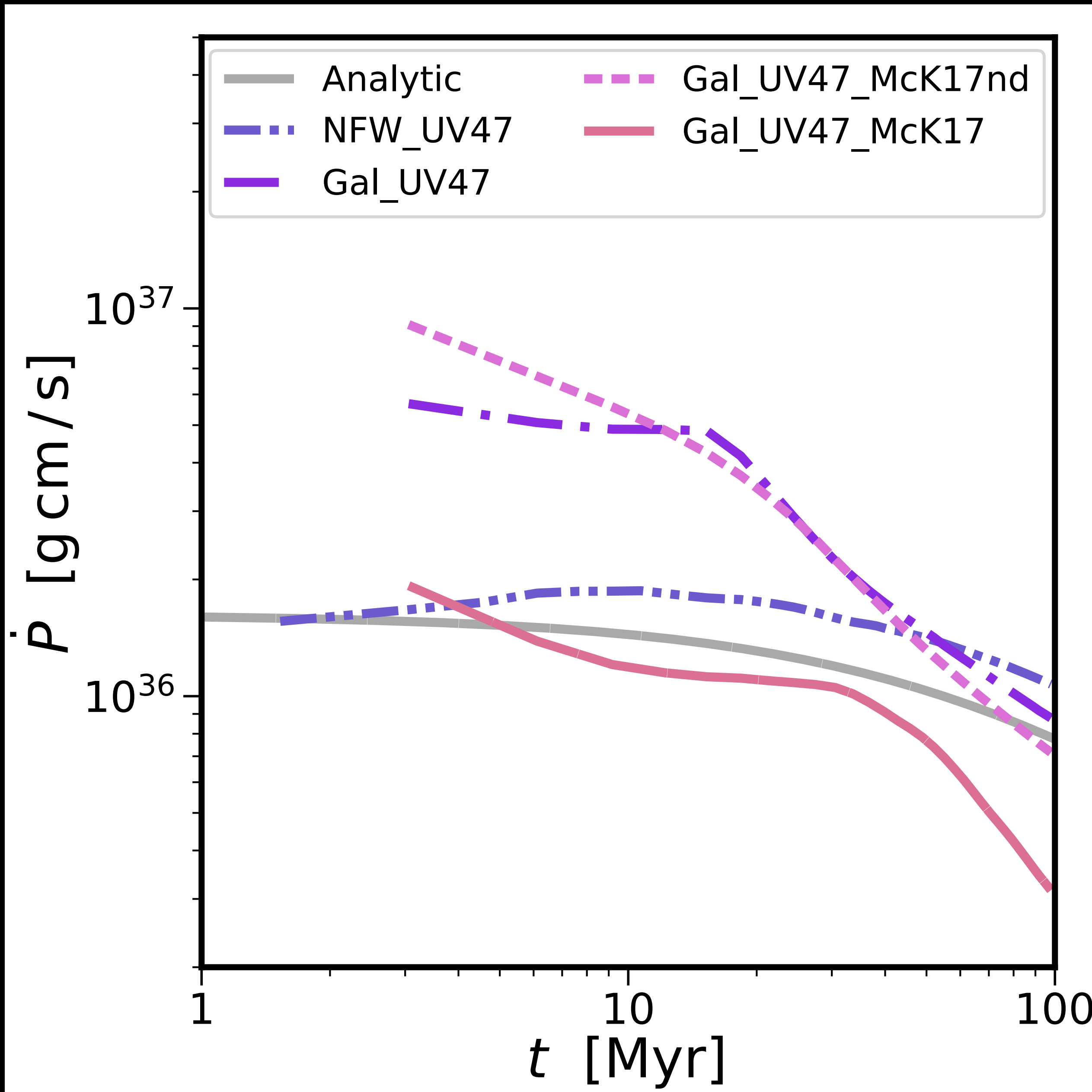
- Inject radiation field isotropically form a BH into a NFW halo with gas in hydrostatic equilibrium.
- Set the dust opacities and look at the outflow properties due to radiation pressure on dust.
- Matches the analytic expectation for both a UV and multi-scattered IR radiation pressure.

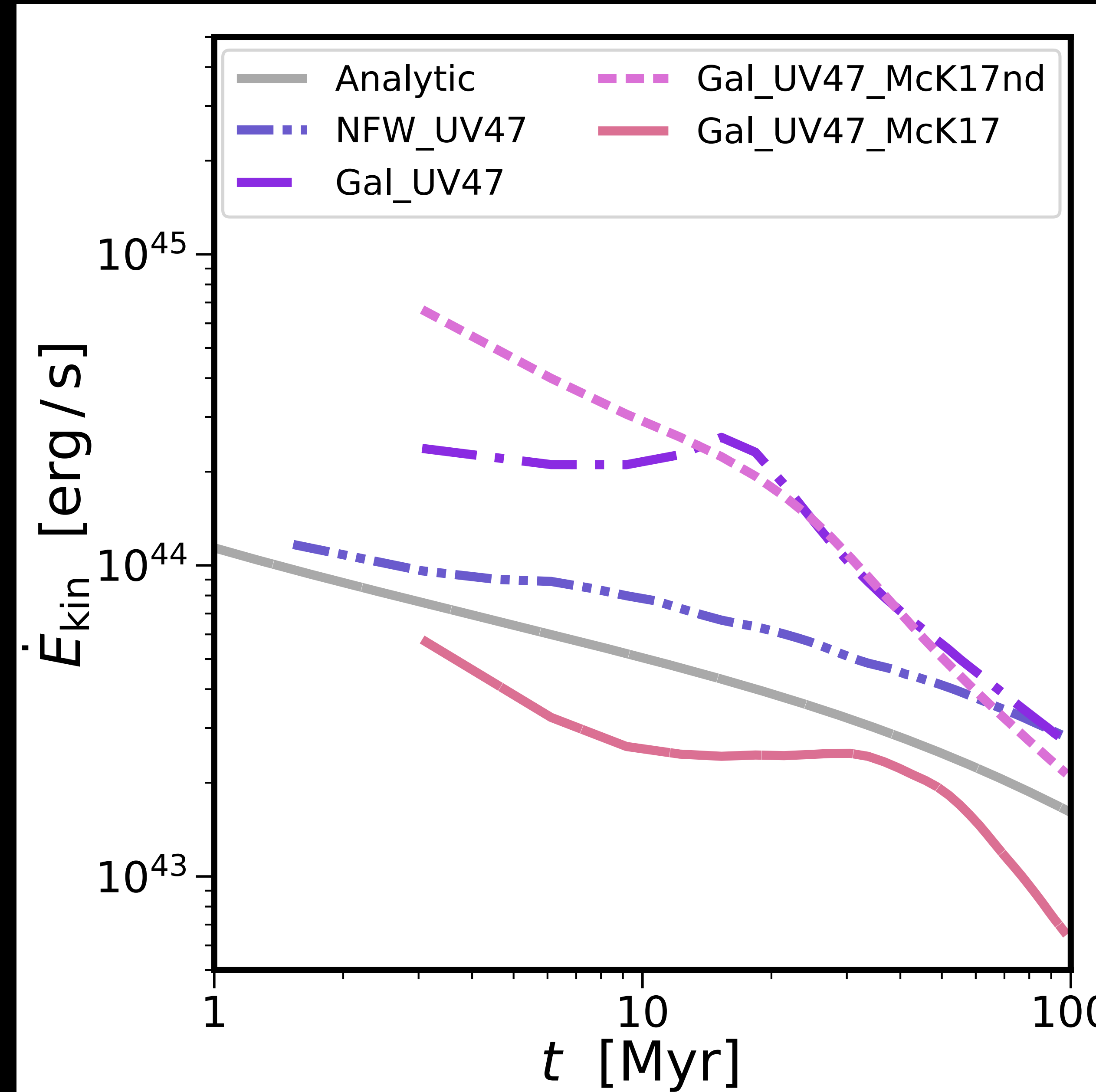
Increase in optical depth from dust formation

- Gas cooling and disk formation increases the IR optical depth by a factor of 20
- On top of this if dust formation physics is included then the optical is further increased by a factor of 5
- These higher optical depths can drive higher velocity outflows



Momentum and Energy loading of winds



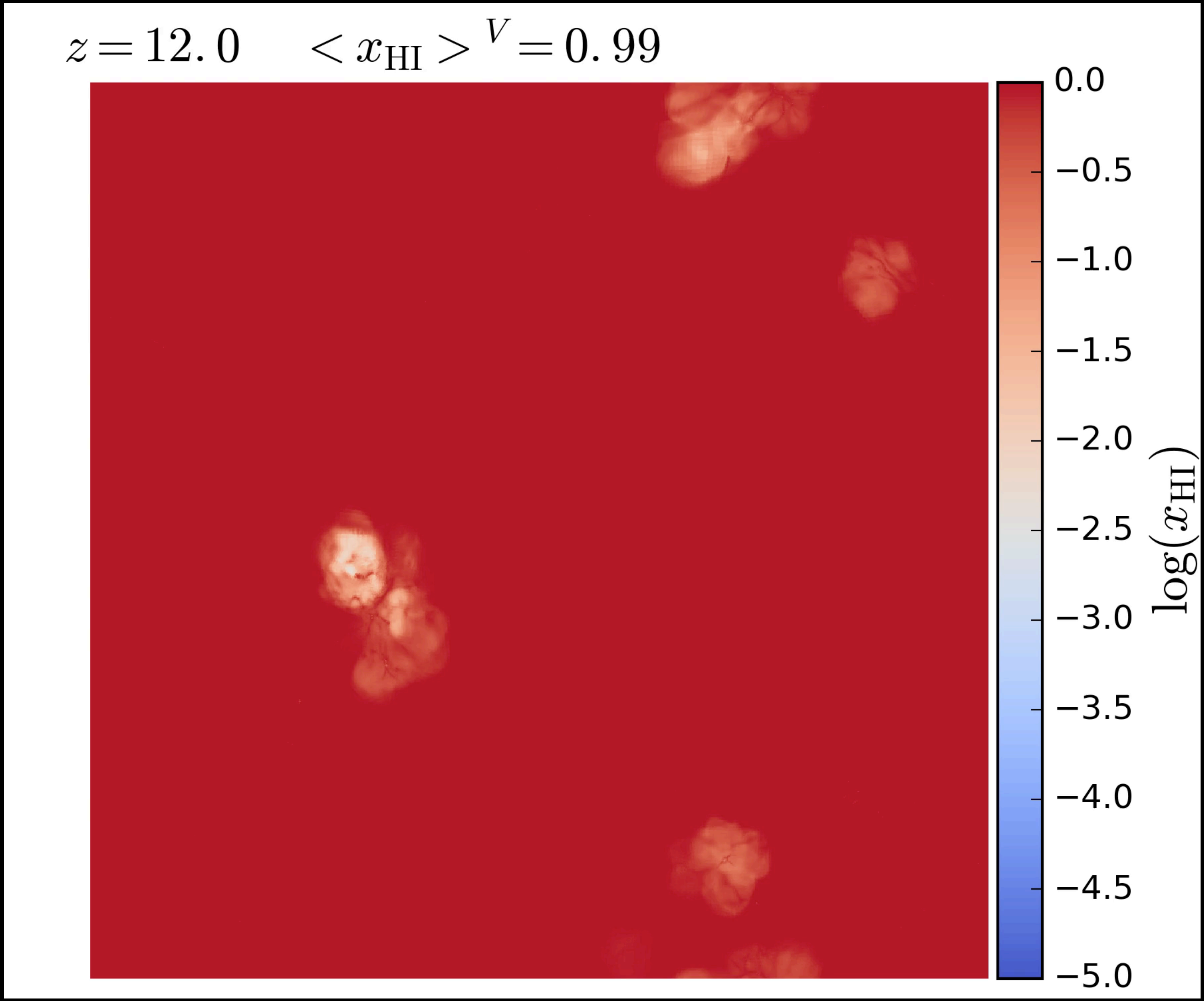


- The higher optical depths increase the mass and energy loading of the winds significantly.
- However, if we turn on thermal sputtering of dust, then the outflow shocks destroy dust and reduces the momentum and energy loading factors

Conclusion - II

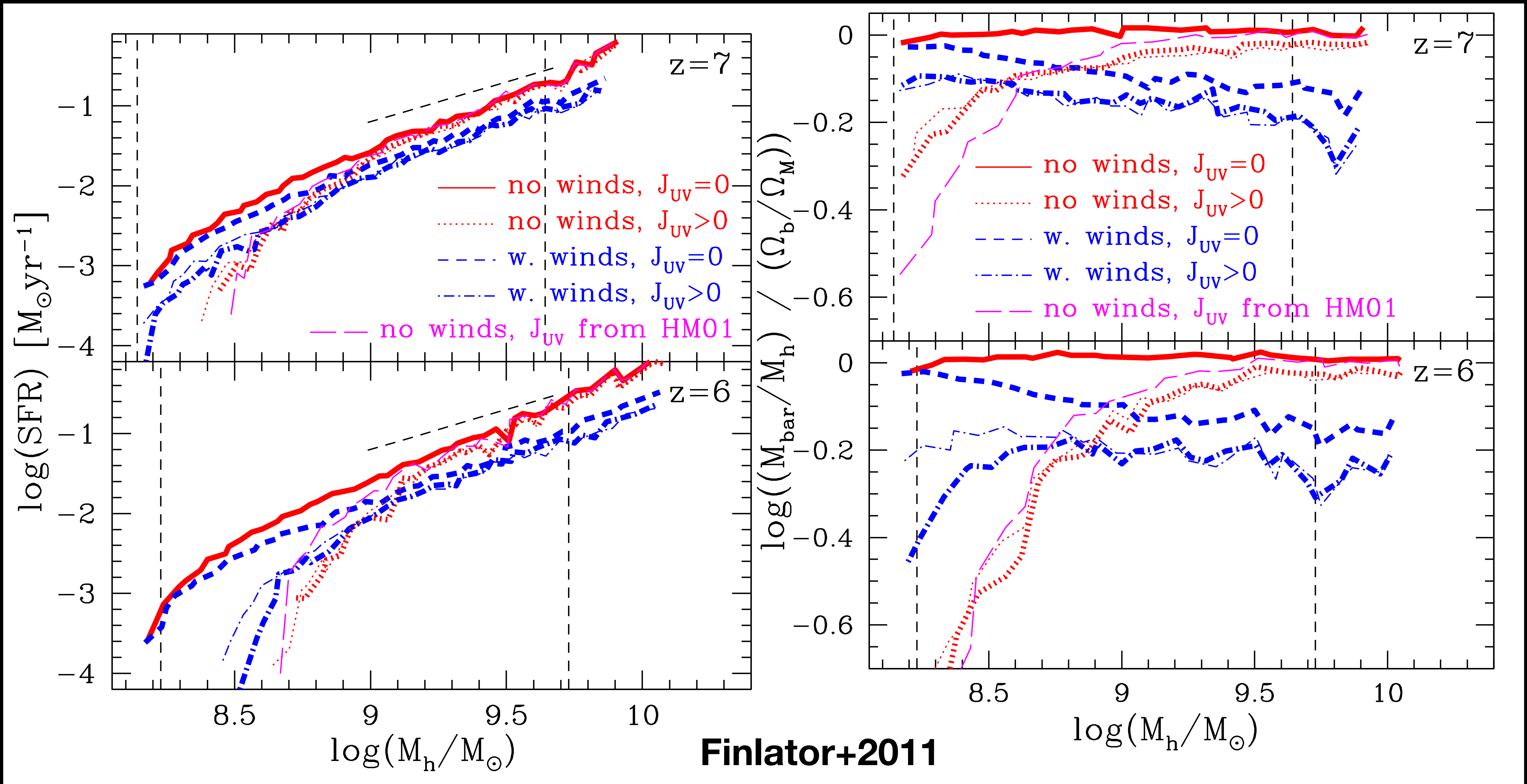
- Radiation pressure on dust can drive high velocity outflows.
- Gas cooling and disk formation enhances the optical depth allowing for lager momentum and energy loading factors.
- However, the outflow shocks will destroy dust due to thermal sputtering reducing the outflow velocities.

Investigating the sources that reionise the Universe and its impact on low mass haloes



Wu, RK+ in prep.

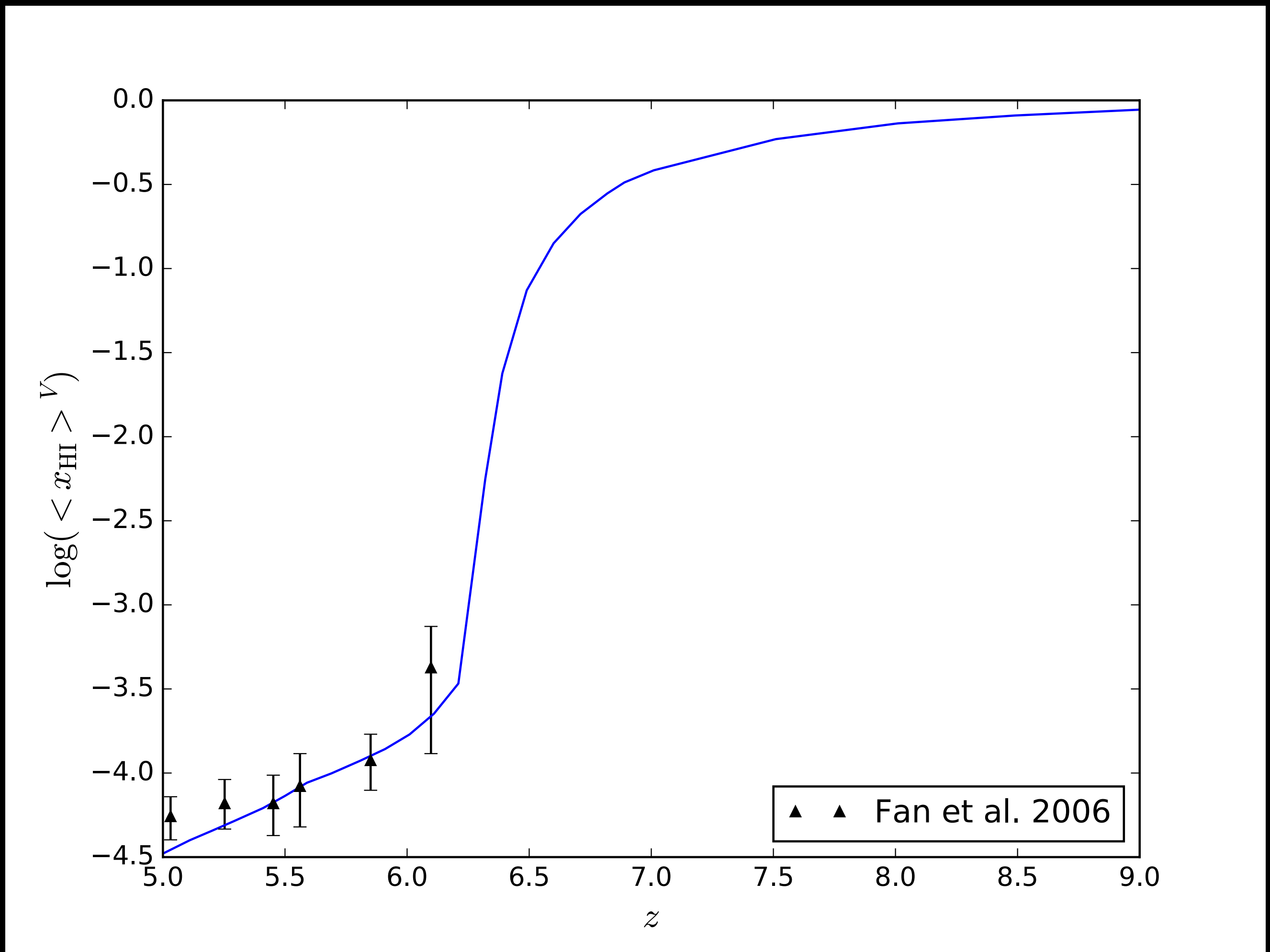
Reionisation and its impact on low mass haloes

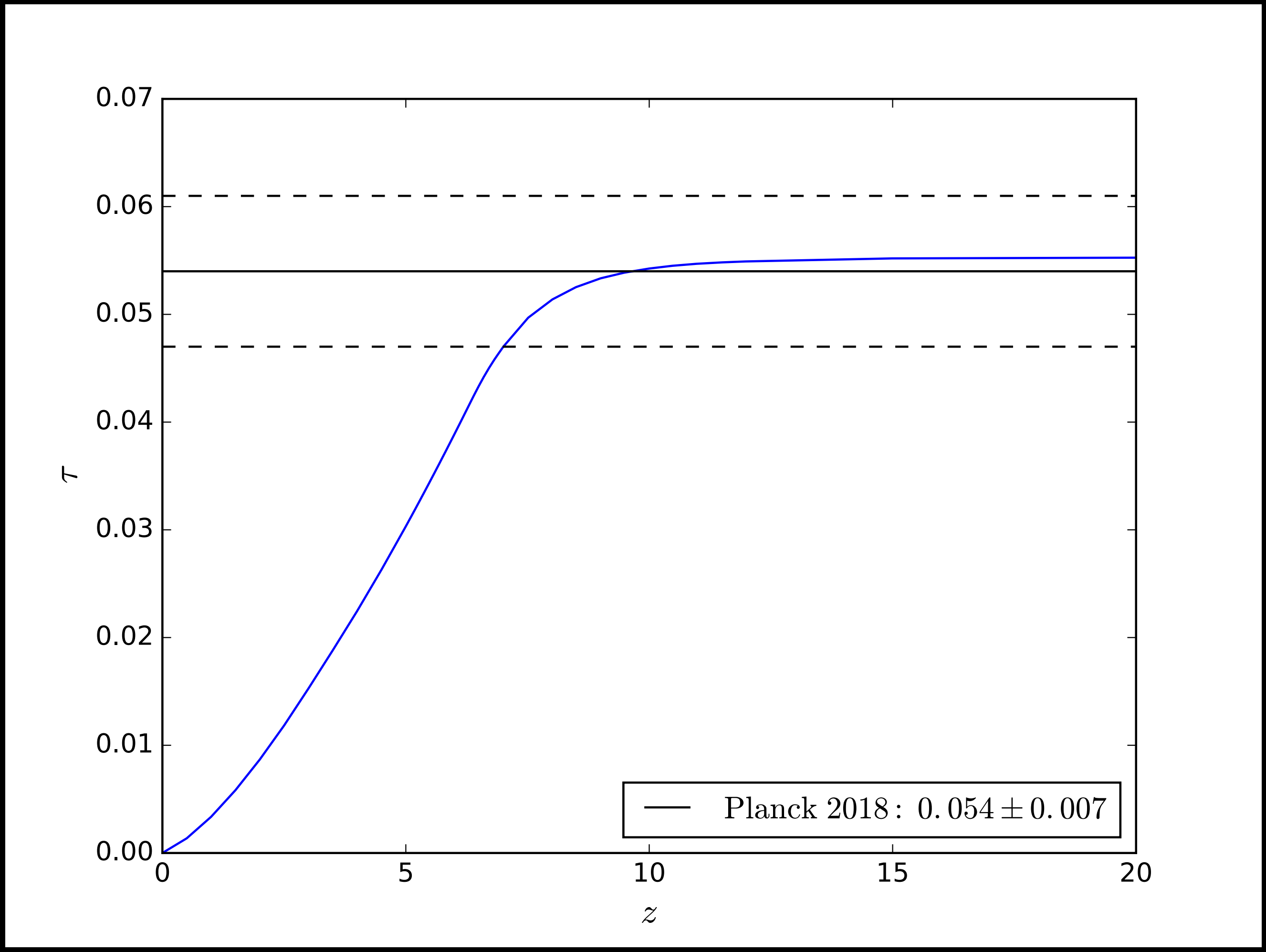


- Finlator+2011 showed that the photo heating during reionisation can reduce the star formation rate in low mass galaxies
- This also reduces the UV luminosity function and the stellar mass functions
- Caveat - These simulations where performed with a weak Sen feedback that **do not** match constraints at z=0.

Reionisation with the Illustris model

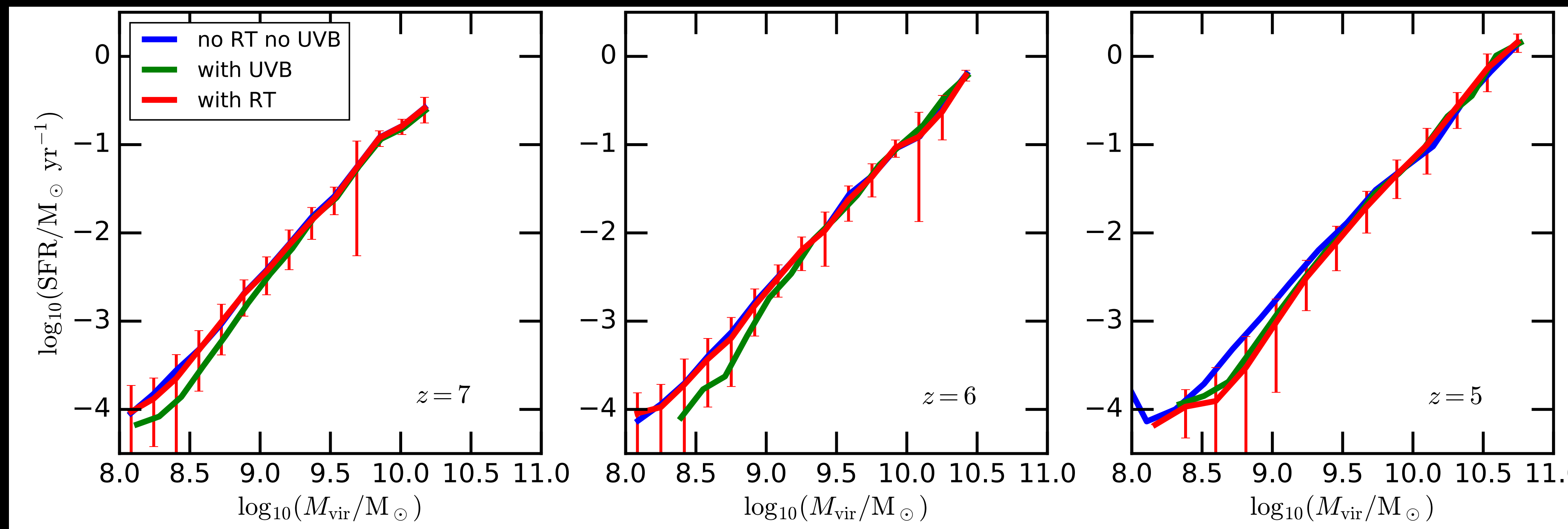
- 3, 6, 12 and 25 Mpc boxes - consider only stellar radiation sources
- 100% escape fraction from stellar nurseries - which is then attenuated by the ISM and CGM
- Illustris model for star formation, feedback and metal enrichment
- Matches the reionsation history and the Thompson scattering optical depth constraints from Planck

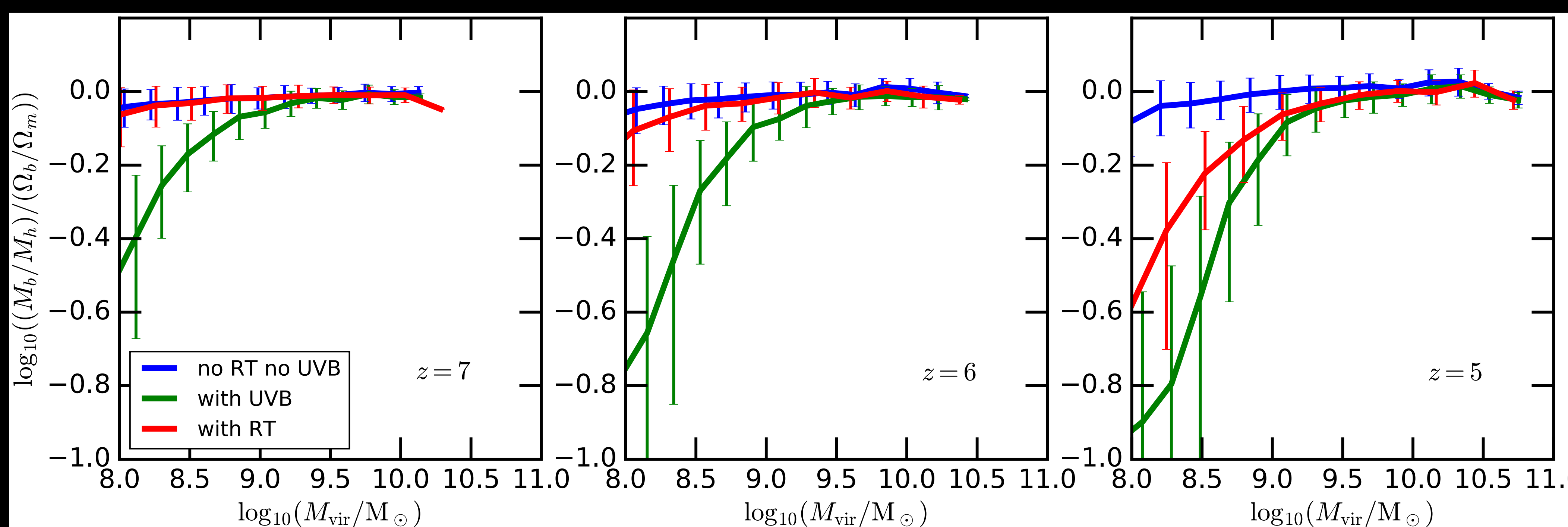




Impact on low mass haloes

- No suppression seen in the our model with radiation fields
- The stellar feedback is already too efficient that the radiation fields do not do much
- The baryon fraction is however suppressed, but not as much if a const UV background is assumed.





Conclusions -III

- Our simple model with Illustris galaxy formation physics reproduces the reionisation history of the Universe.
- The impact of radiation fields on the SFR os low gas galaxies is not as important as previously thought.
- The stellar feedback is efficient enough to drive outflows and regulate star formation.
- Shows the importance of simulating reionisation in a realistic galaxy formation model.

Summary

- Implemented an accurate and efficient RHD solver for Arepo.
- Useful to understand the effect of radiation fields in a wide range of environments.
- In low mass galaxies photo heating from massive stars increase the momentum output of the SNe by a factor of 2.
- Radiation pressure on dust unable to drive high velocity outflows if thermal sputtering of dust is included.
- In the presence of realistically strong stellar feedback, reionisation does not affect the star formation rate of low mass galaxies.