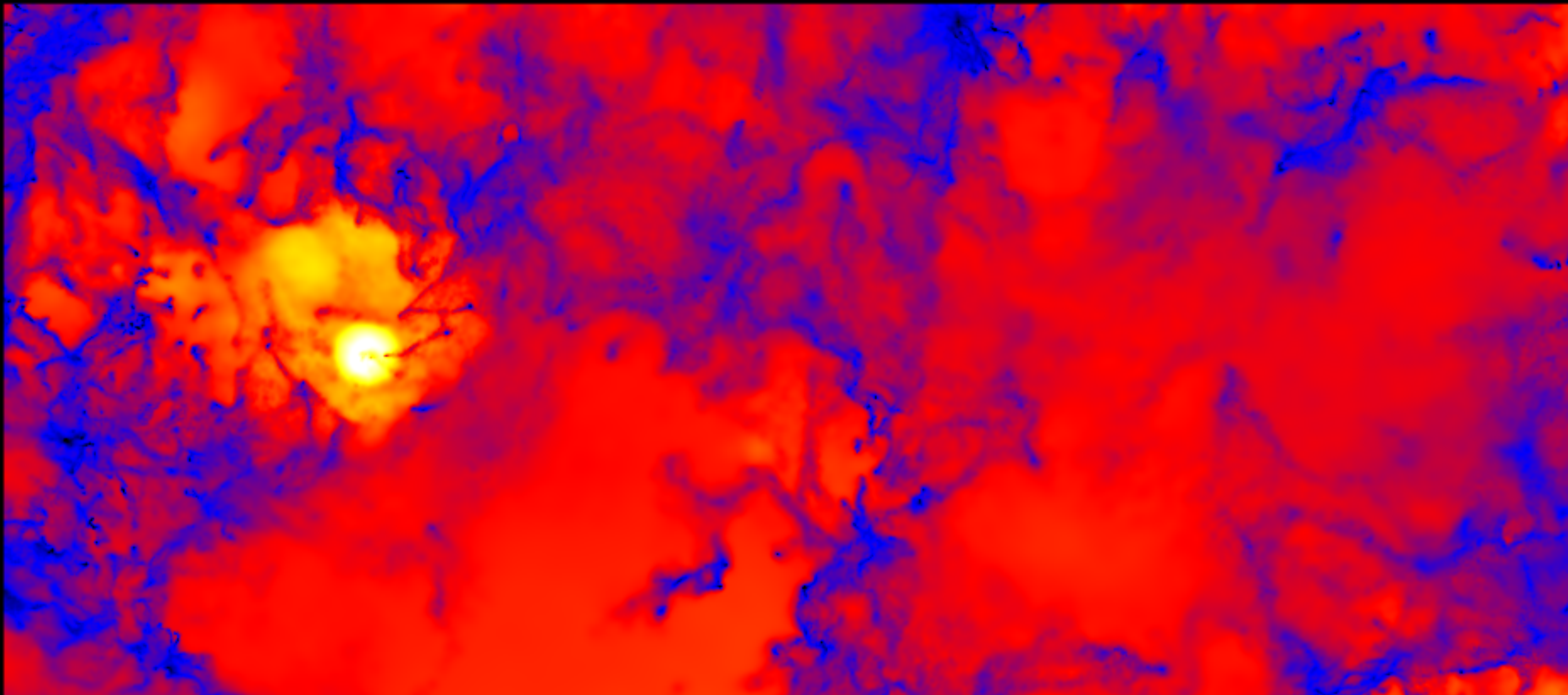

Impact of radiation fields in galaxies

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15th Potsdam Thinkshop - The Role of Feedback in Galaxies

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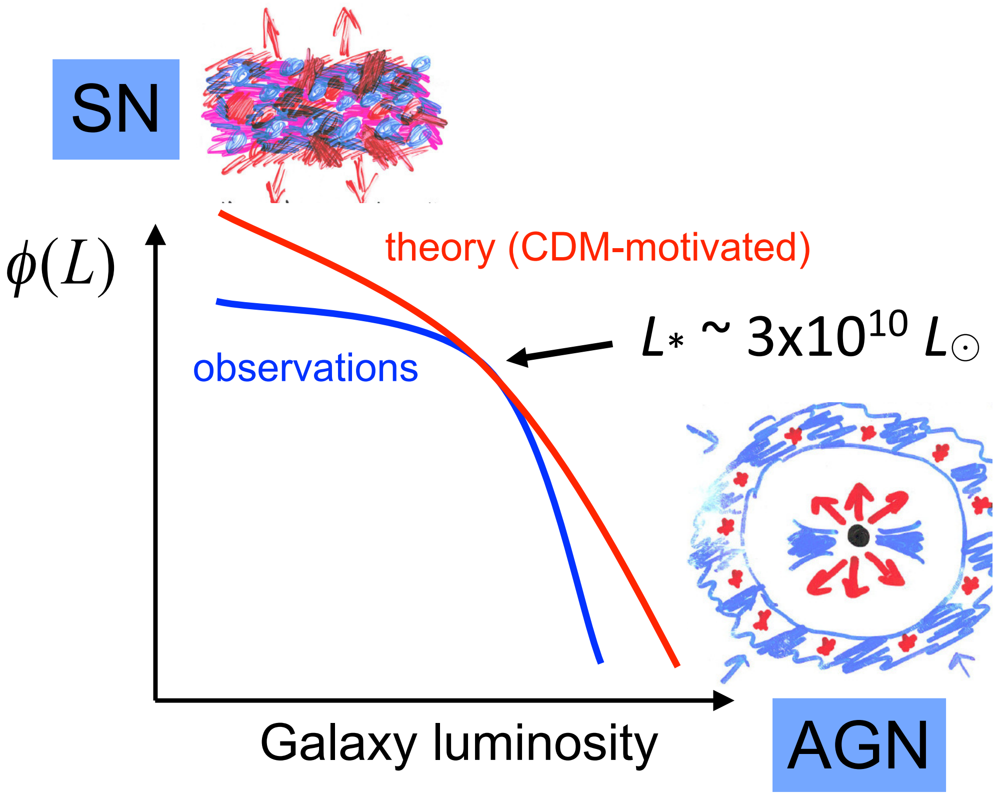
The stellar mass function

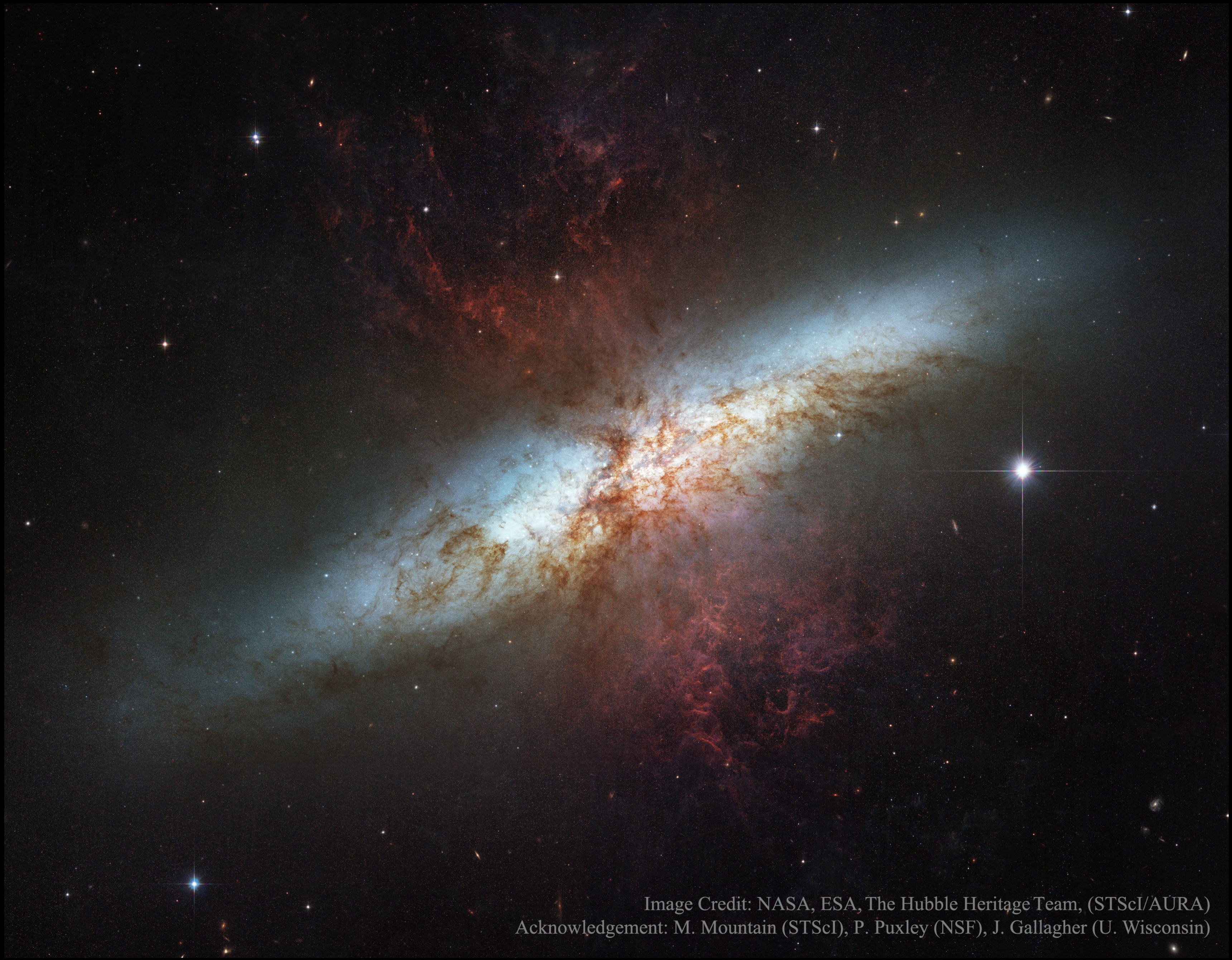


Silk+2012

- DM mass function - galaxy luminosity function have different shapes
- Suppression in star formation in both high and low mass galaxies
- SNe feedback invoked to explain the discrepancy in low mass galaxies
- AGN feedback has been invoked in high mass galaxies

SNe feedback

- SNe feedback has been invoked explain the regulation of star formation for quite some time (Steinmetz & Mueller 1994, Navarro et al. 1996)
- They inject huge amounts of energy and momentum into the inter-stellar medium (ISM)
- They help drive large galactic scale outflows thereby regulating the SFR

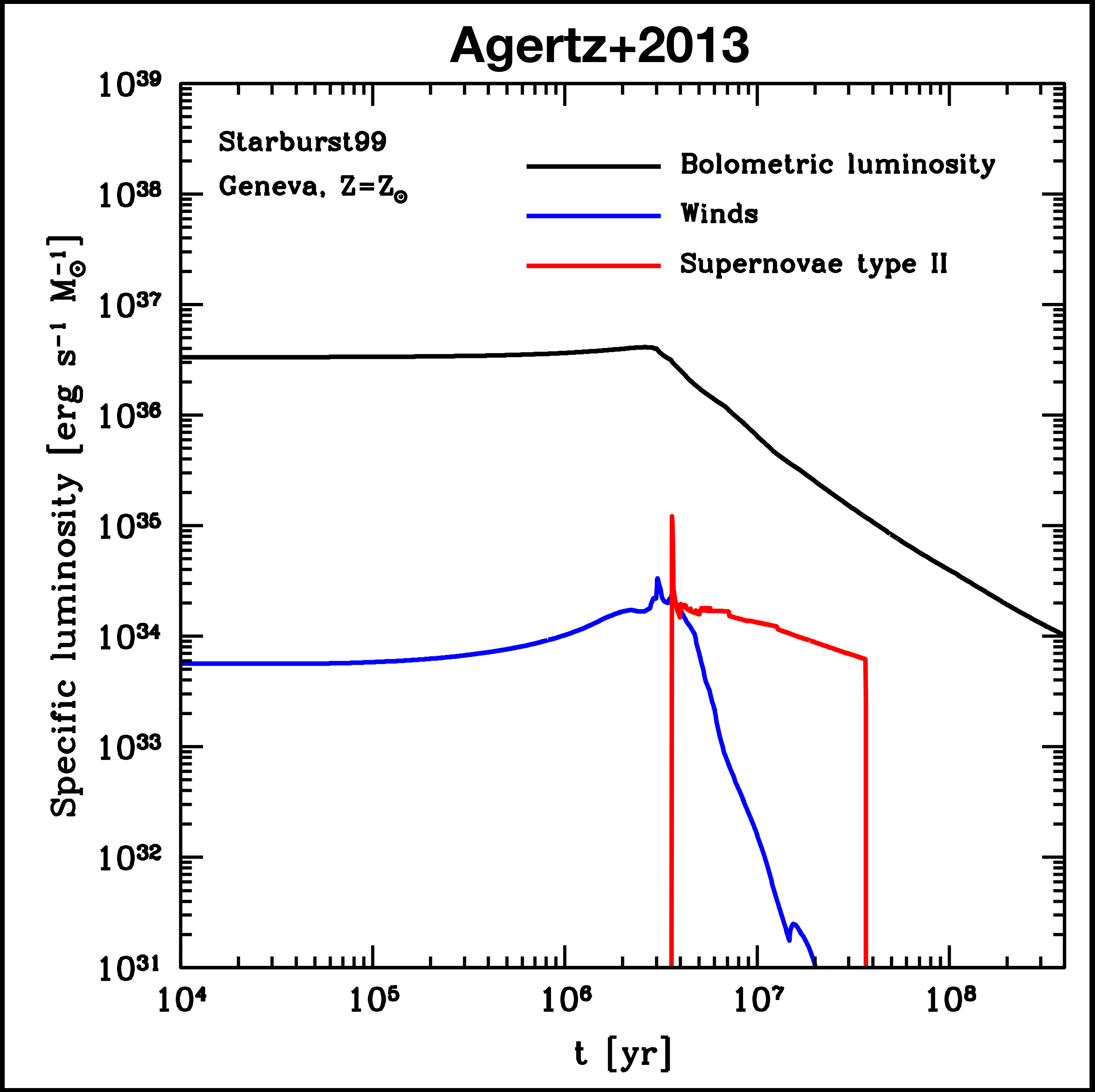


SNe feedback

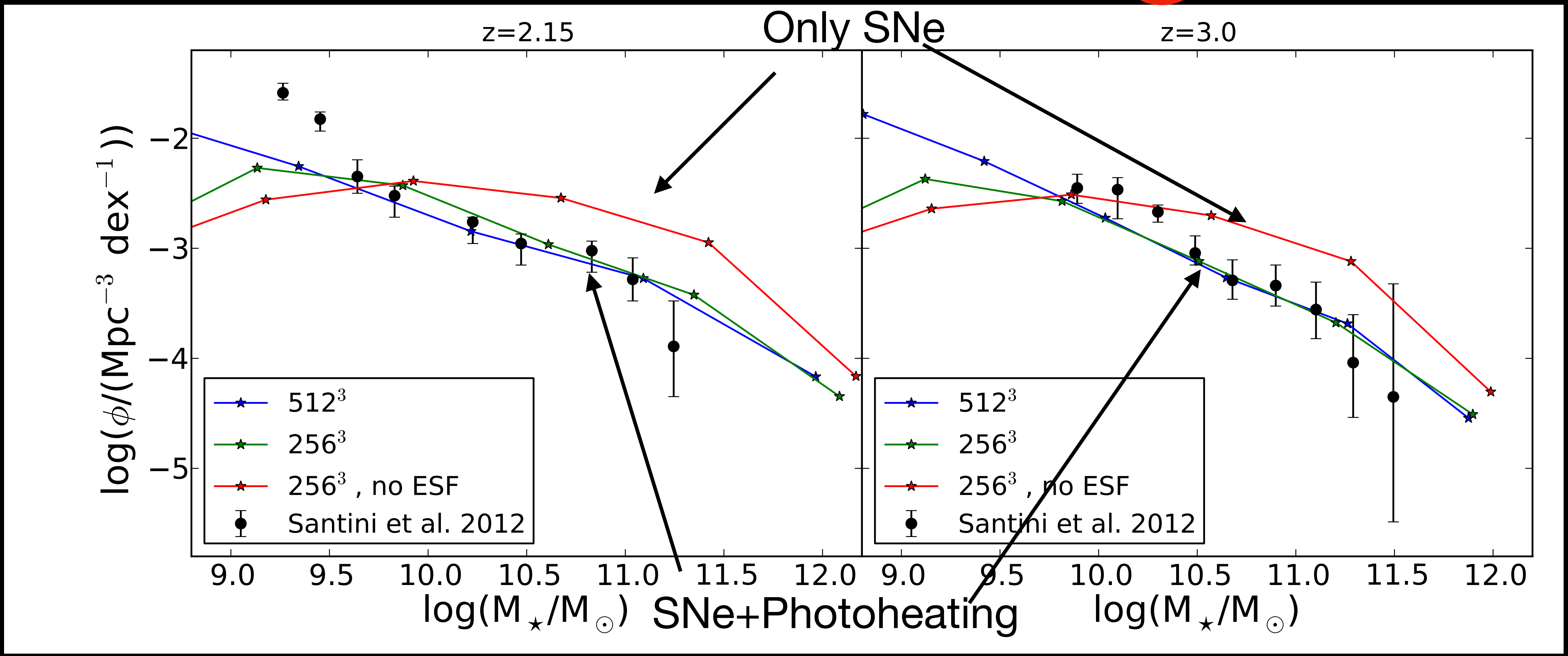
- Various sub-grid models exist : delayed cooling (Stinson+2006), Kinetic kicks (Springel+2003, Vogelsberger+2014), stochastic thermal feedback (Della Vecchia+2008) etc
- These models have been quite successful in reproducing the properties of galaxies in a broad sense (EAGLE-Schaye+2015, Illustris-Vogelsberger+2014)
- However, they require tuning various parameters that do not necessarily map to a set of physical processes
- The models miss the important physical processes like **radiation fields** (Rosdahl+15) and cosmic rays (Pfrommer+16, Simpson+16) that can also help regulate star formation in galaxies

Radiation fields from Massive stars

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



Photoheating

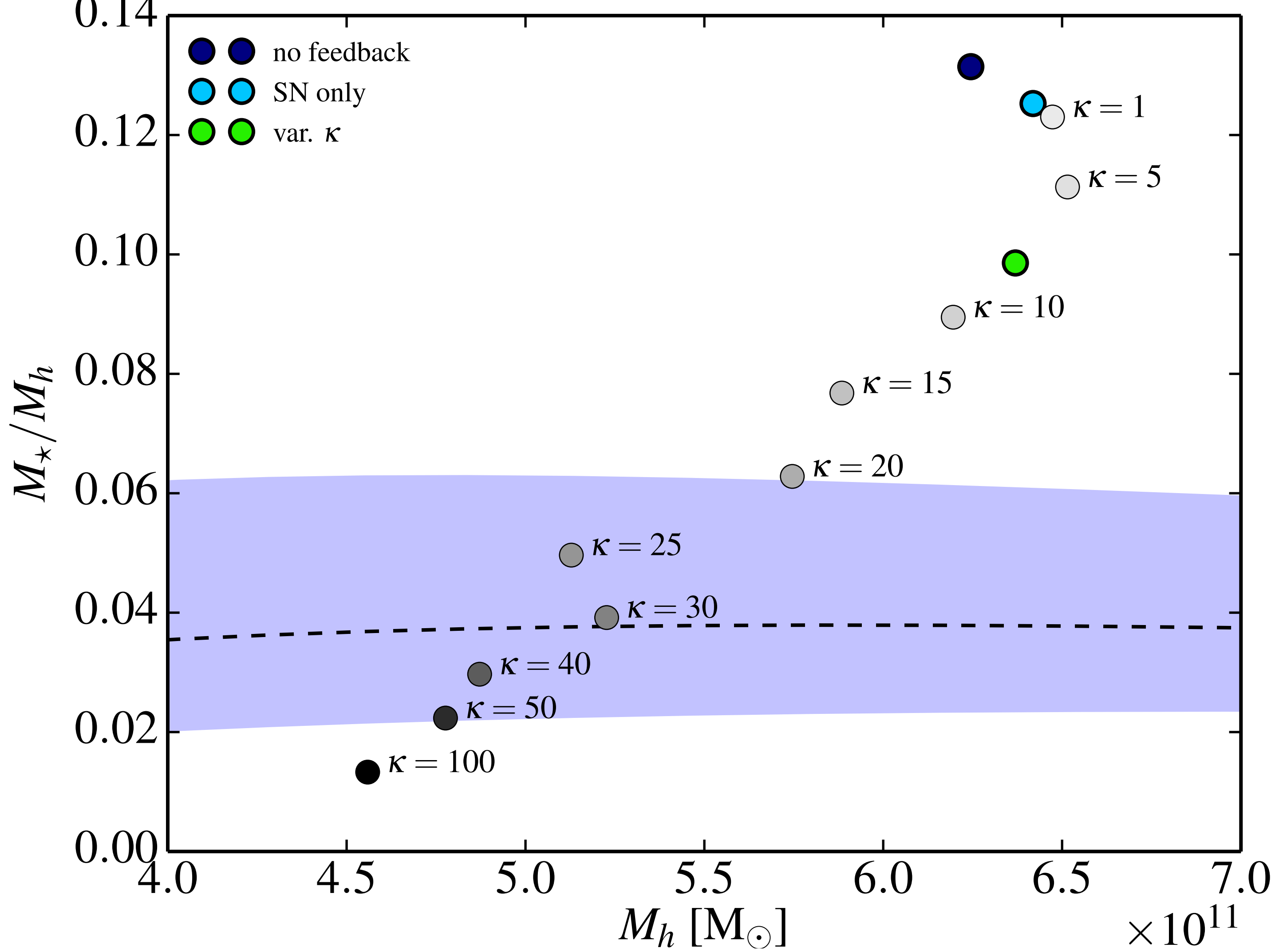


Stinson+2013, Kannan+2014a

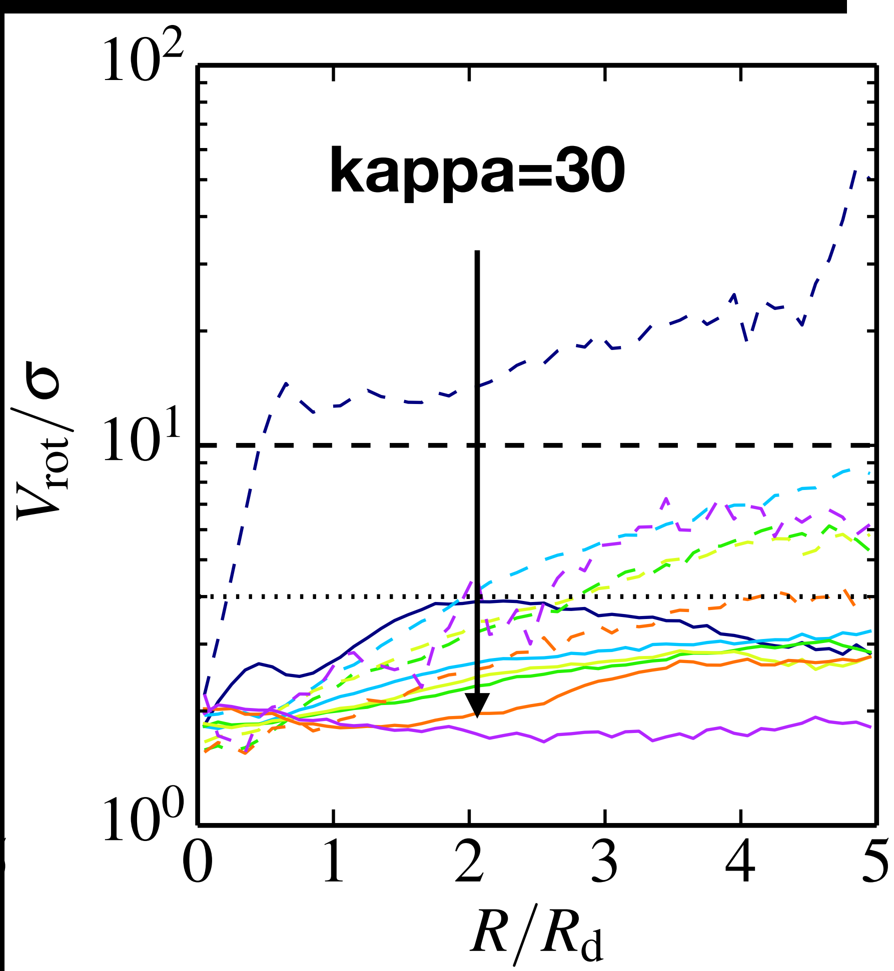
- Stinson+2013 : Subgrid model for photoionization, assume that *10% of the bolometric luminosity of stars thermalizes around stars* and heats the surrounding gusto 1e4 K.
- Reduces SFRs by disrupting the high density regions in the ISM
- Matches a wide range of galaxy properties like galaxy luminosity function, stellar-halo mass function etc. (Kannan+2014a)

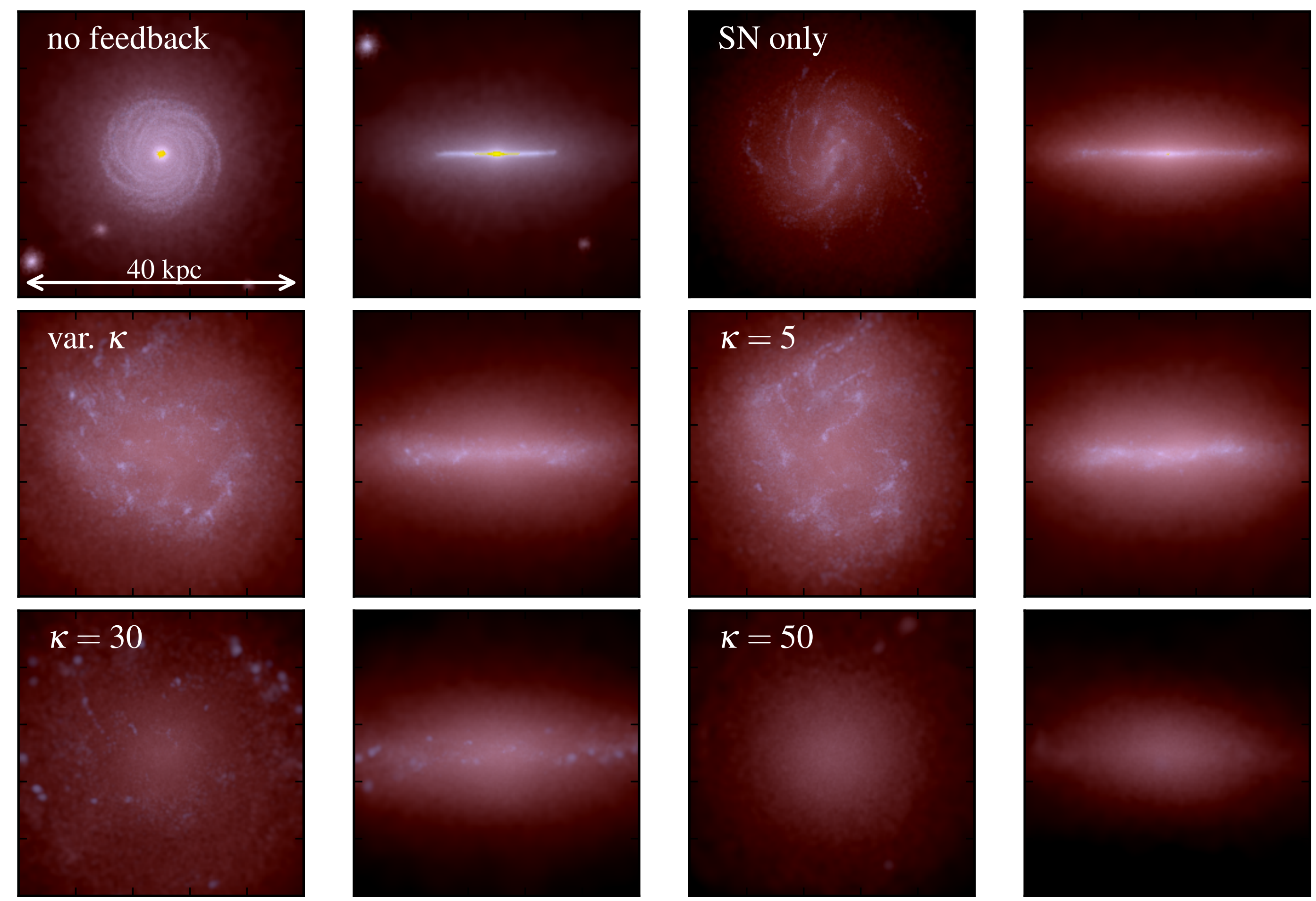
Radiation Pressure

- Radiation pressure can impart momentum around massive stars and maybe able to drive large scale outflows (Hopkins+2011, Agertz+2014)
- Invokes trapped radiation pressure
- $\dot{p} = \frac{L}{c}(1 + \tau_{IR})$ value of τ_{IR} *a free parameter*
- Need high optical depths to reproduce the low star formation efficiencies but it makes make the feedback extremely explosive and destroys the disc in order to obtain self-regulation



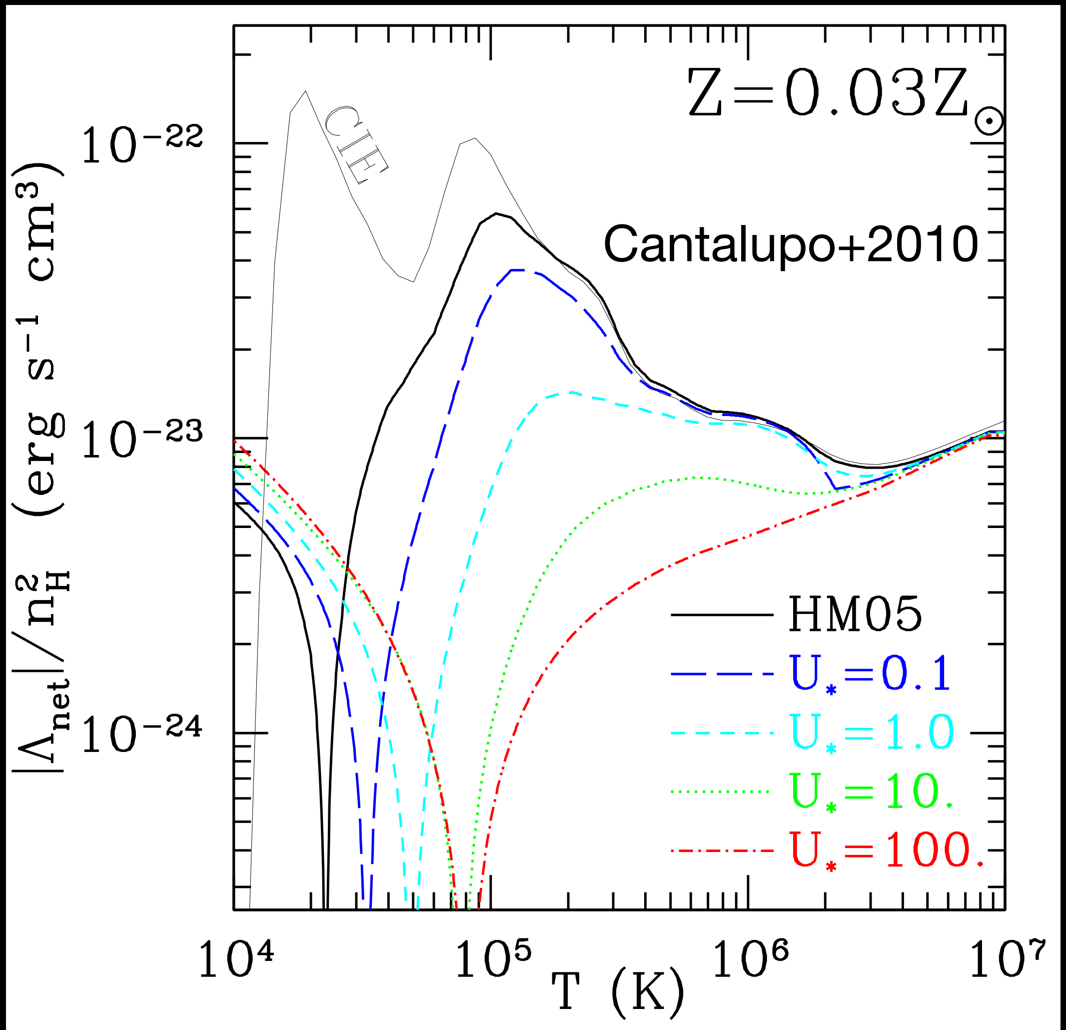
Roskar+2014

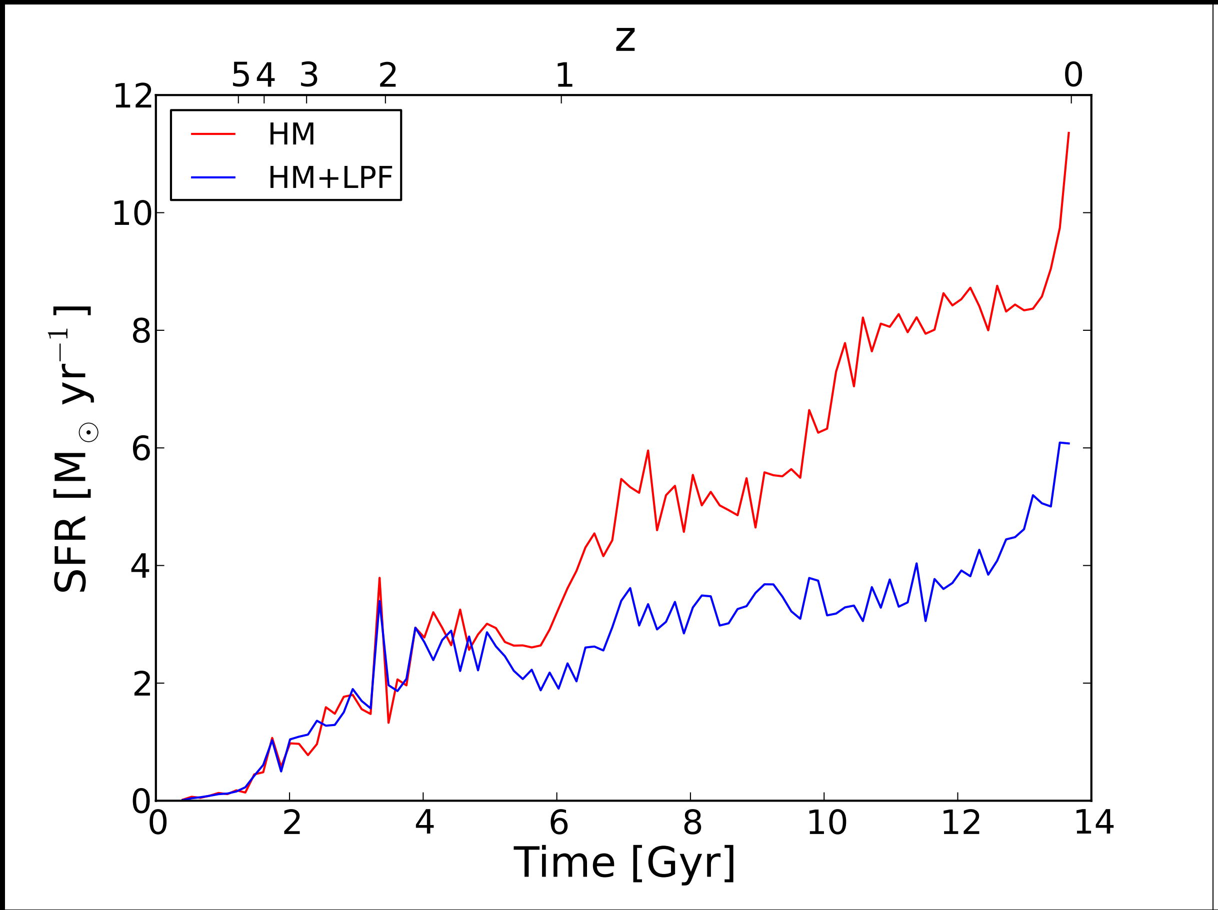


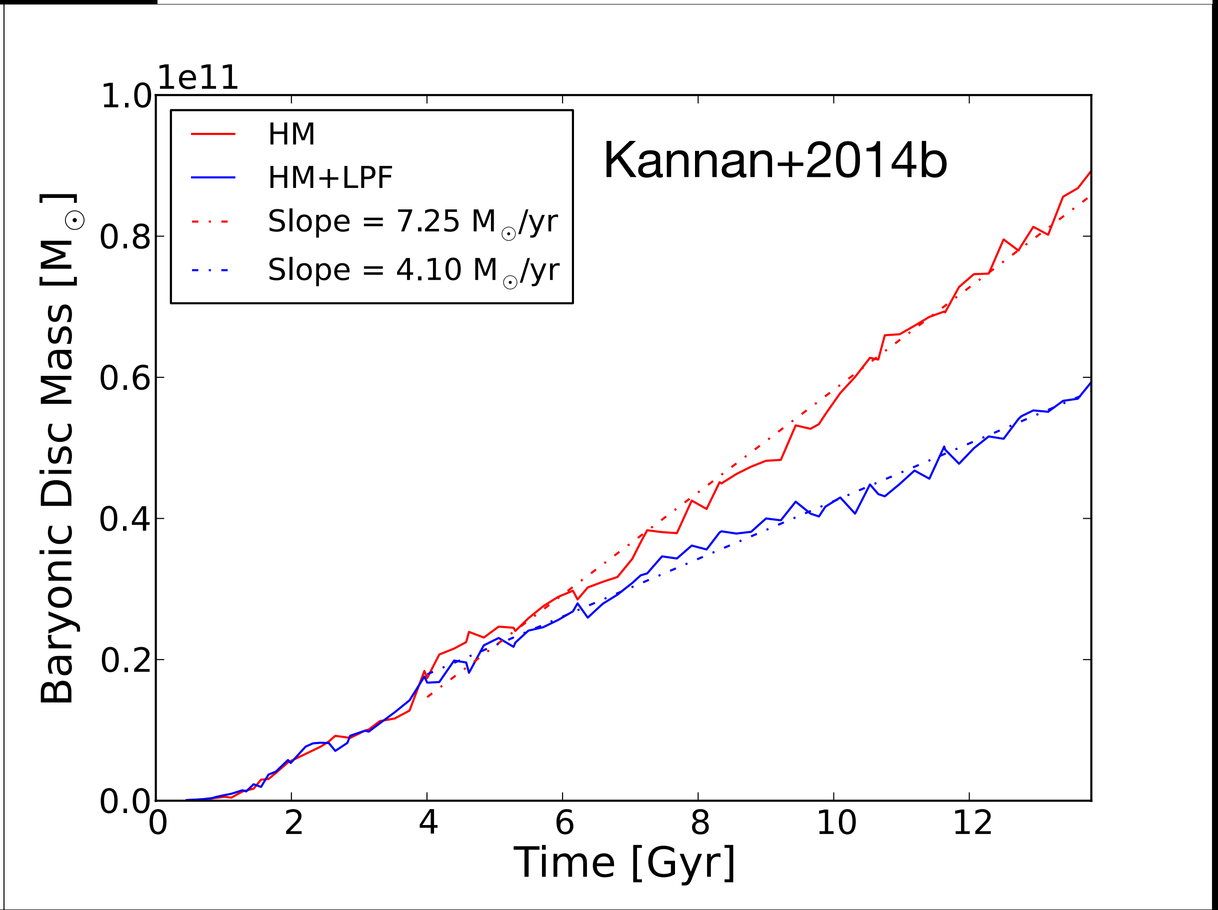


Local Photoionization Feedback

- Radiation fields can also reduce the cooling rate of the CGM gas by ionizing the relevant ionic species (Cantalupo+2010, Kannan+2014b,2016a, Hopkins+2017)
- Using a *source absorption and optically thin* approach Kannan+2014b showed that this affect can reduce the star formation rates in MW like galaxies by a significant amount





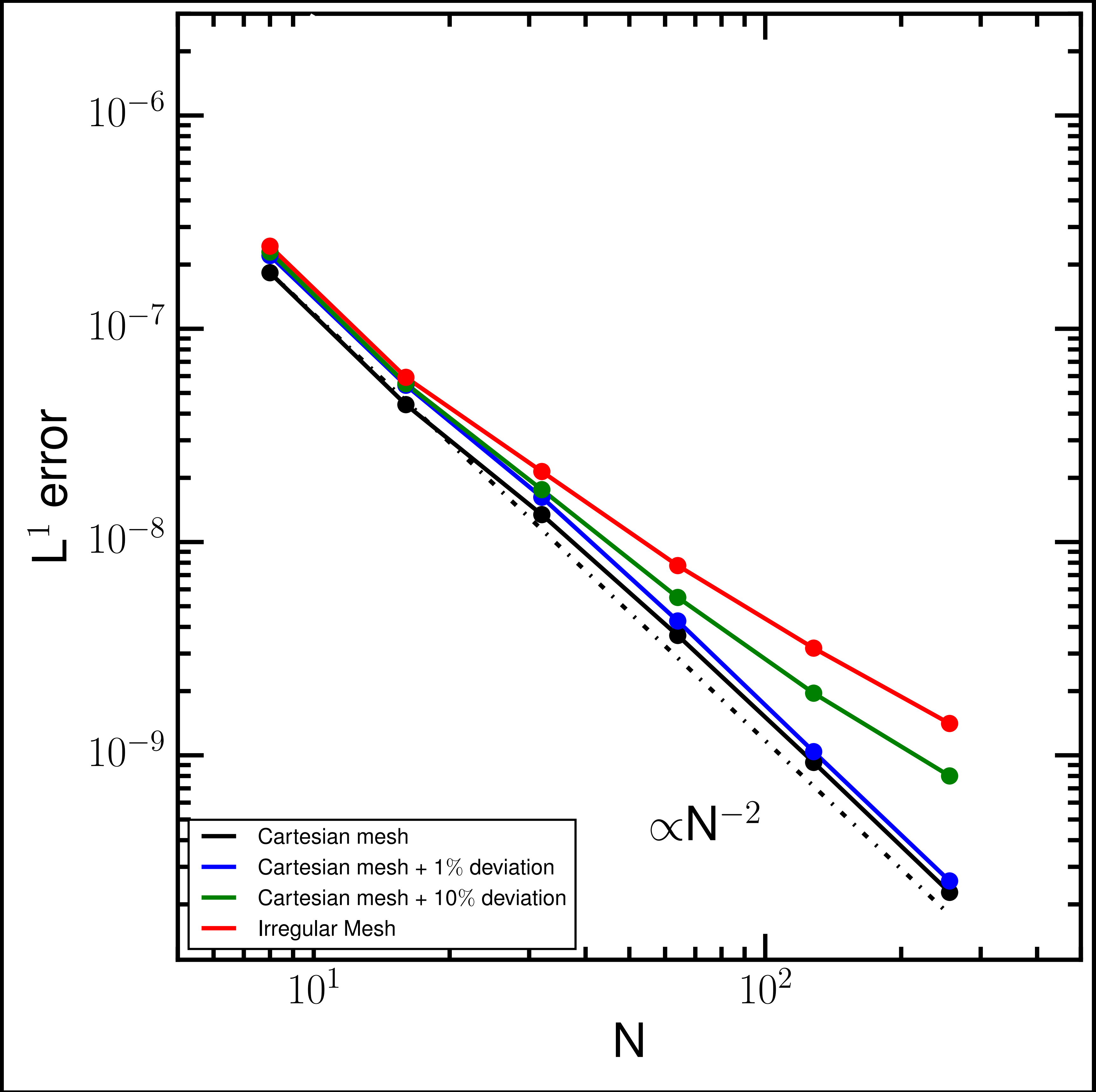


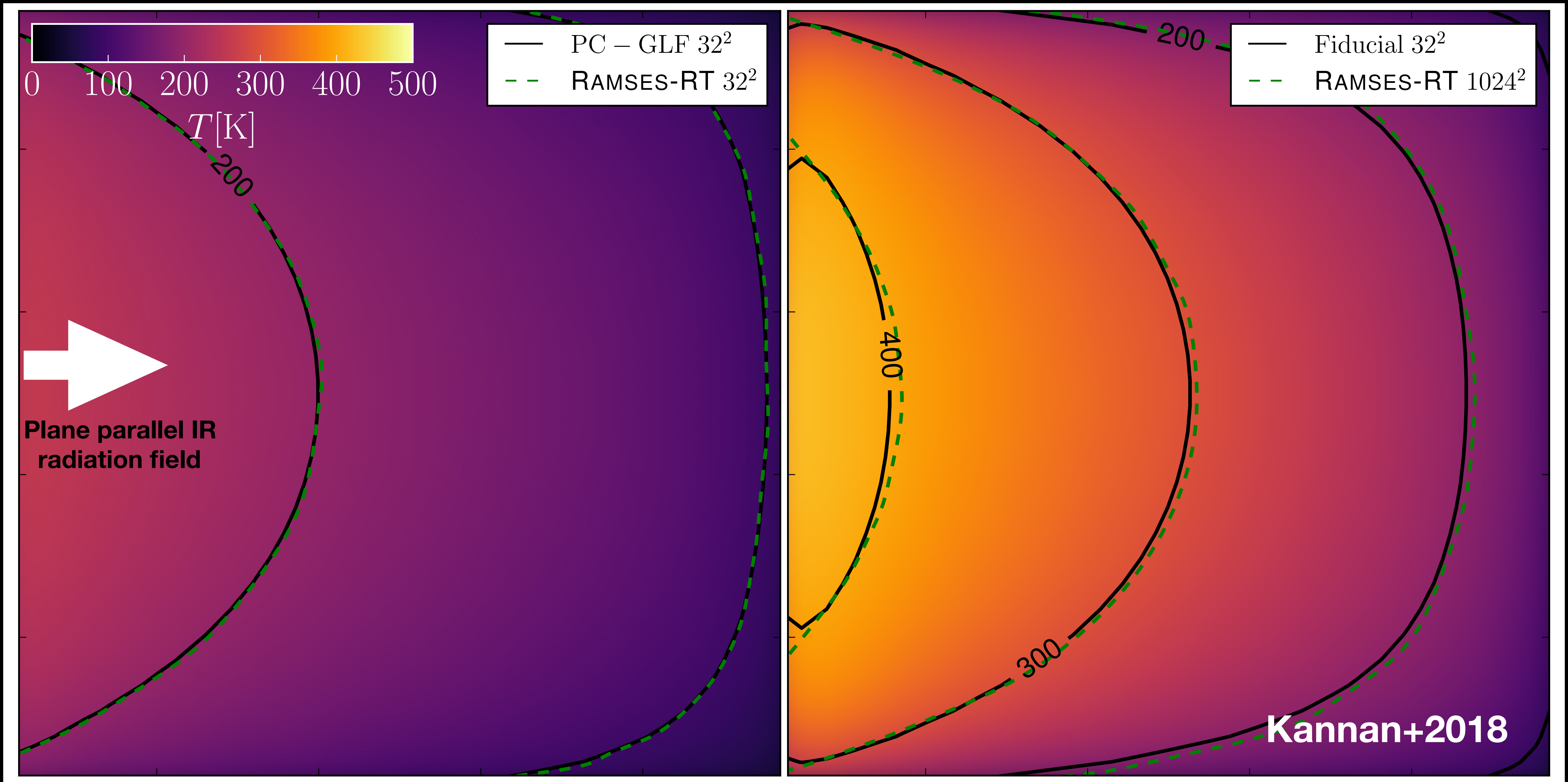
Radiation fields from Massive stars

- Many models invoke radiation feedback to regulate star formation
- However, most of these models use some form of empirical sub grid recipes
- They need to make assumptions about optical depths, gas self-shielding and highly idealized thermalization and momentum transfer rates from the photon field to gas
- These assumptions have not been tested or verified by high resolution simulations that self-consistently include radiation fields
- There is a need to perform full radiation hydrodynamic (RHD) simulations in order to fully understand and quantify the role of radiation feedback (see for eg. Rosdahl+15)
- This requires an accurate and efficient Radiation Hydrodynamics code

Arepo-RT (Kannan+2018)

- Arepo-RT uses the M1 closure relation.
- It uses a linear gradient extrapolation scheme that is coupled to a Runge-Kutta like Heun's scheme to achieve higher order accuracy.
- The source terms are included in a Strang split approach, which makes the scheme formally second order accurate, even in the presence of source terms.

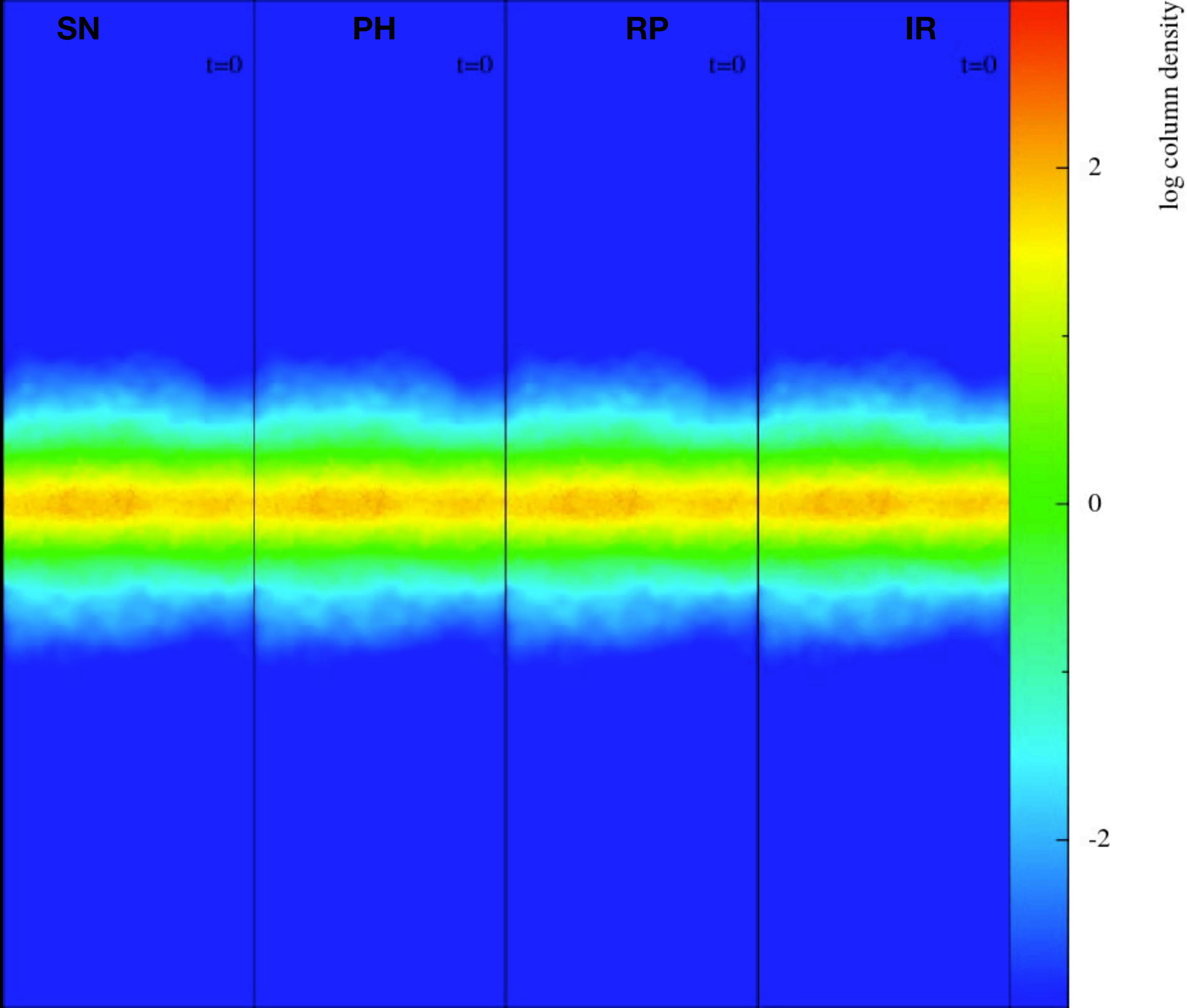




- Test: heating of gad/dust fluid due to the impinging IR radiation field
- Optical depth of the box = 200, for 32^2 resolution cell optical depth in 6.25
- A 32^2 simulation done with Arepo-RT can match the results obtained by a 1024^2 simulation performed by Ramses-RT

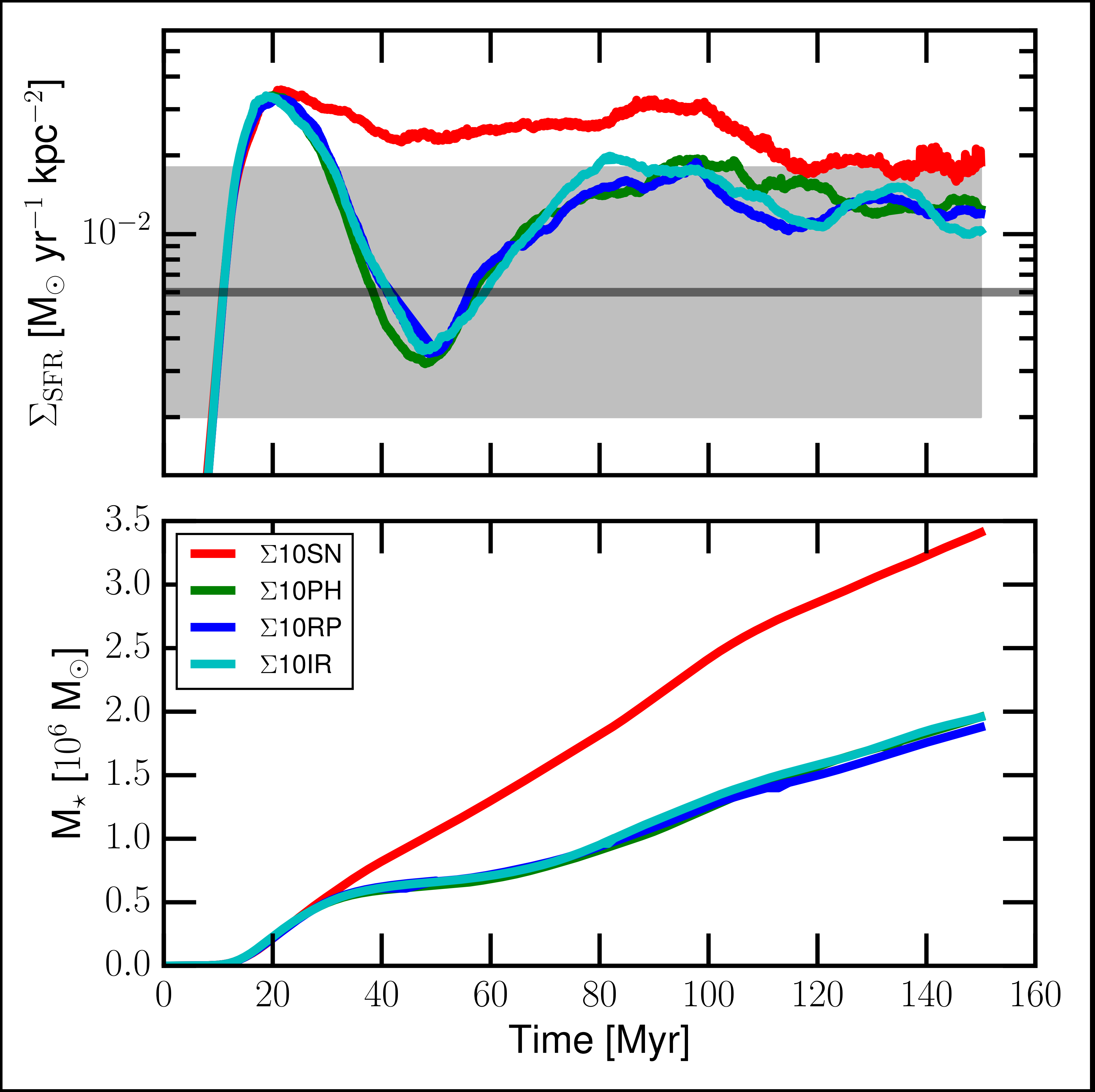
High resolution simulations of radiation feedback

- Tallbox simulations - 1 x 1 x 10 kpc box - solar neighborhood initial conditions ($5\ M_\odot/pc^2$, $10\ M_\odot/pc^2$, $20\ M_\odot/pc^2$)
- Mass resolution - 10 Msun
- Spatial resolution - Softening 0.13 pc (resolve strongmen radii at the SF density threshold - 100 /cc)
- 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

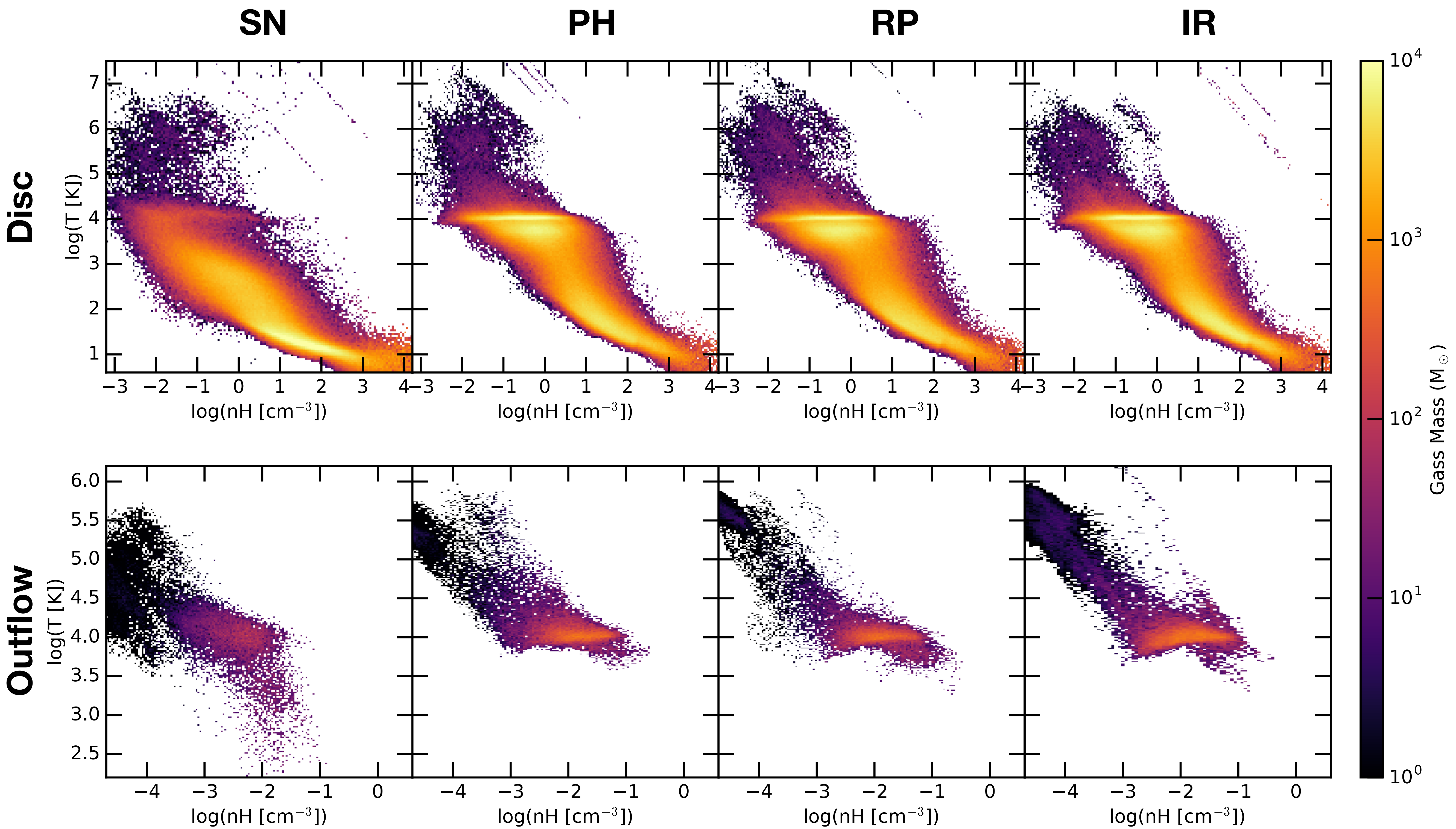

SN
PH
RP
IR
t=0
t=0
t=0
t=0
2
0
-2
log column density

Star formation rate surface density

- 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.
- Photoheating is the mechanism driving the trends

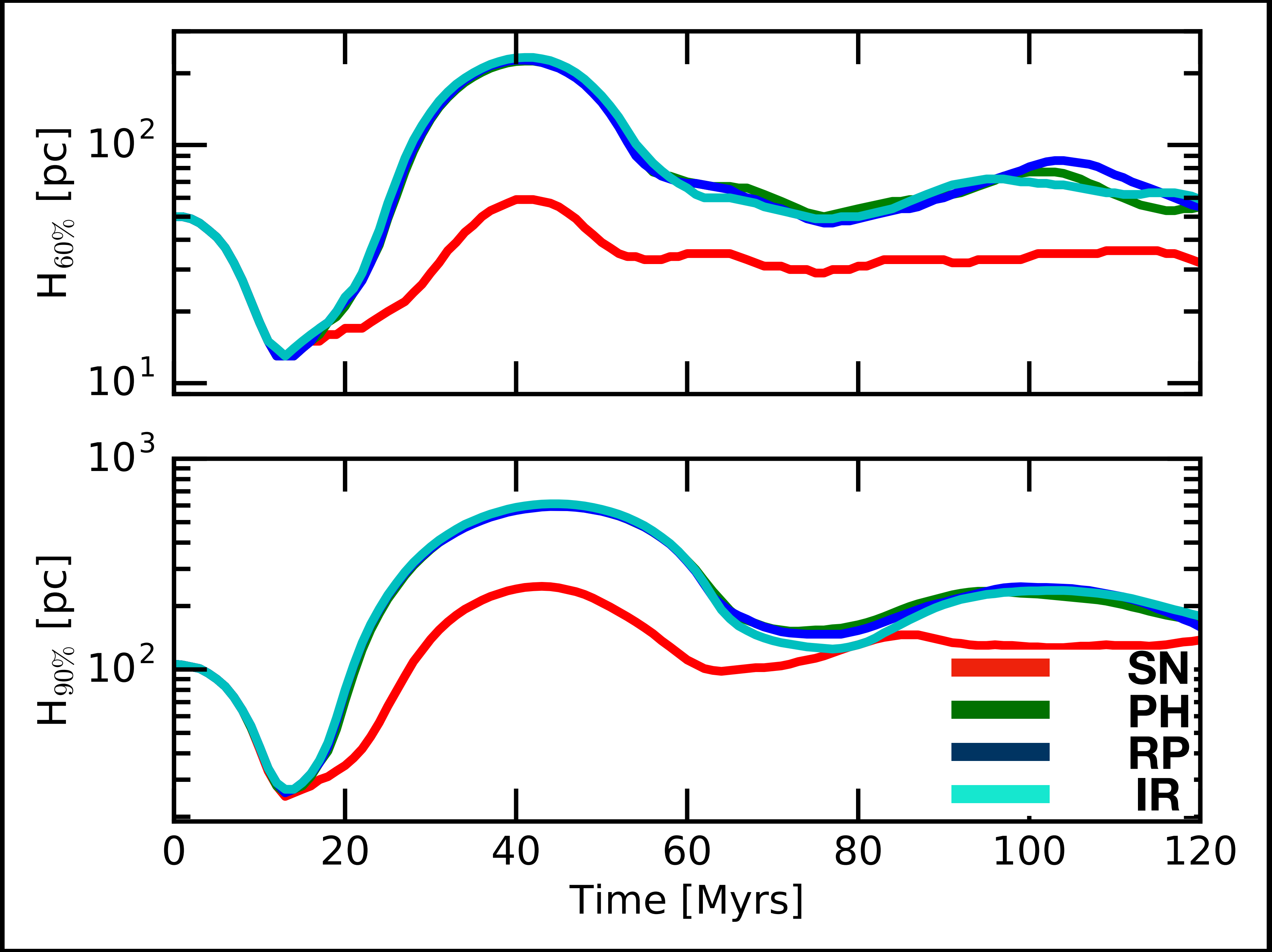


The Phase Space diagram



Vertical disc height

- Top panel - Height at which 60% of mass is enclosed.
- Bottom panel - Height at which 90% of mass is enclosed.
- The disc is generally more puffed up due to the radiation fields.
- At the peak of outflow, the height increases by a factor of 2 indicating larger outflow rates in runs with RT.

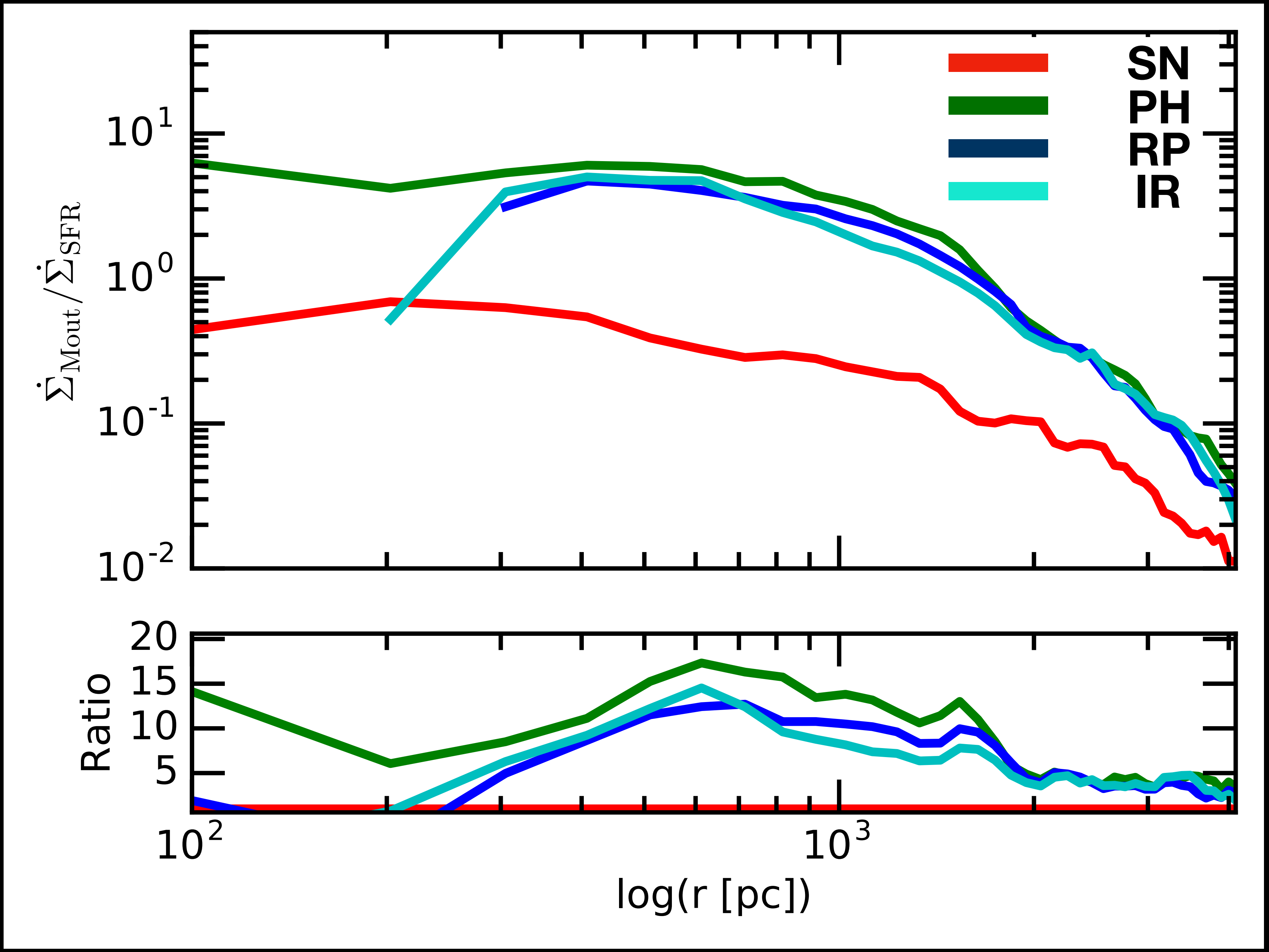


Mass loading factors

- Lower SFR density with higher mass outflows = Higher mass loading factors

- At the peak of outflow (40 Myrs) the mass loading factors at higher in the runs with RT unto very large radii.

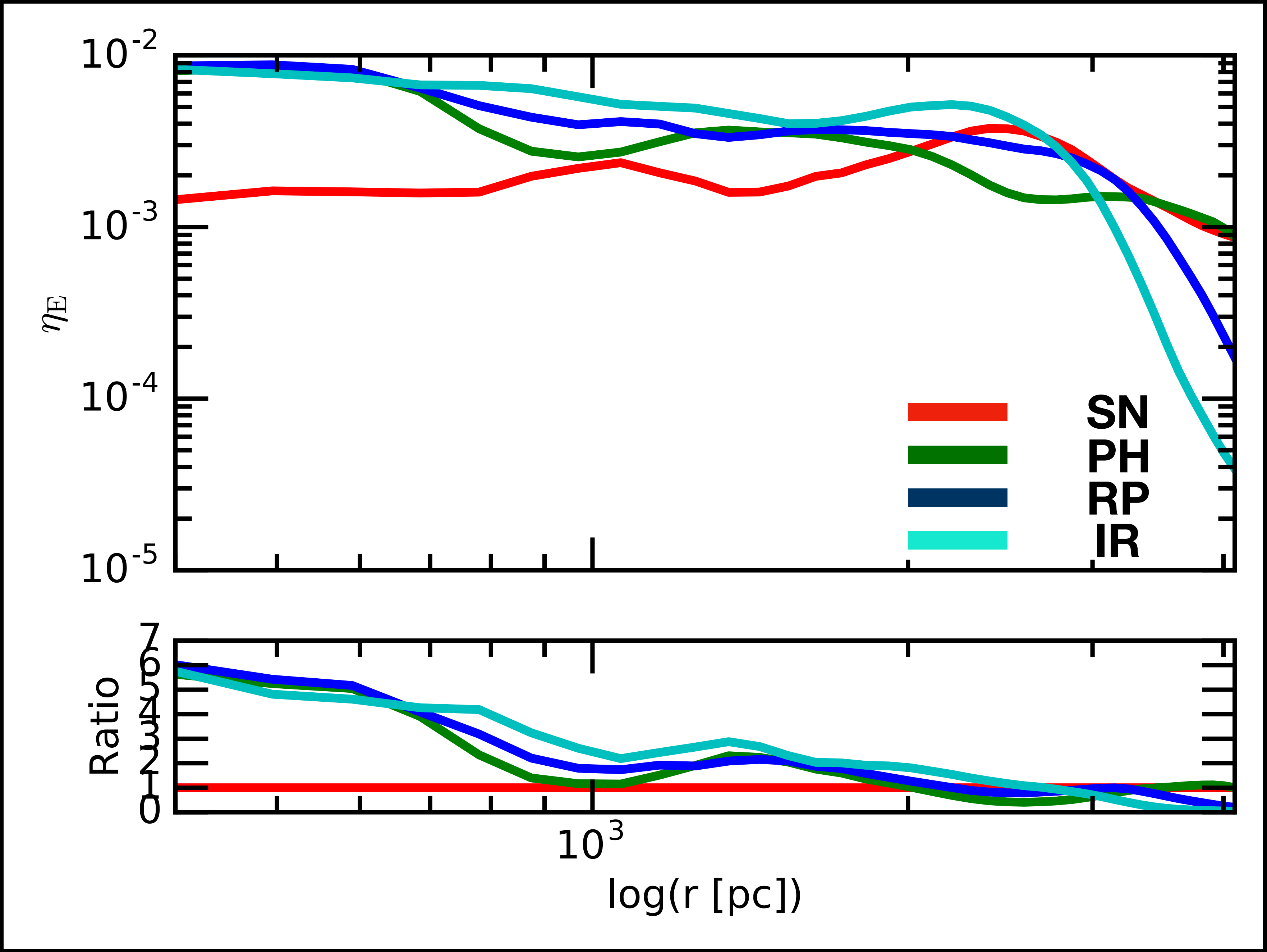
- Radiation fields increase the mass loading factors by a factor of 5-15.



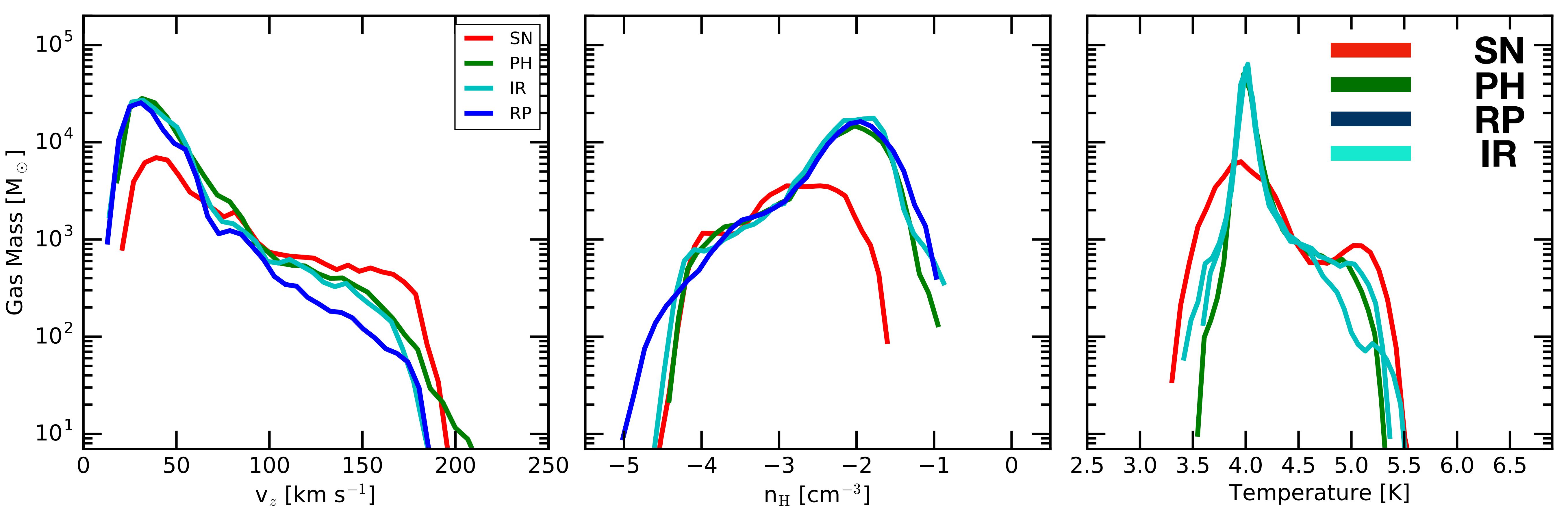
Energy loading factors

- The Energy loading factors are also increased

- The increase occurs mainly at smaller radii, with the central energy loading factors increasing by unto a factor of 5-10.



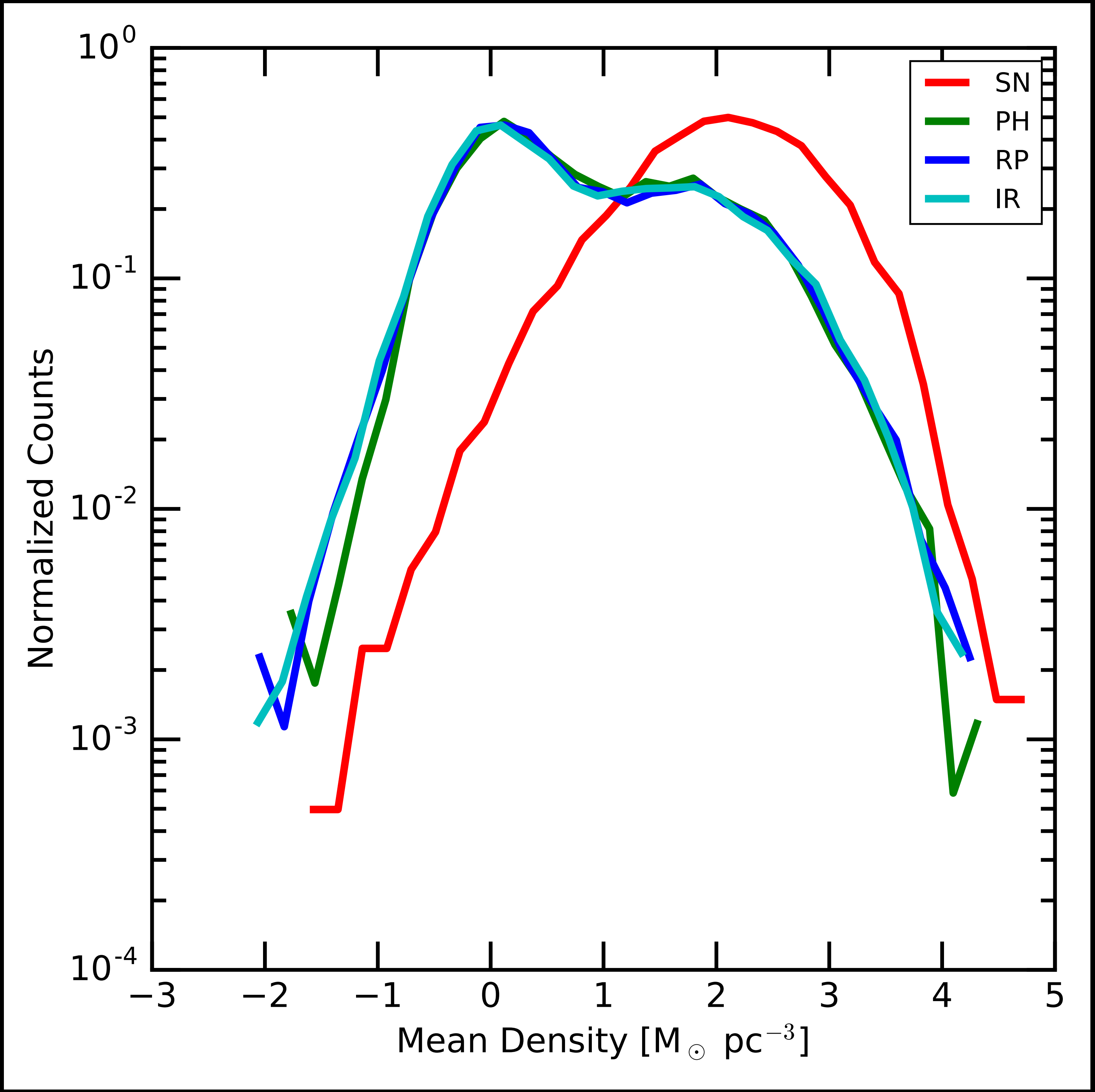
Structure of outflows



- The radiation fields launch slower, higher density and cooler outflows.
- The outflows are launched to larger radii.

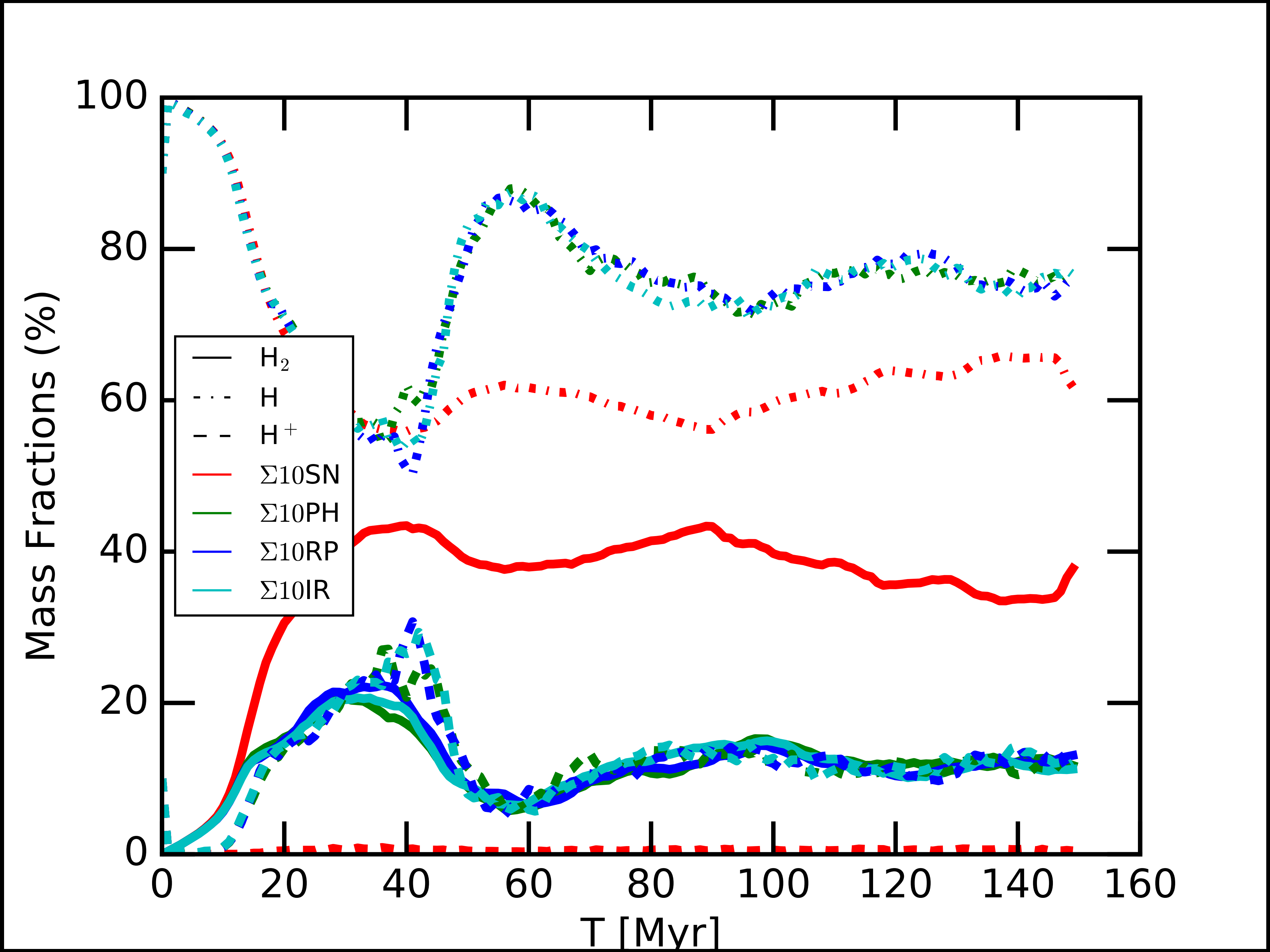
Mean density of SNe

- The mean density of the gas around the star which goes SNe is reduced.
- The peak of the histogram is shifted by almost two orders of magnitude.
- This increases the effectiveness with which the SNe couples to the surround ISM.
- This can in principle account for the larger mass loading factors and lower star formation rates.



Chemical composition of the disc

- Radiation fields reduce the molecular fraction from ~40% to about ~12%.
- The ionized fraction increases from almost zero to about 10%.
- Most of the hydrogen exists in its neutral atomic form.

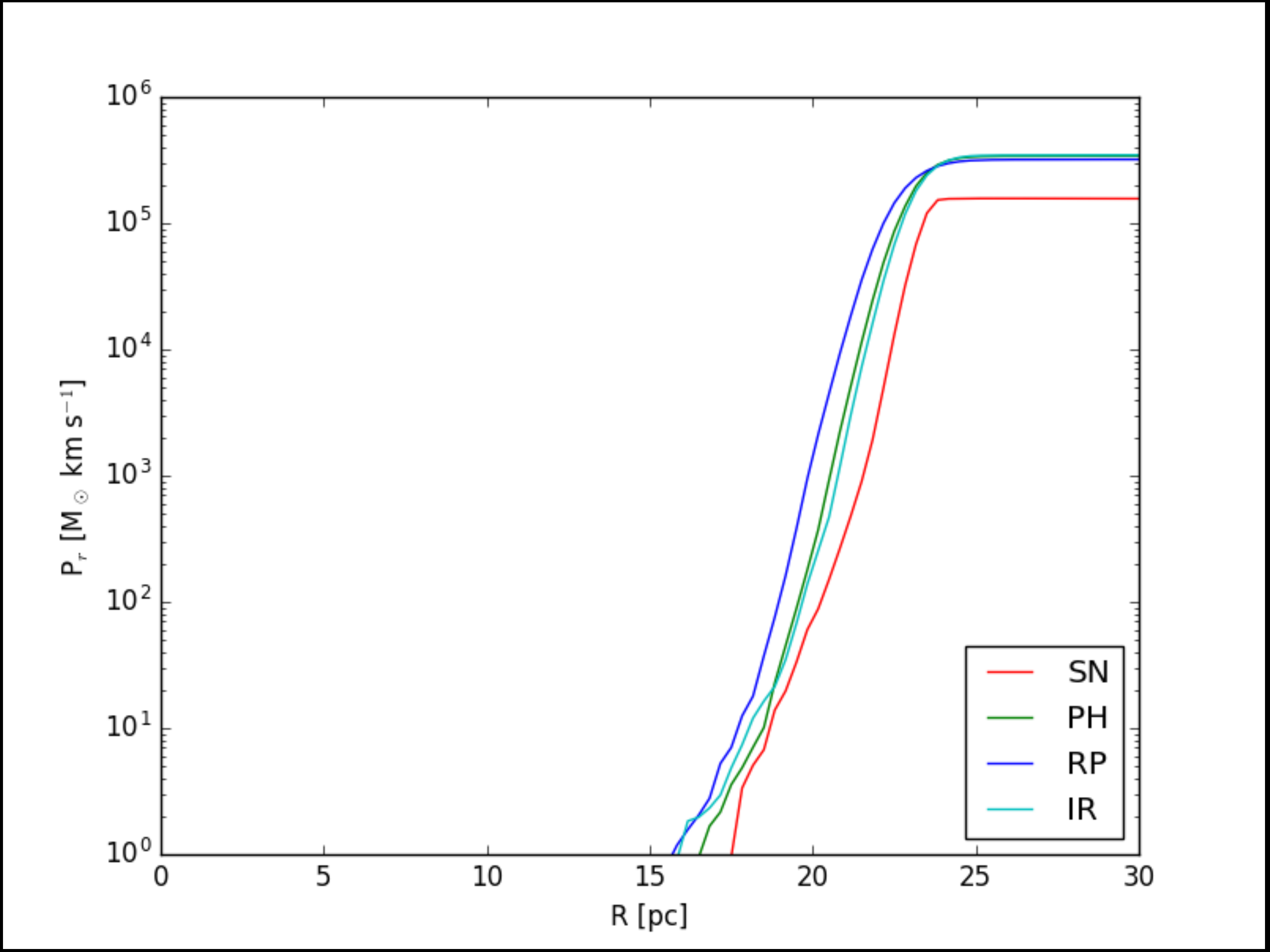


Sub-grid model for radiation feedback

- Very difficult to fully resolve all the relevant scales in RHD simulations
- There is a need for a sub-grid model of radiation feedback
- Take cues from the way SNe feedback has been modeled recently
- Perform simulations of single feedback event and quantify the terminal momentum from a stellar feedback (radiation +winds + SNe) event.
- This terminal momentum can then be input in under-resolved cosmological simulations

Sub-grid model for stellar feedback

- Initial simulations show that radiation fields alone an increase the momentum input by a feedback event by more than a factor of 2.
- At low densities (100 particles/cc) these simple single feedback simulations show that photo heating is the main effect.
- To Do - perform these simulations in wide, density, metallicity and turbulence ranges and provide fitting formulas for sub-grid models.



Summary

- Radiation fields decrease the SFR and the total stellar mass by about 50 %.
- They puff up the disc and increase the vertical scale height of the disc.
- Including radiation fields increases the mass outflow rates and increases the mass loading and energy loading factors by a factor of 5-10.
- The mean density of the gas around the star which goes SNe is reduced, the peak of the histogram is shifted by almost two orders of magnitude.
- Radiation fields can only help drive small scale fountain flows, not large scale winds. Might need CRs to drive large scale winds.
- Simulating fully resolved single stellar feedback events can provide input for future sub-grid models (eg. Marinacci + in prep).