Radiative Feedback and the Low Efficiency of Star Formation in Cosmological Simulations

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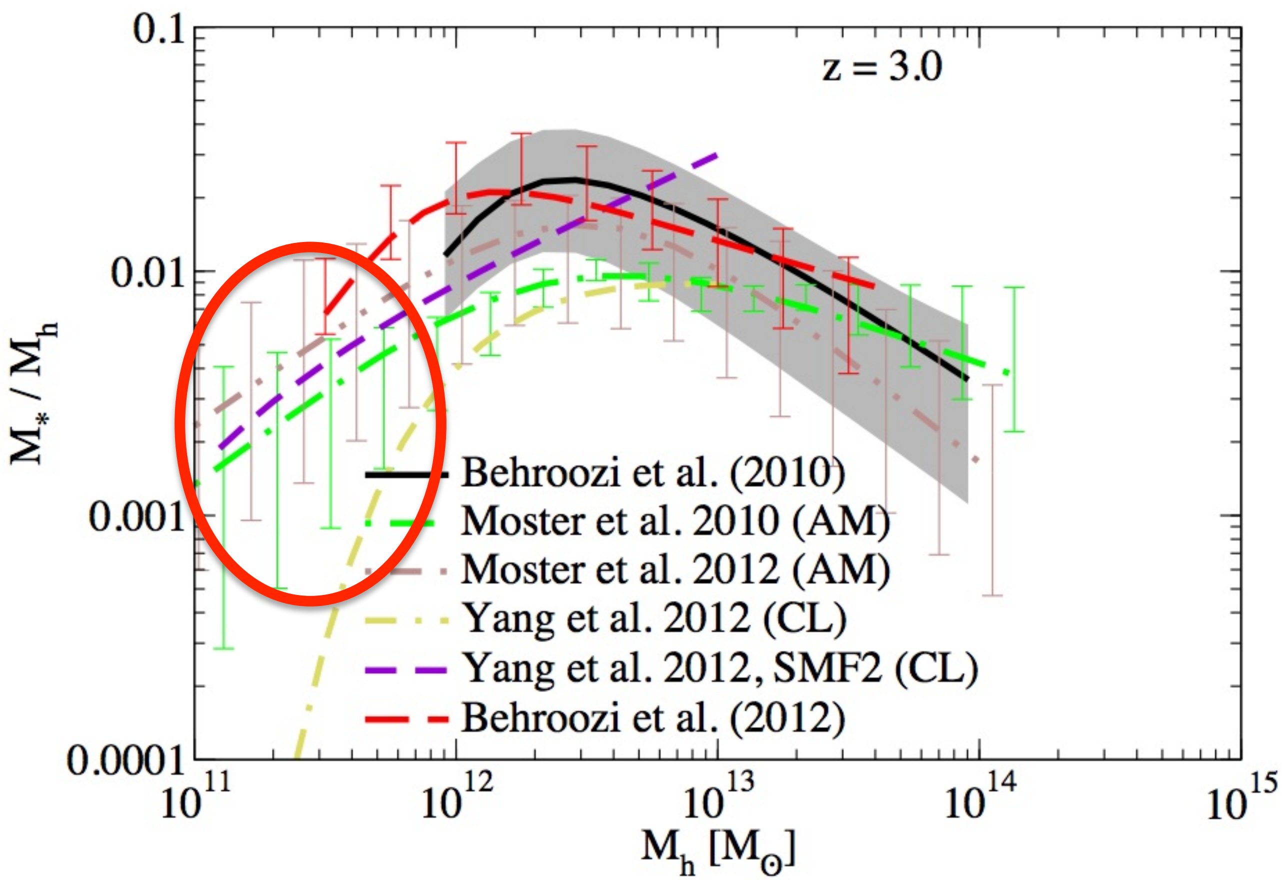
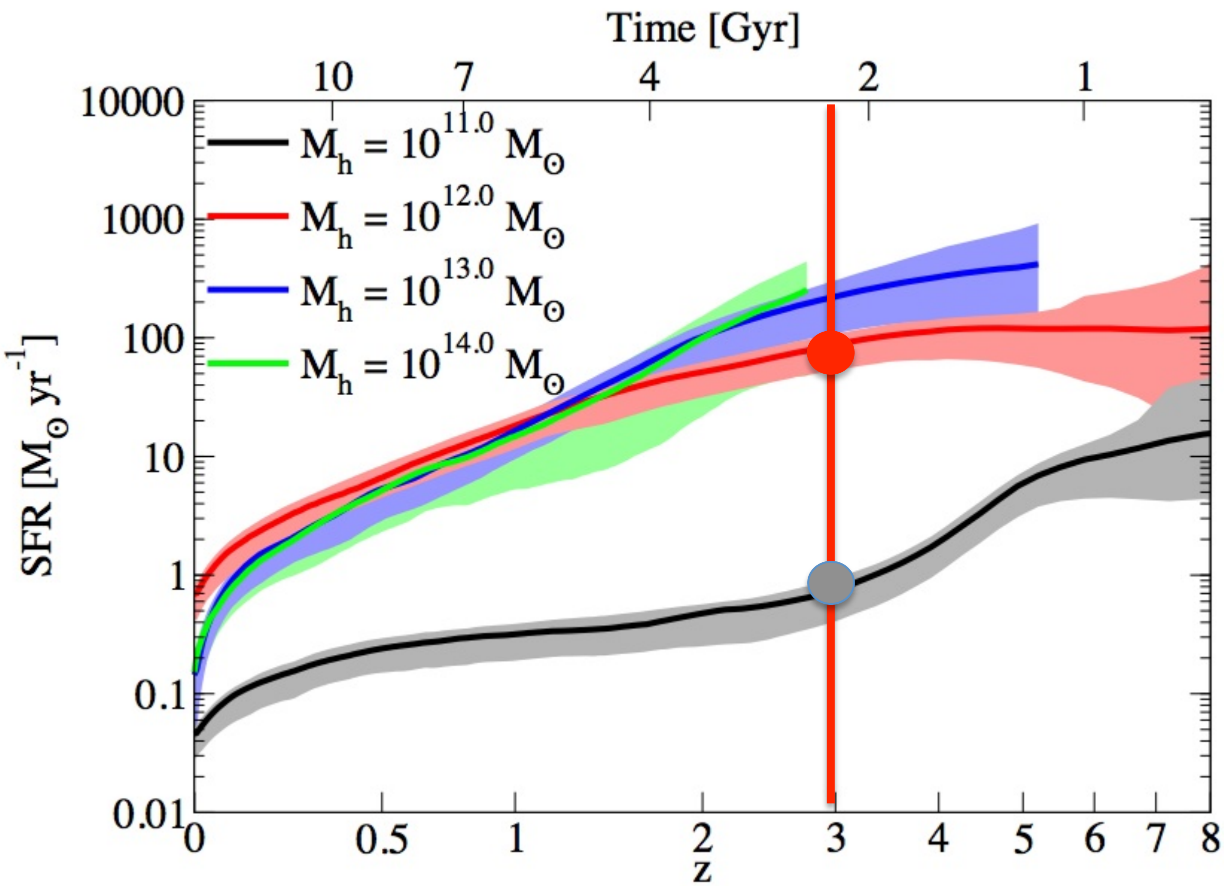
Low efficiency of galaxy formation on low-mass halos at high-redshift



- Abundance matching
- Conditional luminosity modeling
- Stellar fractions lower than 1% for $M_h \approx 10^{11}$ Ms at z=3

Behroozi+12

Low efficiency of galaxy formation on low-mass halos at high-redshift

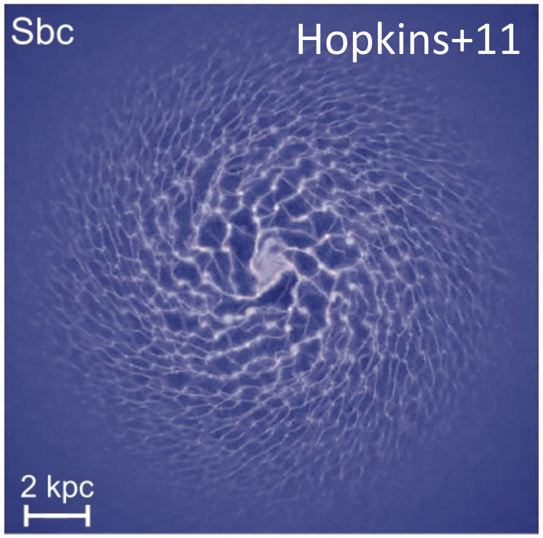


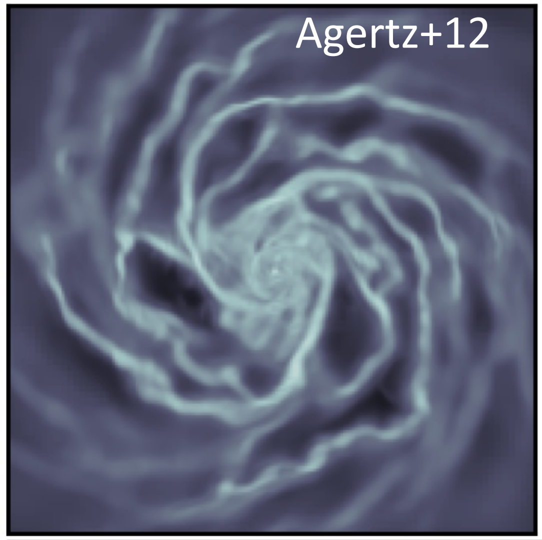
- Star formation and galaxy formation is a rather inefficient process in $M_h \approx 10^{11}$ Ms halos **at any redshift**

Which physical process drives this low efficiency?

Behroozi+12

Beyond supernova feedback



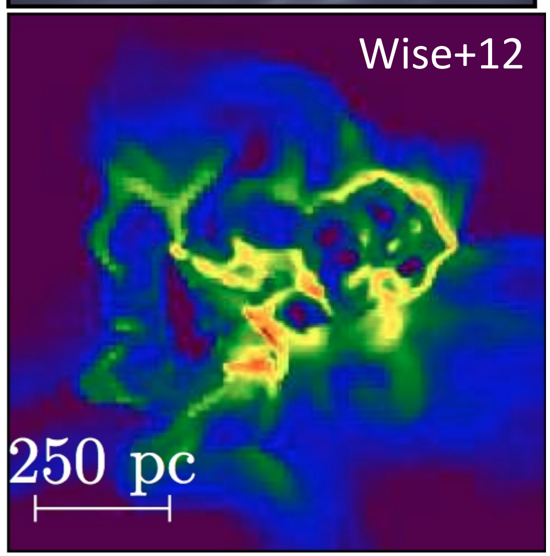


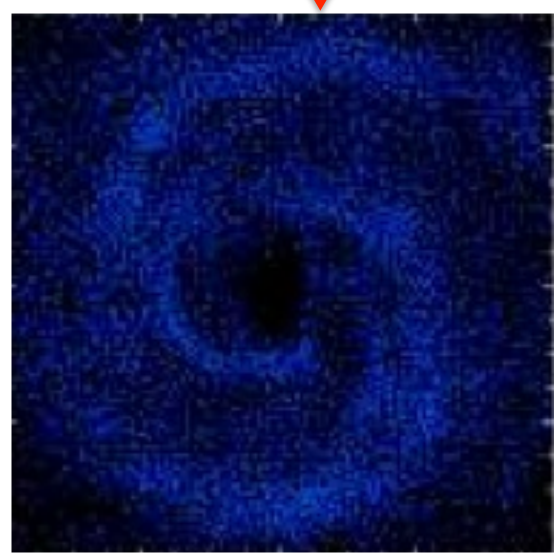
Isolated Disc Simulations

Radiative Feedback

Cosmological Simulations

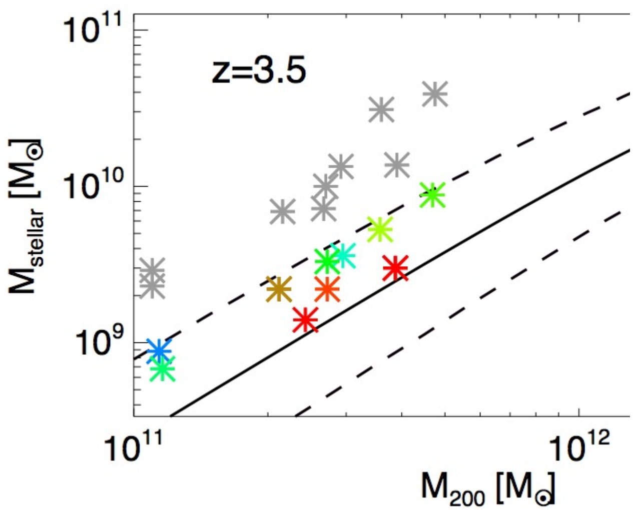
Brook+12



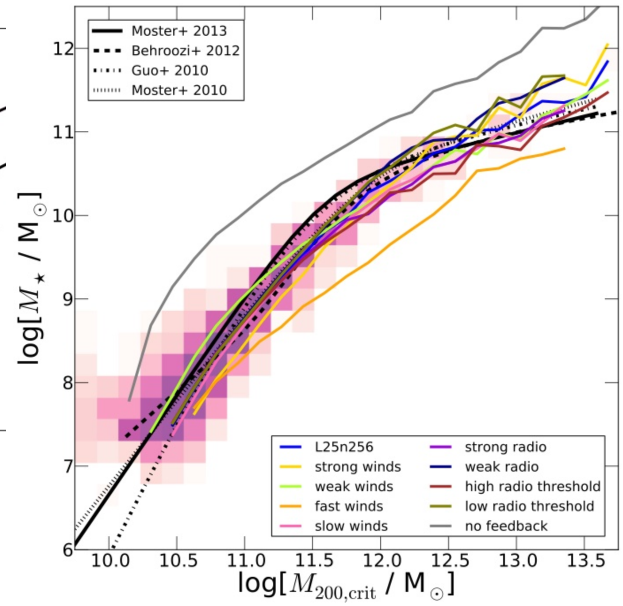


Aumer+13

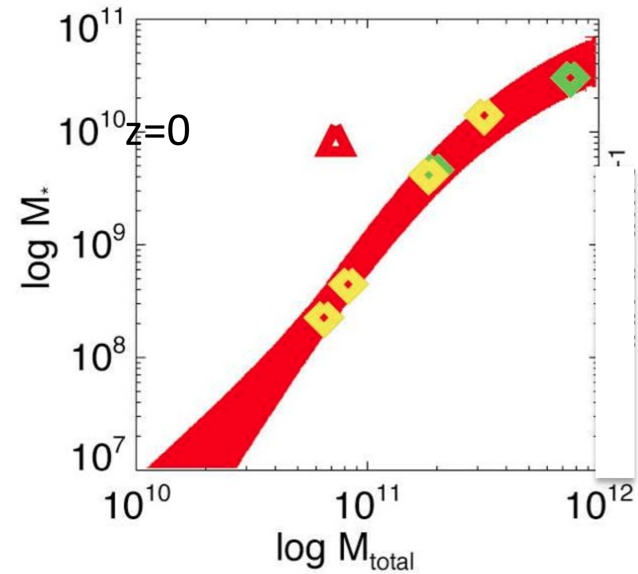
Low galaxy efficiency



Aumer+13



Vogelsberger+13



Brook+12

But … low resolution for accurately following radiative effects (0.3-0.15 kpc)

tuning of feedback parameters

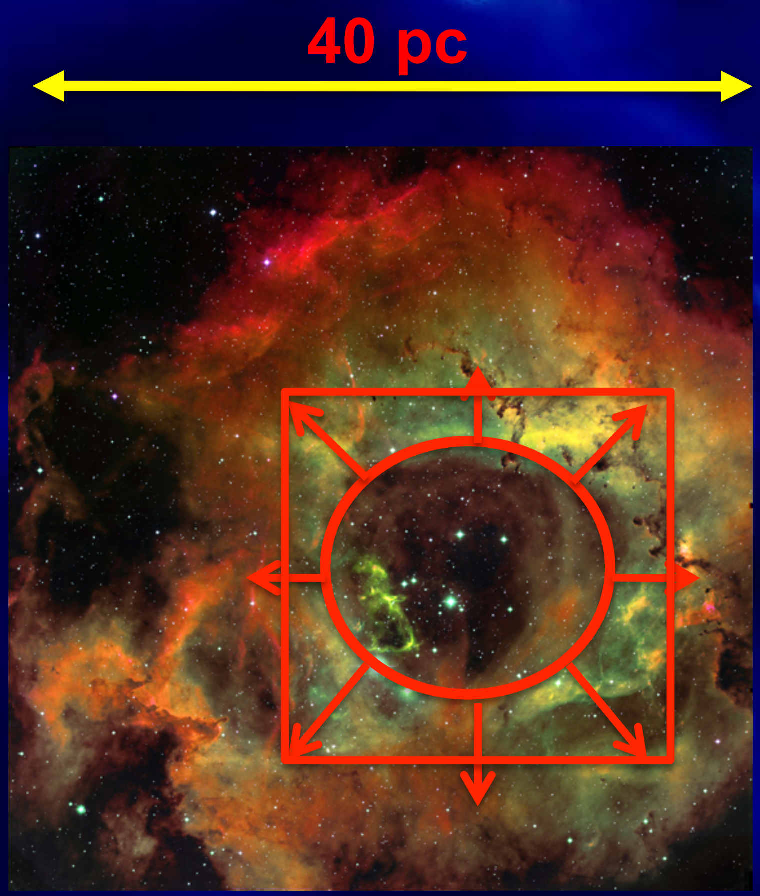
a meaningful physical model or a trick to compensate resolution defects?

Galaxy formation simulations done with ART

- AMR code: HYDRO-ART (Kravtsov et al 1997, Kravtsov 2003)
- Gas Cooling, Star Formation, Stellar Feedback (Ceverino & Klypin 2009; Ceverino, Dekel and Bournaud 2010)
  - Cooling below 10^4 K (minimum temperature of 300 K).
  - Thermal feedback + runaway stars.
- Radiative Feedback (Ceverino et al. 2013, ArXiv 1307.0943)
- Zoom-in simulations: 15-30 **pc** resolution

Radiative feedback

Rosette Nebula



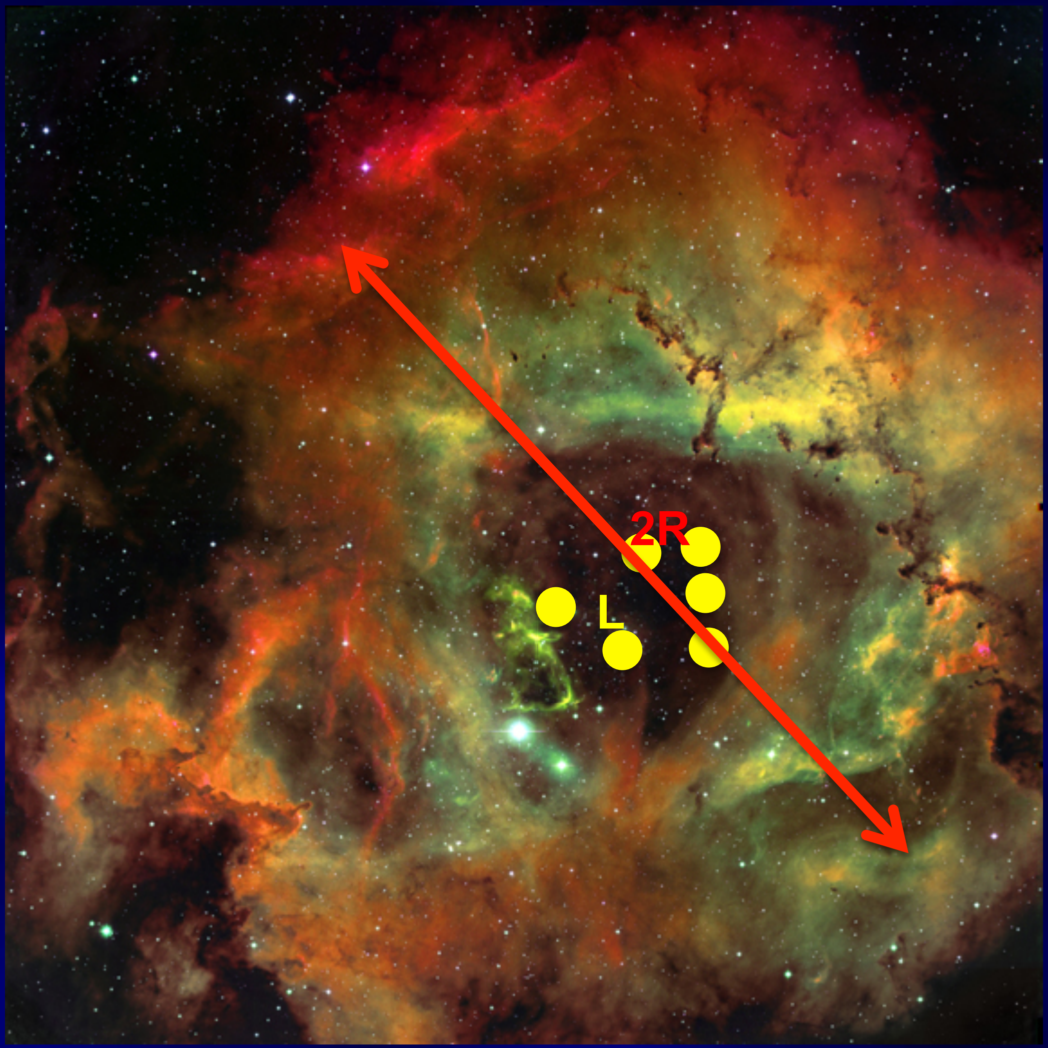
No Supernova explosion yet
- Stellar winds
- Thermal pressure
- Radiation pressure
  - from ionizing photons

Typical resolution of our zoom-in, cosmological simulation: ~ 20 pc

- At low column densities

$P_{rad} \alpha (1\text{-}\exp(-\tau))$

- Optically thin
- No effect from radiation pressure



- At high column densities
- Add pressure

$P_{rad} = L / (R^2 c)$

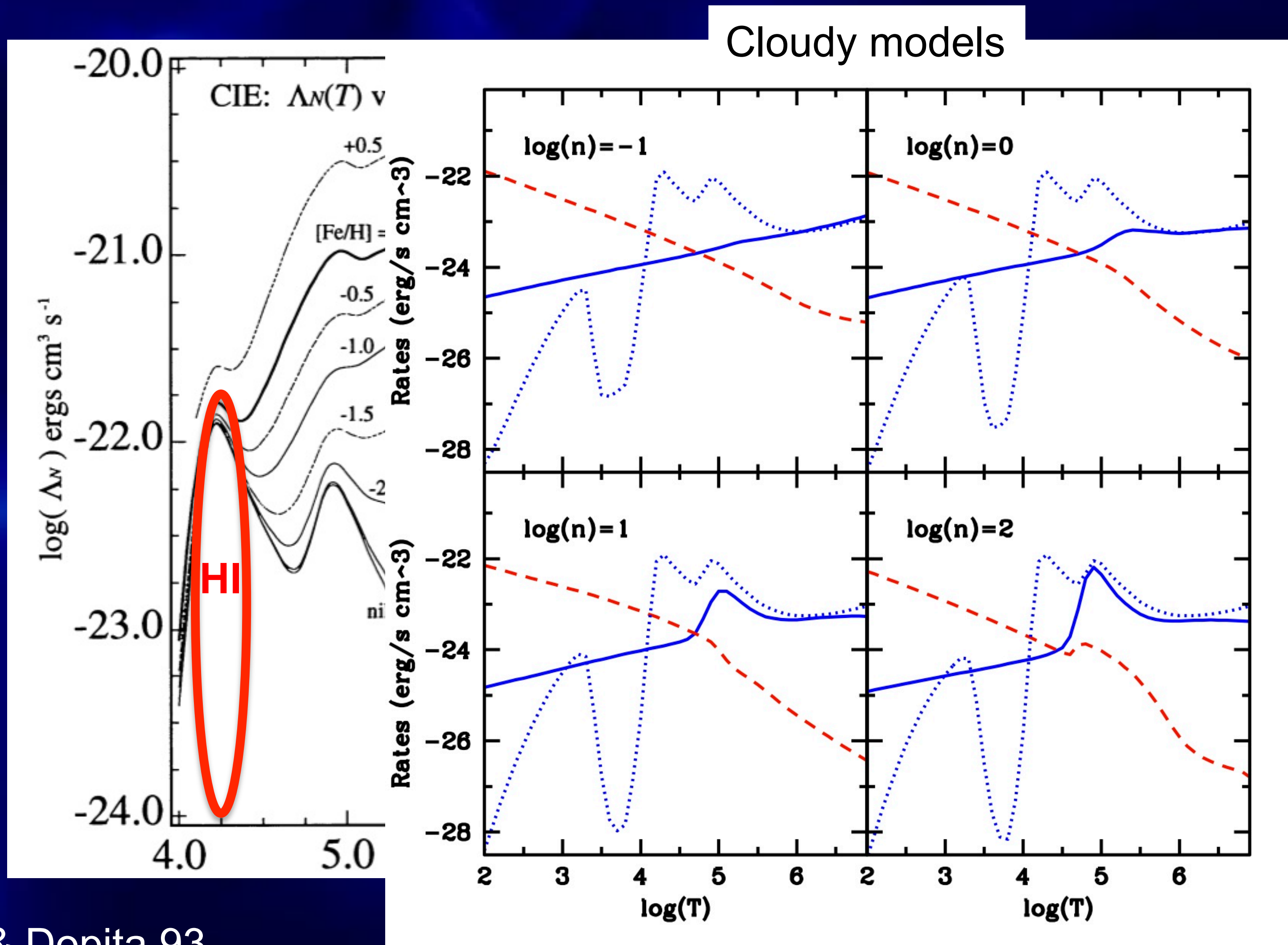
$L = M_* \Gamma$

Γ = cte for 5 Myr

For column densities $>10^{21}$ cm^{-2}

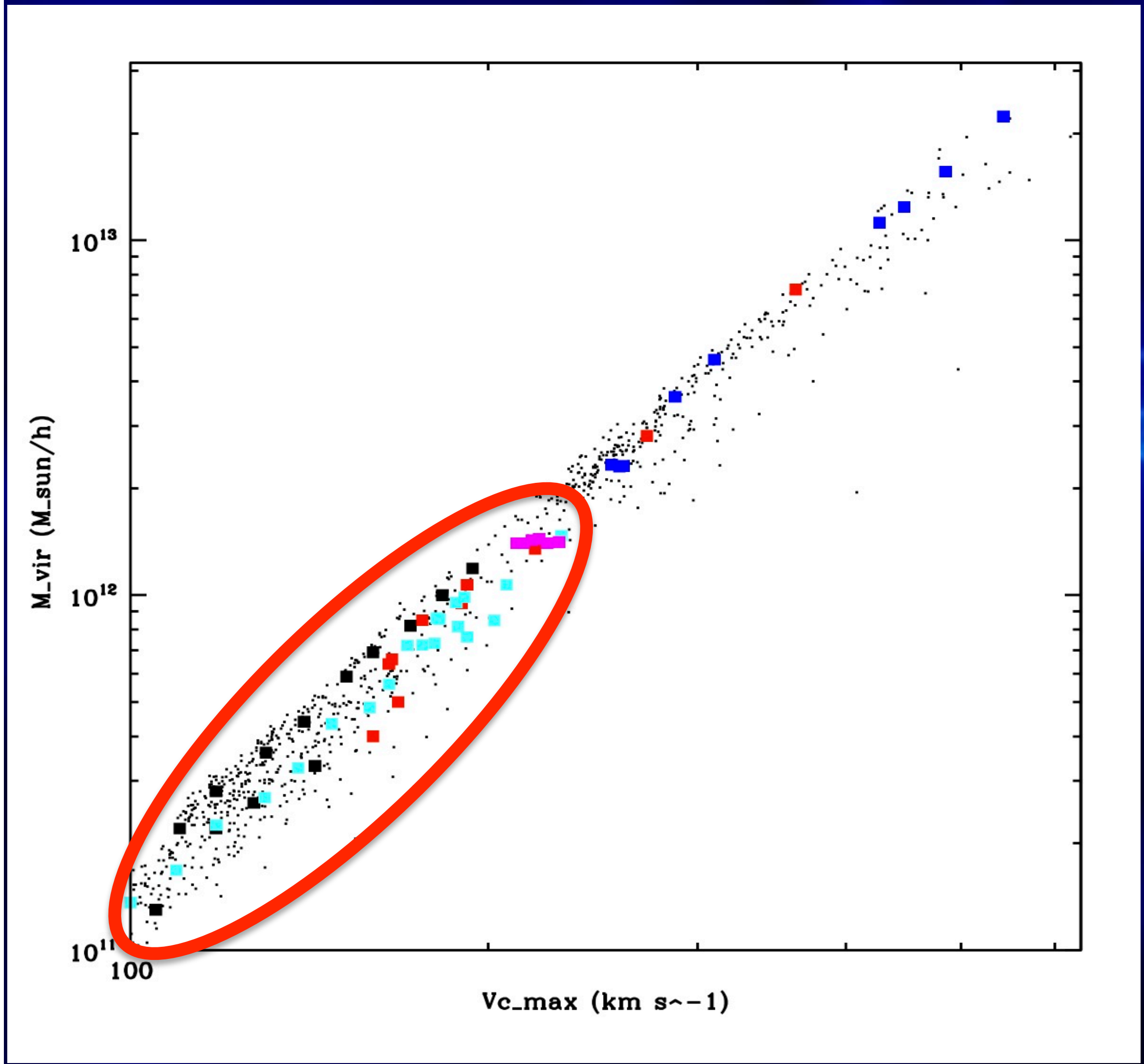
No free parameters

Photoionization & photoheating



Sutherland & Dopita 93

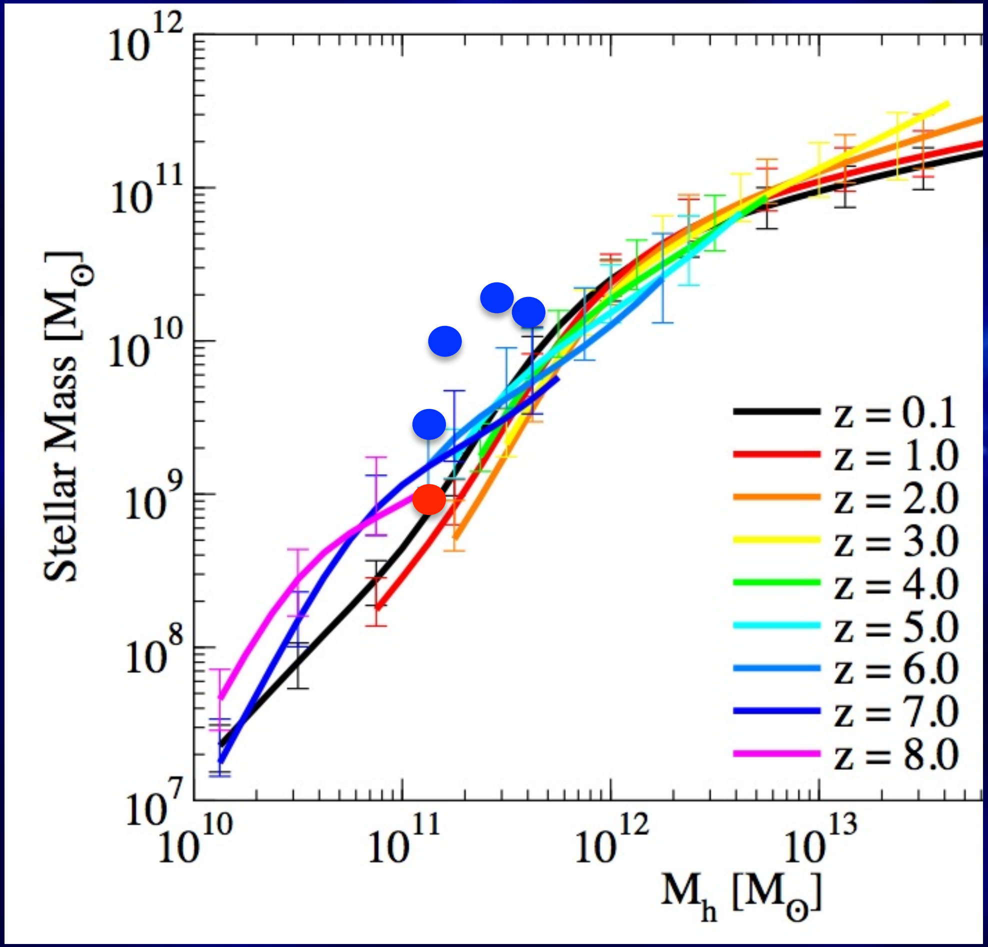
VELAs



- ~35 zoom-in simulations
- 15-30 pc reso
- M_{DM}=8 10^4 Ms
- M_*=10^3 Ms
- z=1-3

10^{11} Ms/h < M_H < 10^{12} Ms/h
Vc_max =100-200 km/s

Low Star Formation Efficiency



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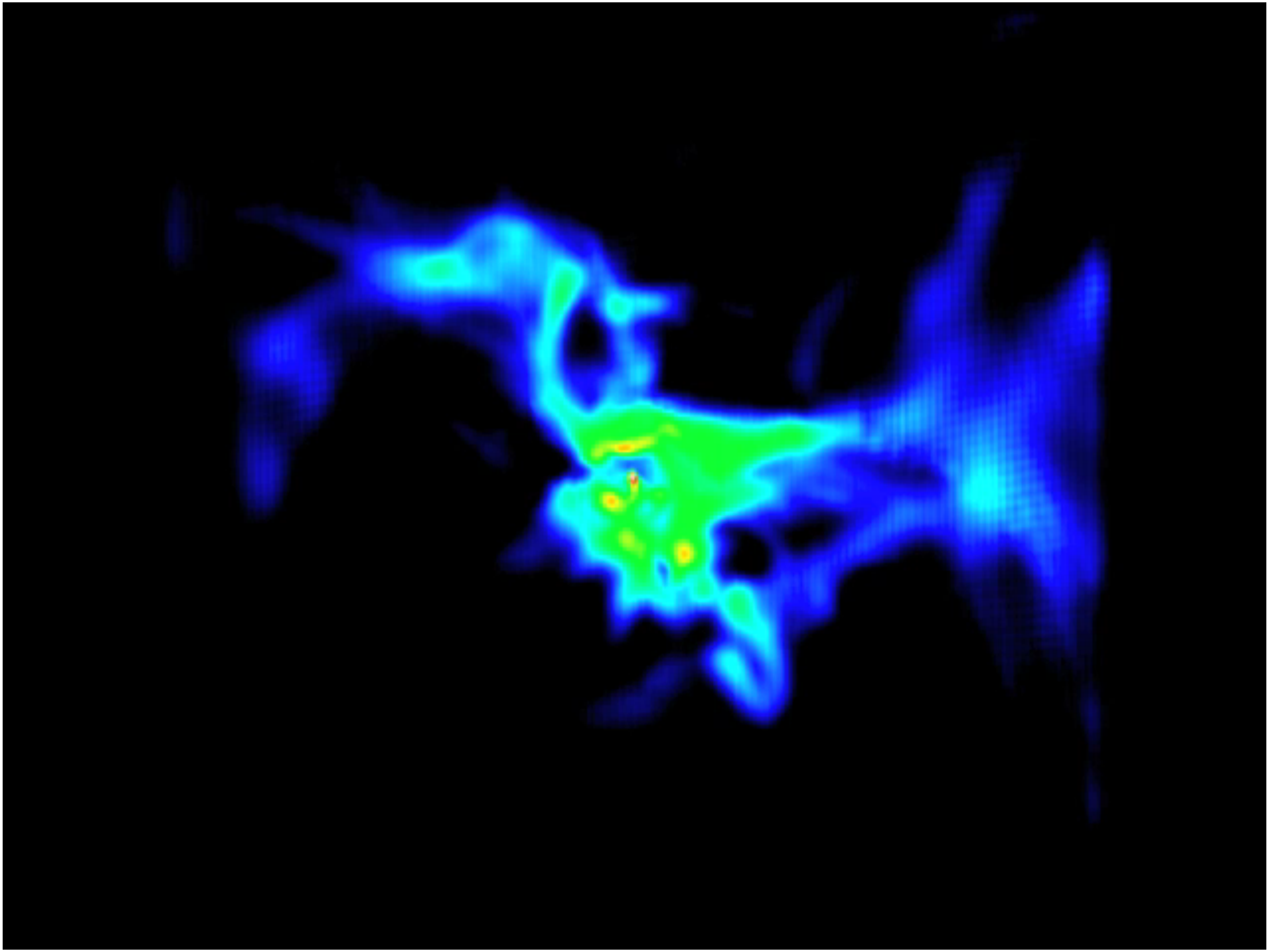
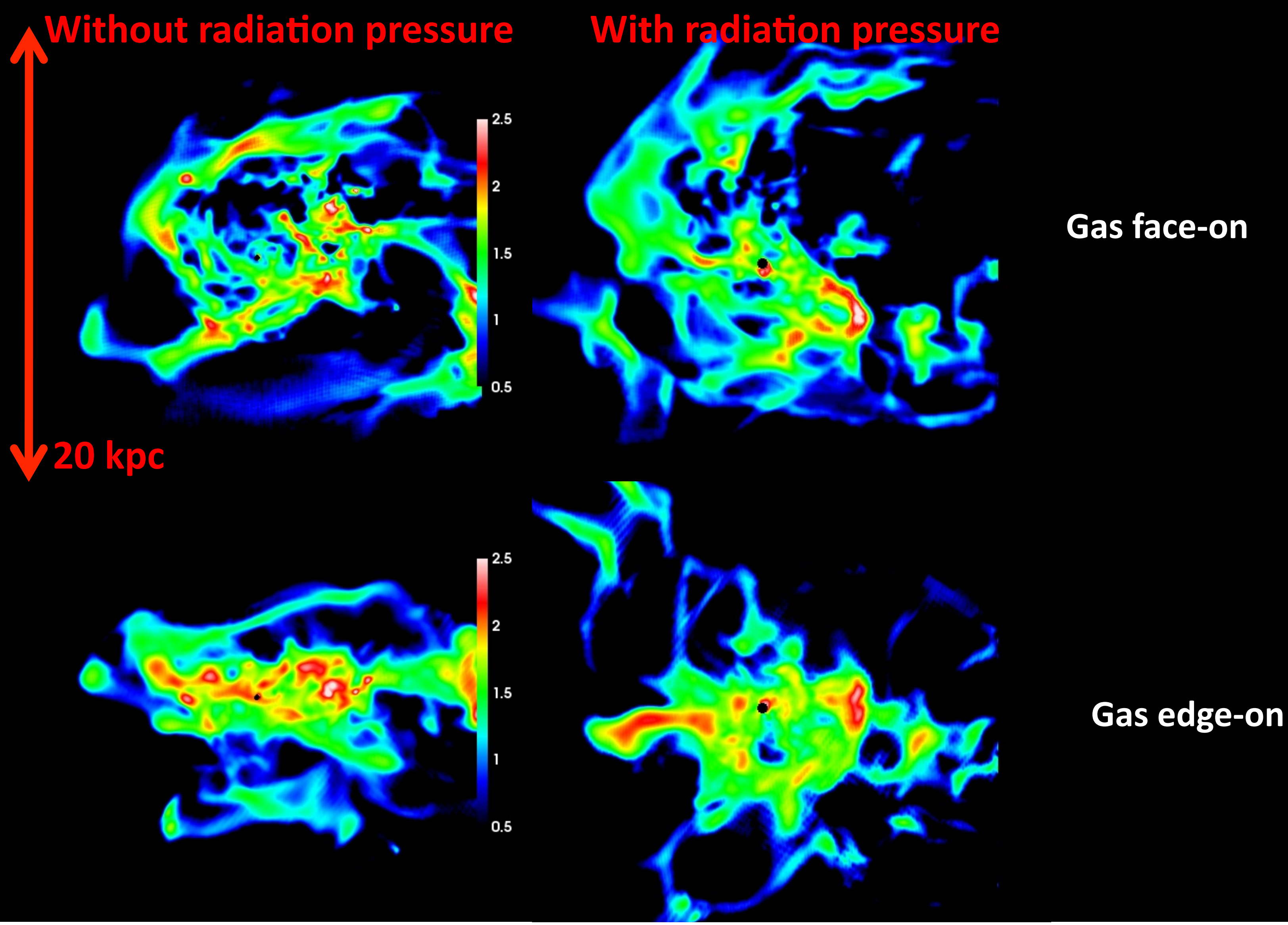
- Radiation pressure reduces SFR and stellar mass by a factor ~3

- M_{star}/M_h=0.7%
- SFR~1 Ms/yr

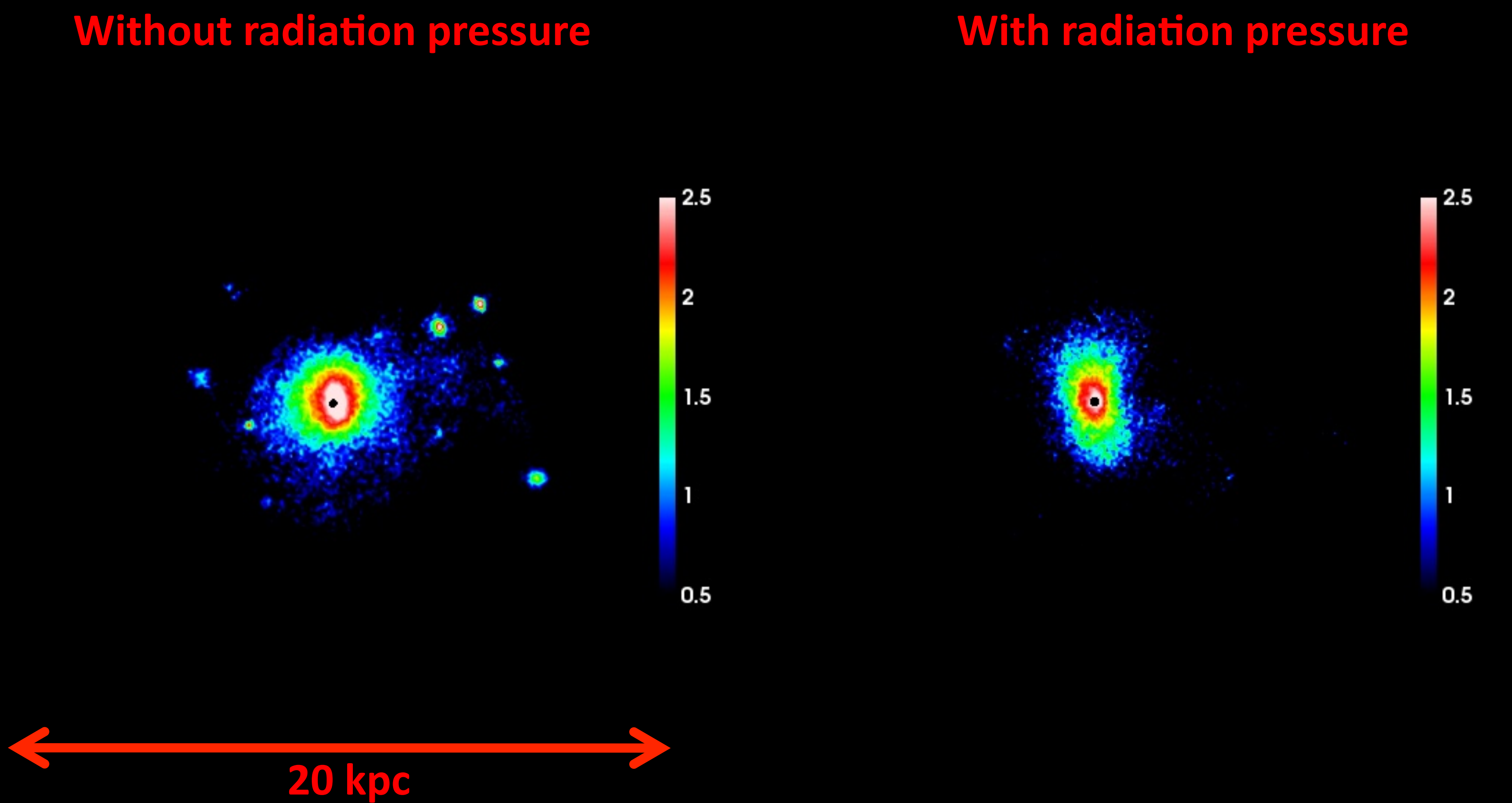
For M_h~10^{11} Ms at z~3

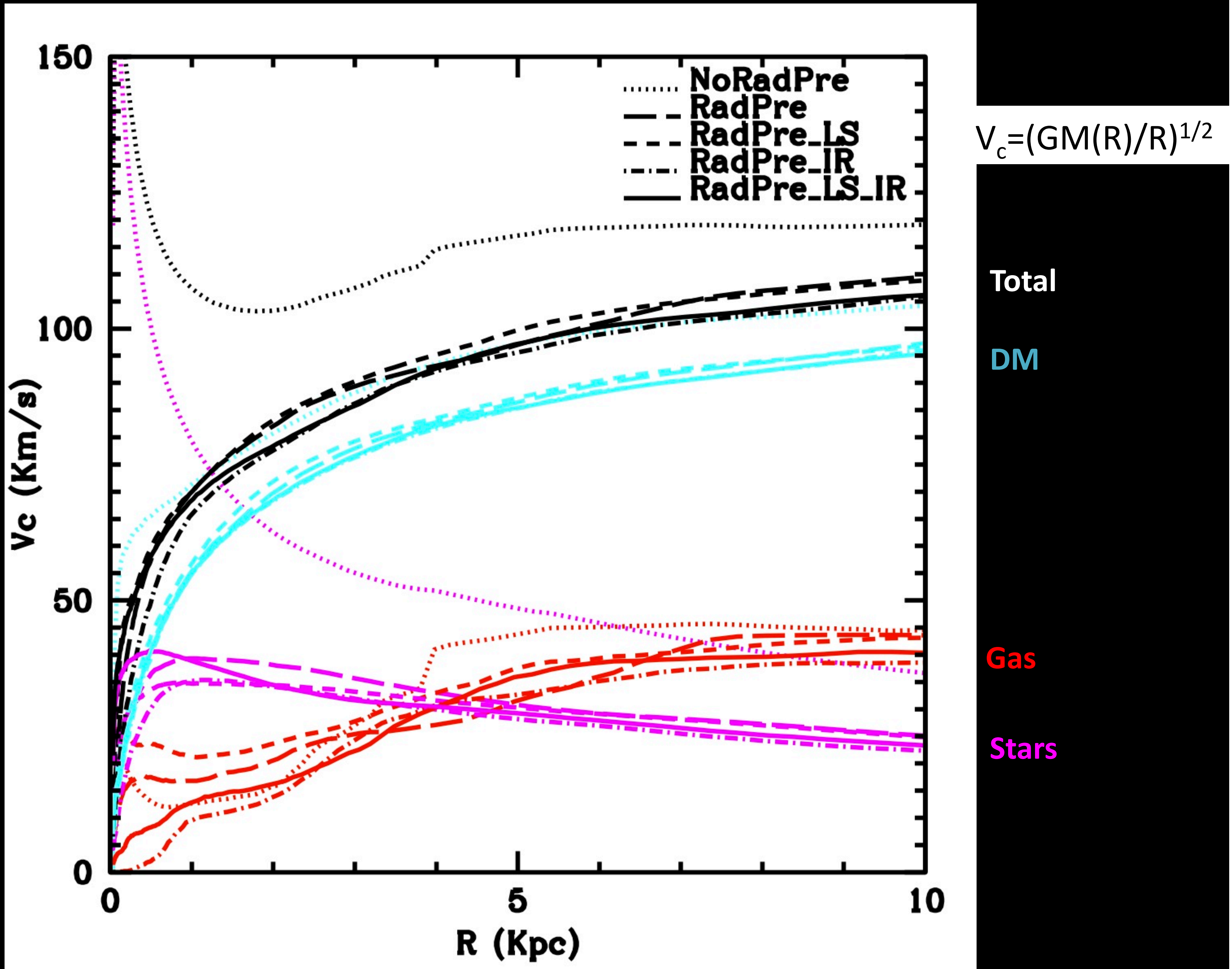


Gas distributions



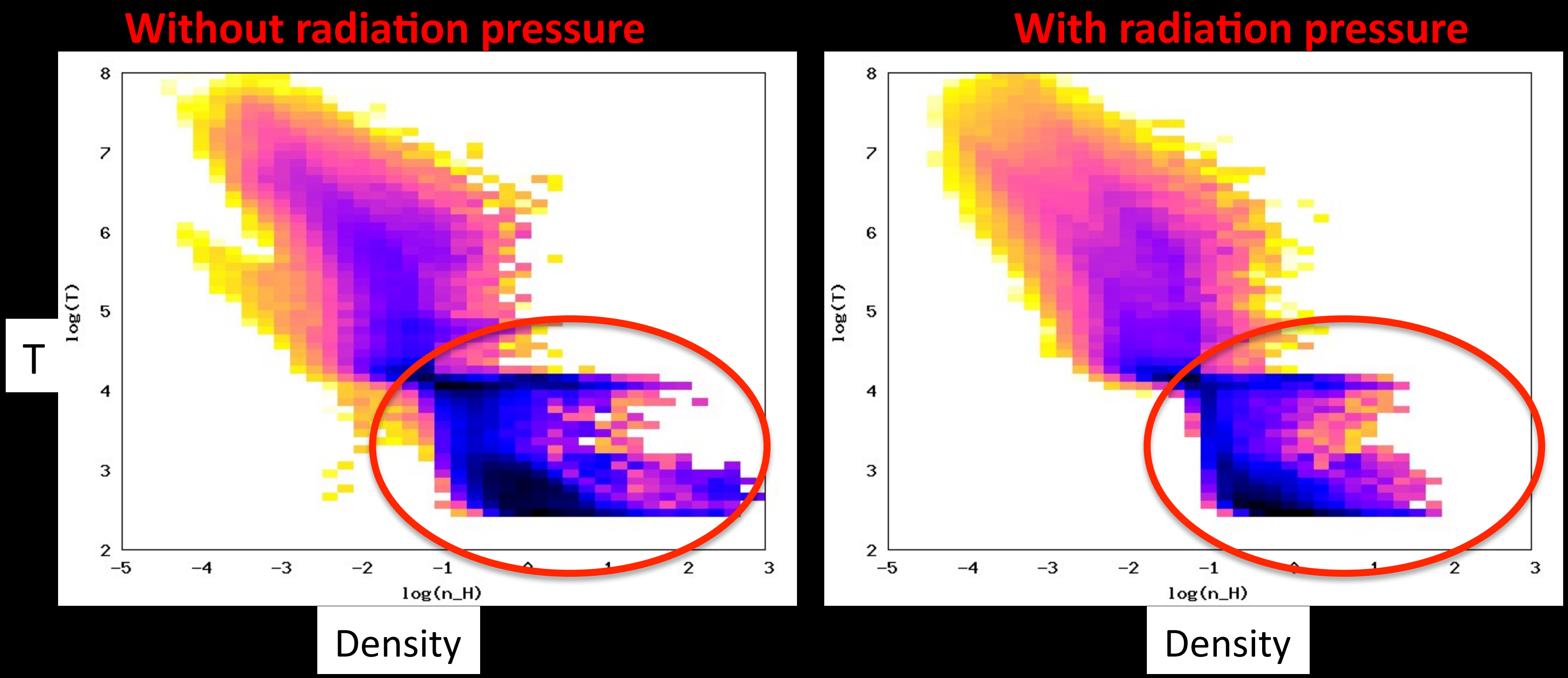
Stars face-on





NoRadPre
RadPre
RadPre_LS
RadPre_IR
RadPre_LS_IR
Vc (Km/s)
R (Kpc)
150
100
50
0
5
10
Vc=(GM(R)/R)1/2
Total
DM
Gas
Stars

Phase Diagrams



Summary

- The low efficiency of star formation in low-mass halos at high redshift is driven by radiation pressure
- Radiation pressure controls the high-density tail of the density distribution
- Results are stable against model variations
- Photoionization and photoheating can prevent cooling in the log(T)=4-4.5 range


The End