Radiative feedback in cosmological simulations of galaxy formation

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Motivation

Radiation pressure expected to have 3-fold effect on galaxy formation:

1. disruption of molecular clouds before SNe/ regulation of SF (Hopkins+11)
2. provide turbulence in MCs (Krumholz+12)
3. drive (warm) gas outflows at high-z (Murray+11)

radiative feedback in *hydroART:*

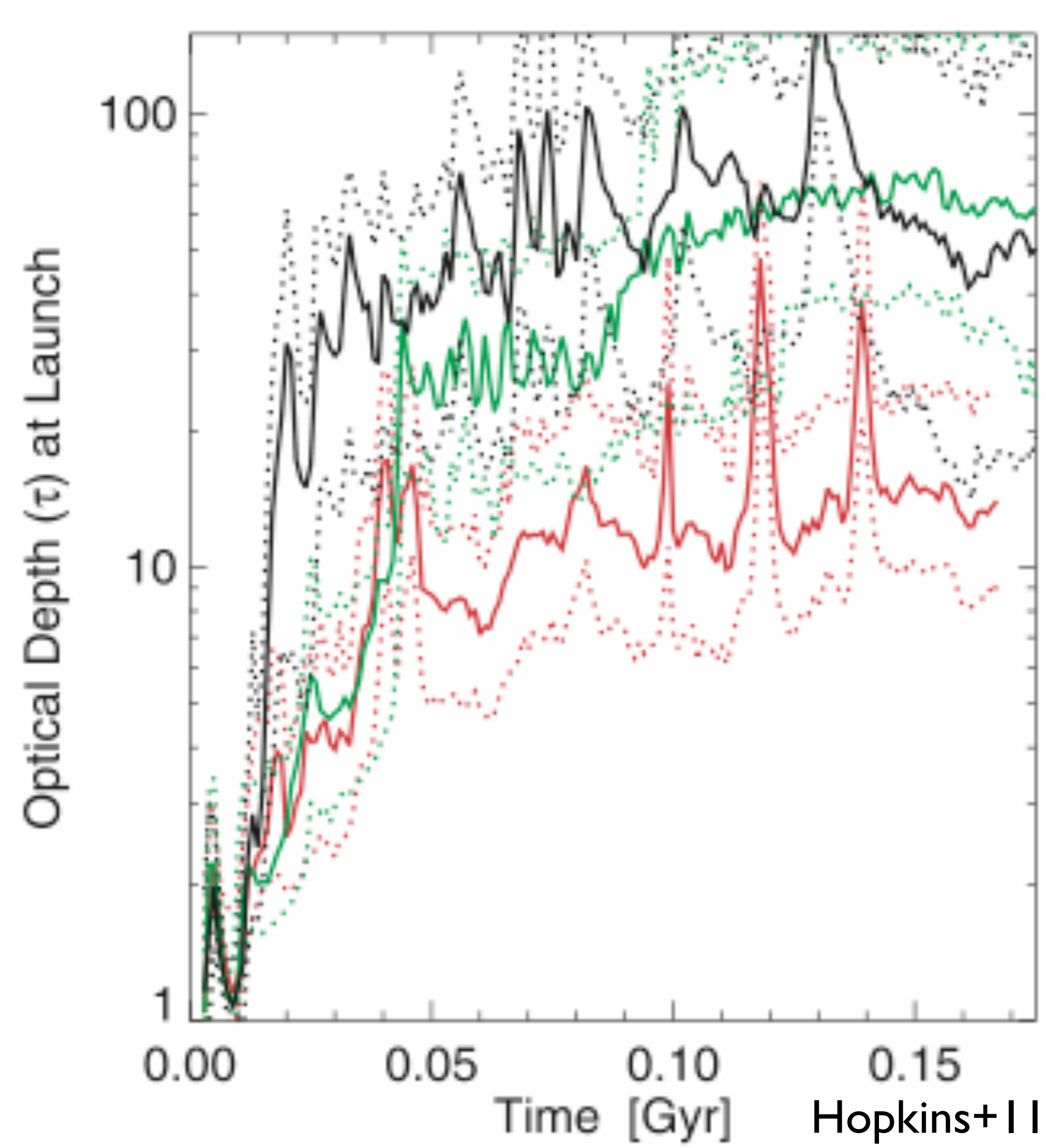
$$F_{\rm rad} = (\tau_{\rm UV} + \tau_{\rm IR})\frac{L}{c}$$ (Murray+10)

$$P_{\rm rad} = \frac{F_{\rm rad}}{r^2}$$ (Hopkins+11)

$$\tau_{\rm IR} = \Sigma_{\rm gas}\kappa_{\rm IR}$$

estimate **L ~ 100P_{SN}** per solar mass for ~ 3Myr (STARBURST99)

-> no free parameters



Hopkins+11

The simulations

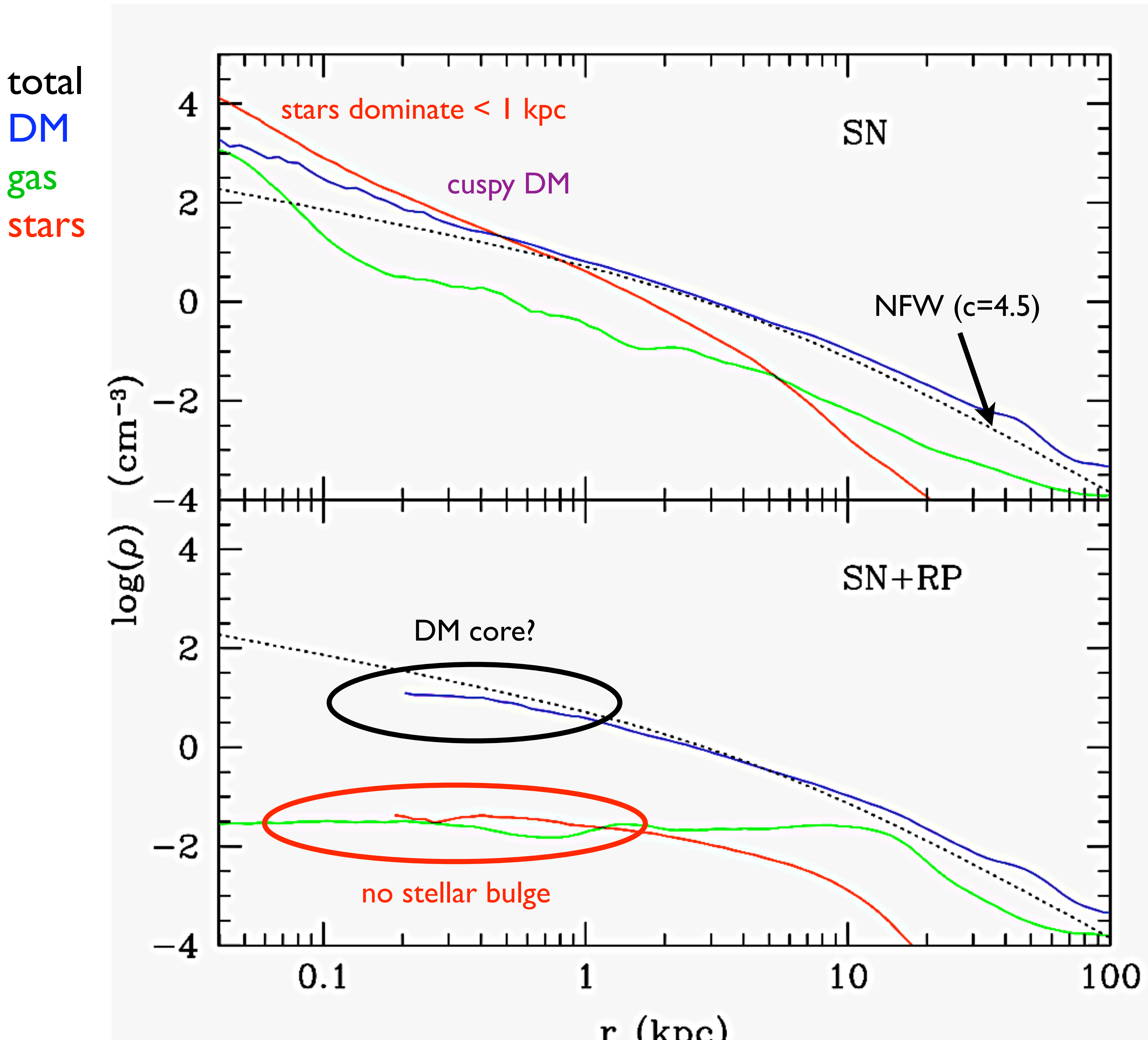
in a fully cosmological setting, we would like to know if radiation pressure is able to:

1. **drive massive outflows**
2. **prevent formation of a massive bulge**
3. **regulate SF**
4. **reduce the baryon fraction**

τ_{IR} ~ 50 gives maximum possible radiative forcing

run	volume	redshift	halo mass	R_{vir}	resolution (proper)	SF model	FB model	τ_{UV}	τ_{IR}
MW_SN	10 Mpc^3	z=3	1.8×10^{11} M_s	45 kpc	19 pc	n_{SF} = 1 cm^{-3}	SN+stellar winds	-	-
MW_SN+RP	10 Mpc^3	z=3	1.8×10^{11} M_s	45 kpc	19 pc	n_{SF} = 1 cm^{-3}	SN+stellar winds+RP	1	50
dwarf_SN+RP	10 Mpc^3	z=0	3.0×10^{10} M_s	80 kpc	38 pc	n_{SF} = 6 cm^{-3}	SN+stellar winds+RP	1	50

MW: mass distribution



MW_SN:

$M_{stars} = 6.8 \times 10^9\ M_{sol}$

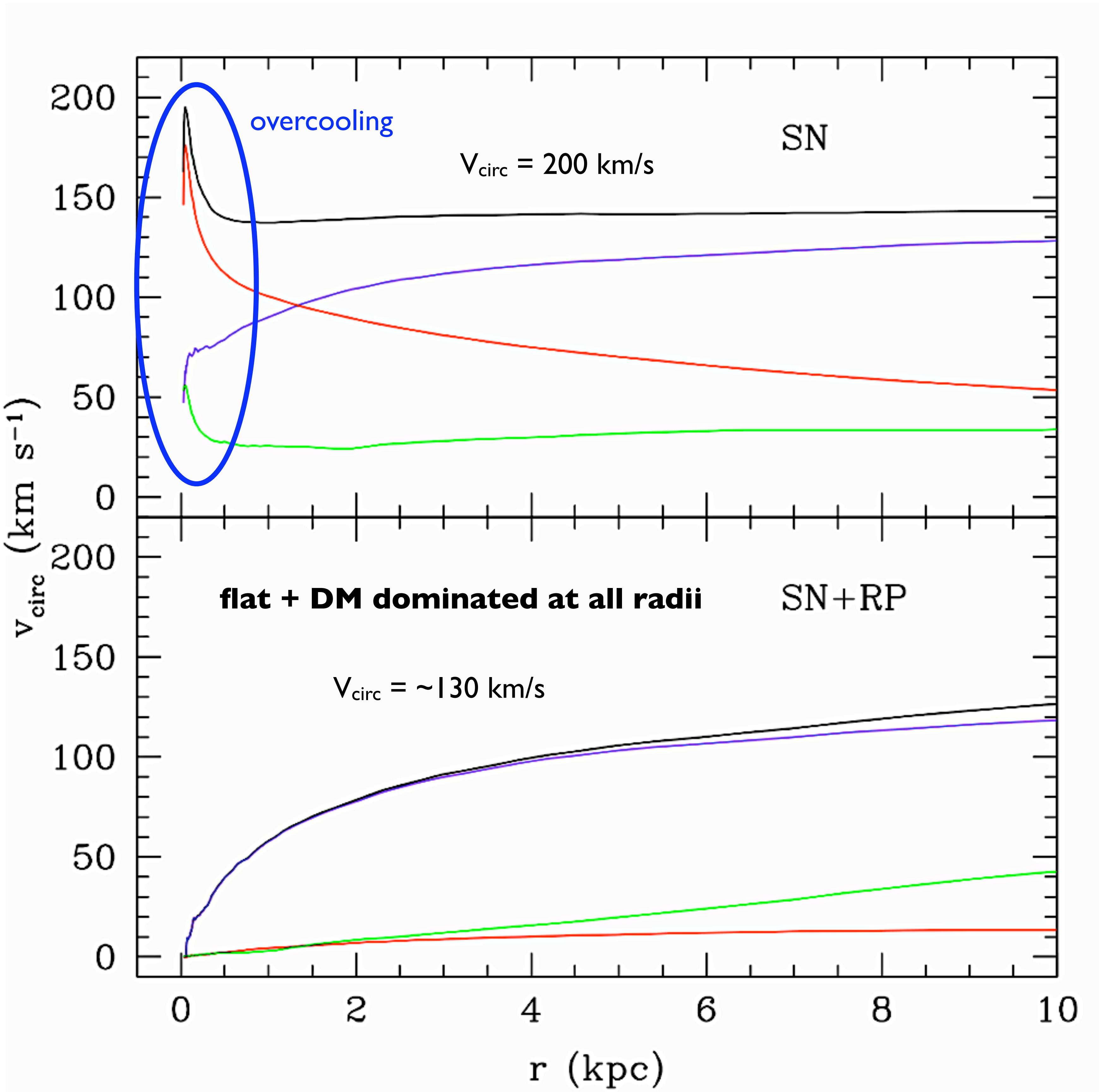
$M_{gas} = 3.0 \times 10^9\ M_{sol}$ (~50% cold)

MW_SN+RP:

$M_{stars} = 4.5 \times 10^8\ M_{sol}$

$M_{gas} = 5.2 \times 10^9\ M_{sol}$ (~30% cold)

MW: mass distribution



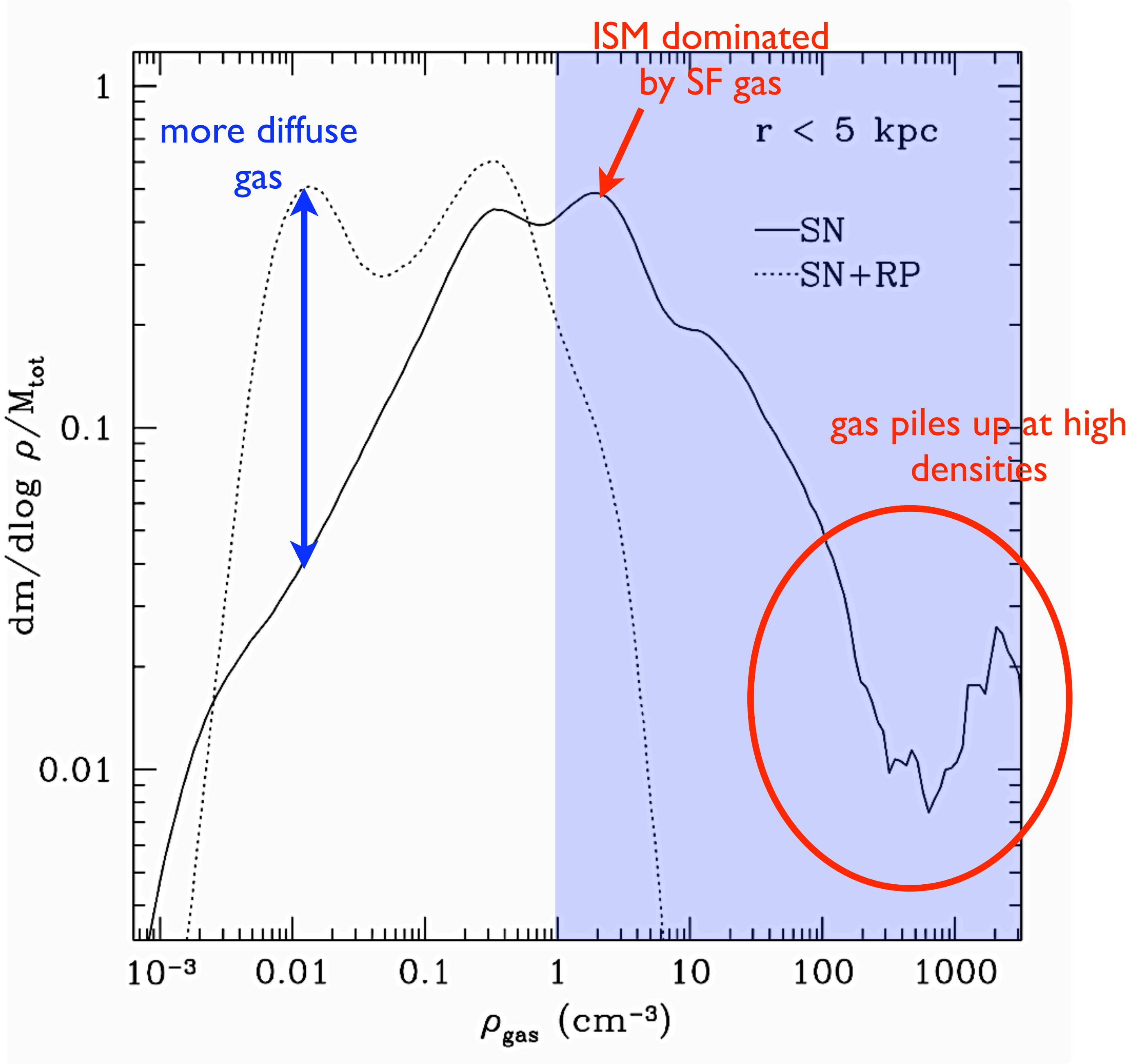
total
DM
gas
stars

RP prevents runaway collapse of gas to center

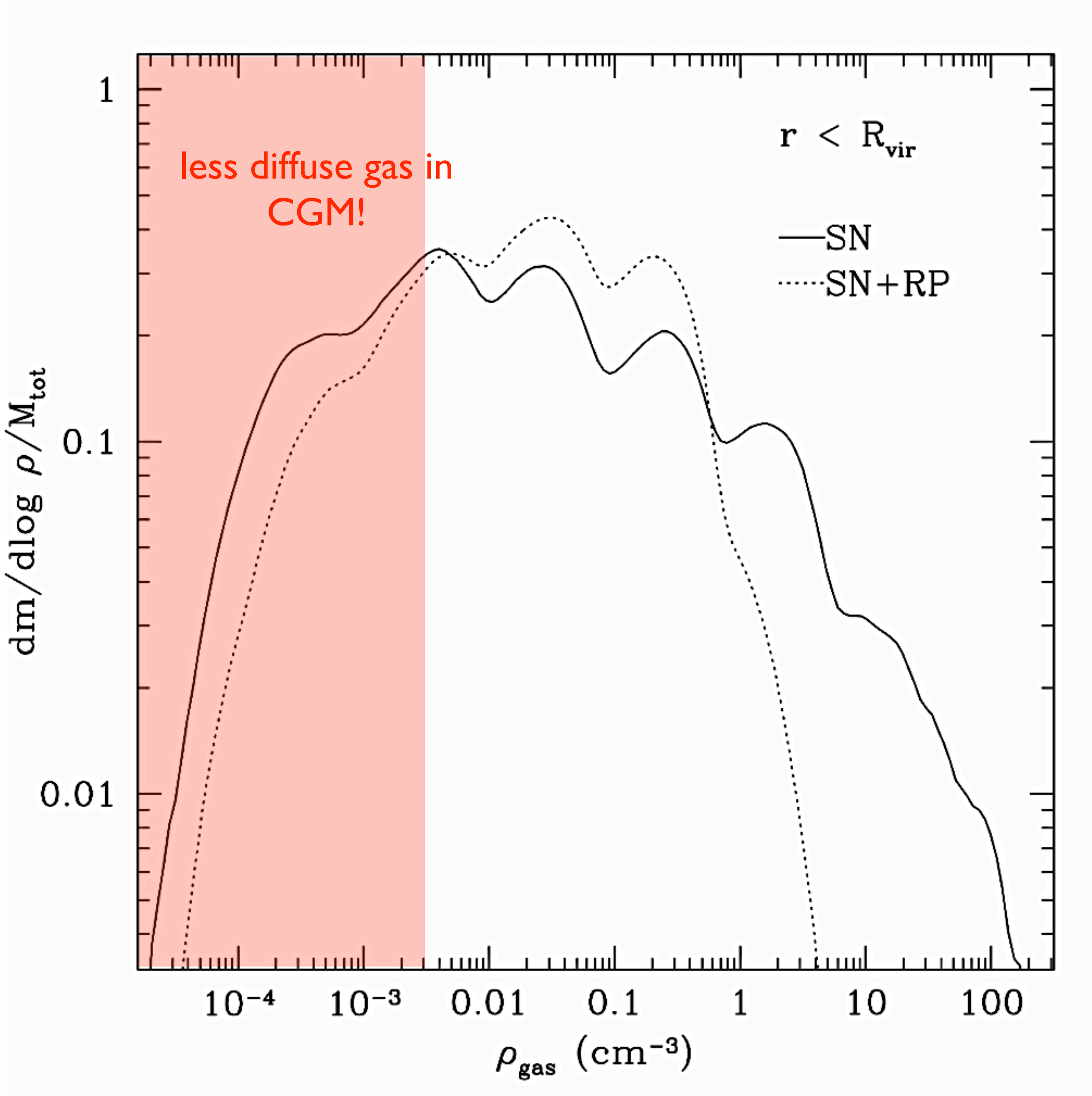
-> star formation drastically reduced in central 1 kpc

MW: gas properties - density

within galaxy



within virial radius

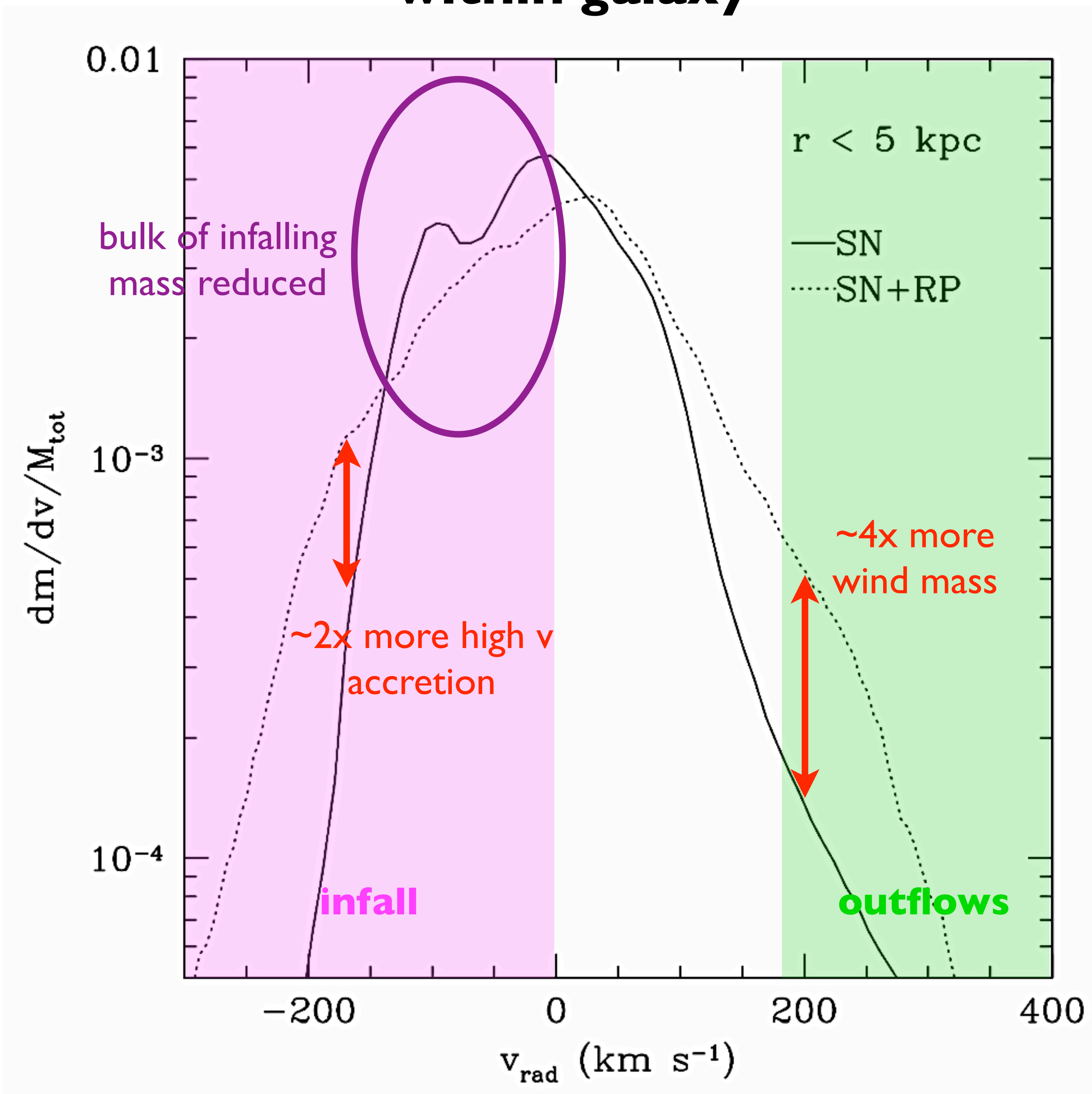


RP regulates star formation by preventing gas collapse

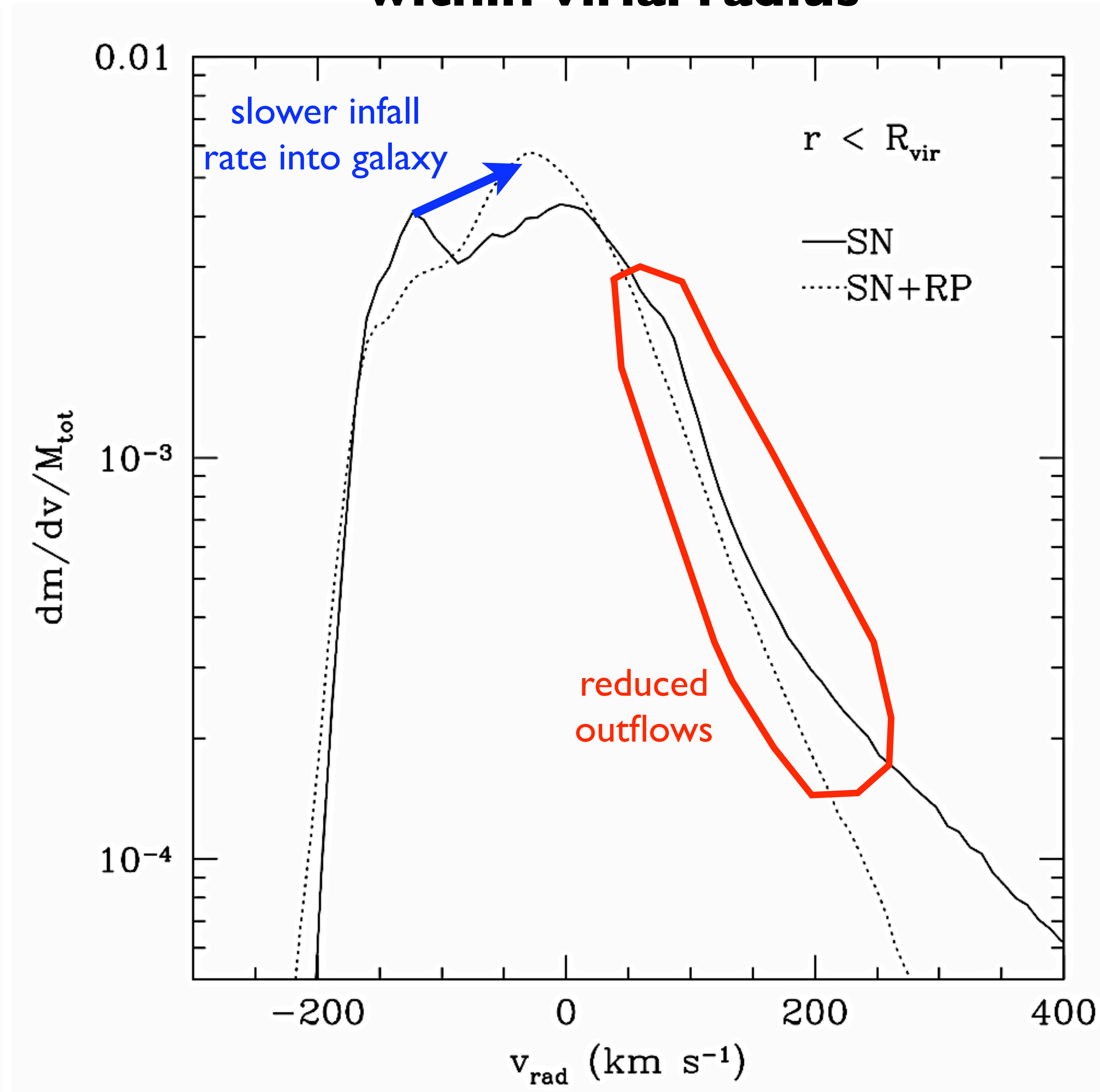
-> galaxy dominated by diffuse phase
but
CGM becomes denser

MW: gas properties - radial flows

within galaxy



within virial radius

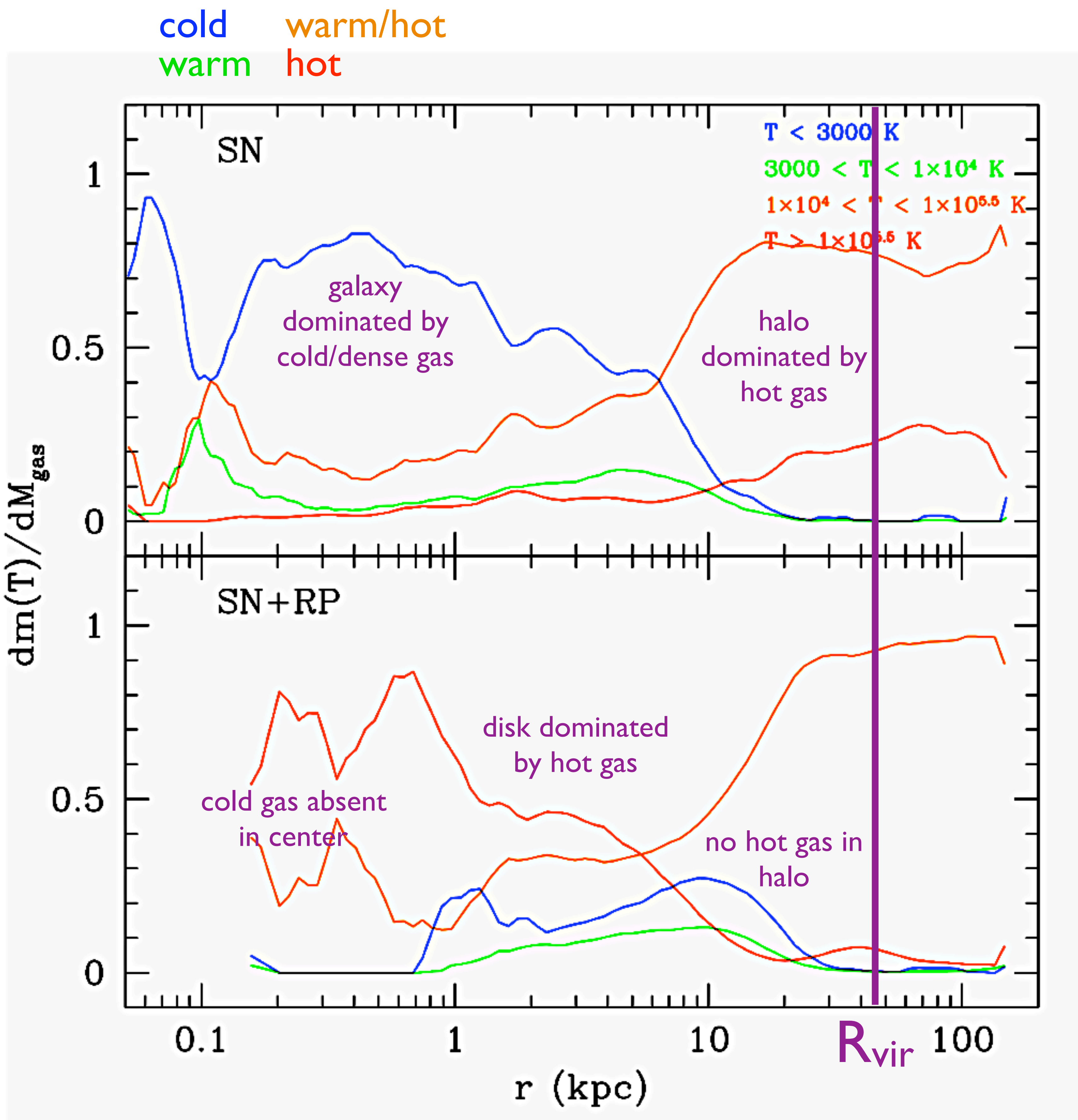


RP increases galactic wind *but* gas is reaccreted
-> gas circulates in galactic fountains / prevents bulge buildup

RP *quenches* accretion of halo gas into galaxy

reduced feedback energy limits mass and velocity of large-scale outflows

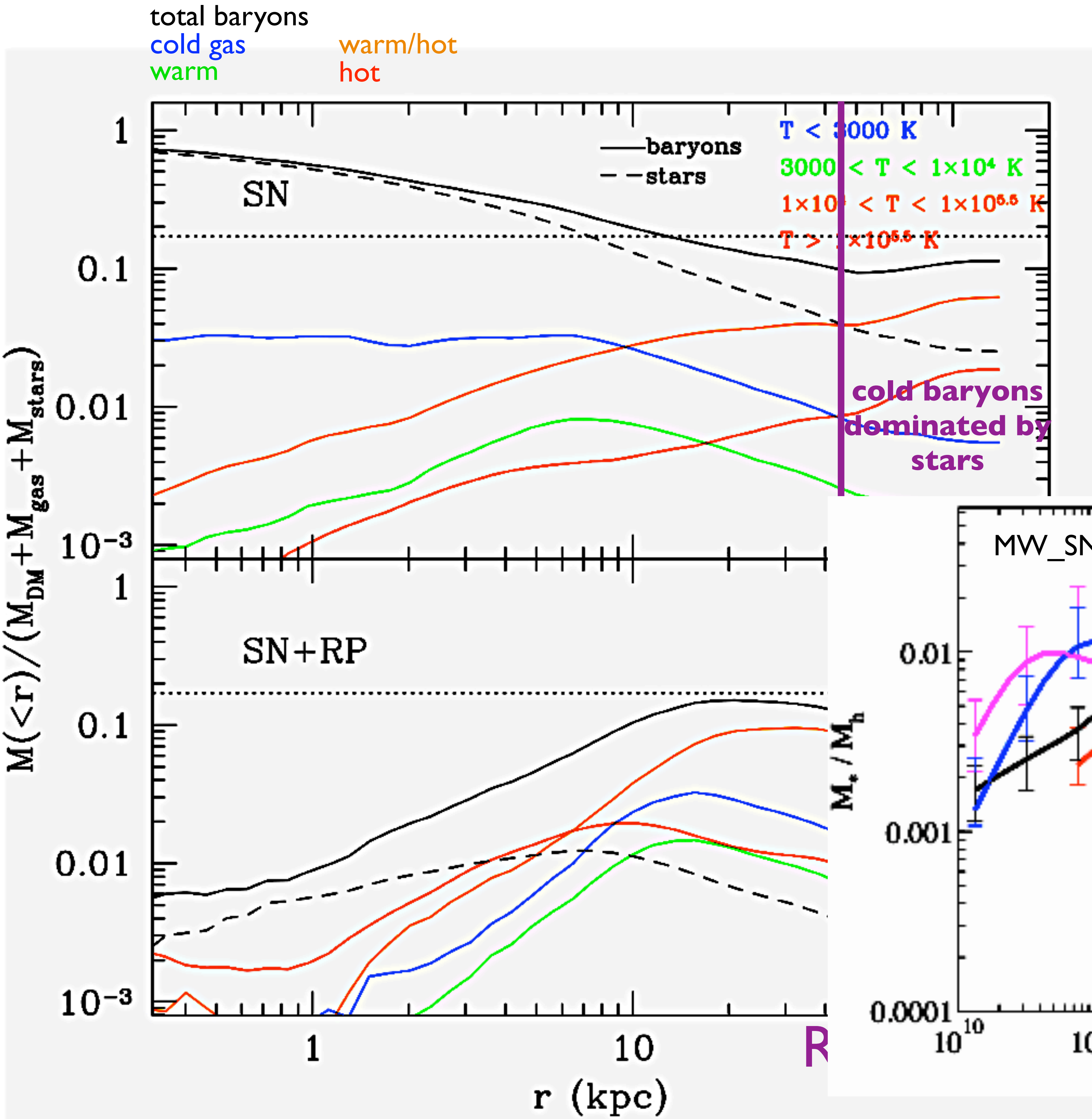
MW: gas temperature profiles



RP+SNe eject most of inner disk cold gas + heat it above a million K

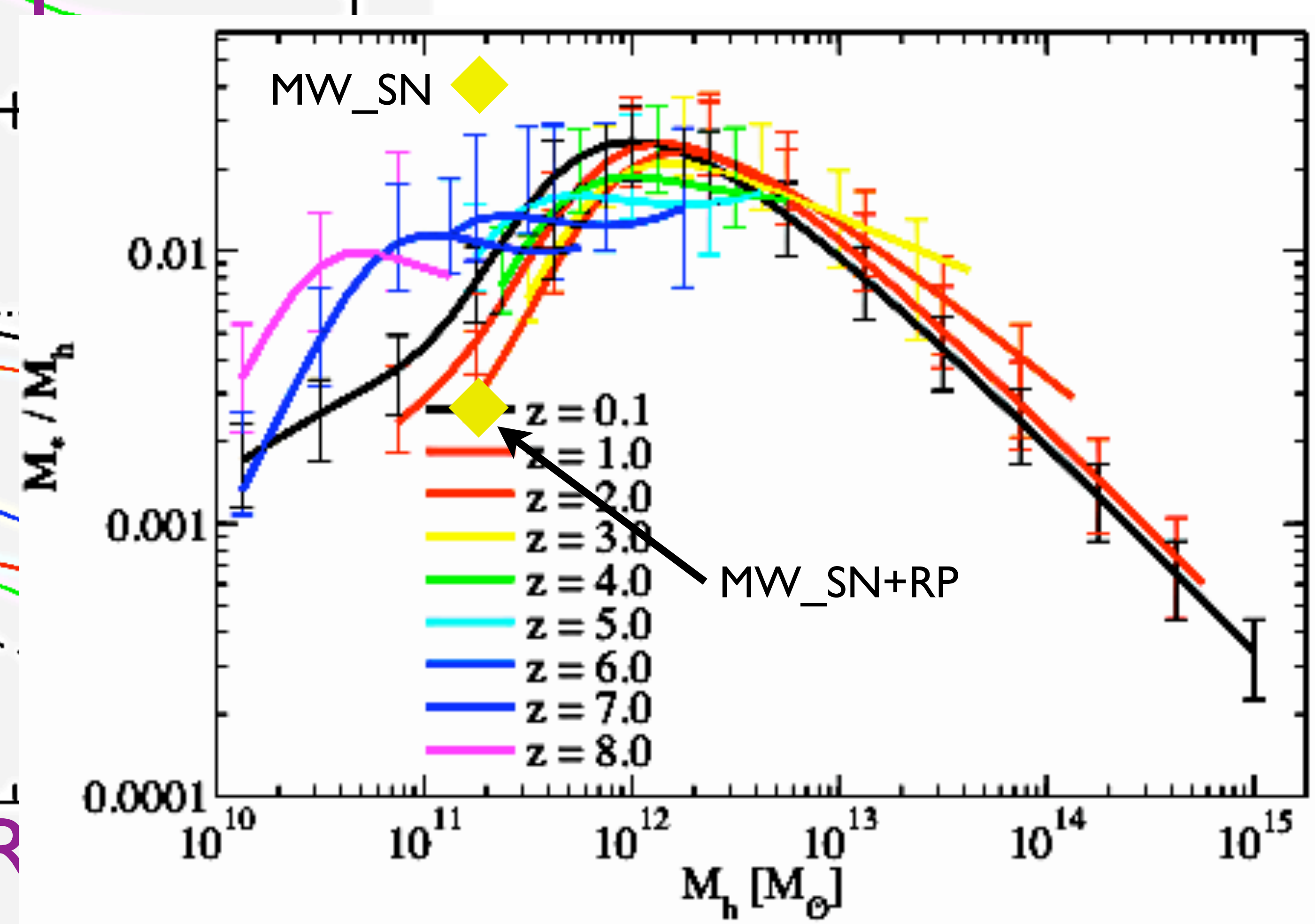
RP reduces SFR -> not enough total FB energy to heat halo

MW: baryon fractions



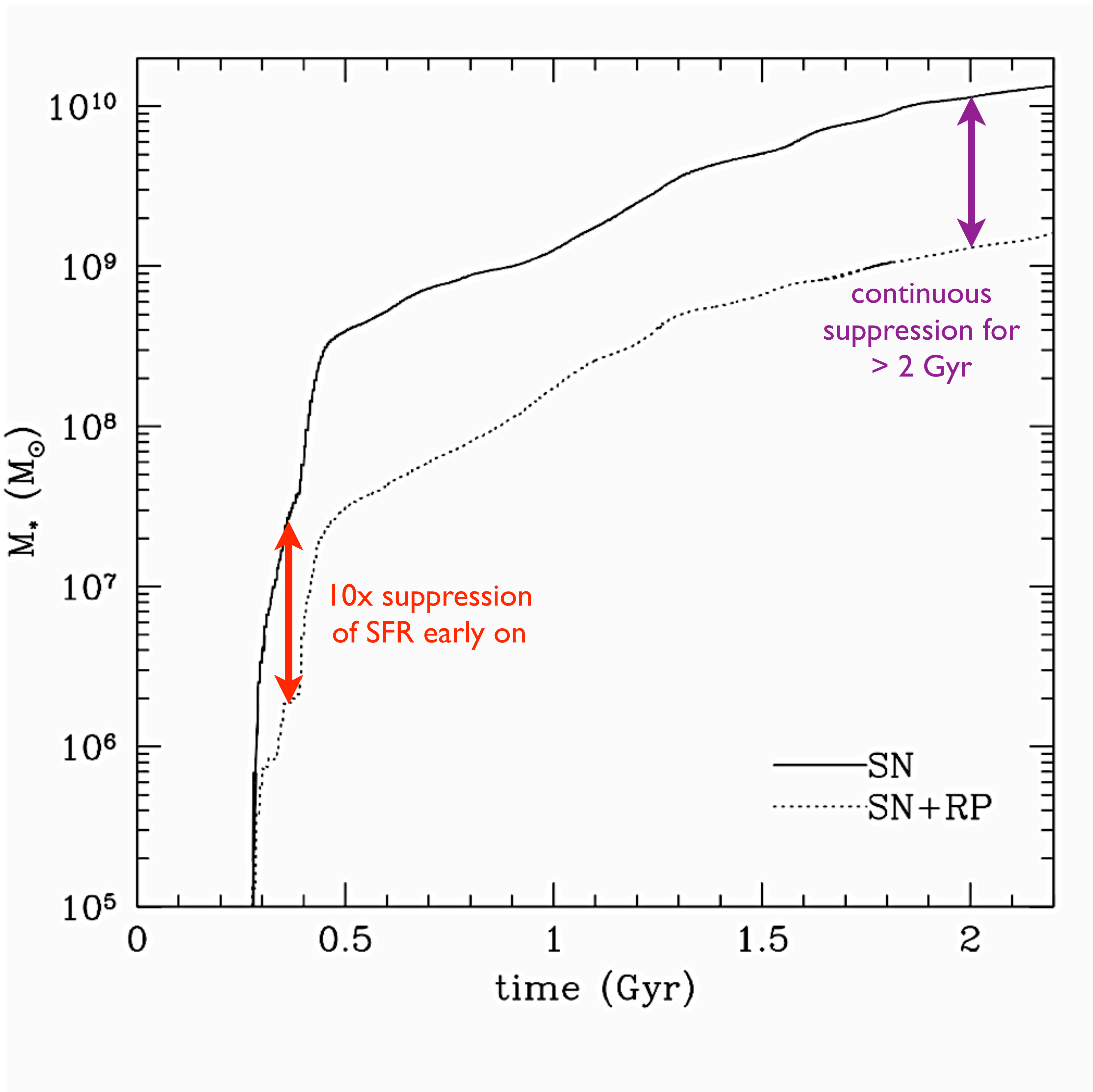
RP reduces *cold* baryon fraction to ~10% and reduces the stellar fraction to ~1.8%

however, baryons are pushed outside 10 kpc but kept within halo -> f_{bar} = 1



Behroozi+2012

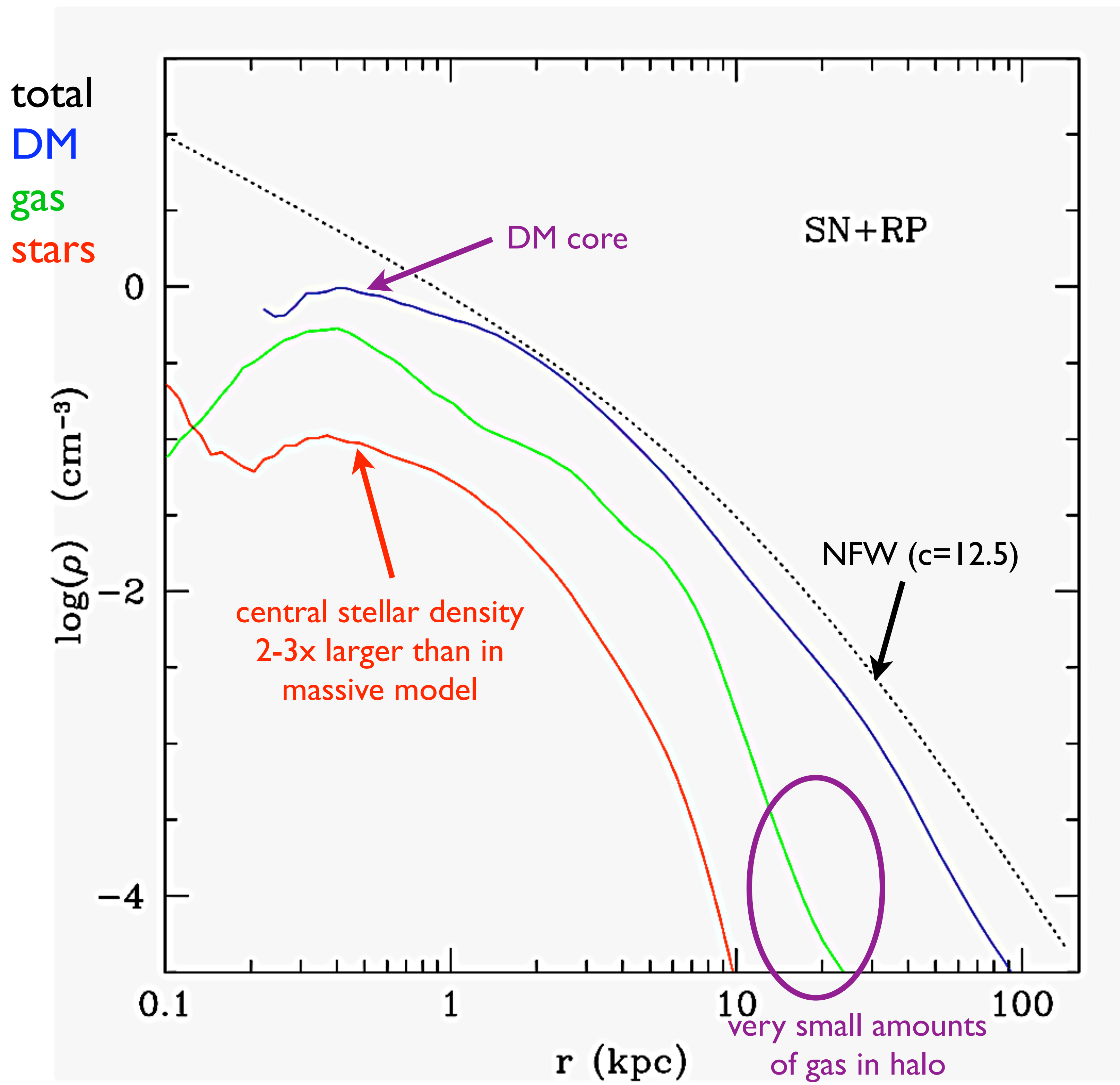
MW: star formation history



dwarf: mass distribution

$M_{stars} = 1.4\mathrm{x}10^8\ M_{sol}$

$M_{gas} = 1.5\mathrm{x}10^9\ M_{sol}$ (mostly cold within 10 kpc)

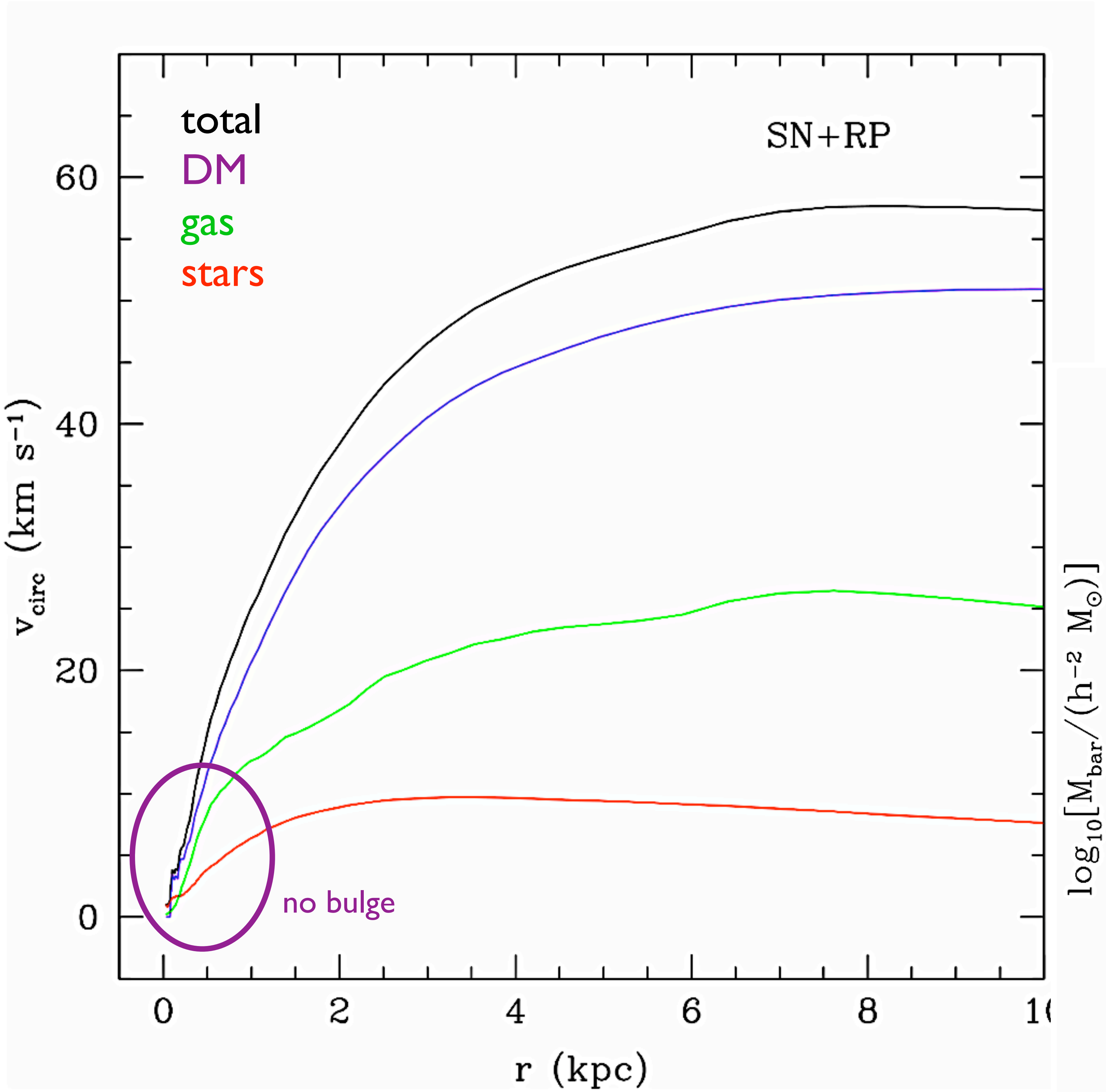


despite strong RP, extended massive stellar component builds up

strong RP feedback results in DM core - episodic gas blowouts?

RP depletes halo gas

dwarf: mass distribution

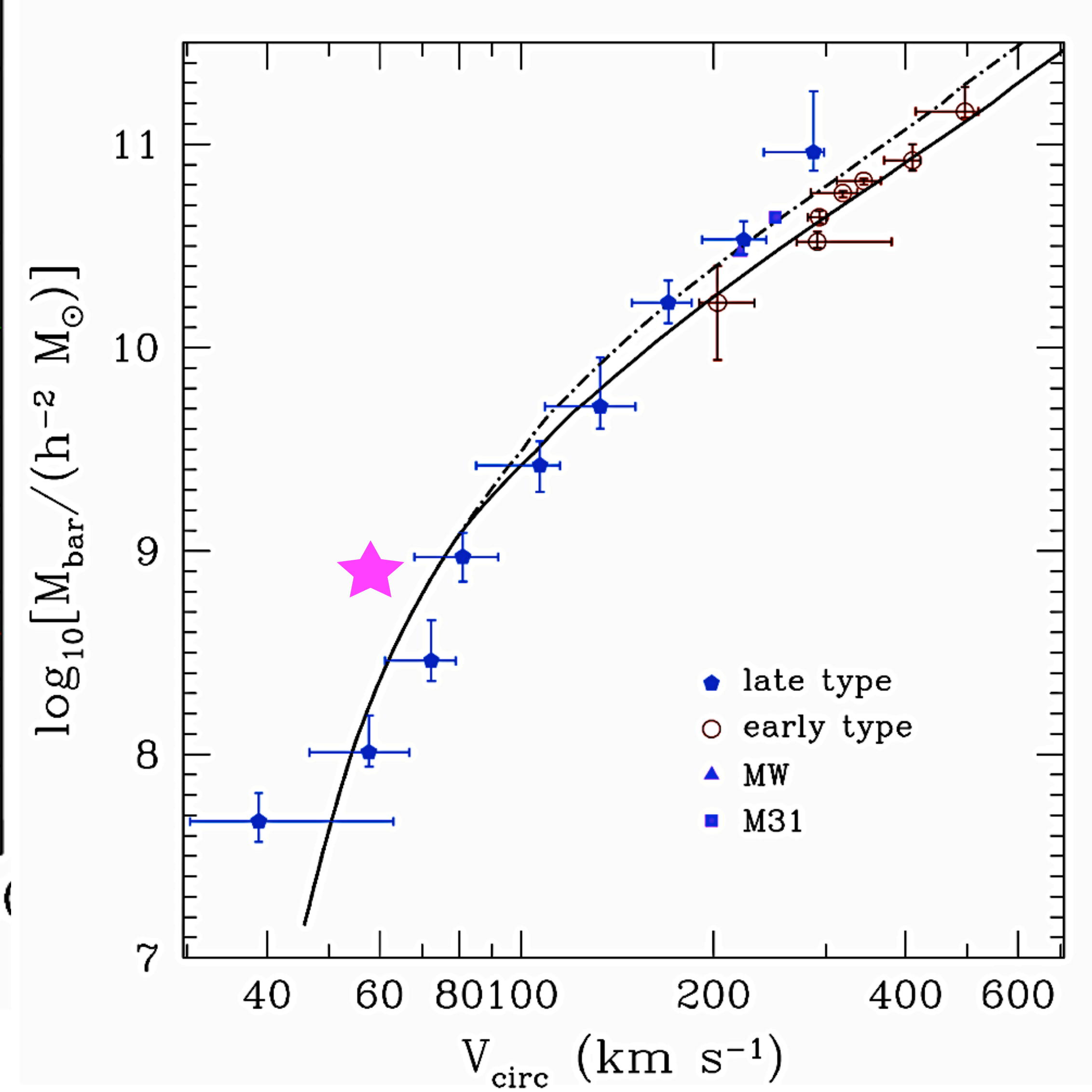


slowly-rising, DM-dominated at all radii

V_{circ} ~ 58 km/s

$f_{gas} = M_{gas}/M_* \sim 10$

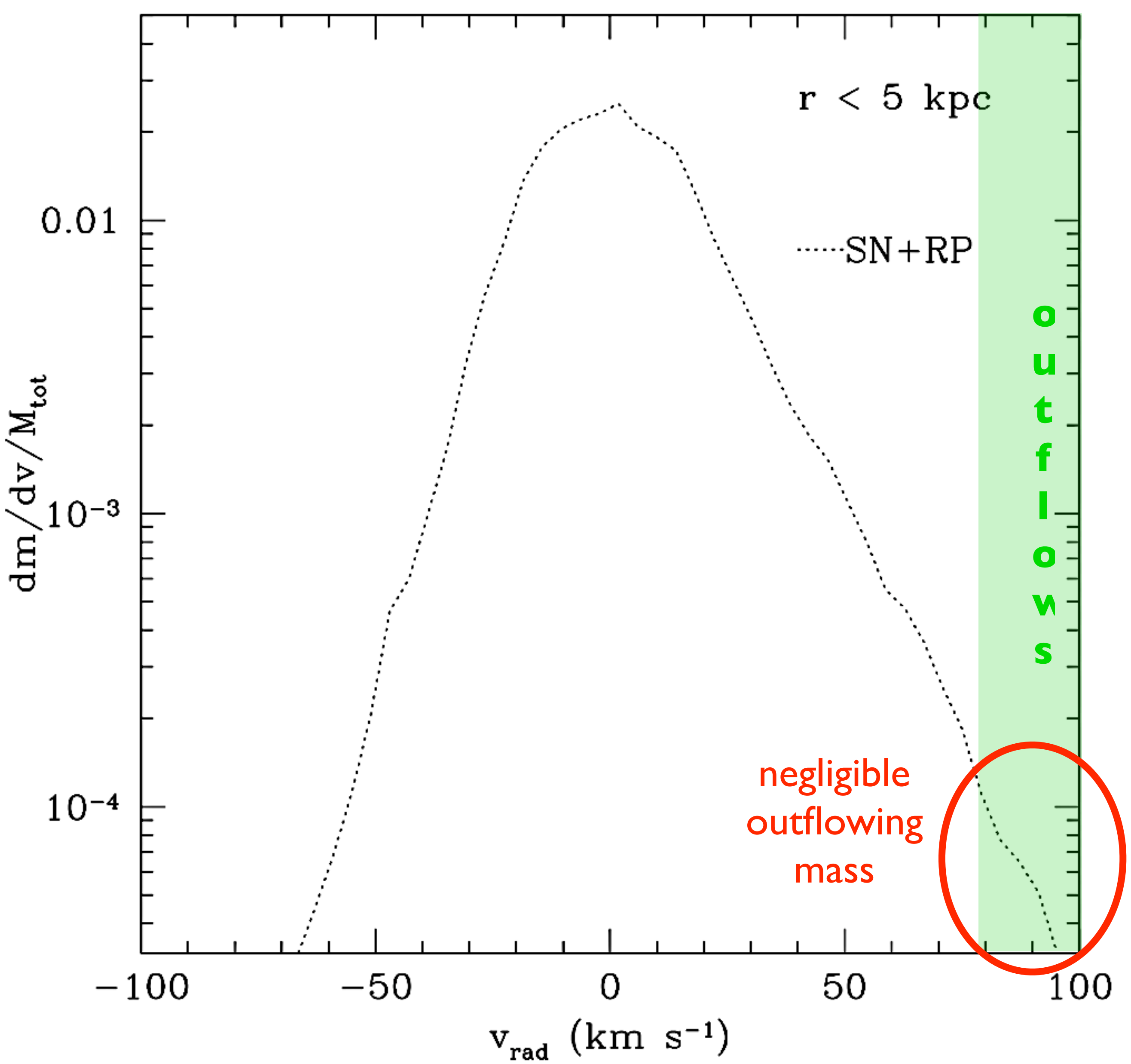
sits slightly above baryonic T-F relation



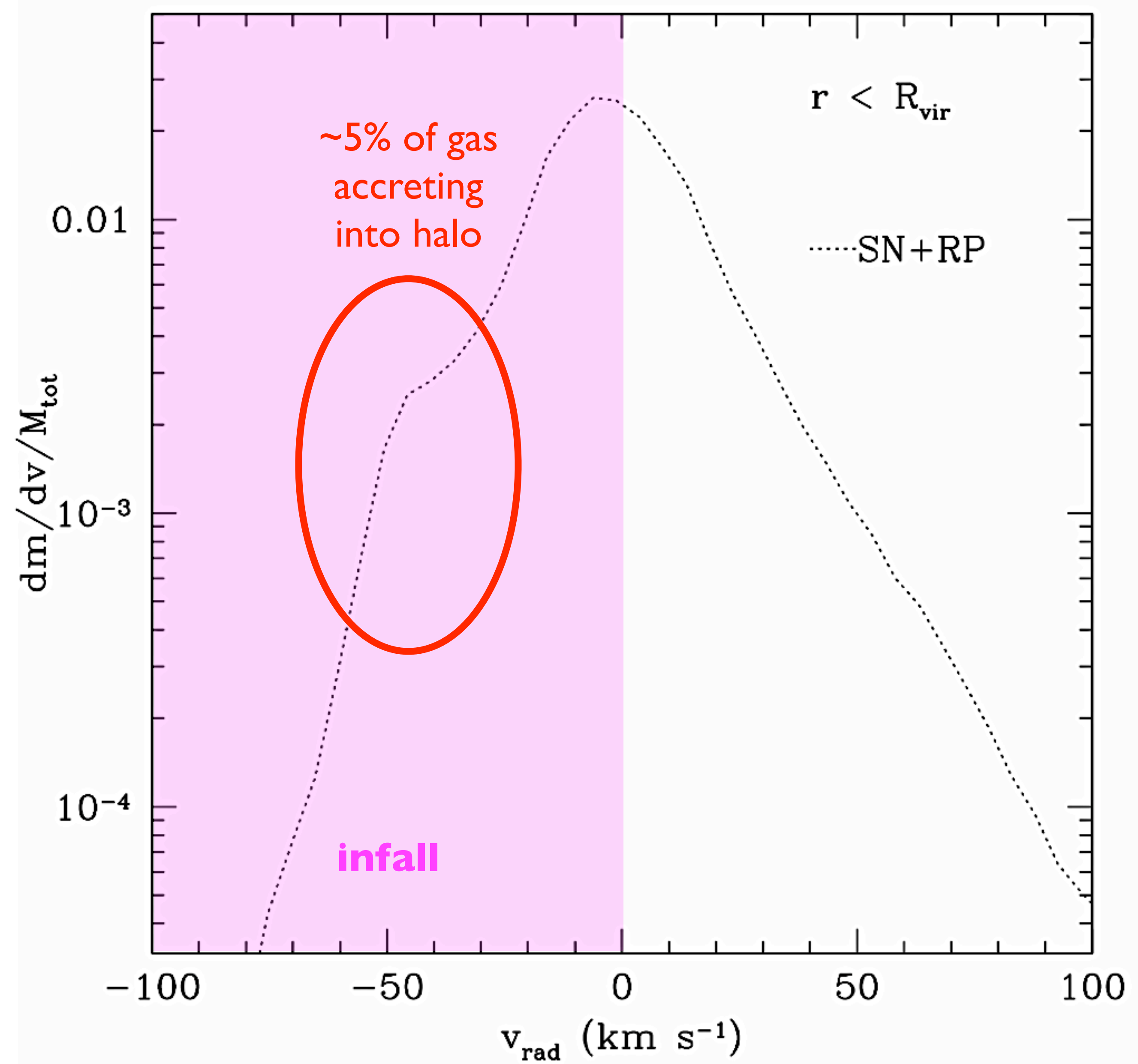
Trujillo-Gomez+11

dwarf: gas properties - radial flows

within galaxy

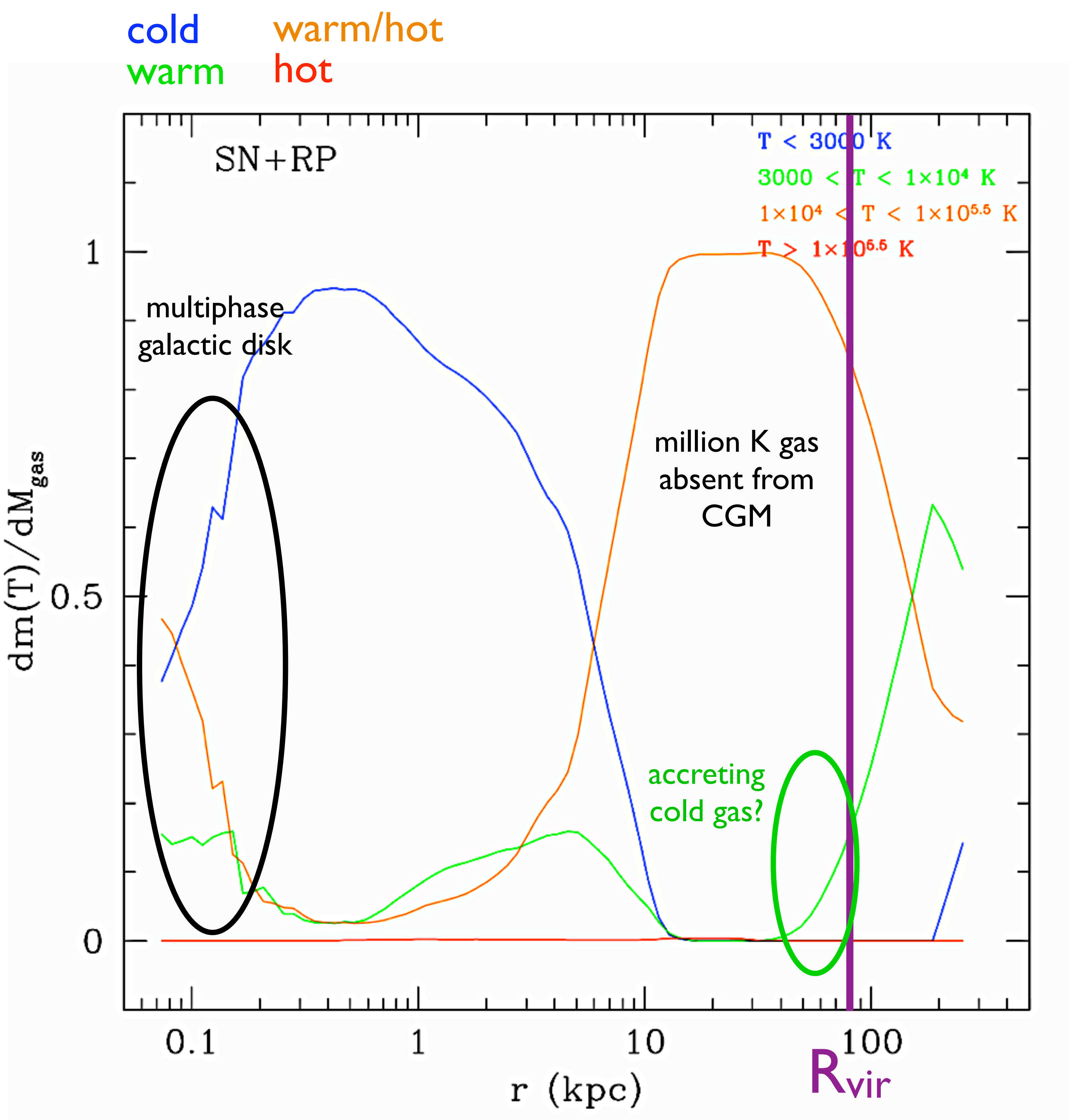


within virial radius



at z=0, very small amount of mass in galactic winds
and
considerable amount of (cold) accretion into CGM

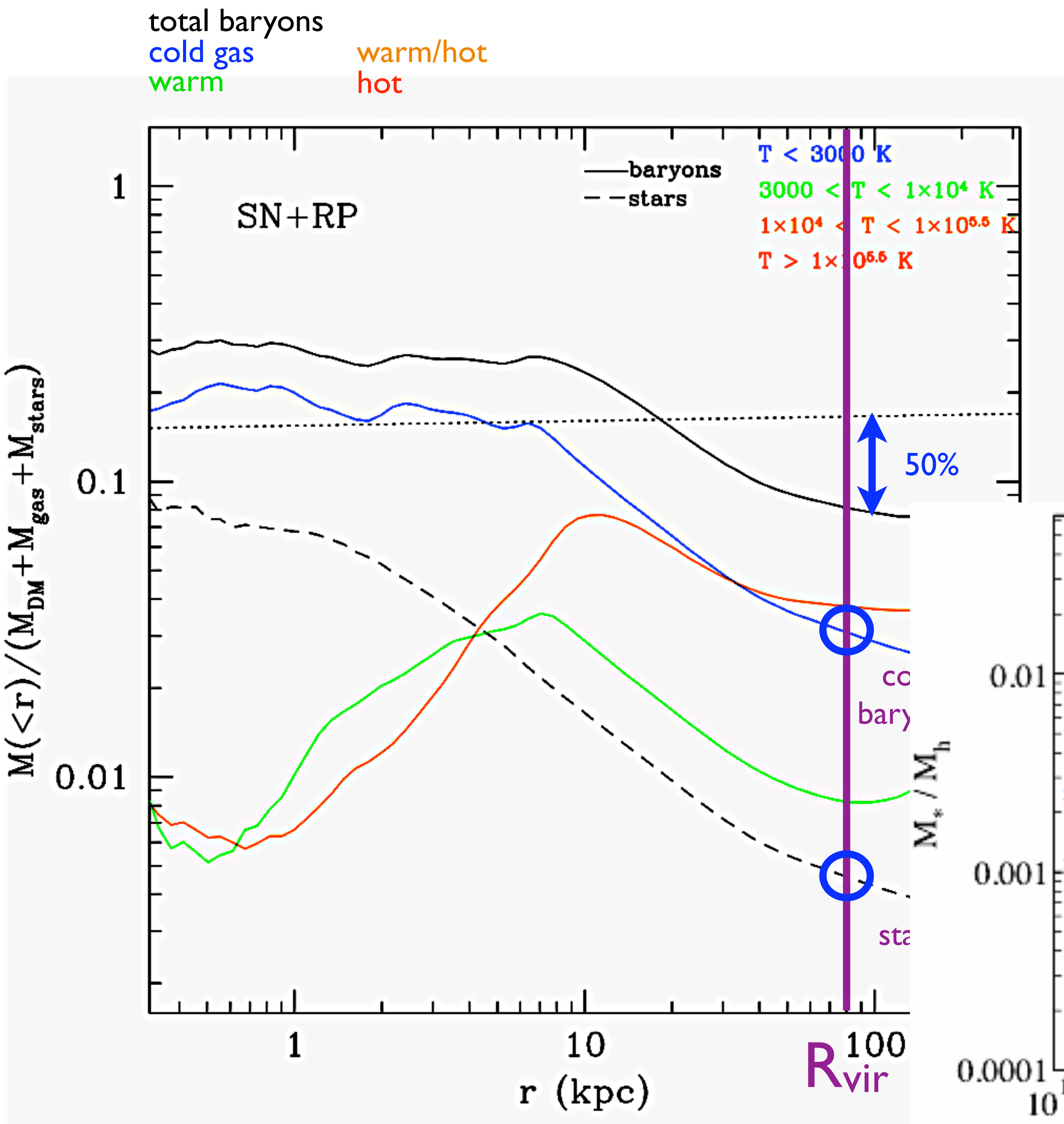
dwarf: gas temperature profiles



at z=0, dwarf has a multiphase gas disk and warm/hot CGM

no hot gas, some cold gas accreting from IGM

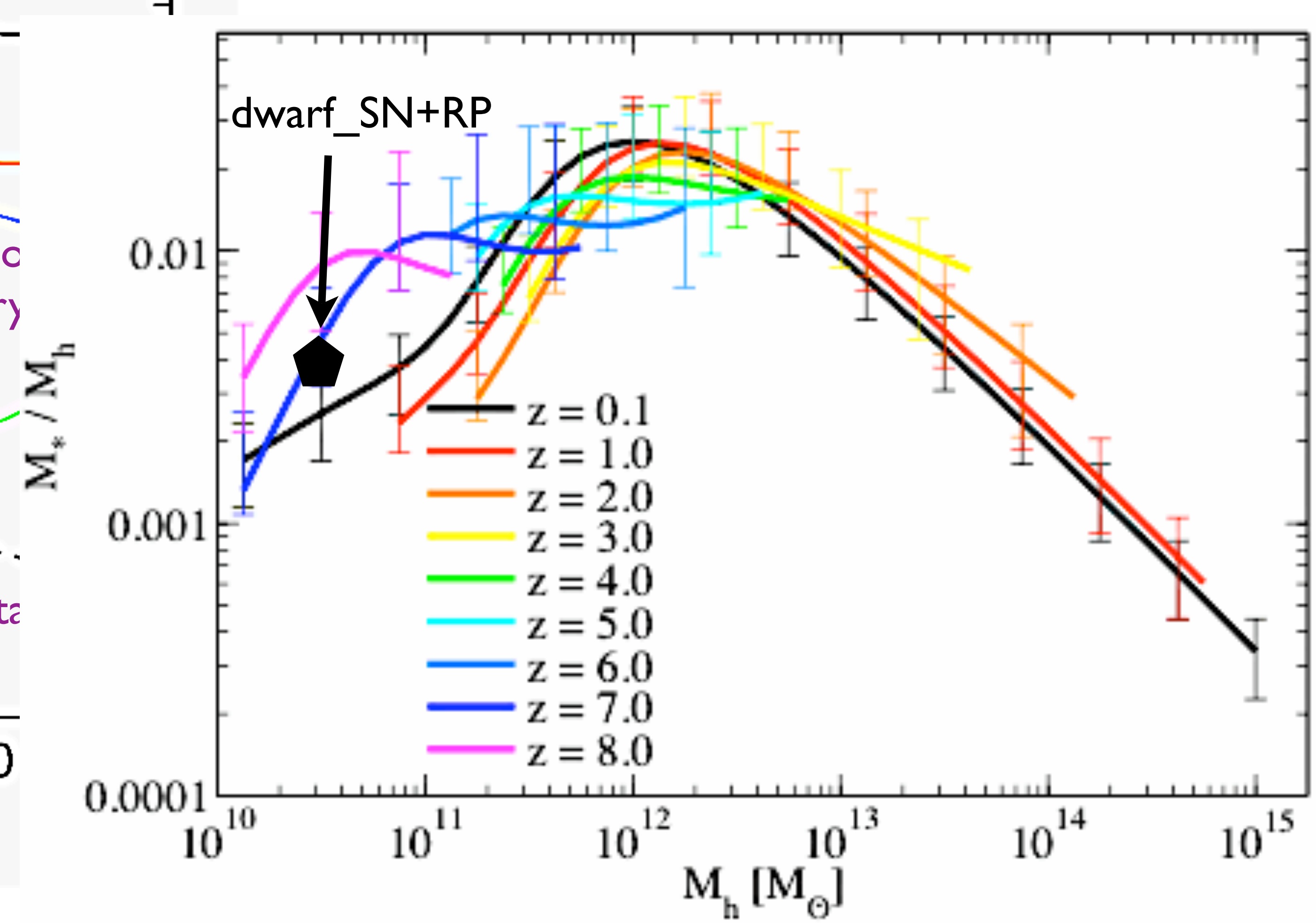
dwarf: baryon fractions



at z=0:
50% of cosmic baryons *lost* within virial radius

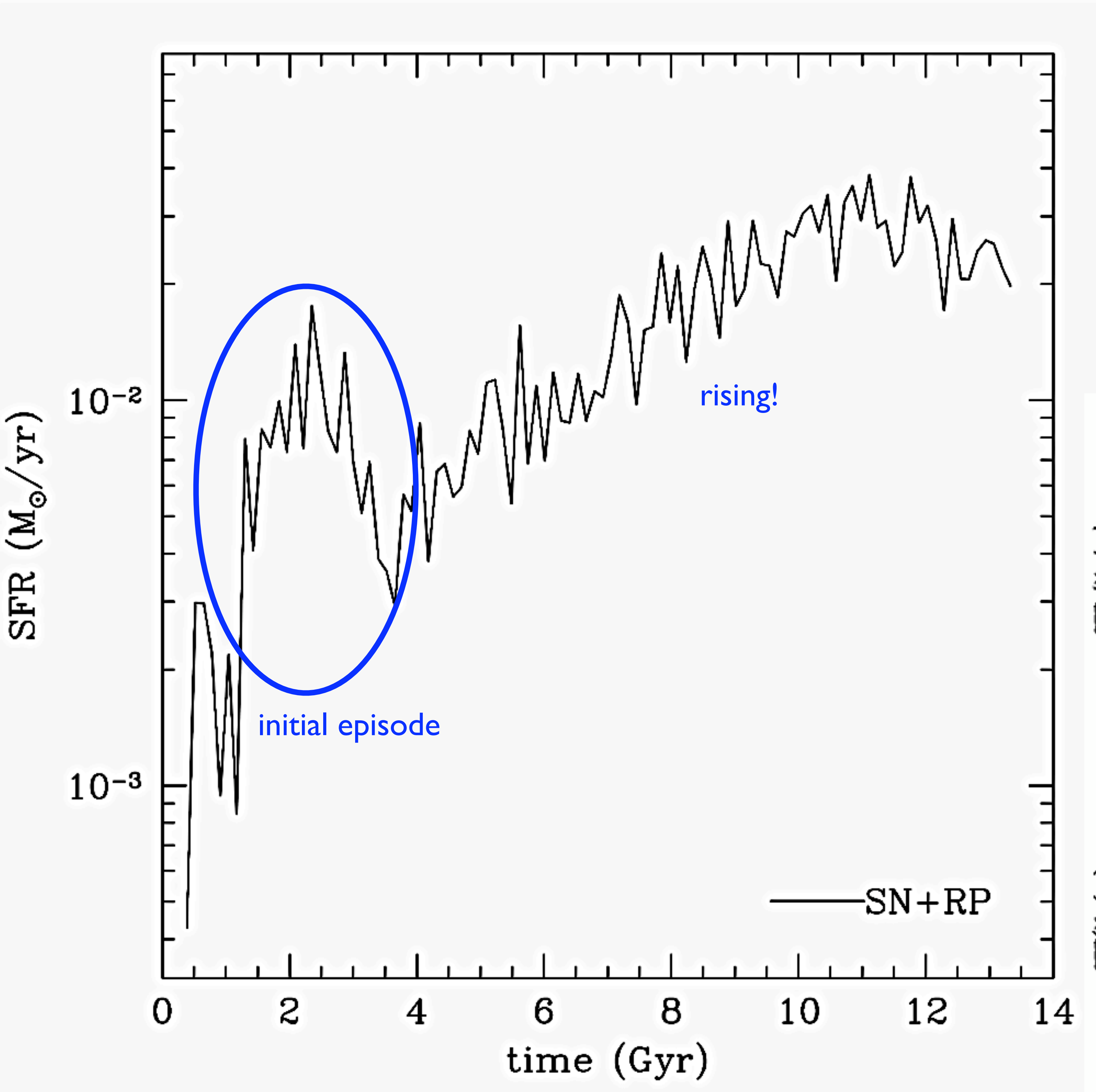
only ~18% of cosmic baryons locked in cold phase

only ~2% in stars



Behroozi+2012

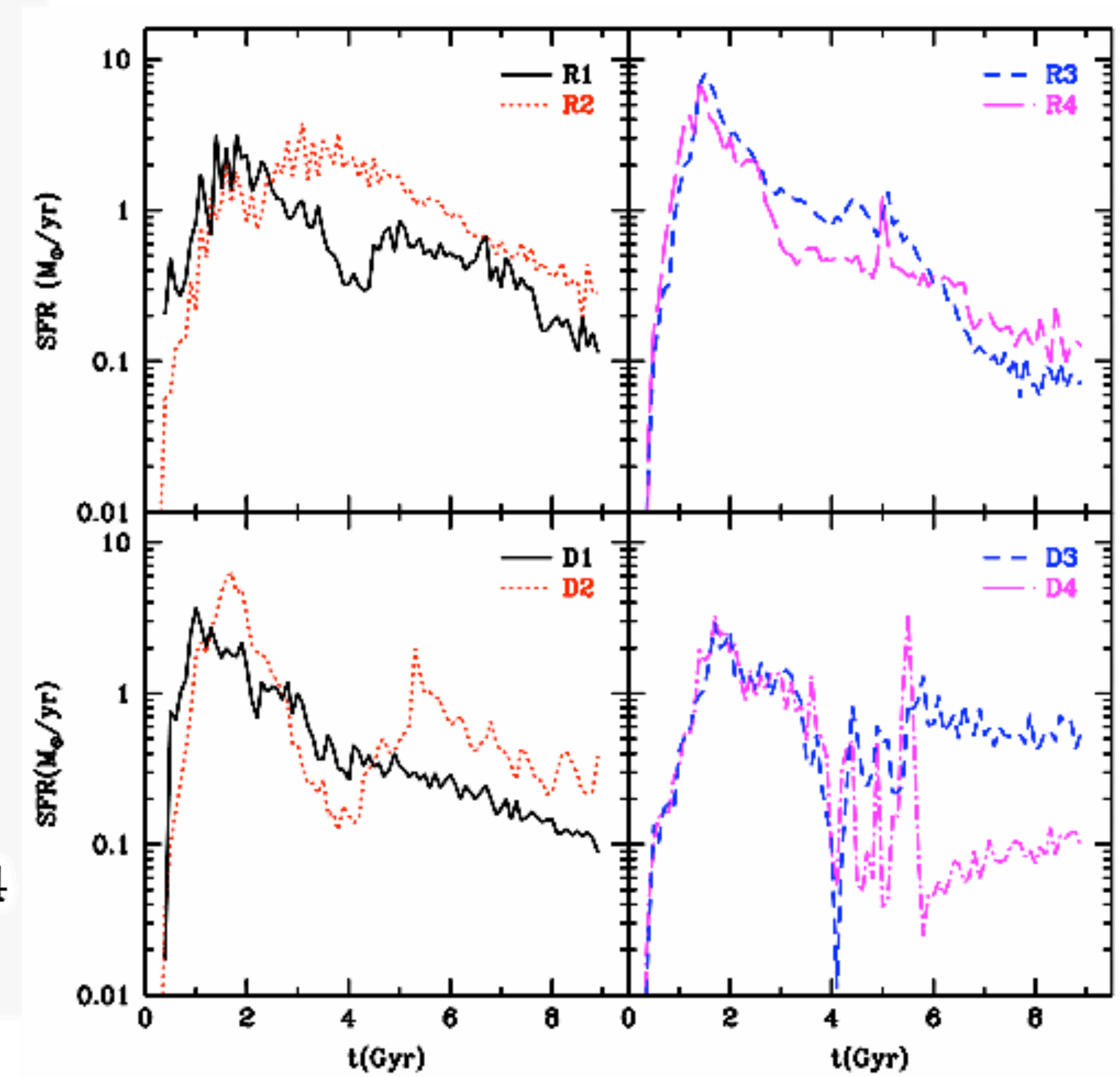
dwarf: star formation history



most of the stellar mass assembled in last few Gyr

agrees with observations (Salim+07)

SN feedback alone does not produce rising SFR



Colin+2010

Conclusions

✓ RP feedback is able to strongly reduce and regulate the SF in massive galaxies *and* dwarfs

✓ It does so by ejecting/heating the disk gas in a continuous galactic fountain

✓The formation of a massive bulge is completely suppressed at z > 3 in an M^* galaxy

✓RP produces a dwarf galaxy with slowly rising rotation curve

✓ In a dwarf's shallow potential, even a modest stellar component is able to reduce the fraction of baryons within R_{vir} by 50%

✓ RP reduces the early SFR by a factor of ~10. It leads to a late buildup of the stellar component in dwarfs consistent with downsizing

➡ In massive galaxies strong RP does not produce outflows

➡ in a dwarf, the fraction of baryons locked in stars is ~2 times larger than predictions - sits slightly above BT-F thanks