Max Planck Institute
for Astrophysics

The (non-ionizing) interstellar radiation in resolved dwarf galaxies

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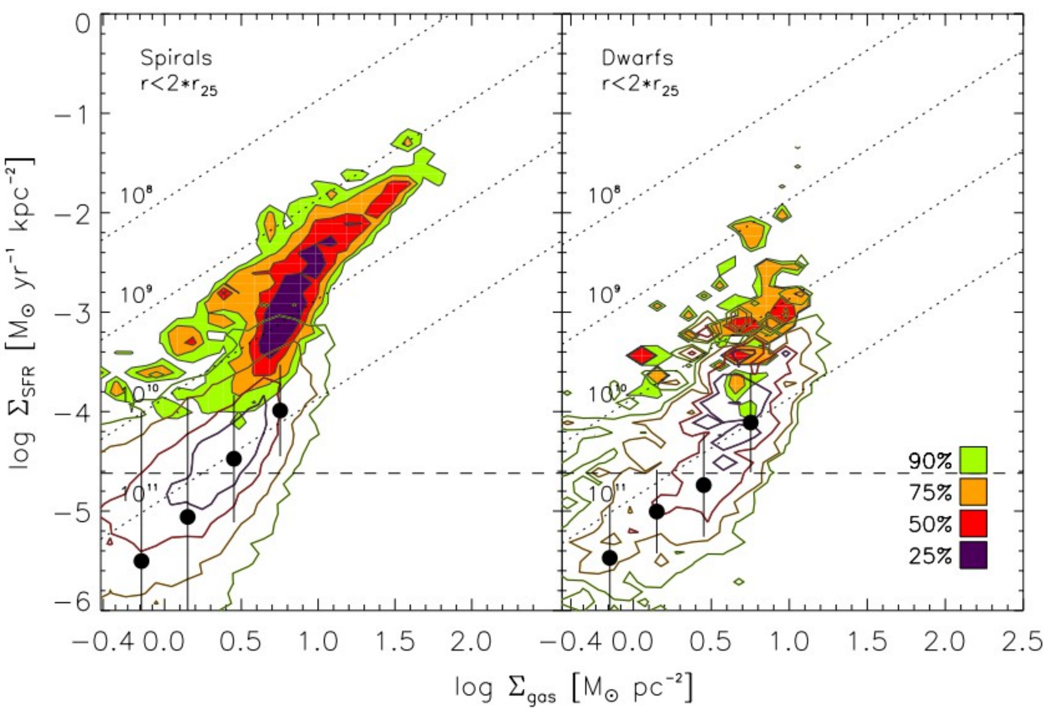
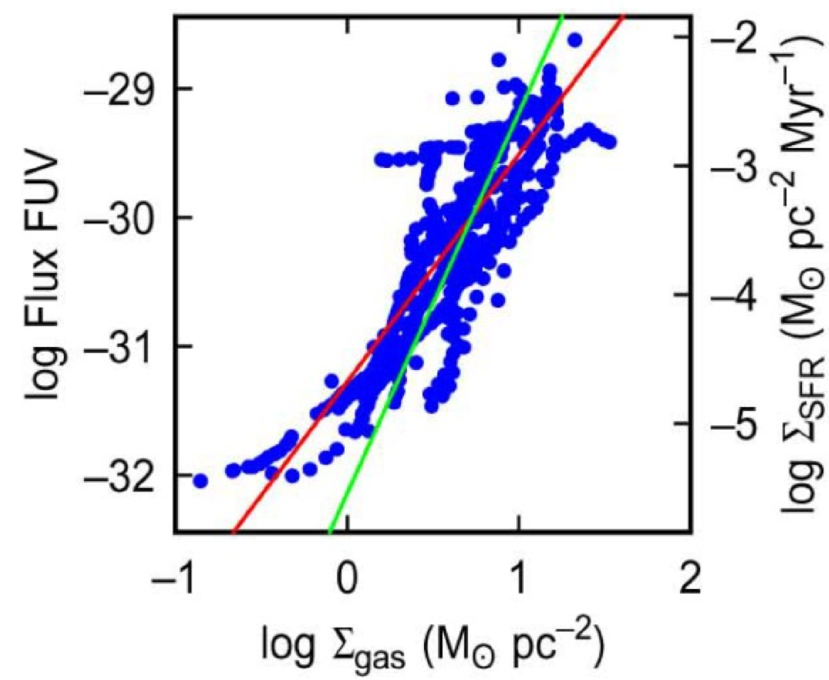
KS relation in dwarf galaxies

Bigiel et al. 2010



Elmegreen & Hunter 2015

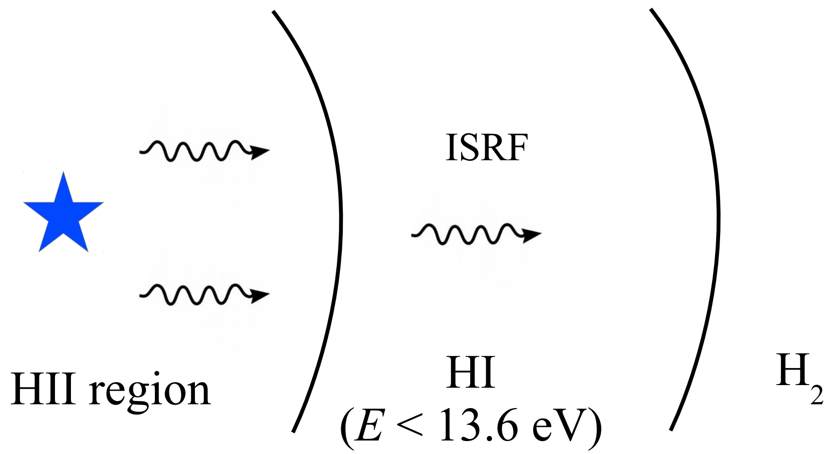


Very steep slope (N=2~3) below $\Sigma_{SFR} < 10\ M_{\odot}\ pc^{-2}$

Transition from $t_{dep} \sim 1$ Gyr to $t_{dep} \sim 100$ Gyr (extremely inefficient SF)

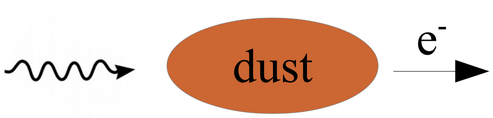
The interstellar radiation field (ISRF)

ISRF:
Stellar radiation with energy less than 13.6 eV
(not enough to ionize hydrogen)



What does ISRF do?

1) Heat up the ISM by photoelectric (PE) effect



2) Destroy H_2 via photodissociattion

$H_2 + \gamma \rightarrow 2H$

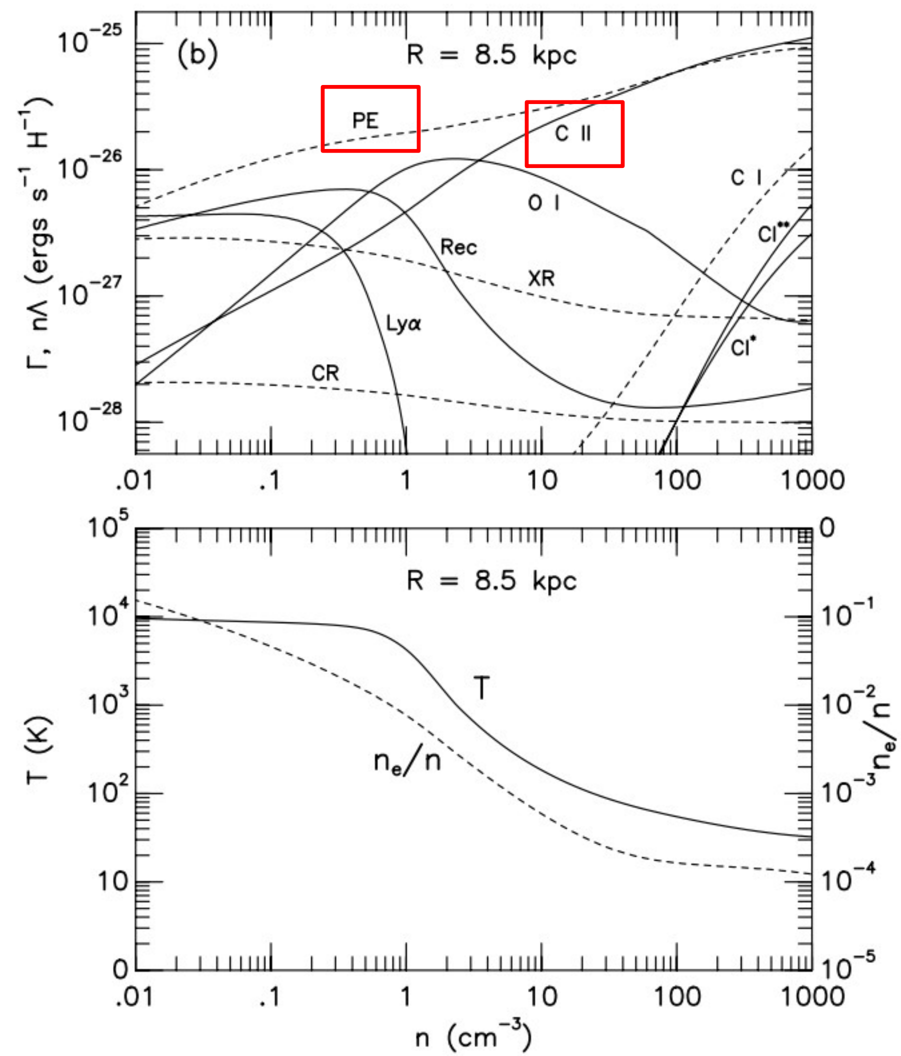
Heating and cooling in MW

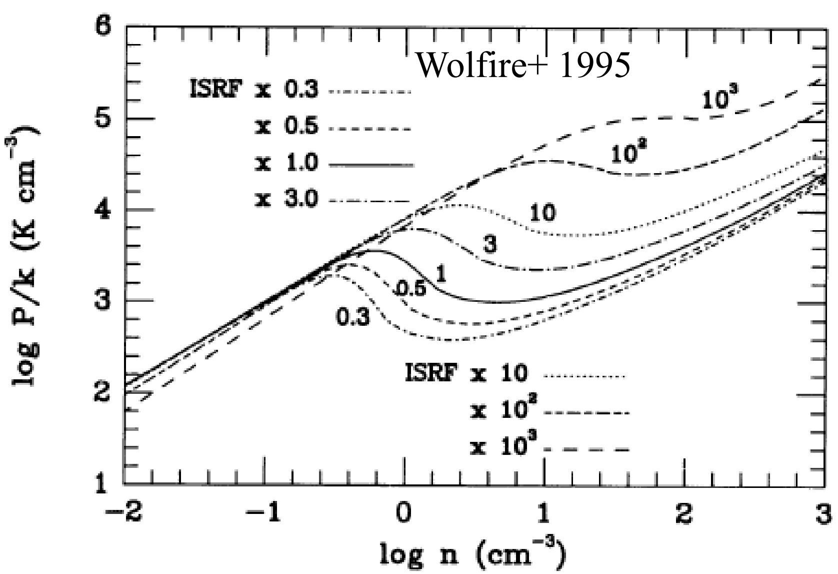
In the Milky Way (or typical spiral galaxies), the PE effect is the dominating heating mechanism.

While the metal line emission (CII, OI) dominates cooling.

The thermal balance in the ISM is largely controlled by these processes.

Wolfire+ 2003





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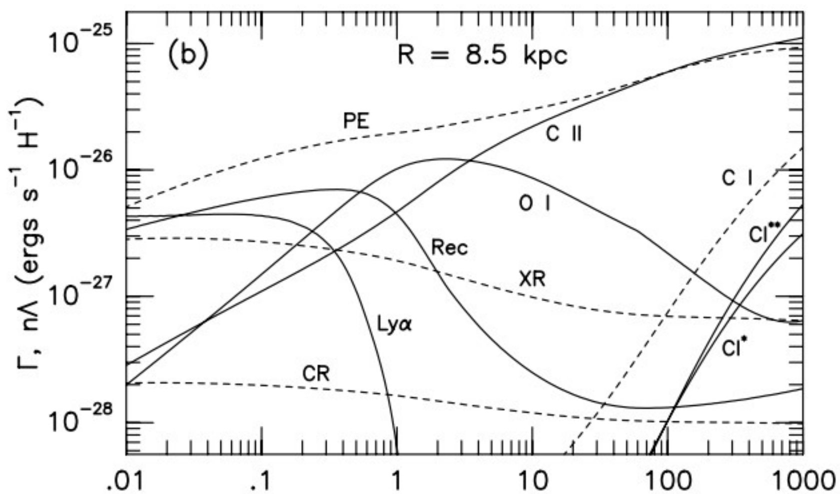
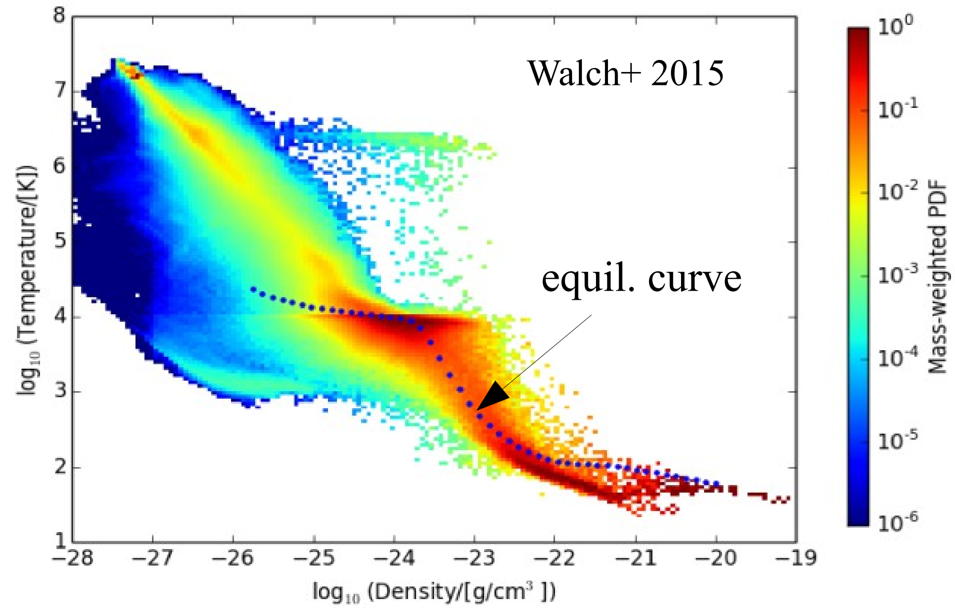
SN feedback drives turbulence and shocks which perturb the gas and cause scatter. However, the majority of gas is still in thermal equilibrium (i.e. they sit on the equil. curve)

Wolfire+ 2003



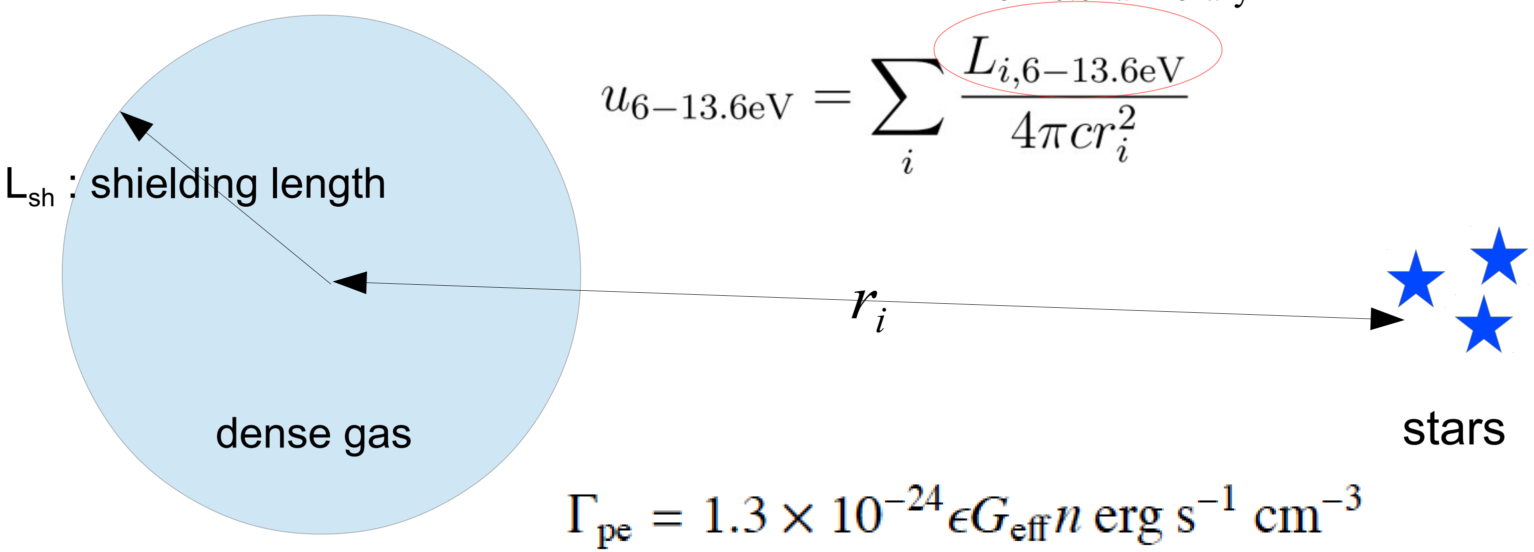


Modeling spatially varying ISRF in dwarf galaxies

Due to the low surface density and low dust abundance in dwarf galaxies, we can neglect dust extinction and calculate the ISRF directly from stars using the simple r^{-2} law.

from stellar library

$$u_{6-13.6\mathrm{eV}} = \sum_i \frac{L_{i,6-13.6\mathrm{eV}}}{4\pi c r_i^2}$$



$$\Gamma_{\mathrm{pe}} = 1.3 \times 10^{-24} \epsilon G_{\mathrm{eff}} n \ \mathrm{erg\ s^{-1}\ cm^{-3}}$$

To speed up, we calculate the ISRF using the tree approximation during the tree walk.

Is it really a fair approximation? => need radiative transfer to confirm (T. Peter's talk).

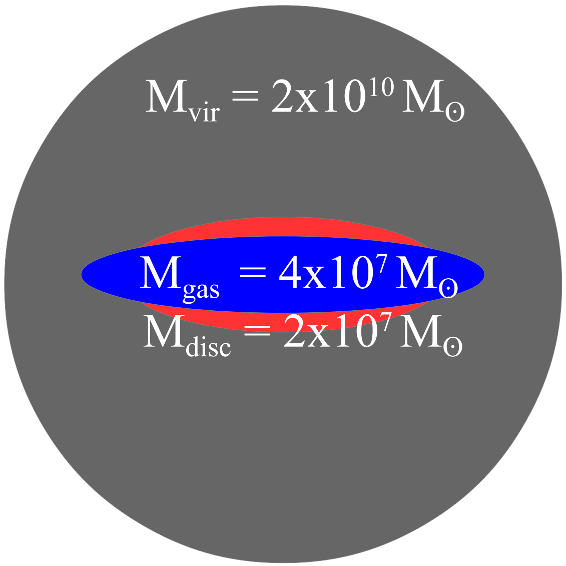
Simulations

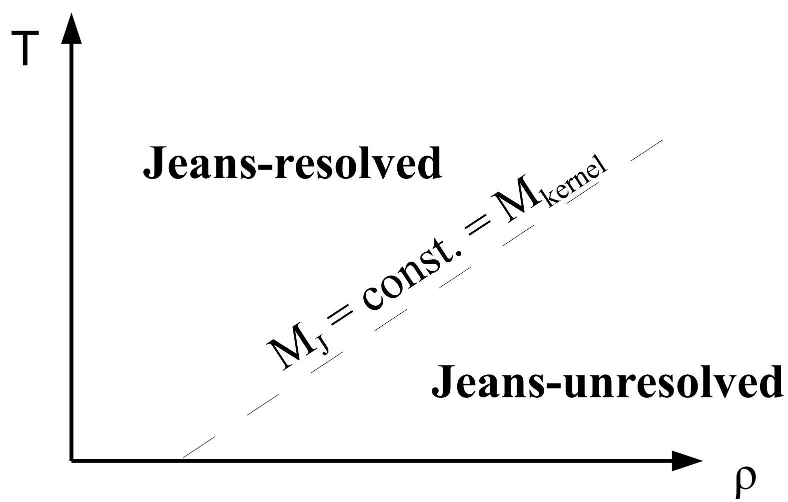
Physics:

- gravity & hydrodynamics (Gadget-3 + modern SPH)
- non-equilibrium cooling & chemistry network (similar to SILCC)
- star formation ($SFR = \varepsilon\, \rho_{gas} / t_{ff}$, threshold = 100 cm^{-3} & 100 K, ε=2%)
- SNII feedback (individual explosions)
- metal enrichment (SNII+AGB)

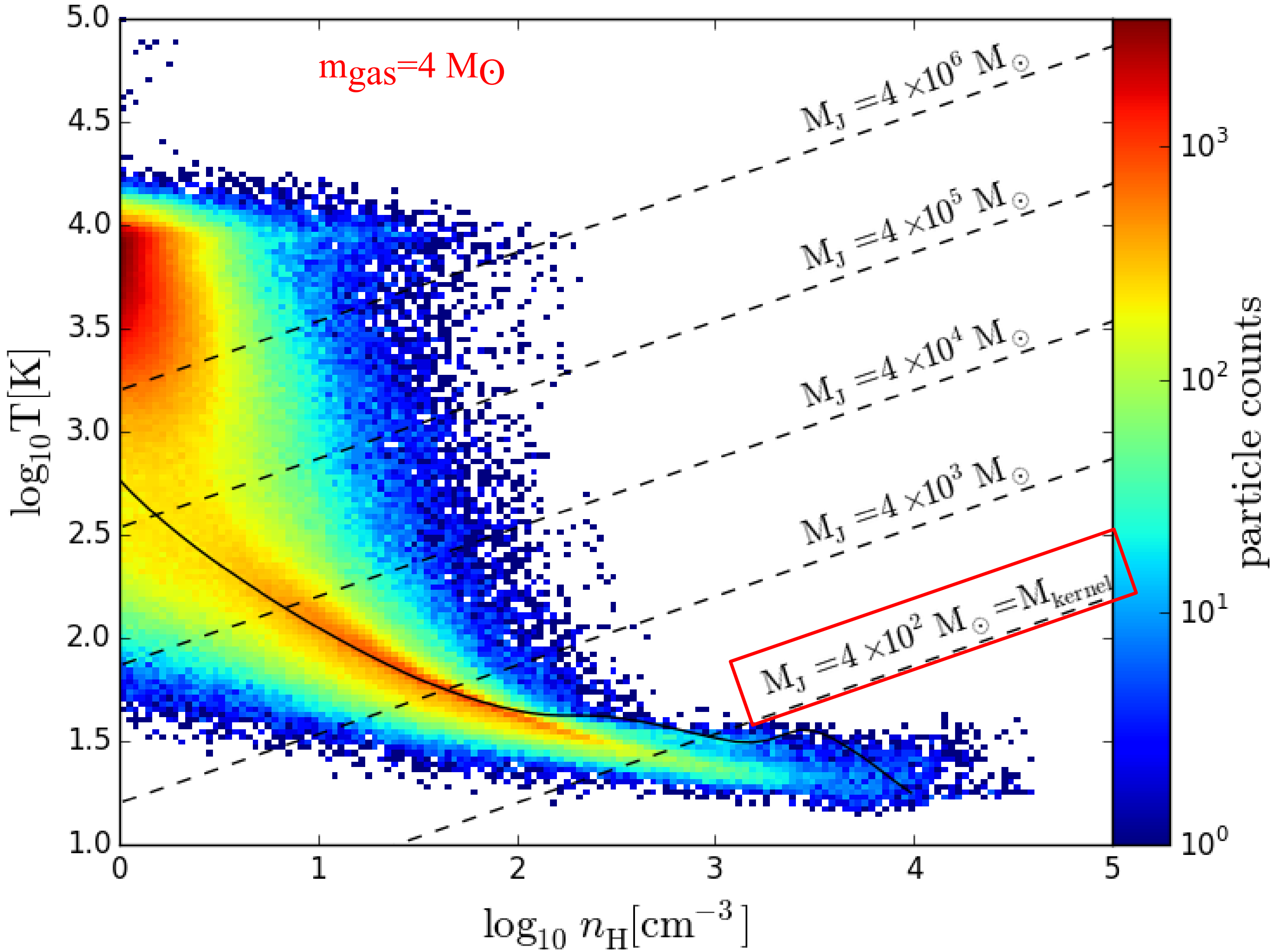
Setup:

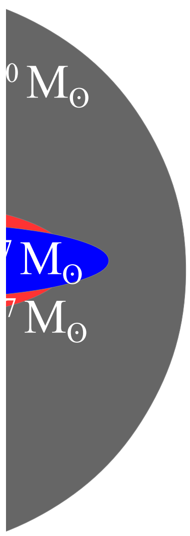
- isolated dwarf galaxy
- $Z = 0.1 Z_{\odot}$, dust-to-gas ratio = 0.1% , uniform distribution
- SPH particle mass = 4 $M_{\odot}$ in order to resolve cold gas (no pressure floor)





Simulations





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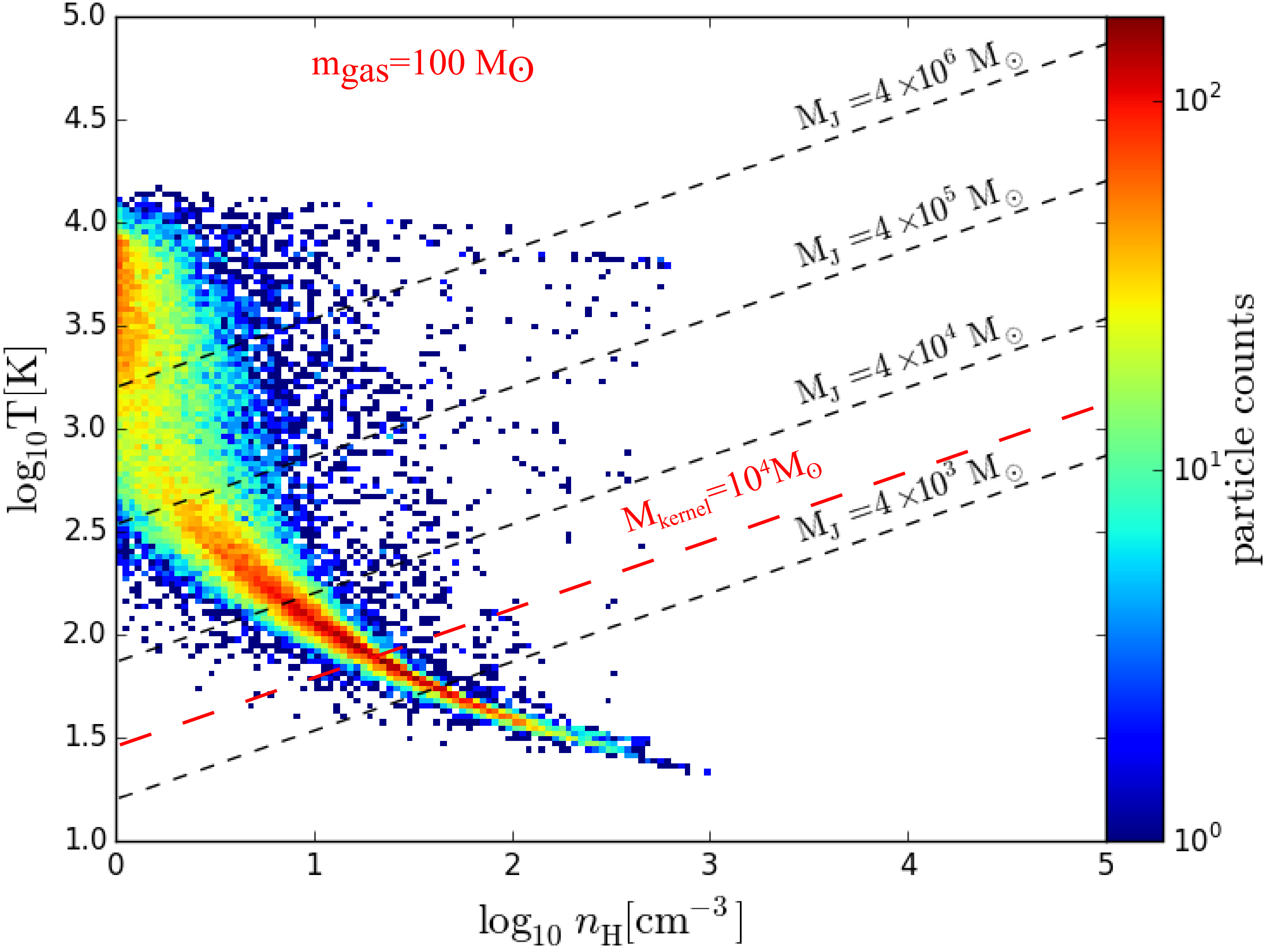
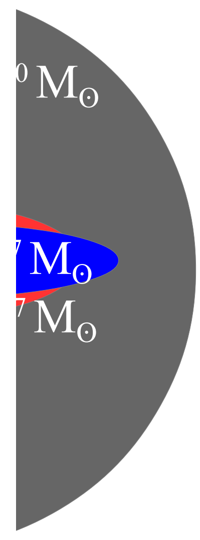
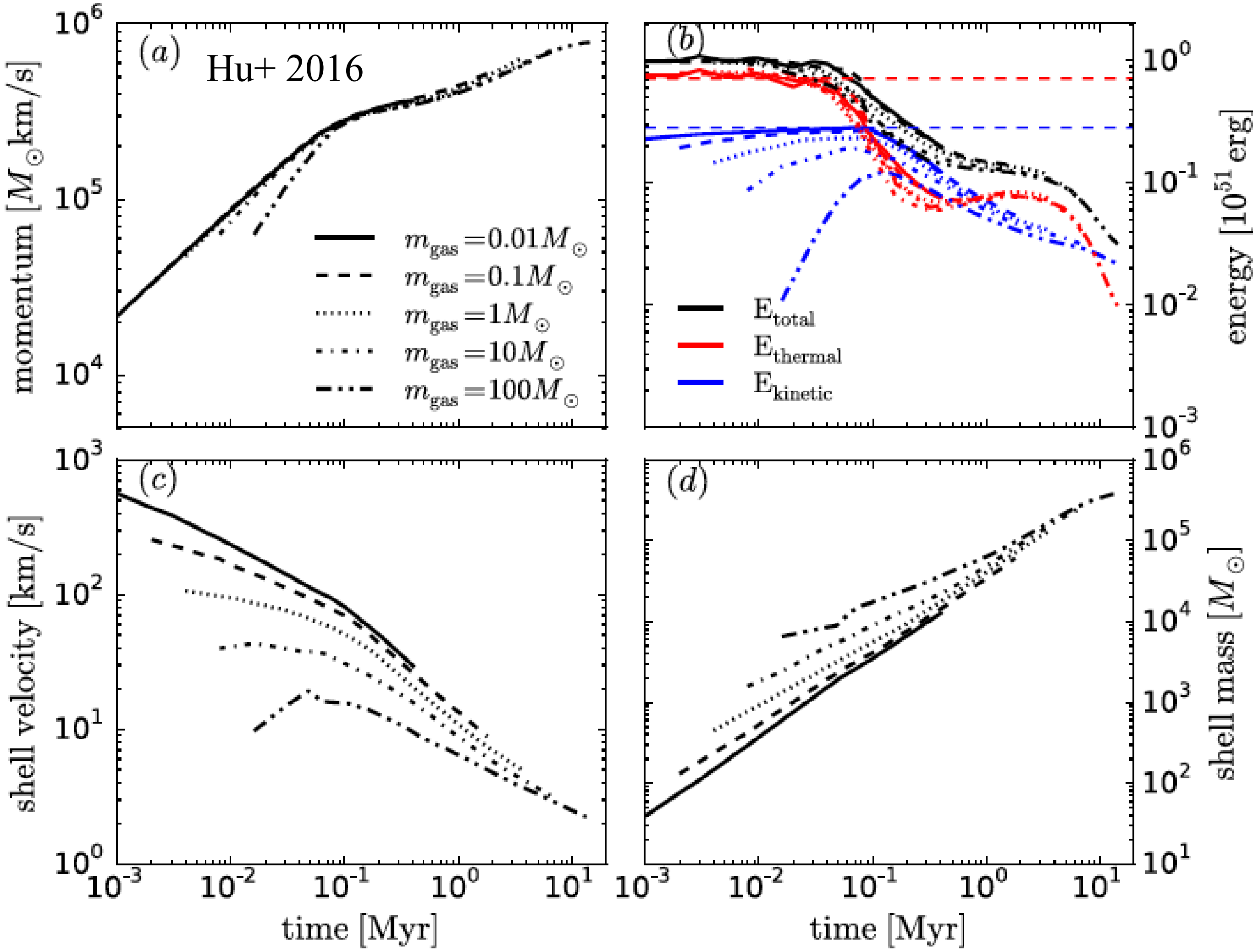




Resolving individual SN feedback

In a medium density of 1 cm^{-3} & Z=0.1Z$_\odot$, we need SPH particle mass ~ M$_\odot$.



Should be worse if
Z=Z$_\odot$ and/or
with metal enrichment

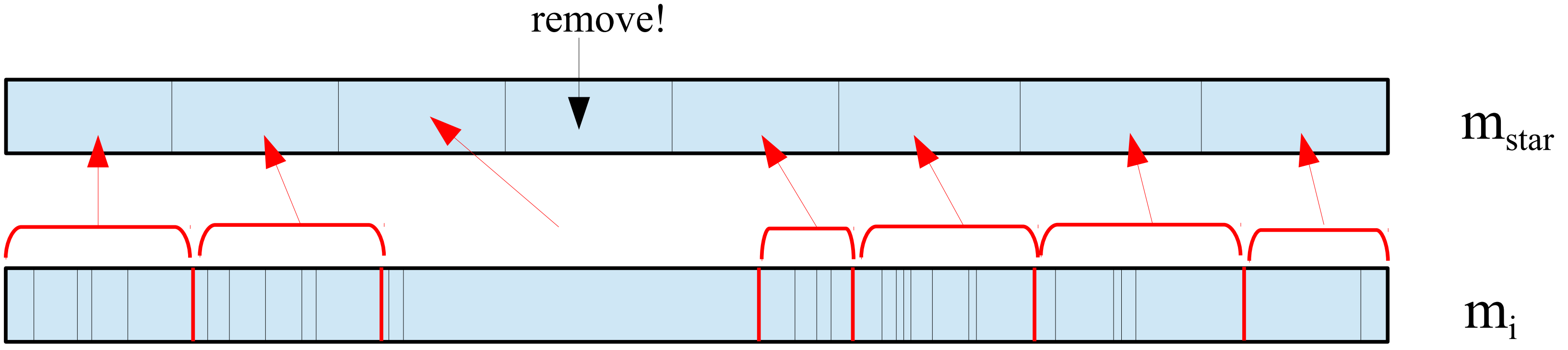
but should be better if
n<0.1 cm^{-3}
(e.g. Steffi's talk)

Numerical difficulties with too high resolution

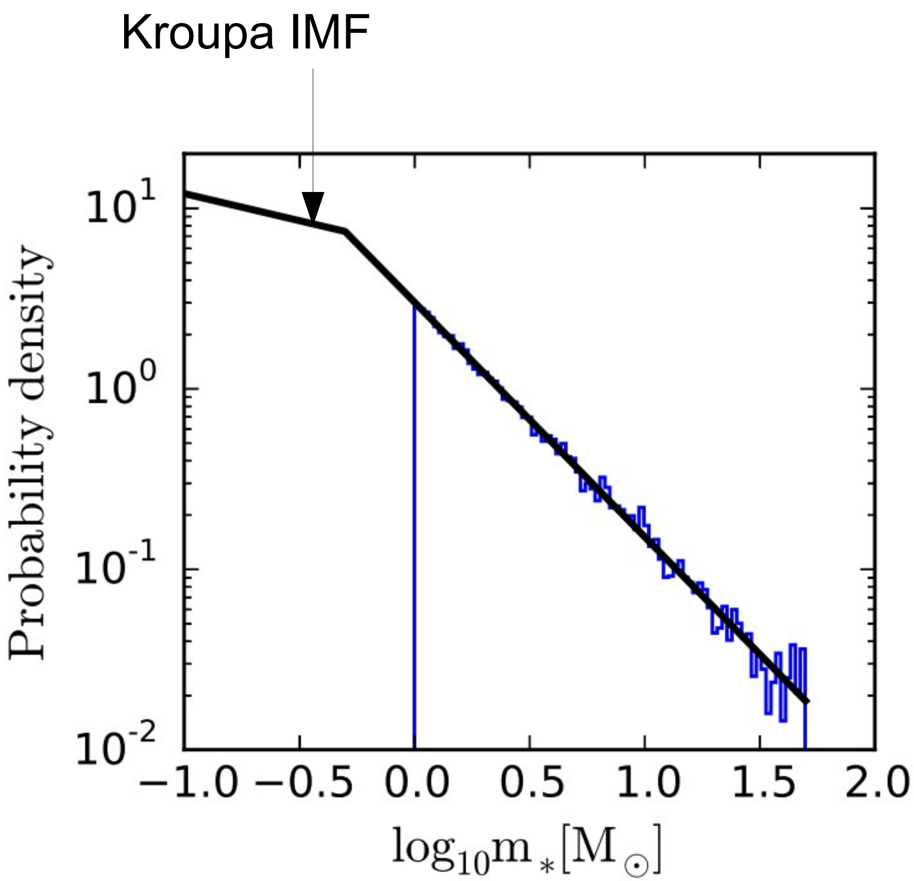
Stellar population approach: every 100 $M_{\odot}$ stellar population there is one SNII event.

What if your particle mass is below 100 $M_{\odot}$? (e.g. $4M_{\odot}$)
- stochastic injection: do one SNII feedback for every 25 particles.
- how about metal enrichment? There's only $4M_{\odot}$ available...

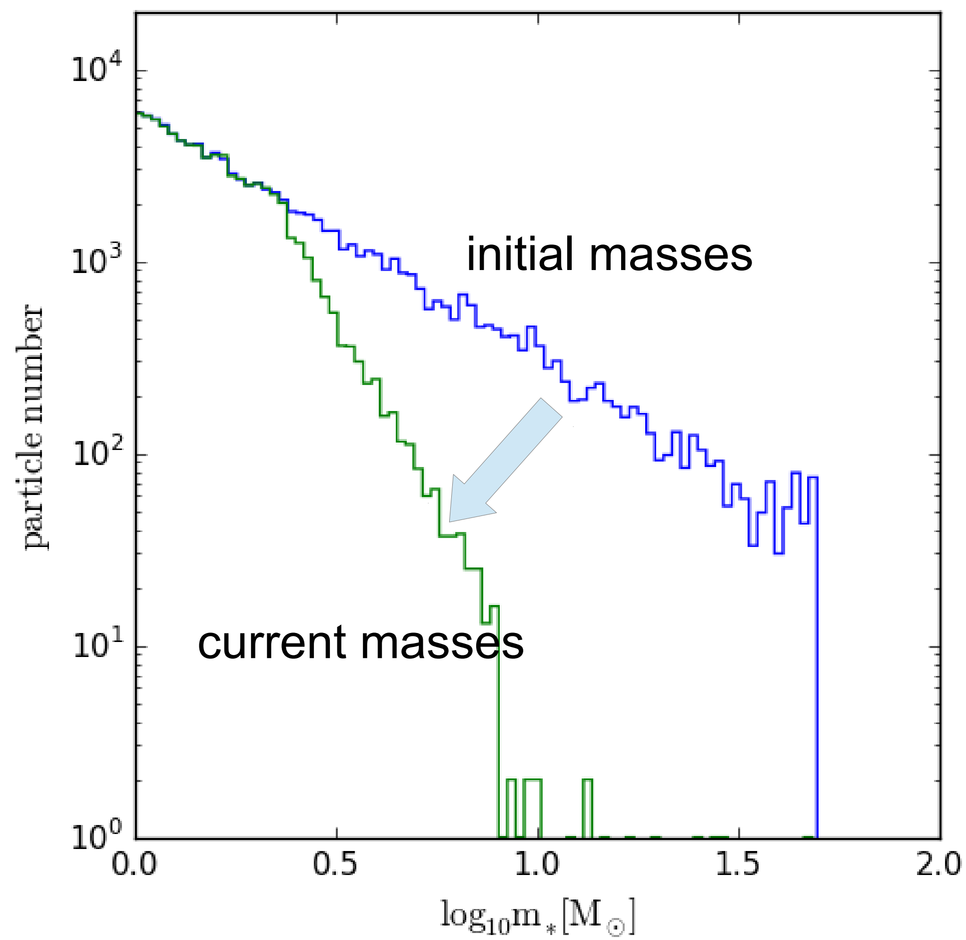
Direct IMF sampling:
- assign an array of stellar masses m_i from IMF to a star particle until $\sum_i m_i > m_{star}$
- the residual mass $m_{res} = \sum_i m_i - m_{star}$ is borrowed from the next star particle ($\sum_i m_i > m_{res} + m_{star,2}$ for the next particle)
- if a star particle is assigned with zero mass, remove it



Stellar masses

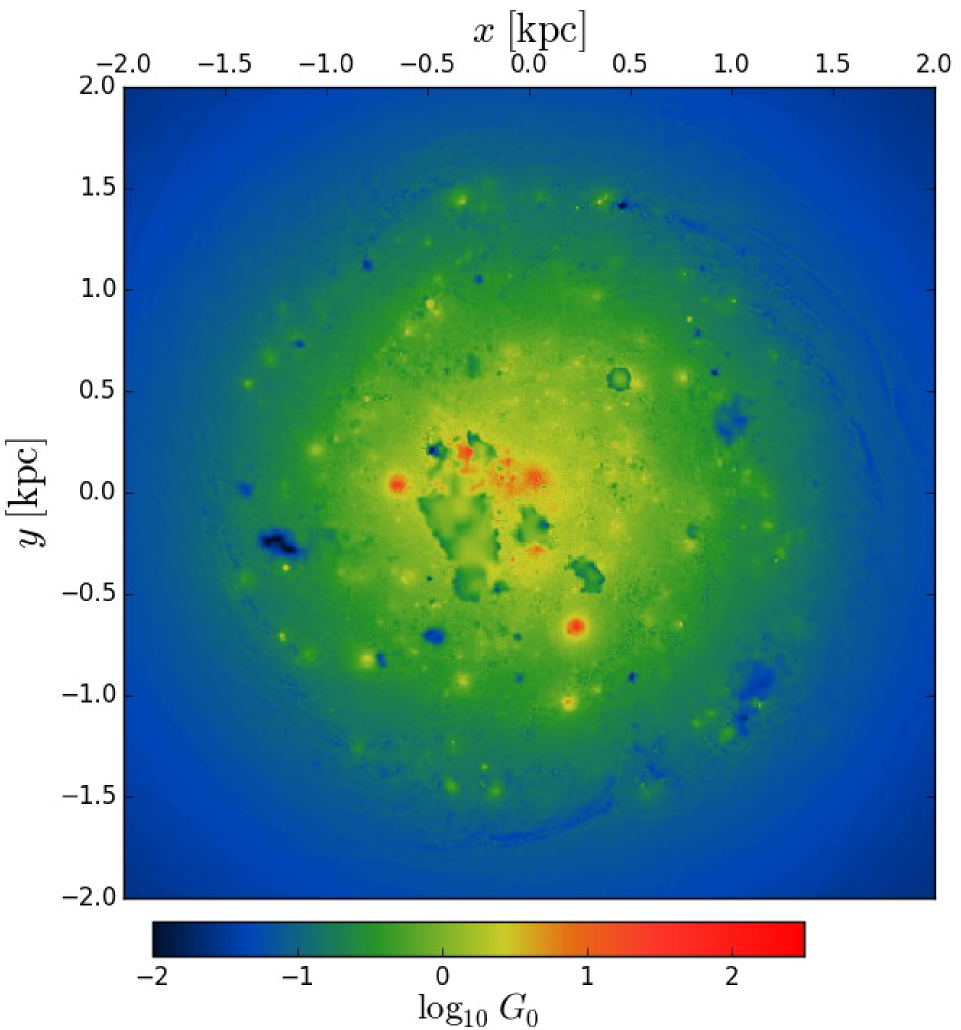


Only keep track of m* > 1M⊙ to save memory



Massive stars die immediately

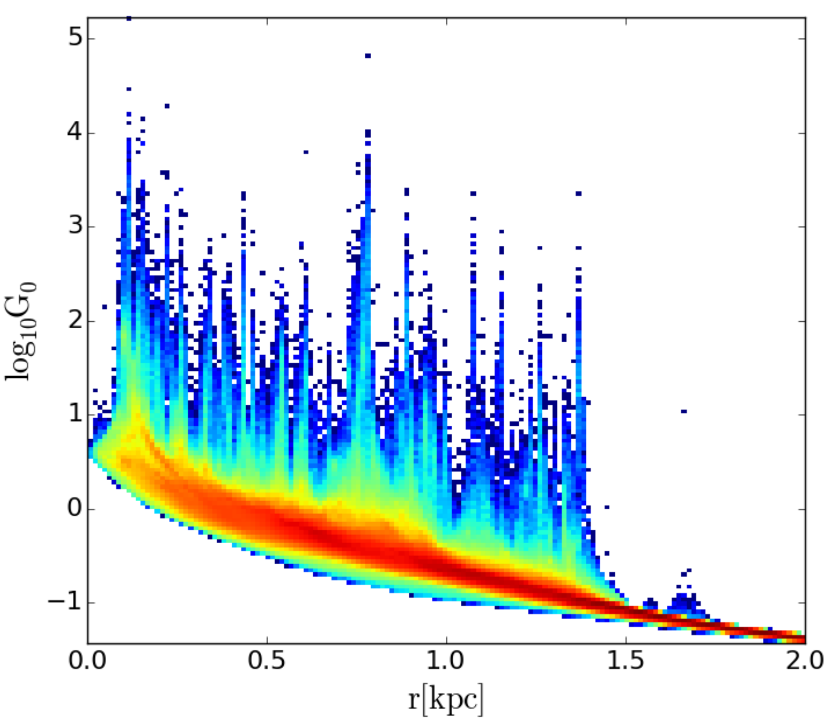
The spatial distribution of ISRF



$G_0 \sim 1$ in the solar neighborhood.

The majority of gas feels a smoothly varying ISRF.

Nearby the young stars, ISRF can be enhanced by orders of magnitude (bright PDRs).



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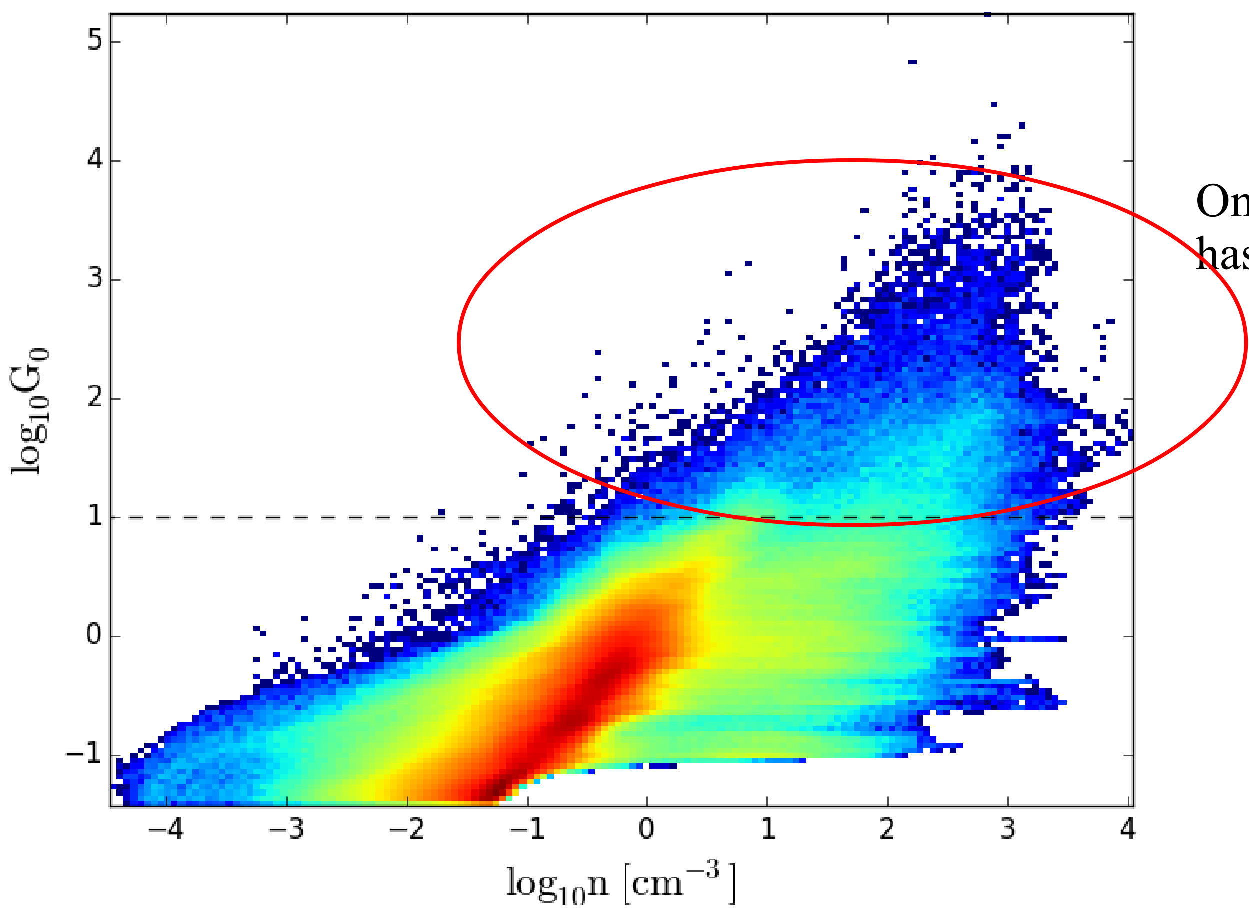
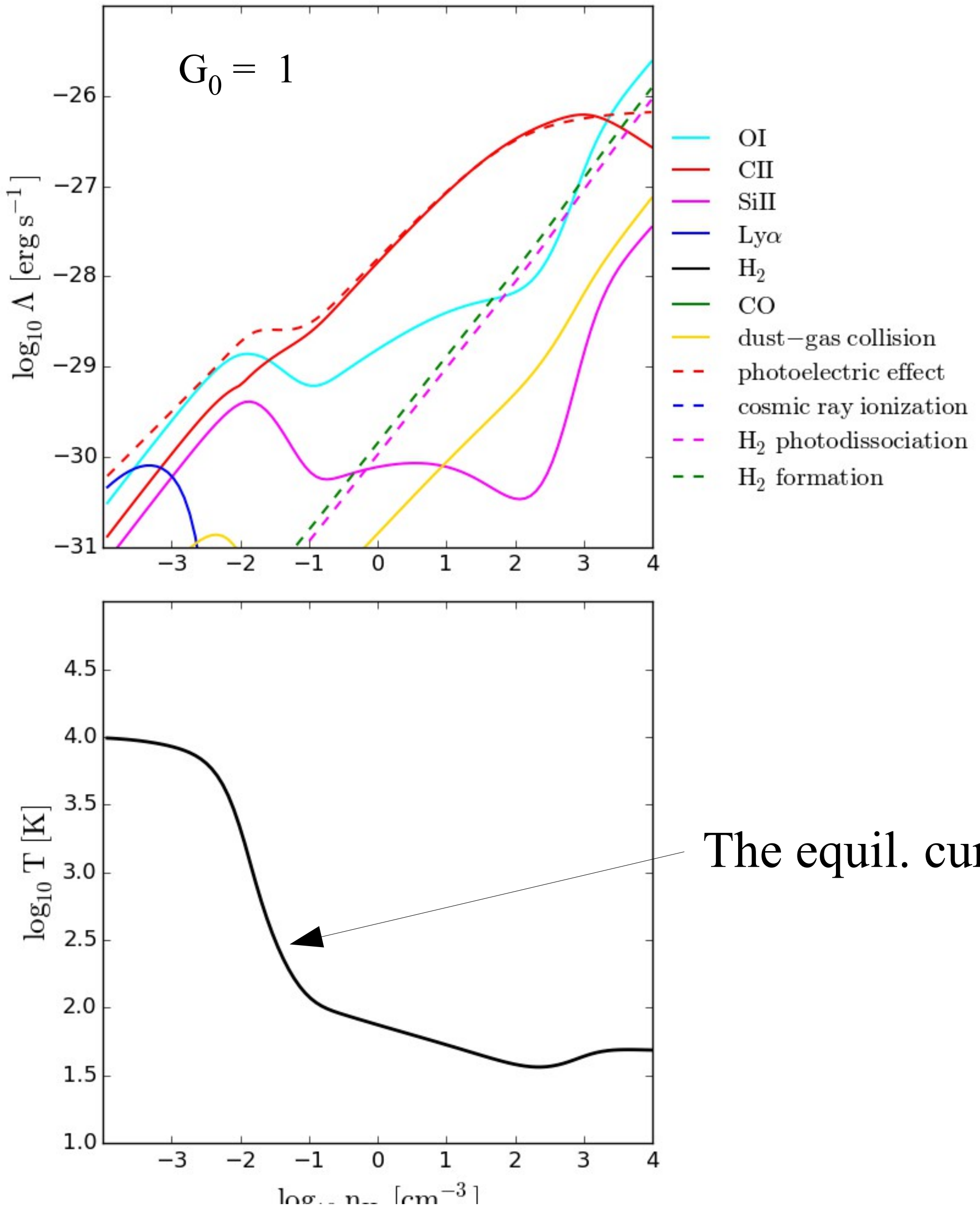


Only ~ 1% of the total gas has $G_0 > 10$

Radial trend of ISRF changes thermal balance



main heating: PE effect
main cooling: CII emission.

The equil. curve changes as G0 changes

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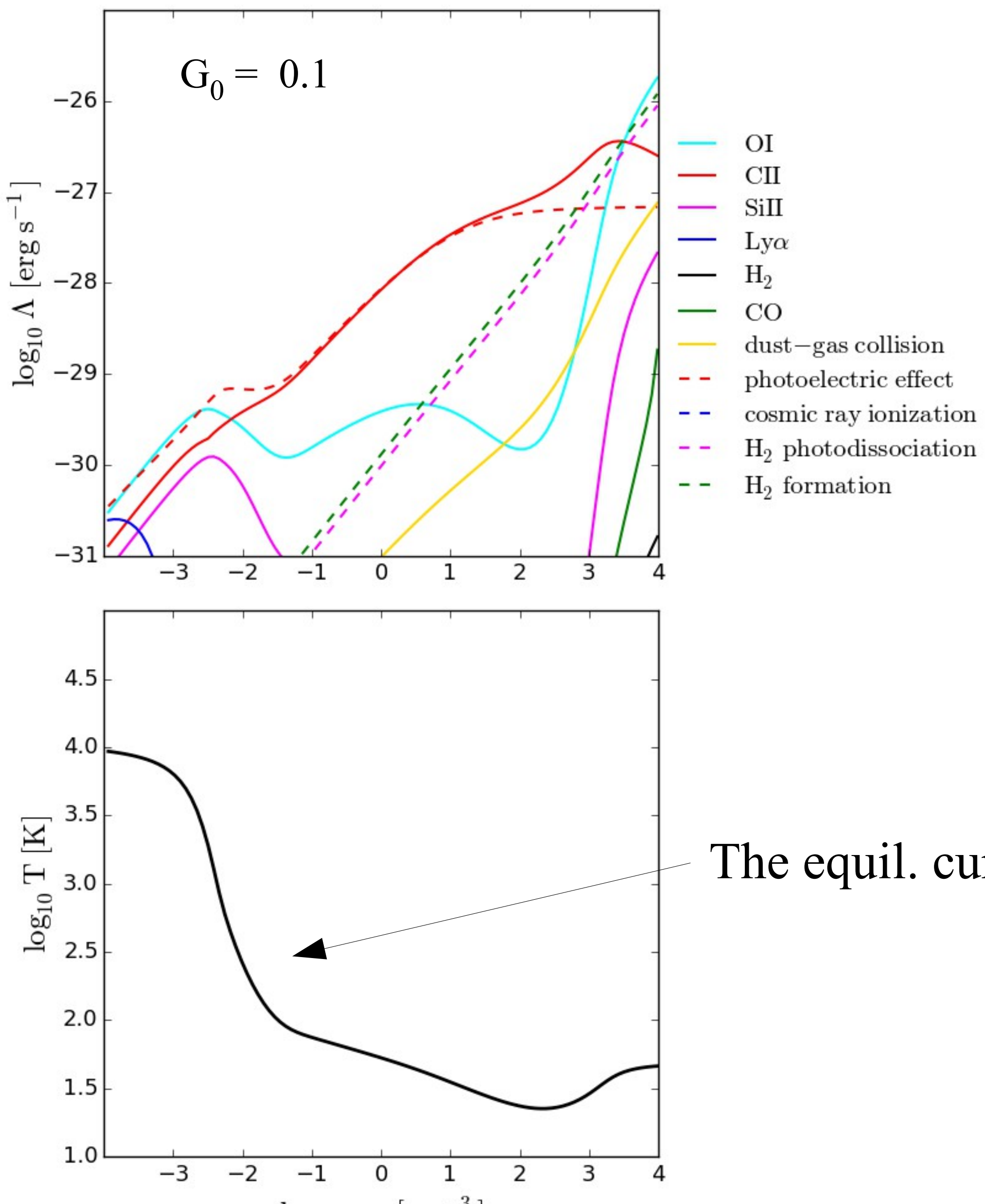

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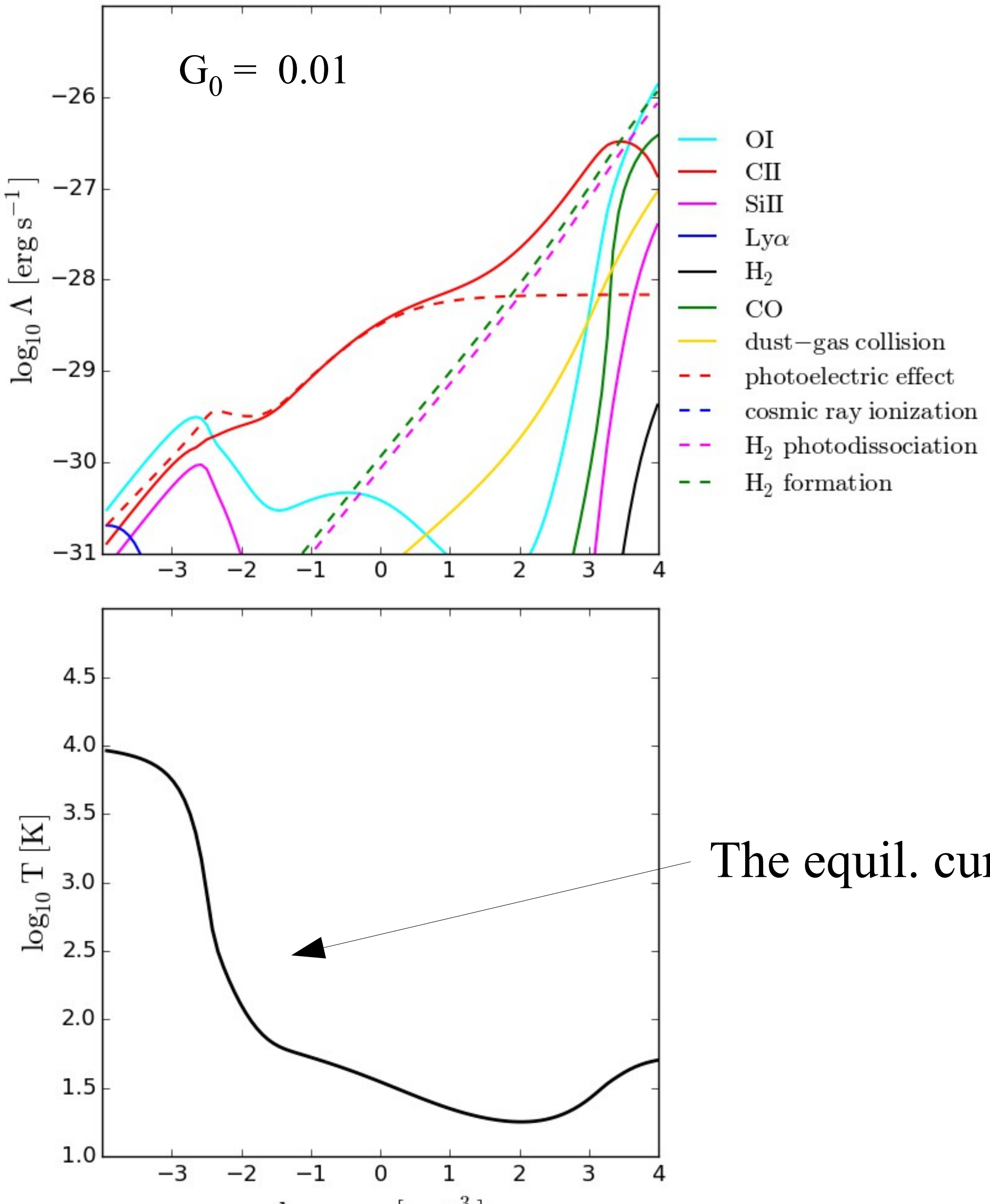

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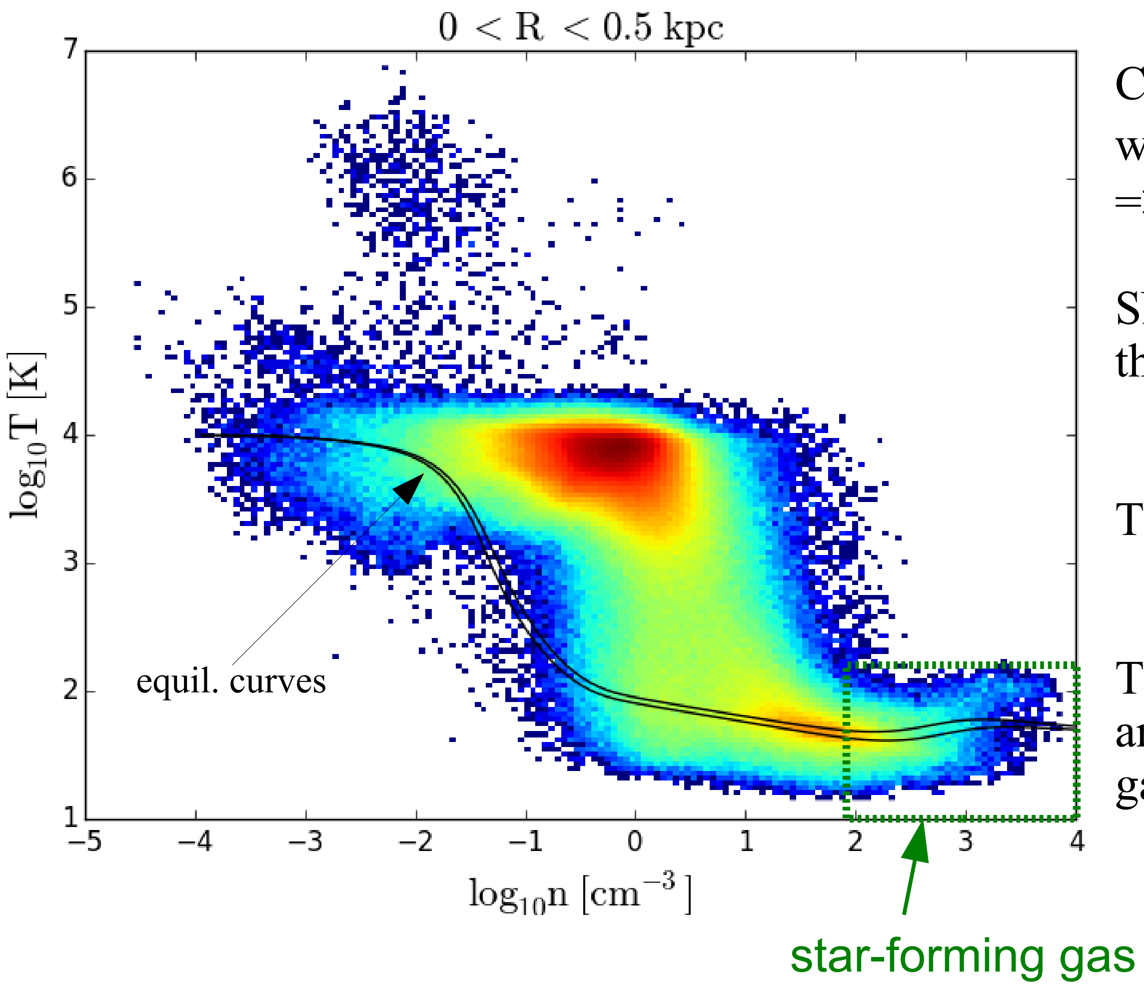
The equil. curve changes as G0 changes

But it doesn't seem to be relevant...

SN feedback creates turbulence and shocks fast enough to drive the gas out of thermal equilibrium



Cooling time $t_{cool} \approx$ 50 Myr when $n=1cm^{-3}$ & $Z=0.1Z_{\odot}$
=> no time to cool...

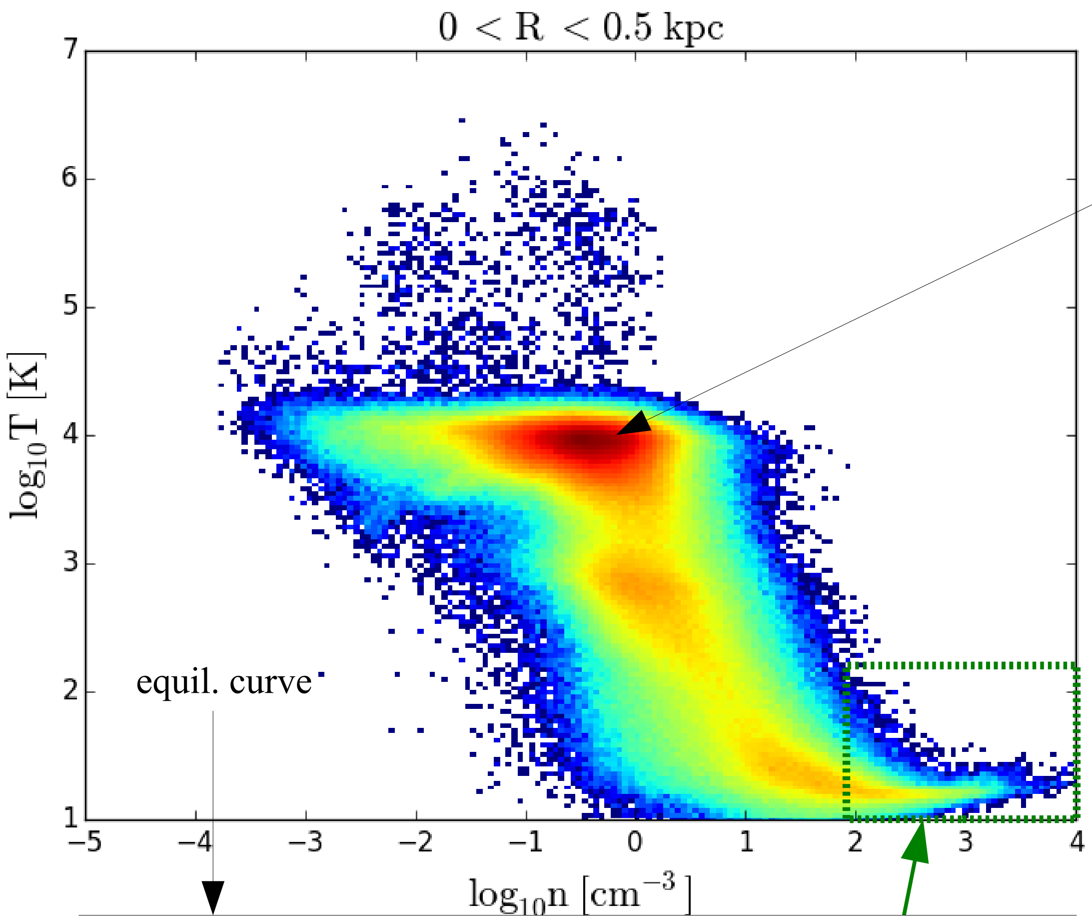
SN feedback not just causes the scatter in the phase diagram, as is the case in spirals.

The PE heating becomes sub-dominant.

The balance between metal line cooling and the SN heating controls how much gas can cool and form stars.

Even when PE heating is turned off completely

Without PE & CR heating, the equil. temperature should be zero...
The only heating source here is the SN feedback.

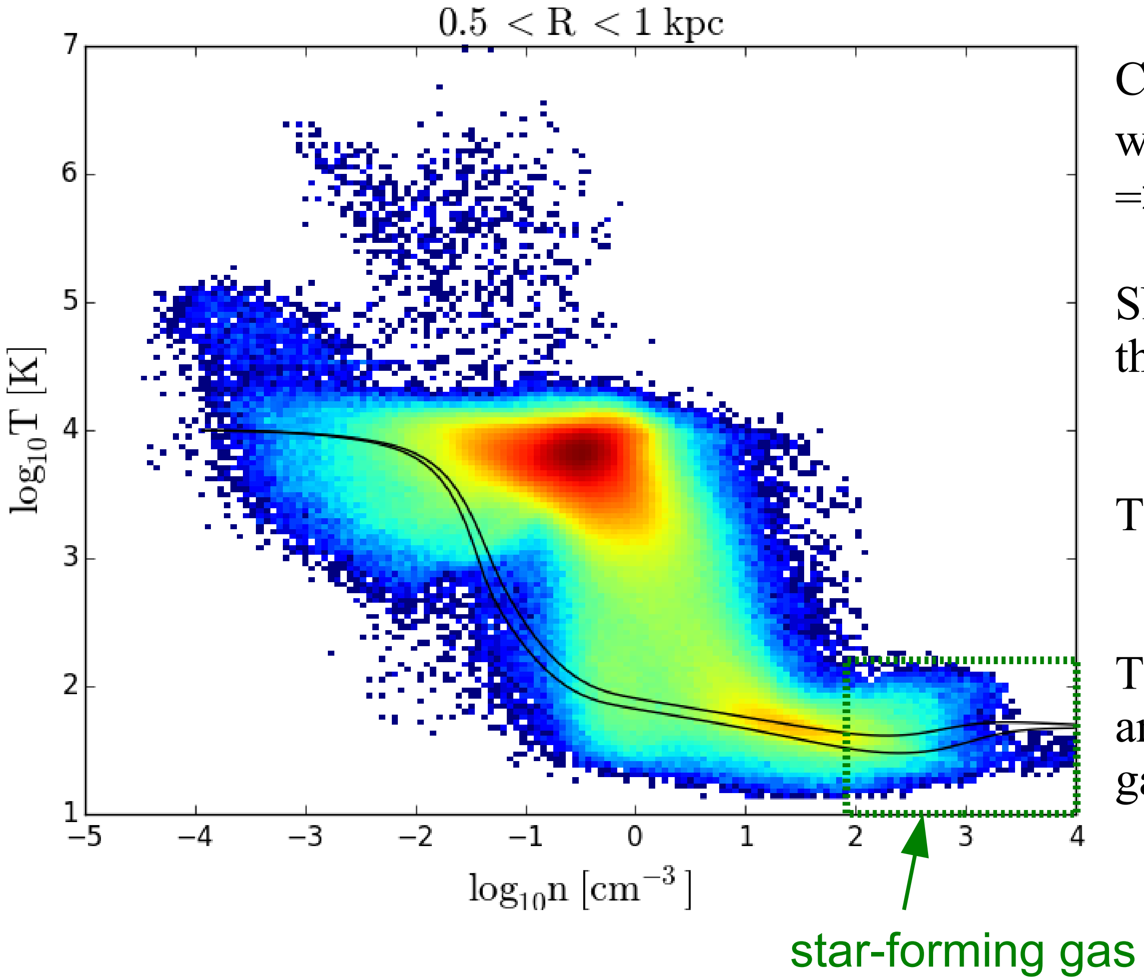


But the majority of gas is still kept warm here!

star-forming gas

SN heating dominates PE heating

SN feedback creates turbulence and shocks fast enough to drive the gas out of thermal equilibrium



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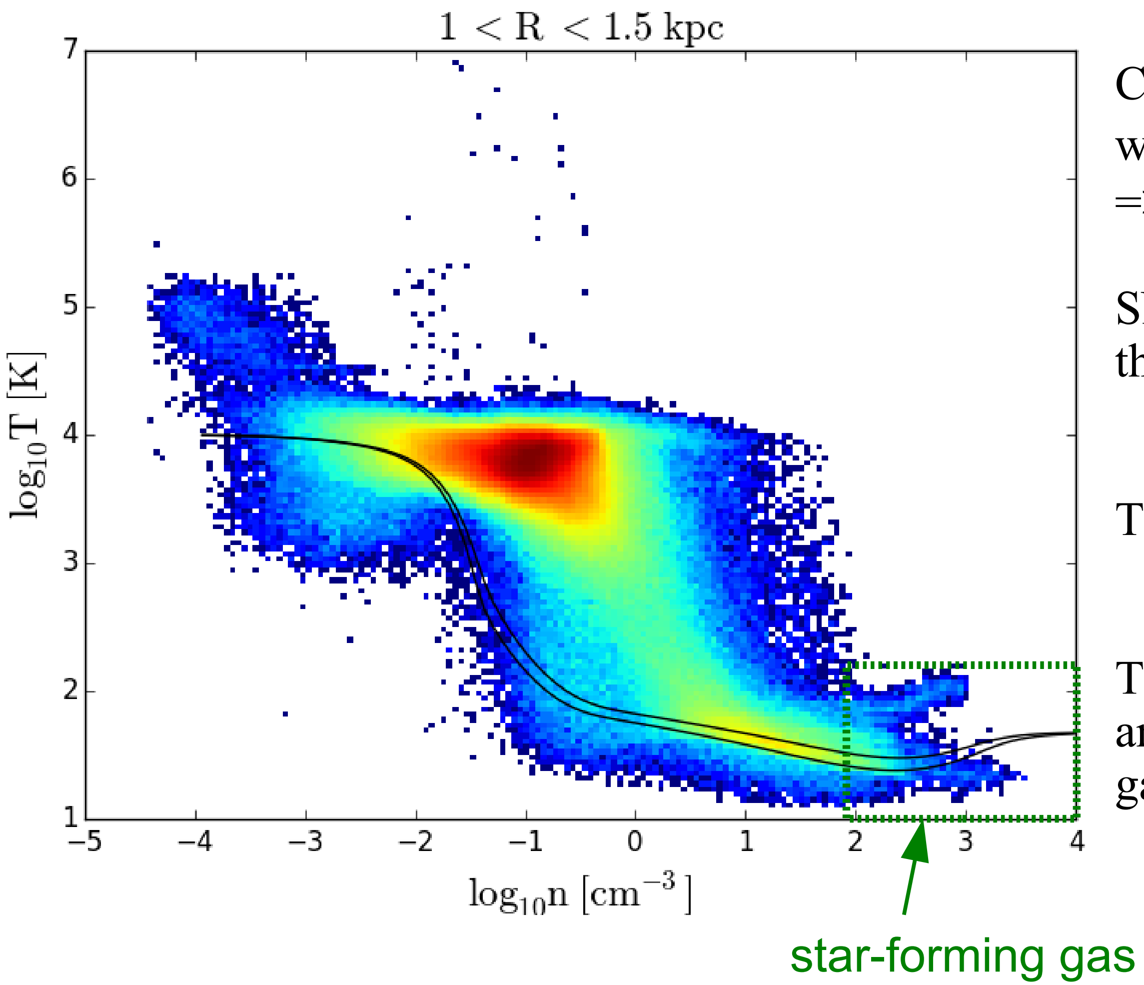

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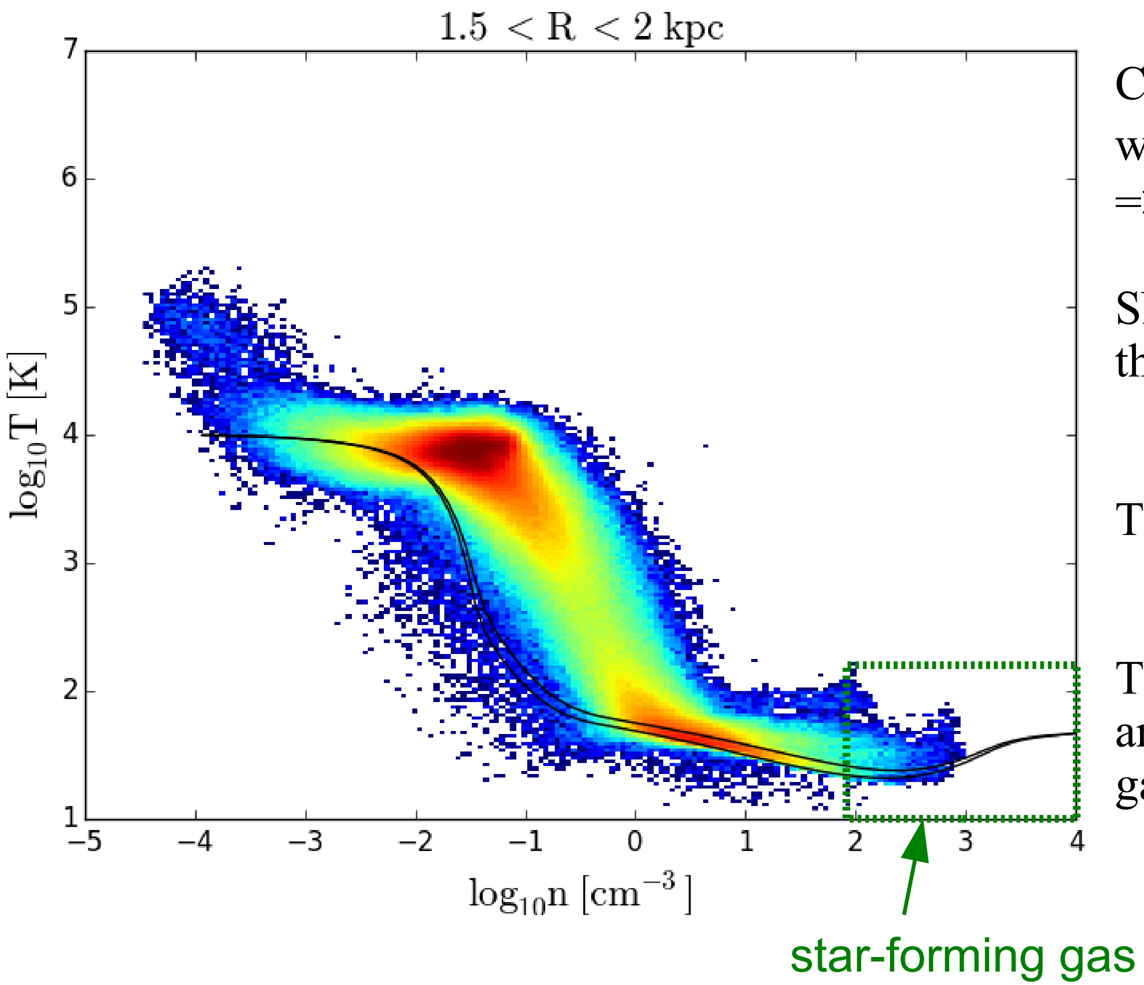

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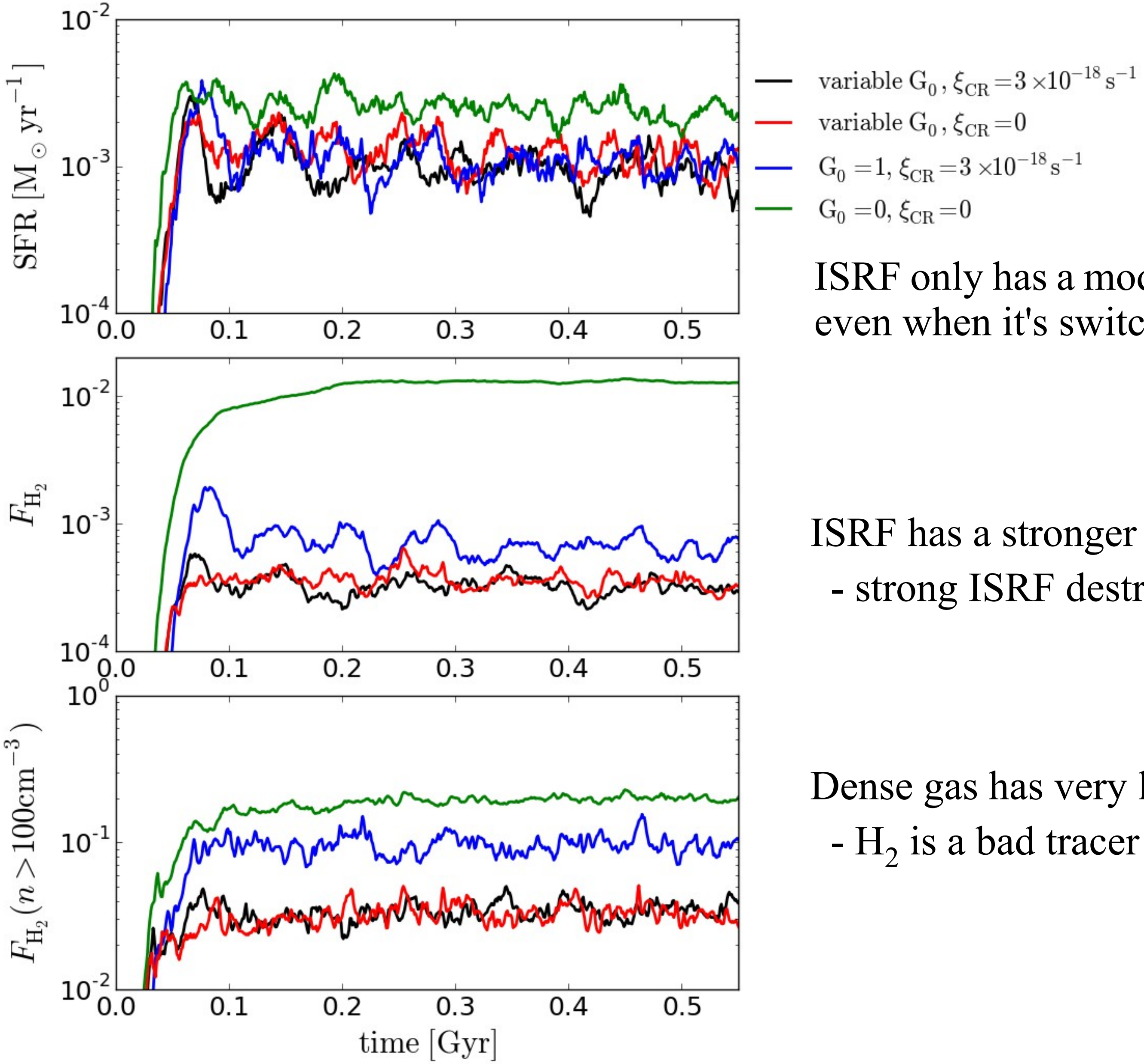
SFR and H_2 fraction



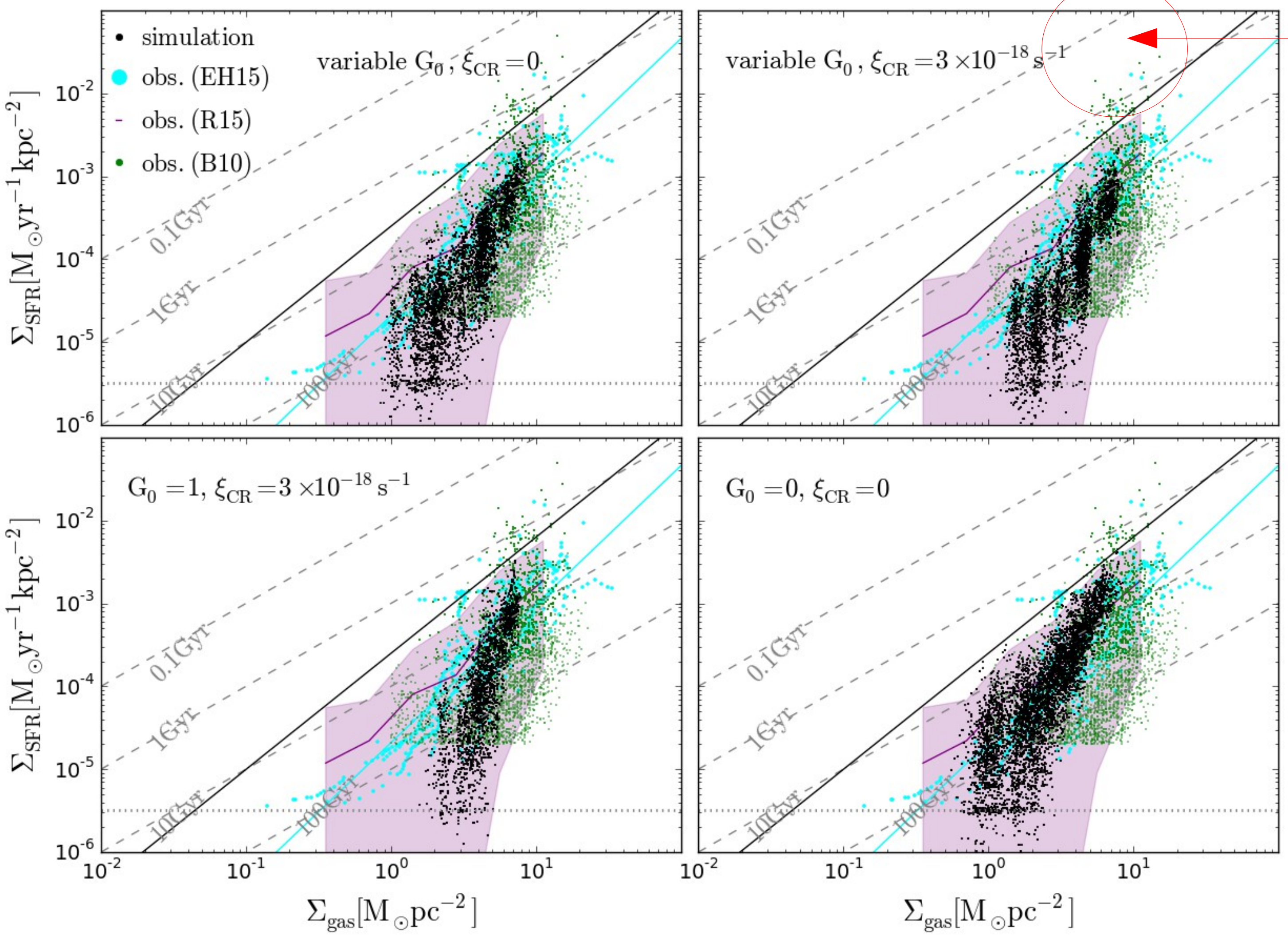
ISRF only has a modest effect on SFR, even when it's switched off completely.

ISRF has a stronger effect on the H_2 fraction.
- strong ISRF destroys H_2 in dense clouds.

Dense gas has very low H_2 fraction
- H_2 is a bad tracer of star formation in dwarfs.

KS relation

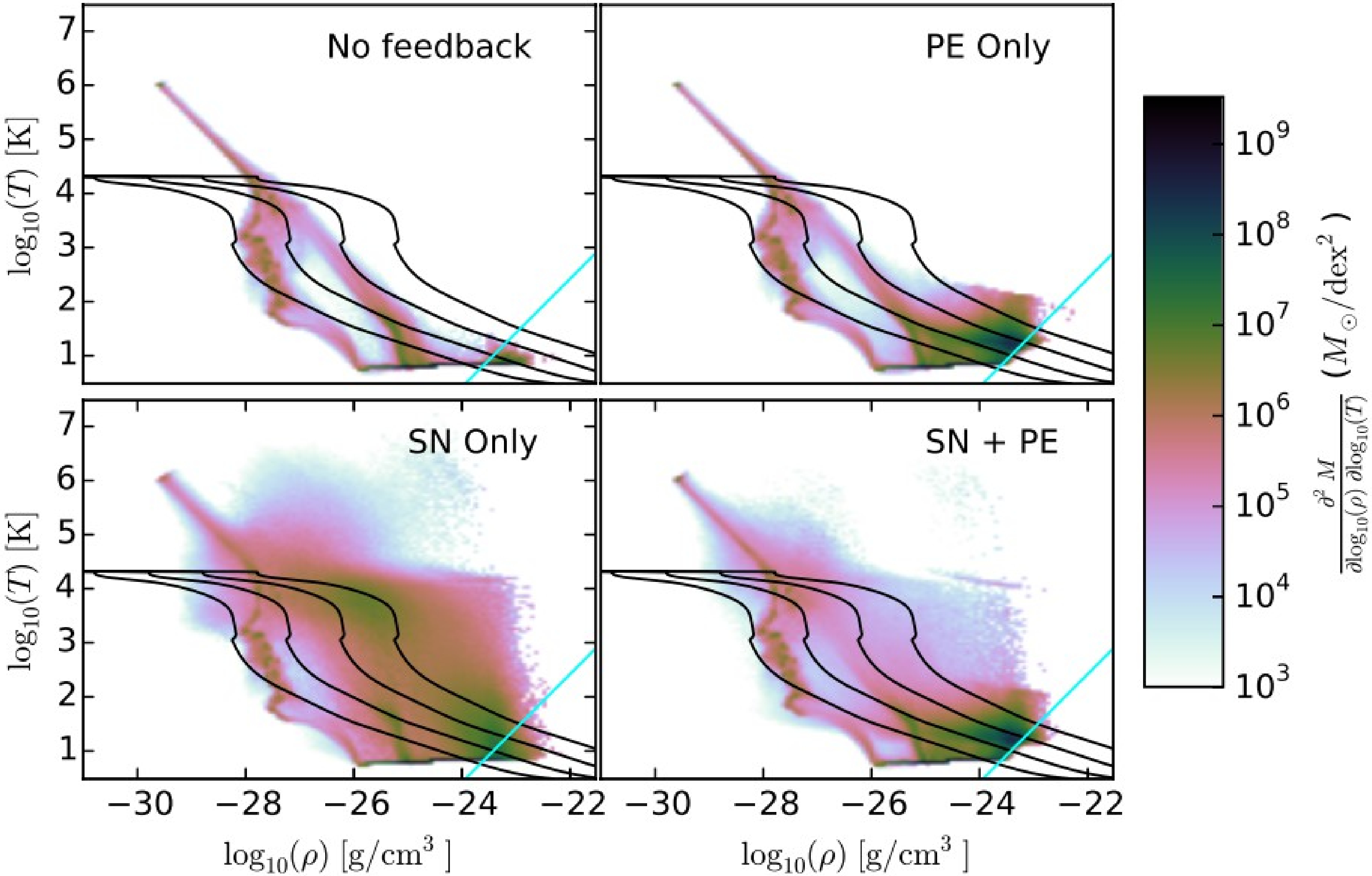
Agree well with observations with whatever PE and CR heating, as long as the SN feedback is on.



Without SN feedback the gas will be here, even with PE heating.

In tension with Forbes+ 2016 ...?

Forbes+ 2016 concluded that PE heating alone can suppress SFR in dwarfs.



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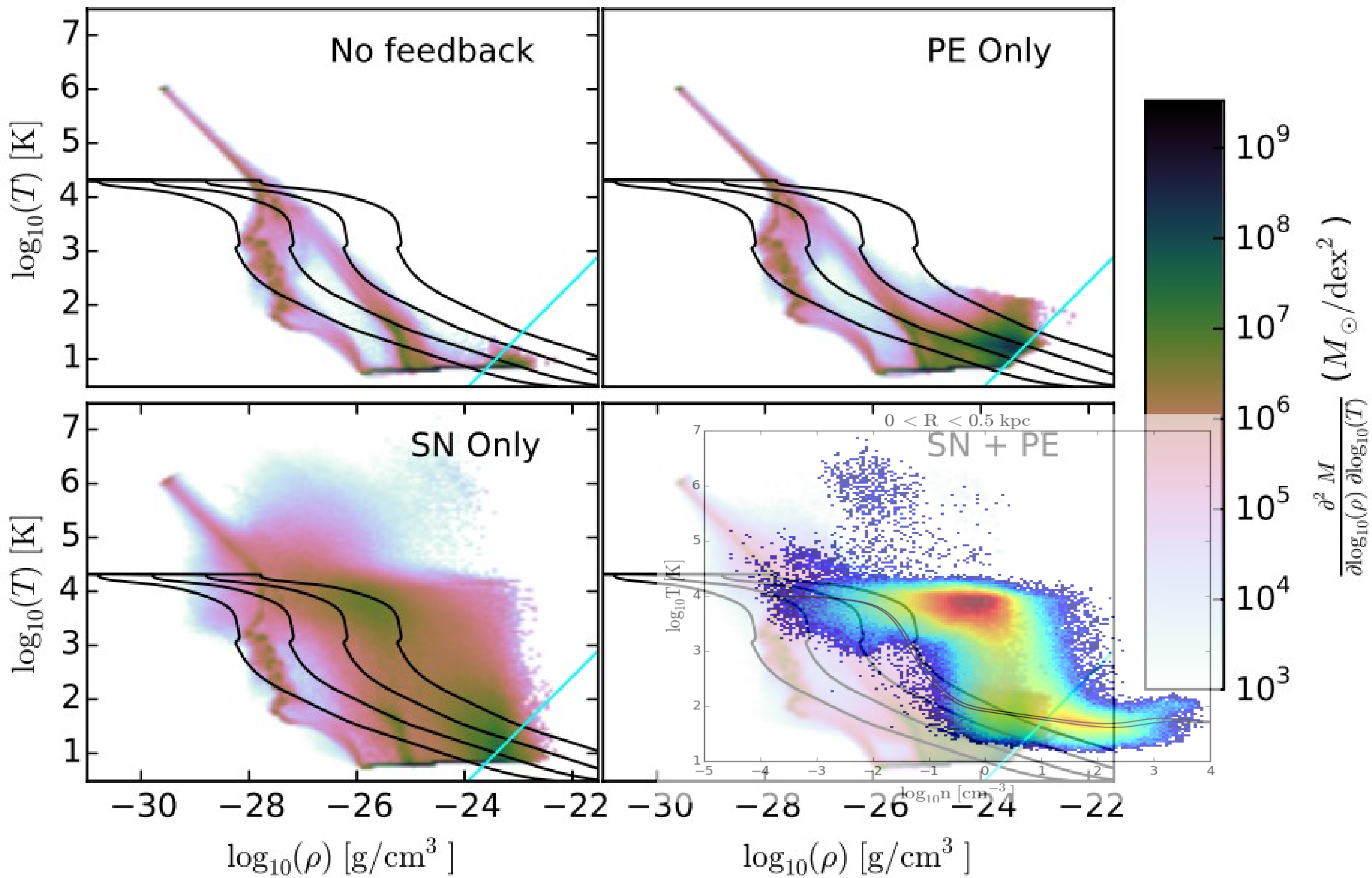


Why so different?

Differences:

	ours	Forbes+2016
Resolution	$4M_\odot$ x 100	2.5-10 pc
SF threshold	100 cm^{-3} & 100 K	Jeans (~ 1-10cm^{-3})
SF efficiency	2%	1%
SN delay time	3 Myr	individual
Gas surface density	1-10 $M_\odot$ /pc^2	?

Summary

We conducted isolated dwarf galaxy simulations with detailed ISM physics and high enough resolution ($m_{gas} = 4\ M_{\odot}$) to resolve the cold and dense gas.

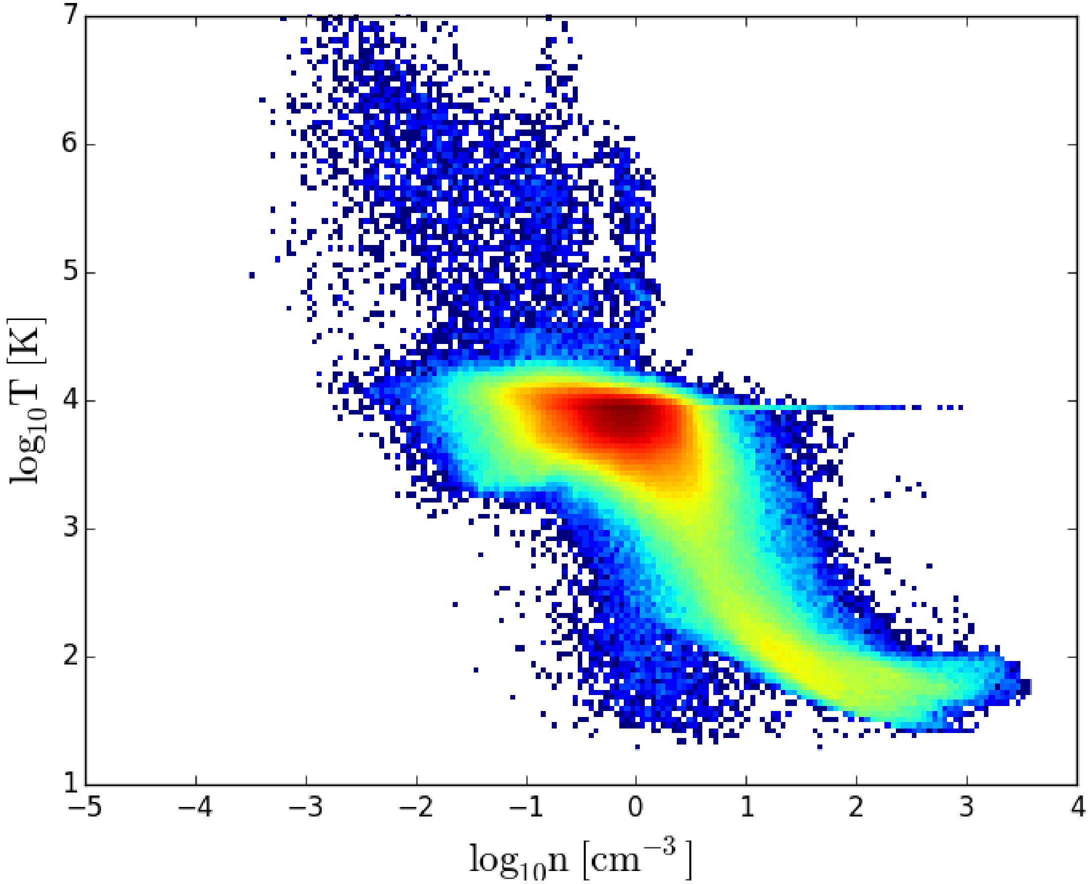
We implemented a spatially varying IRSF calculated directly from stars without free parameters, which naturally produces a smooth varying background ISRF, while nearby the sources the ISRF can get much higher.

The ISM in dwarfs is not in thermal equilibrium! SN feedback generates turbulence and shocks which dominates over PE heating, drives the gas out of thermal equilibrium and regulates star formation.

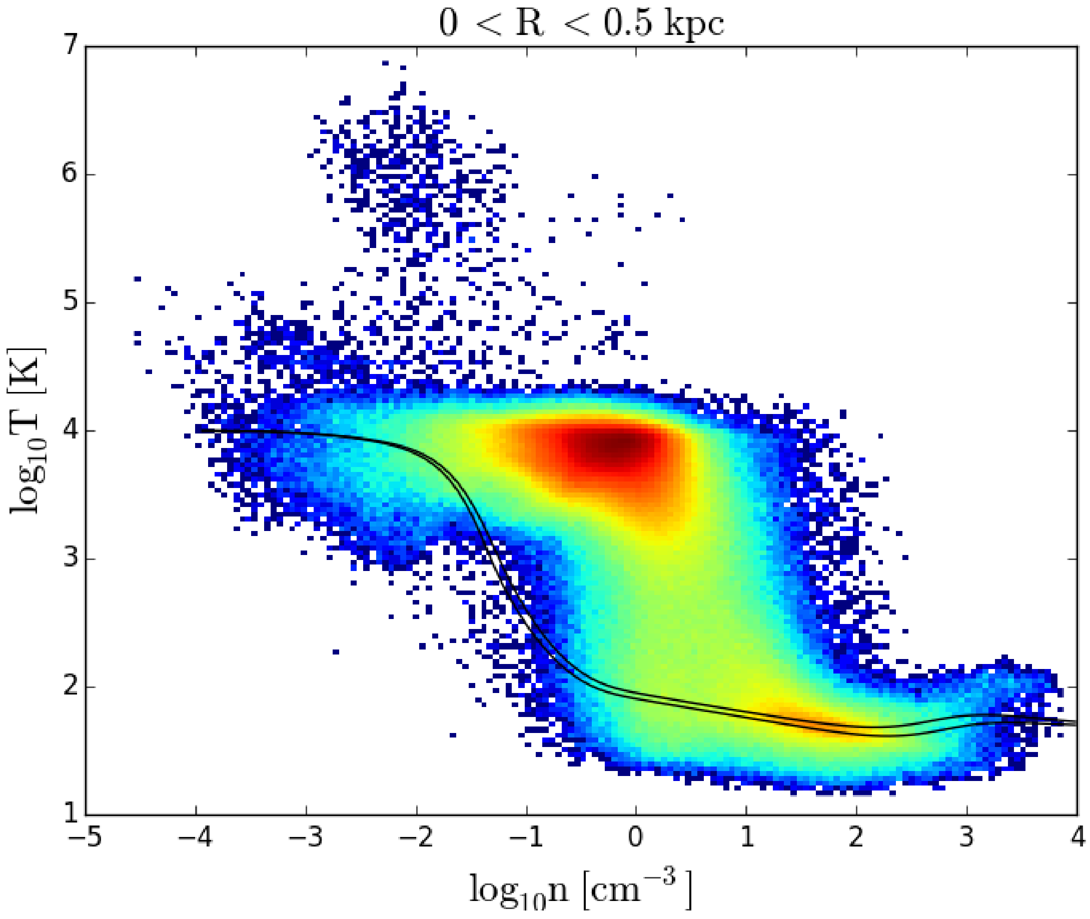
The ISRF has a significant effect on the H_2 fraction, even though H_2 is not relevant for star formation.

Including ionizing radiation

Use the correct delay times of individual massive stars.
Still much warmer than the equil. curves.



No ionizing radiation



Radial profile