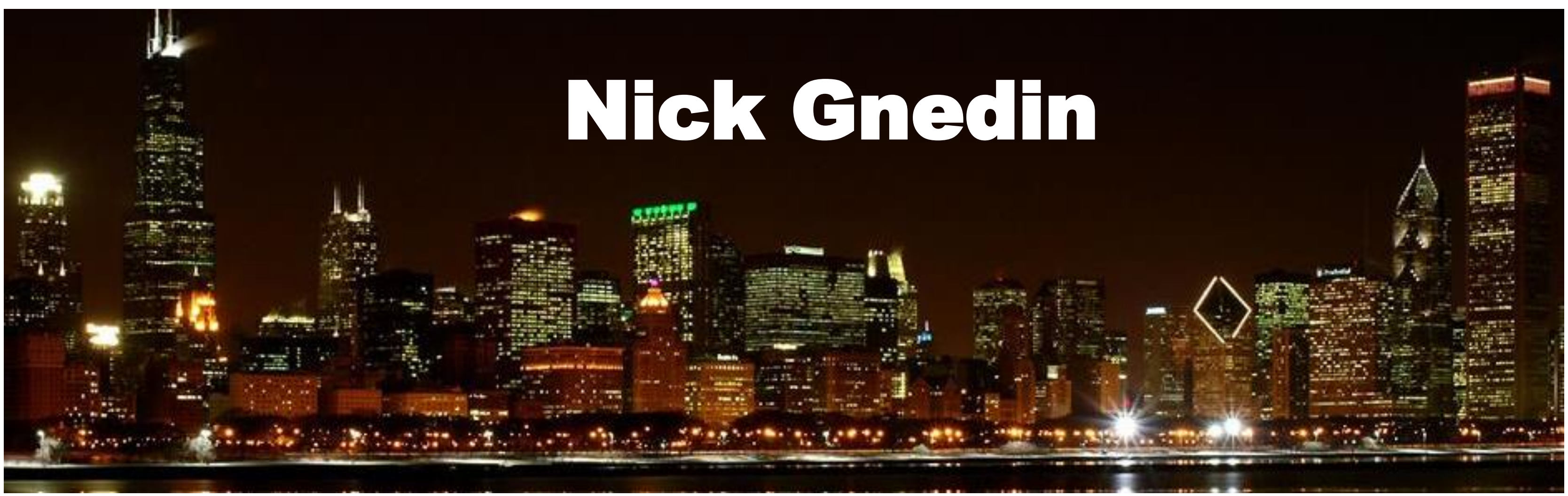
Accounting For Something You Don't Want To: Radiation Field



Fermilab

THE UNIVERSITY OF CHICAGO

Why We Need To

- Unless we are modeling reionization, we do not really want to add an RT solver to our code…
- We also do not need to – reionization has little effect on star formation in galaxies.*
- There are 3 physical effects that **must** account for the radiation field:
  - Molecular hydrogen formation
  - Gas cooling and heating
  - Radiation pressure

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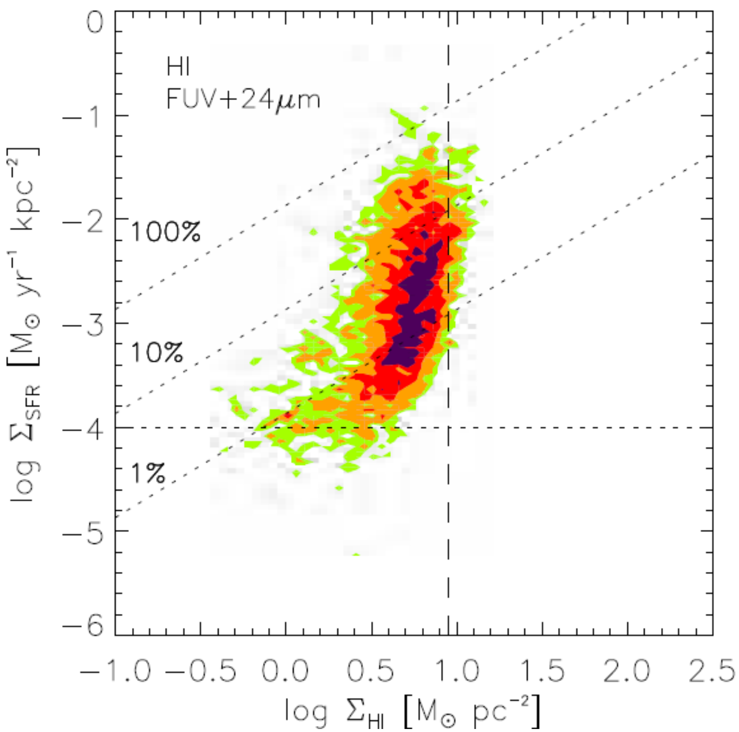
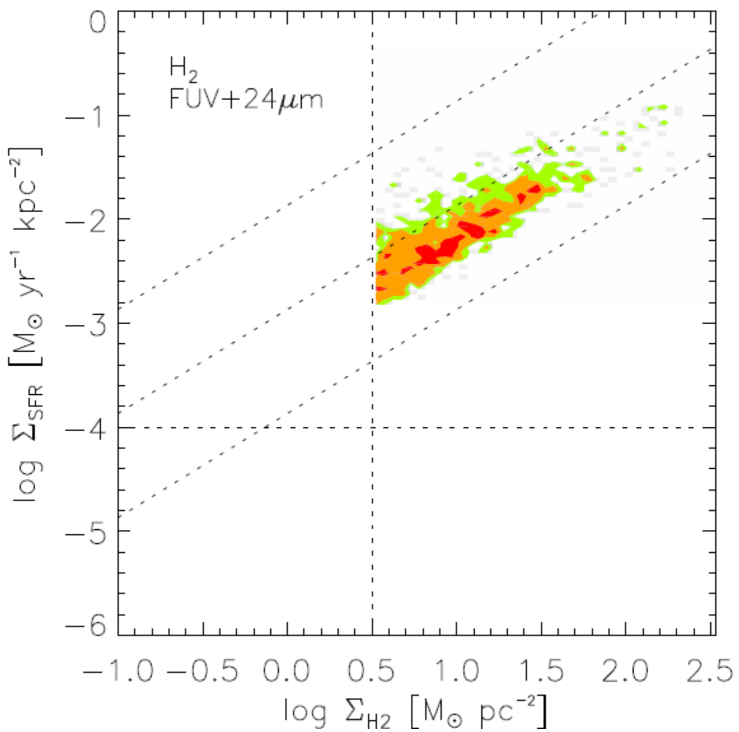
* And yes, claims to the contrary that you might have heard are wrong!

HI-H_2 Transition

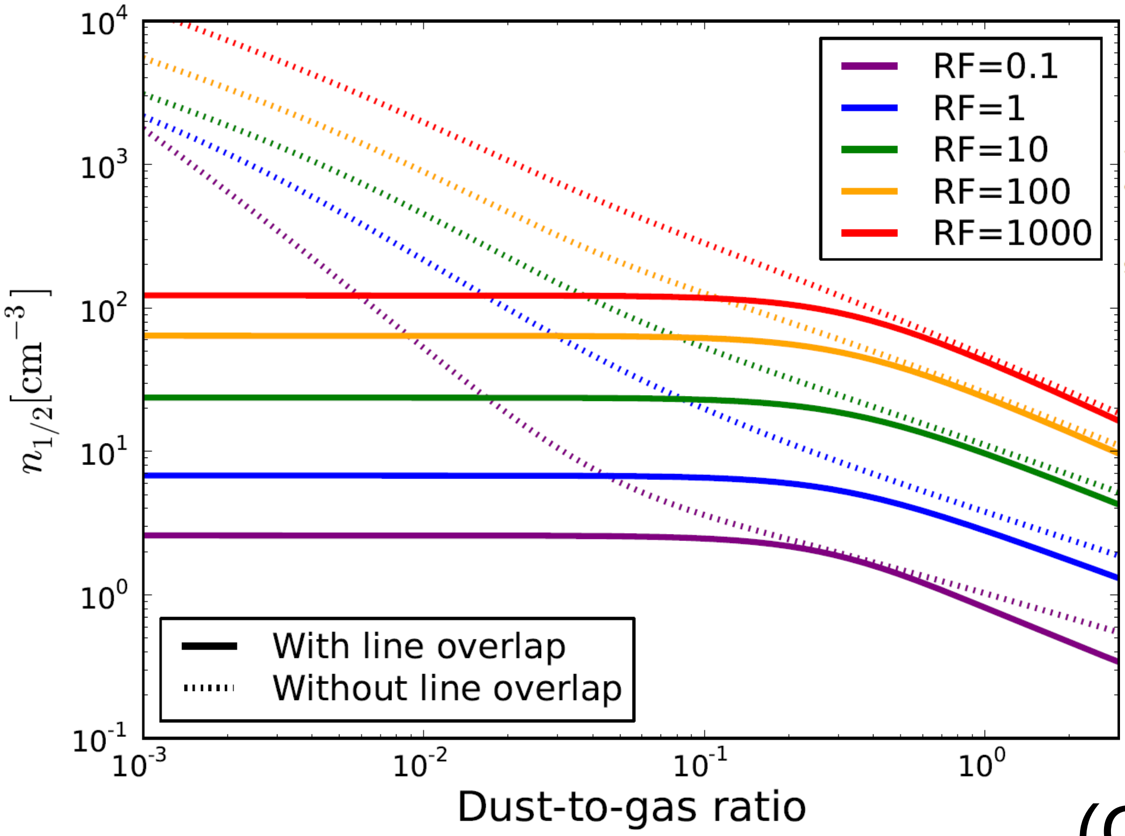
- There exist several models for that transition, all mutually compatible.
- Molecular gas determines star formation rate, atomic gas does not.

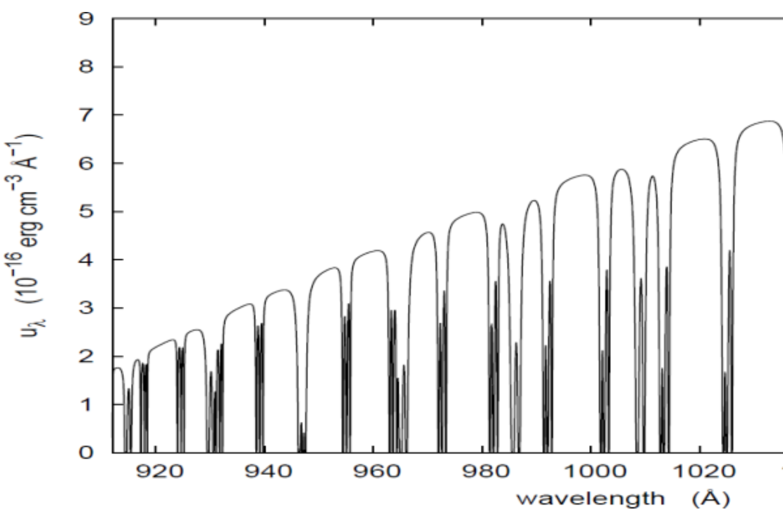




HI-H_2 Transition

- One small correction: line overlap enhances H_2 formation in very low metallicity environments.





(Gnedin & Draine 2014)

HI-H_2 Transition

- Dependence of the HI-H_2 transition on radiation field is weak, only ~ logarithmic for RF like in the Milky Way and stronger.
- Hence, one does not need to know the radiation field very precisely.

HIGH-REDSHIFT STARBURSTING DWARF GALAXIES REVEALED BY γ-RAY BURST AFTERGLOWS[1,2]

HSIAO-WEN CHEN[3], DANIEL A. PERLEY[4], LINDSEY K. POLLACK[5], JASON X. PROCHASKA[5], JOSHUA S. BLOOM[4,11], MIROSLAVA DESSAUGES-ZAVADSKY[6], MAX PETTINI[7], SEBASTIAN LOPEZ[8], ALDO DALL'AGLIO[9], AND GEORGE D. BECKER[10]

galaxy luminosity in the star-forming galaxy population at $z = 2-4$; (4) the interstellar UV radiation field is found $\approx 35-350\times$ higher in GRB hosts than the Galactic mean value; and (5) additional galaxies are found

Cooling Function 101

- Most general cooling and heating functions:

$$\left.\frac{dU}{dt}\right|_{\mathrm{rad}} = n_b^2(\Gamma - \Lambda)$$

$$\Lambda = \Lambda(T, n_b, Xij, J_\nu, \tau_{ij})$$

$$X_{ij} = \mathrm{H\,I},\ \mathrm{He\,I},\ \mathrm{He\,II},\ \ldots,\ \mathrm{C\,I},\ \mathrm{C\,II},\ \ldots$$

One needs a code like ***Cloudy*** to compute Λ in its full glory.

Cooling Function 101

$$\Lambda = \Lambda(T, n_b, \xcancel{X_{ij}}, J_\nu, \xcancel{\tau_{ij}})$$

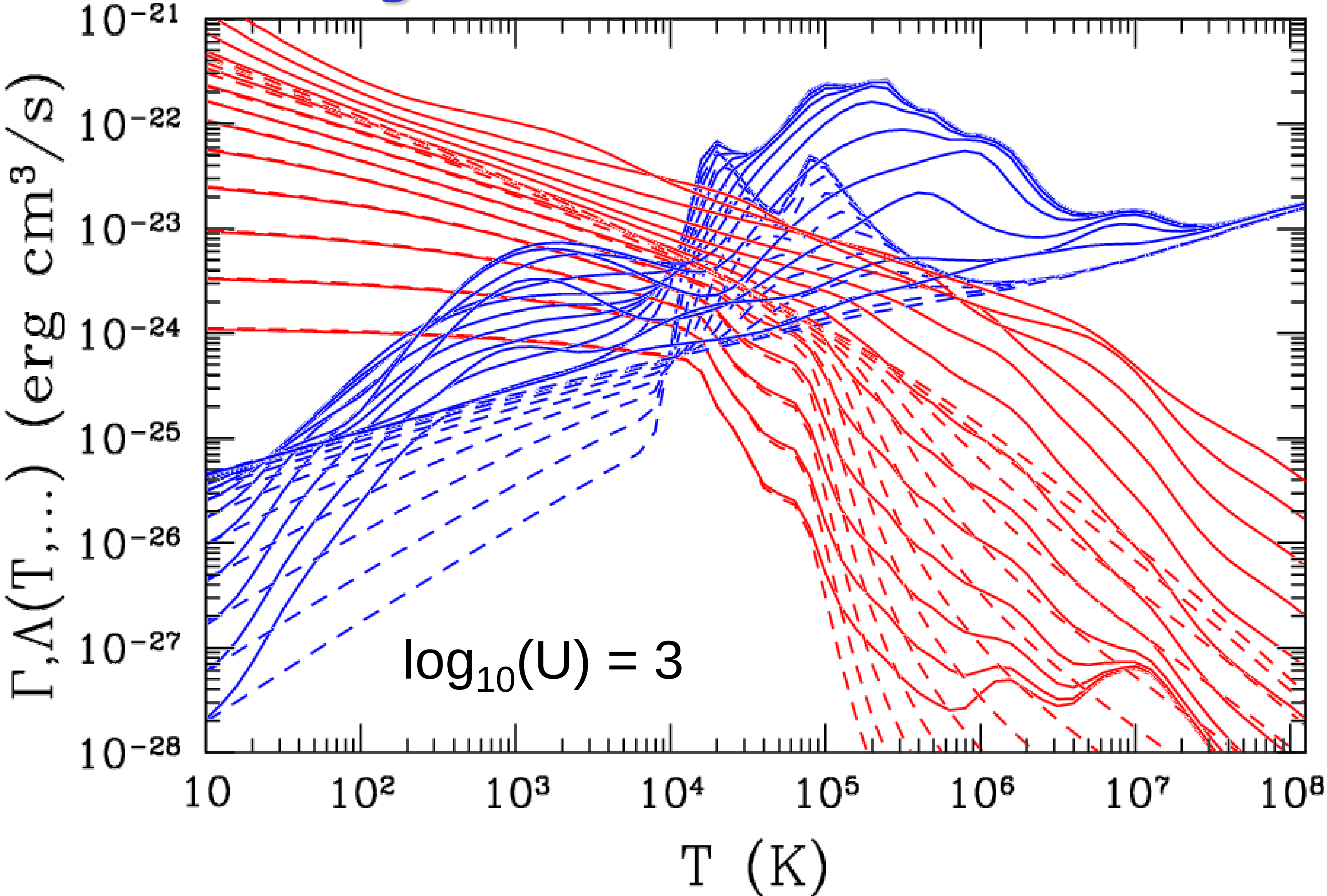
- Simplification #1: optically thin
- Simplification #2: ionization/excitation balance

$$\Downarrow$$

$$\Lambda = \Lambda(T, n_b, Z, J_\nu)$$

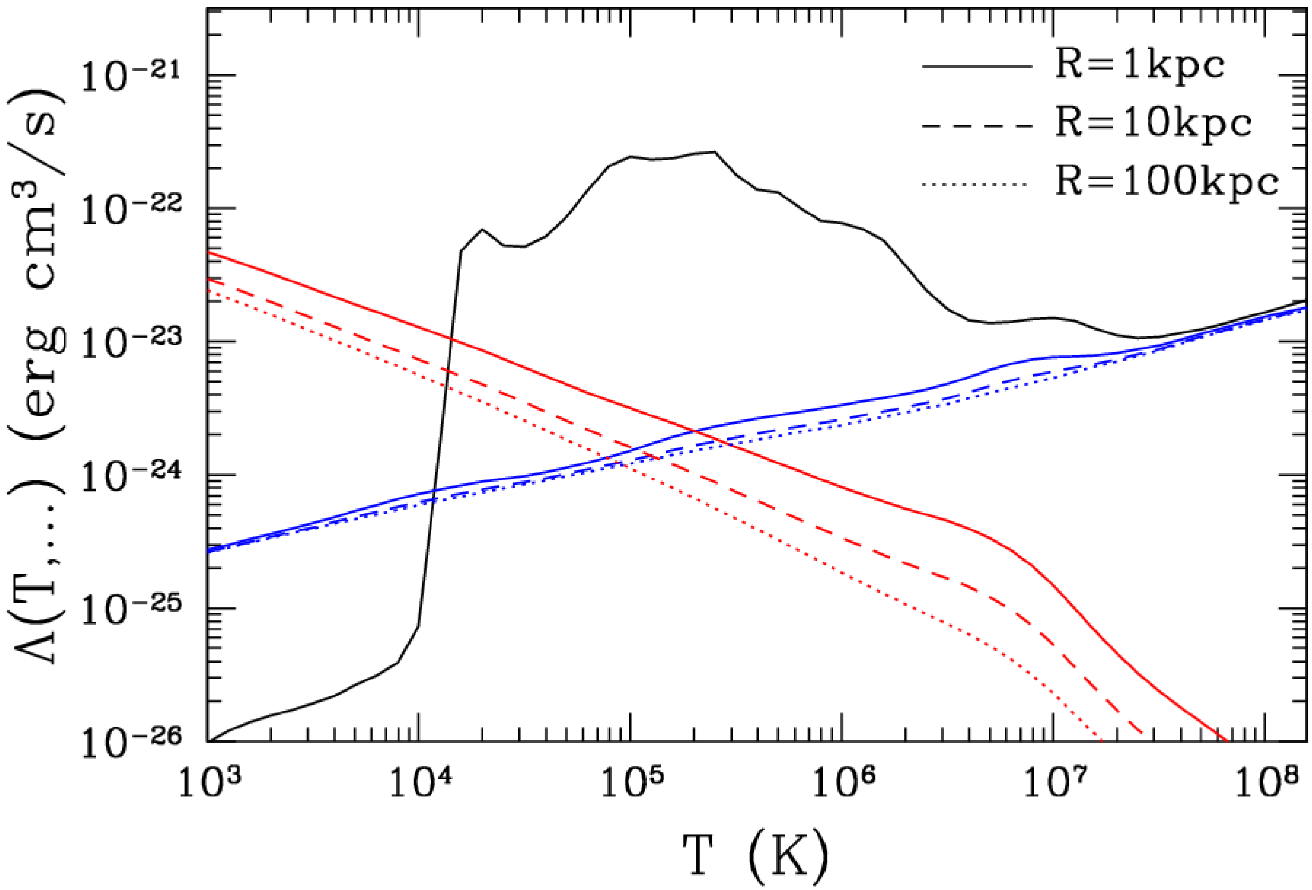
- Often, this is what is actually called a “cooling function”.

Sunny Places are Warm



Cute Example

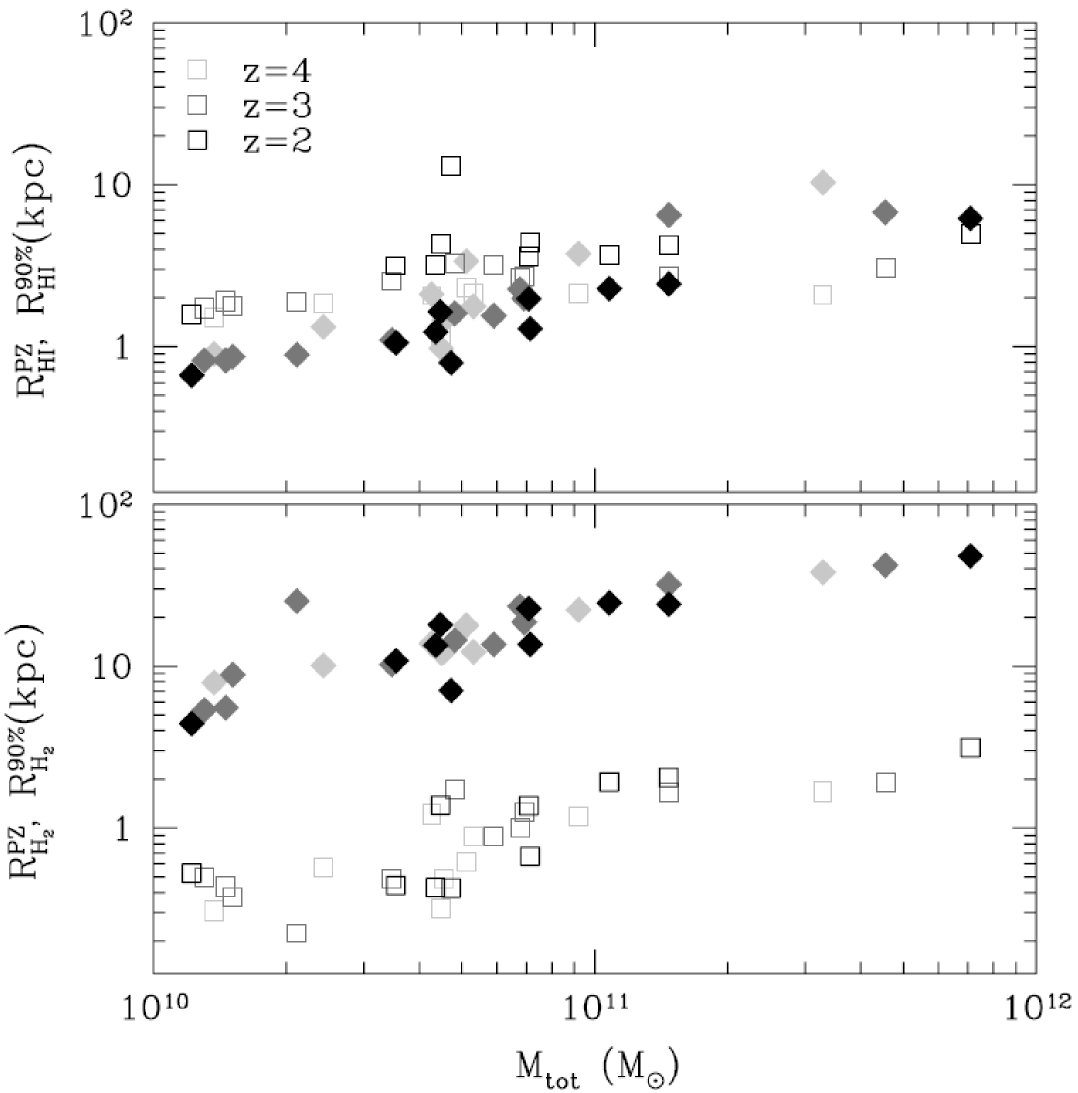
- A host halo of a quasar:



- No cooling at all – novel feedback mechanism!

Does It Really Matter?

- Proximity zones around galaxies are not large.
- Cooling/heating functions are strongly RF dependent only in the ISM.



99.9999% Of the Volume Is Easy

- When the cosmic background dominates ($J_\nu = f(z)$):

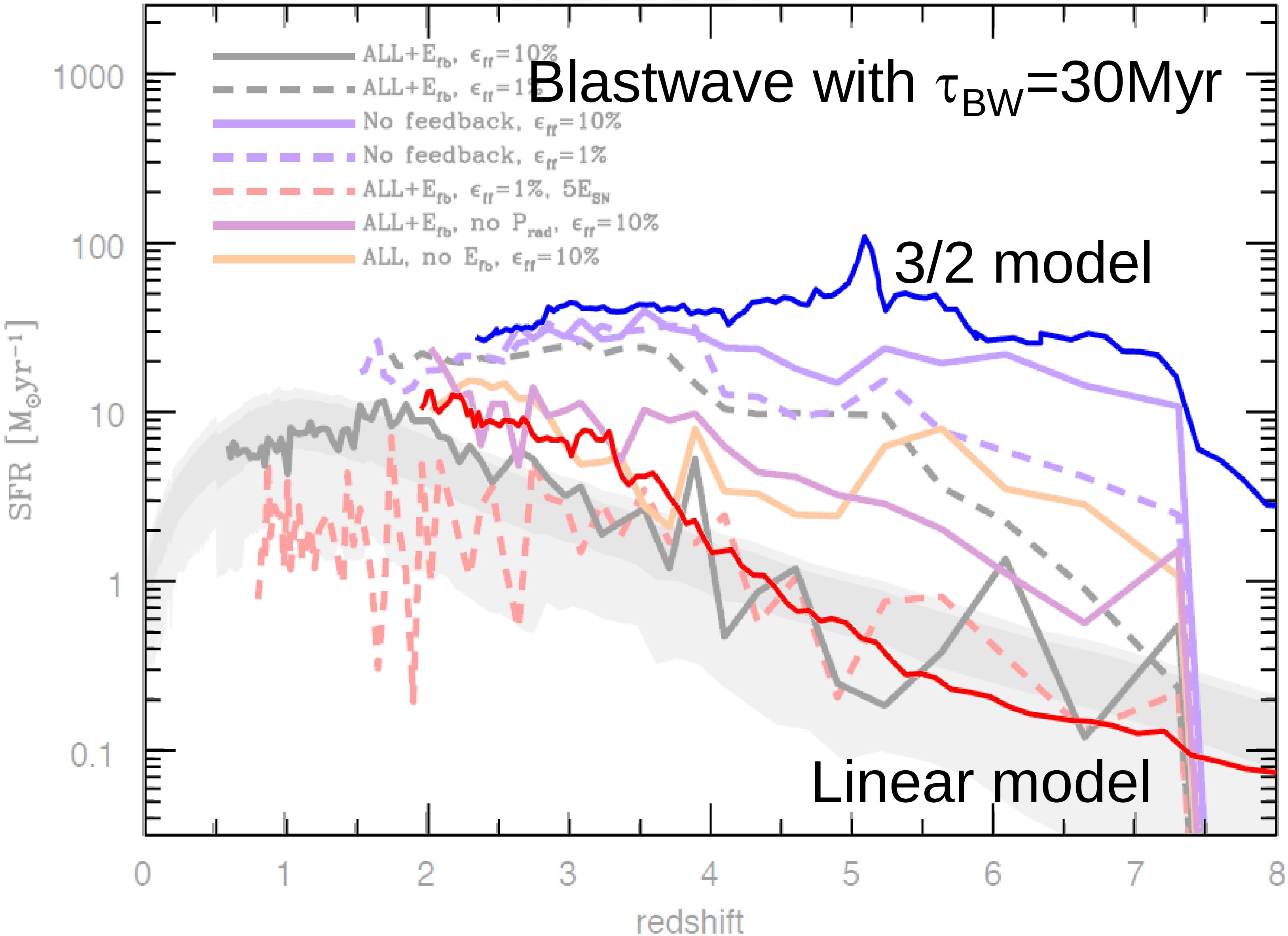
$$\Lambda(T, n_b, Z, J_\nu) \rightarrow \Lambda(T, n_b, Z, z)$$

- …
- Wiersma, Schaye, & Smith 2009
- …

00.0001% Of the Volume May Not Matter

- We never model stellar feedback, we always model SF+feedback together.

In A Relationship Both Sides Matter



00.0001% Of the Volume May Not Matter

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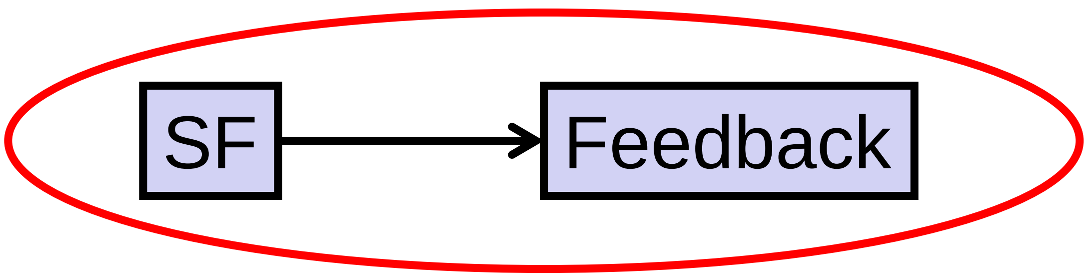
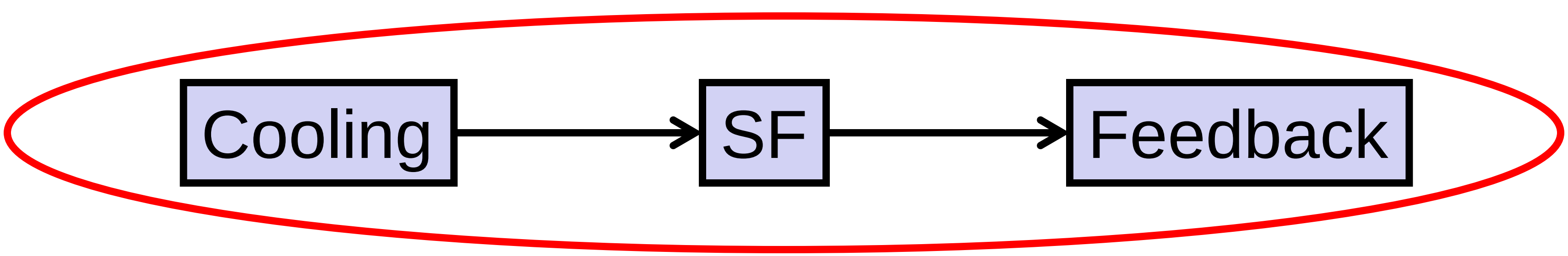


- One can just add cooling to the pool.



- In fact, that’s what most people actually do!

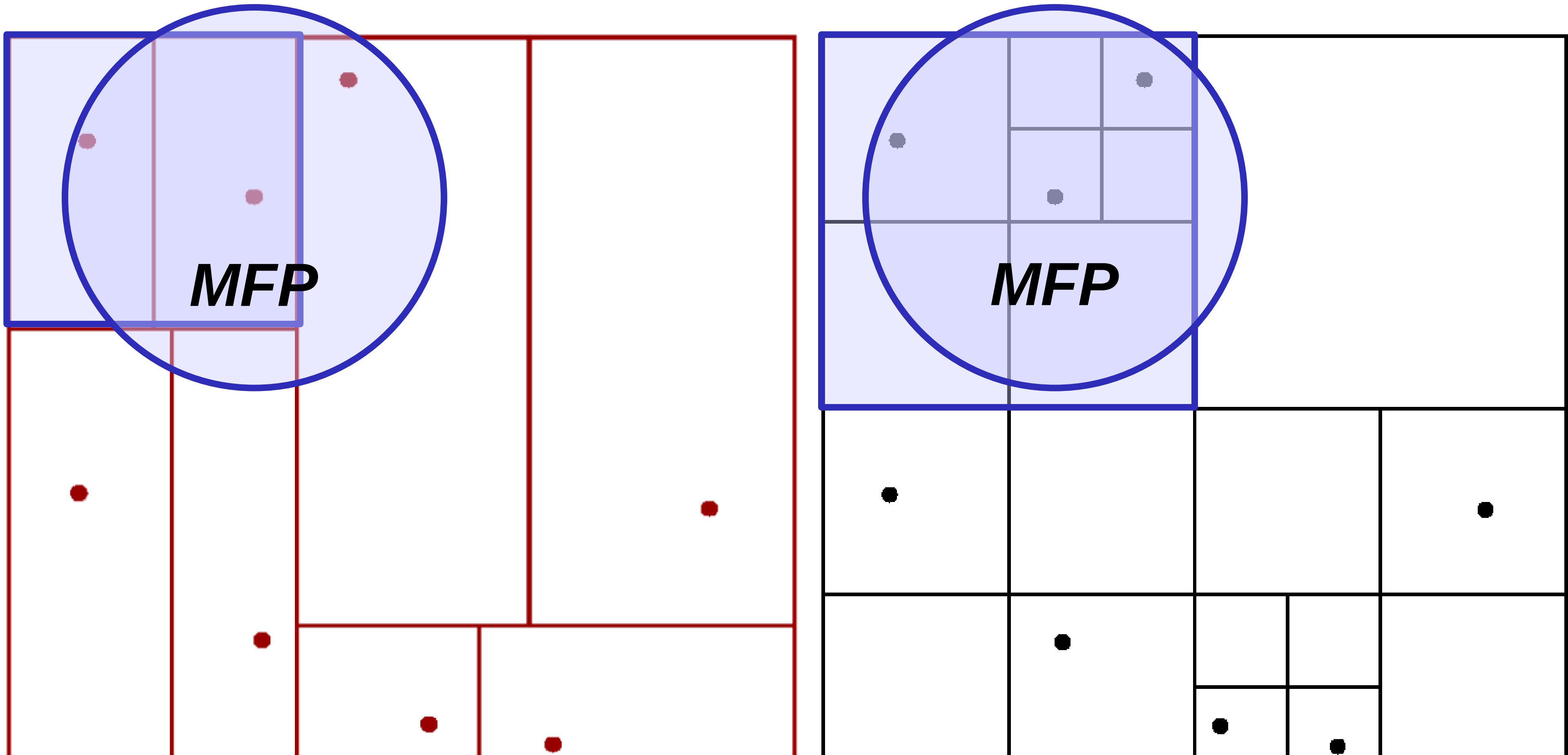
If You Are Stubborn: RT-Lite

$$
\begin{aligned}
J_\nu(\vec{r}) &= \frac{1}{4\pi}\int d^3r' \frac{L_\nu(\vec{r'})}{(\vec{r}-\vec{r'})^2} e^{-\tau_\nu(\vec{r},\vec{r'})} \\
&\approx \frac{1}{4\pi}\int_0^{\lambda_{\rm MFP}} d^3r' \frac{g_\nu \dot{\rho}_*(\vec{r'})}{(\vec{r}-\vec{r'})^2} \\
&\approx g_\nu \lambda_{\rm MFP} \langle \rho_* \rangle_{\lambda_{\rm MFP}} \\
&\approx g_\nu \langle \Sigma_* \rangle_{\lambda_{\rm MFP}}
\end{aligned}
$$

- Disk galaxies are RT solvers.

If You Are Stubborn: RT-lite

- Climb the tree to the right branch.



Conclusions

- How to include radiation fields in galaxy formation simulations? Don't.
- In the worst case when you must, use a simple estimate and your code tree data structure: RF = SFR within the MFP.

The End