DarkHistory

Accurate Ionization & Thermal Histories with Dark Matter Energy Injection

Hongwan Liu

with Gregory W. Ridgway & Tracy Slatyer

in preparation

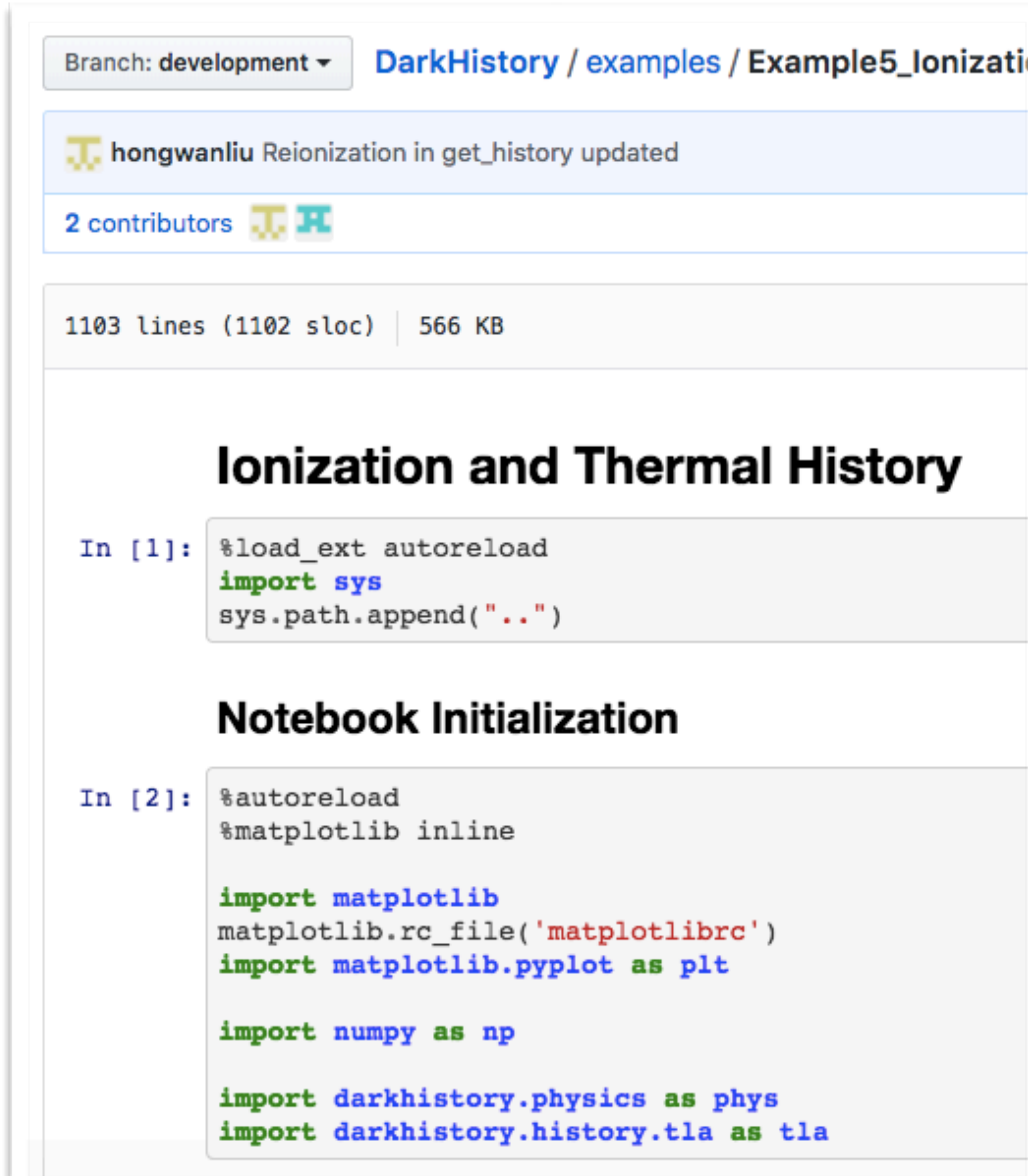
Massachusetts Institute of Technology

DarkHistory

HL, Ridgway & Slatyer

Highlights

Public code to compute ionization and thermal history with **annihilating/ decaying dark matter** or other exotic energy injection.



Branch: **development** ▾ DarkHistory / examples / **Example5_Ionizati**

hongwanliu Reionization in get_history updated

2 contributors

1103 lines (1102 sloc) | 566 KB

Ionization and Thermal History

In [1]:
```
%load_ext autoreload
import sys
sys.path.append("..")
```

Notebook Initialization

In [2]:
```
%autoreload
%matplotlib inline

import matplotlib
matplotlib.rc_file('matplotlibrc')
import matplotlib.pyplot as plt

import numpy as np

import darkhistory.physics as phys
import darkhistory.history.tla as tla
```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Temperature and Ionization Histories

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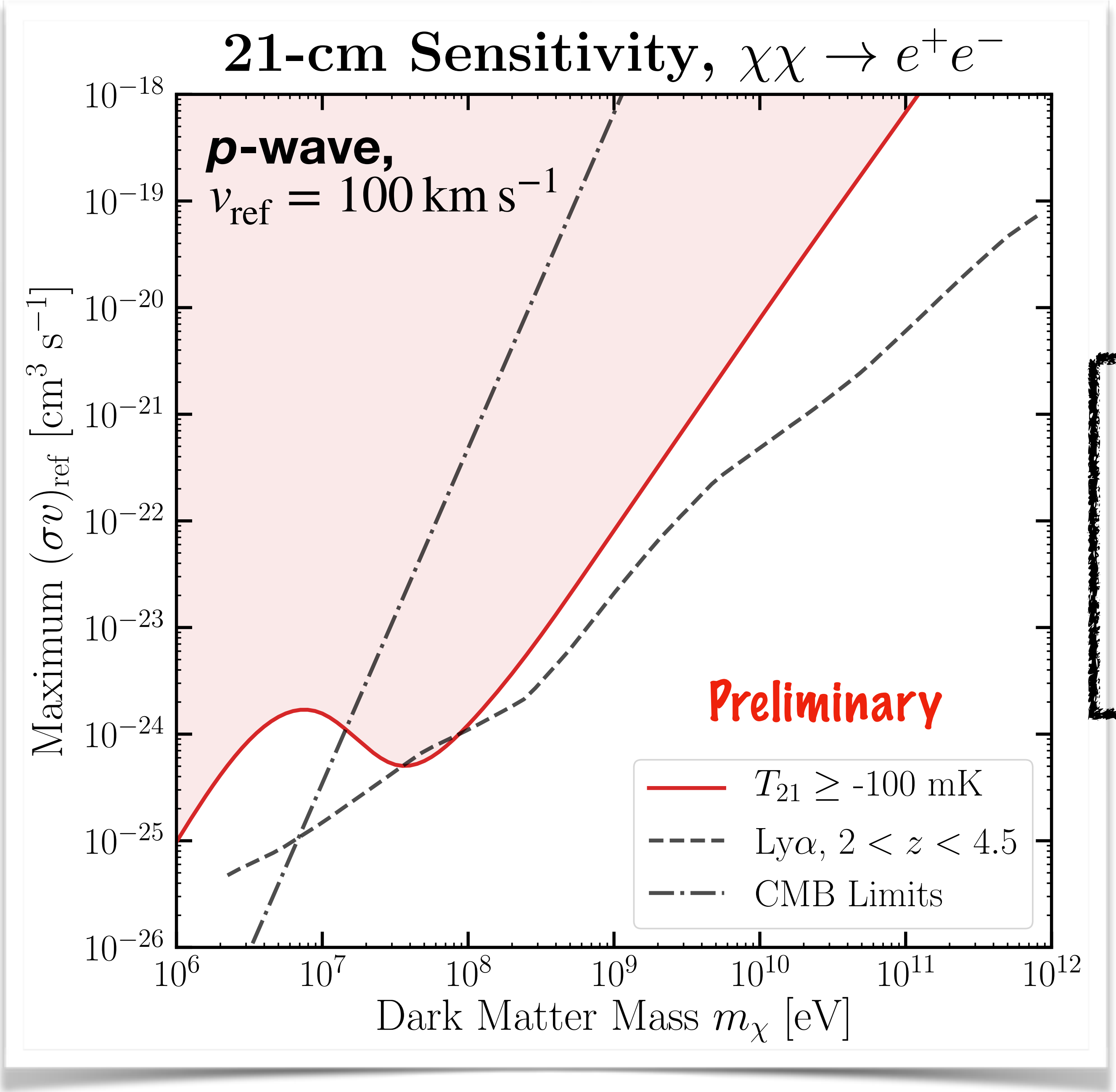
Critical for **CMB**, **21-cm** constraints etc. on exotic energy injection processes.



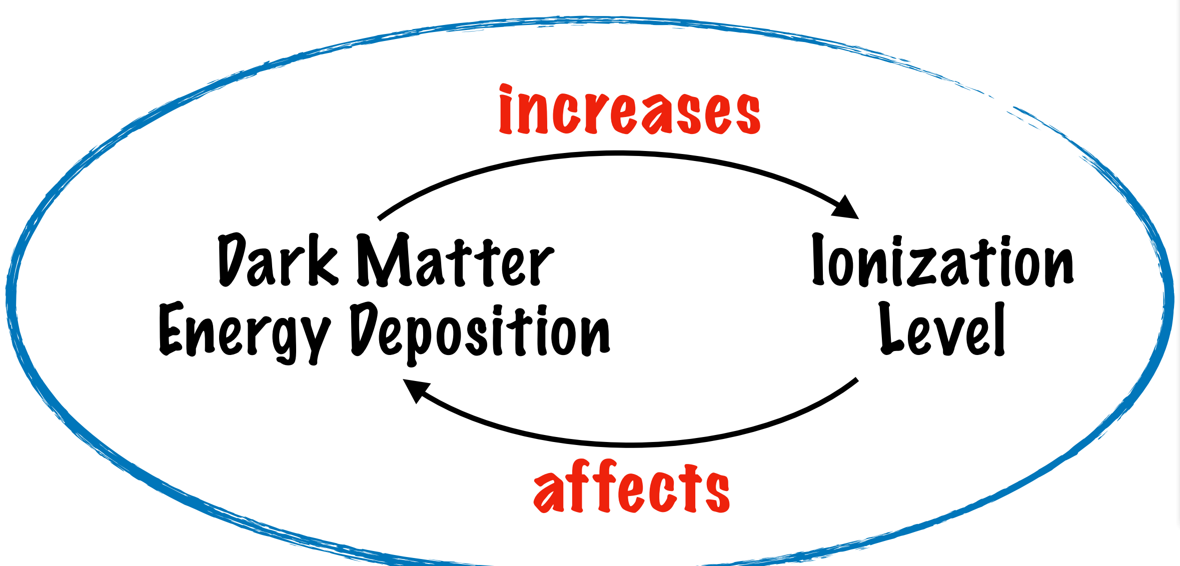
See Gregory Ridgway's talk on 21-cm constraints for *p*-wave annihilating DM.

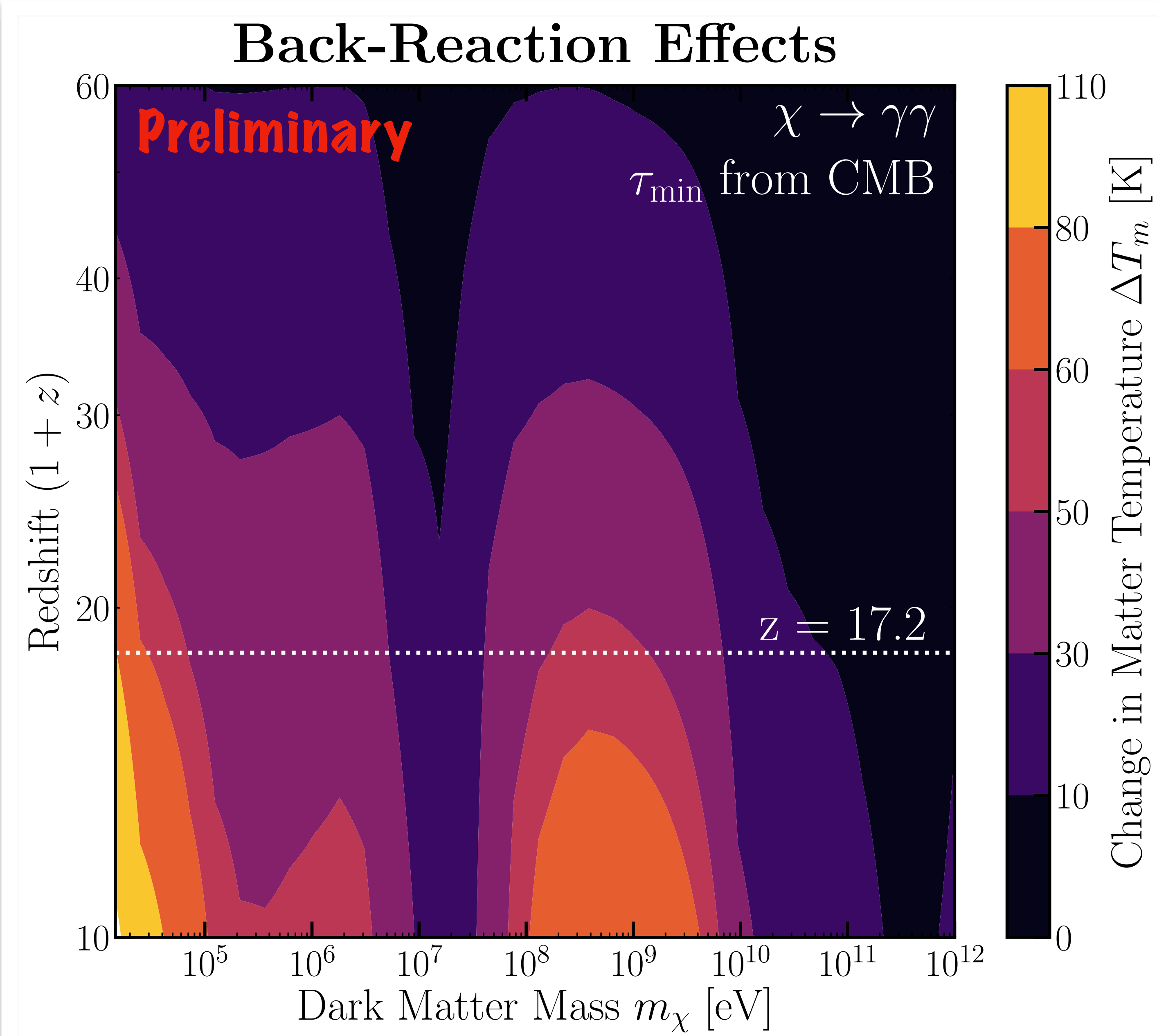
Friday, 31 August, 3:30 pm

Highlights

Public code to compute ionization and thermal history with **annihilating/ decaying dark matter** or other exotic energy injection.

Accurate, self-consistent treatment of significant **back-reaction** from increased ionization levels.



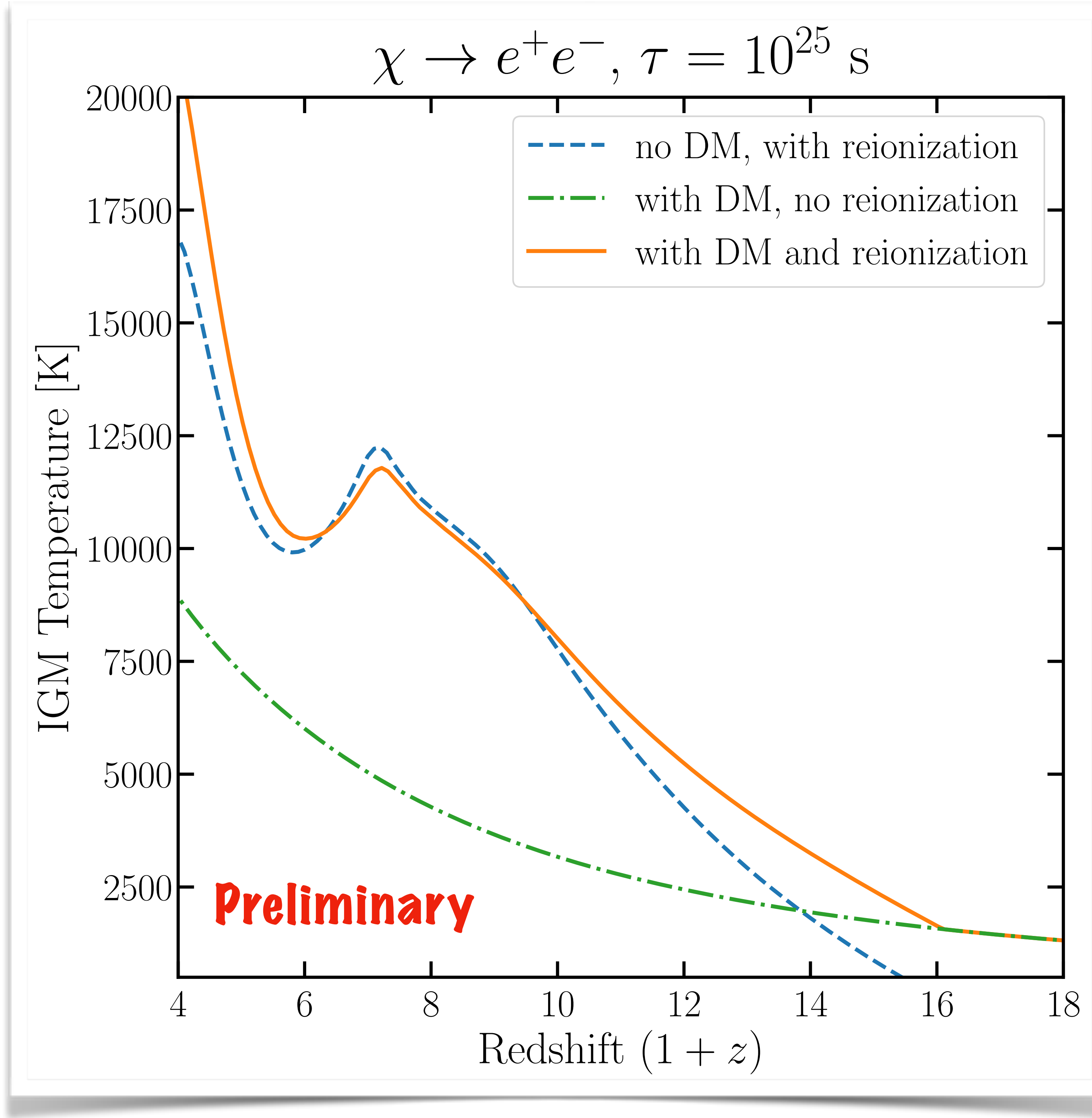


Highlights

Public code to compute ionization and thermal history with **annihilating/decaying dark matter** or other exotic energy injection.

Accurate, self-consistent treatment of significant **back-reaction** from increased ionization levels.

Consistent treatment of **reionization** + **energy injection from dark matter** now possible.



Temperature and Ionization Histories

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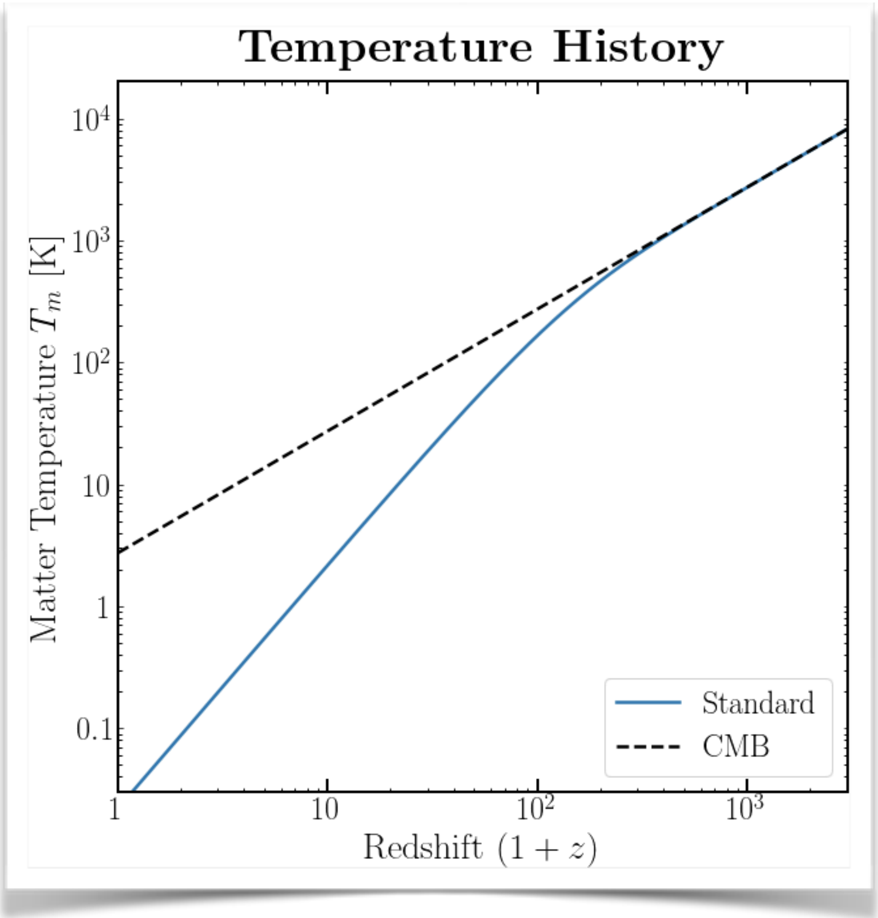
Well-modeled by the **three-level hydrogen atom.**

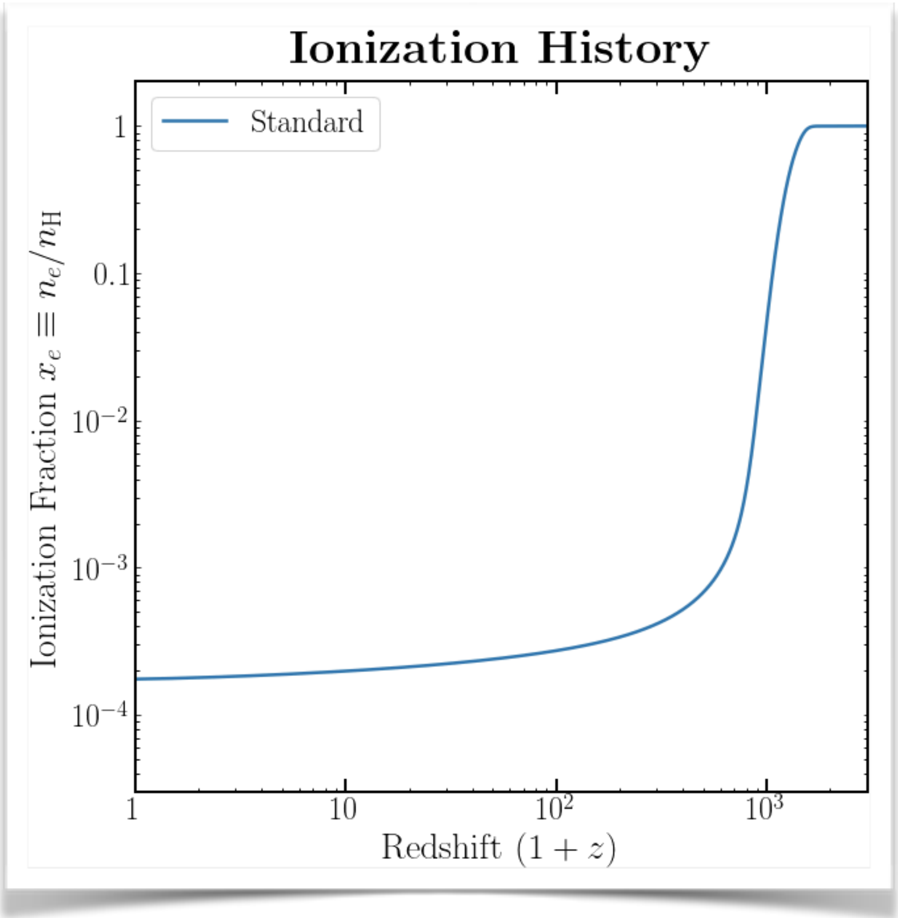
matter temperature

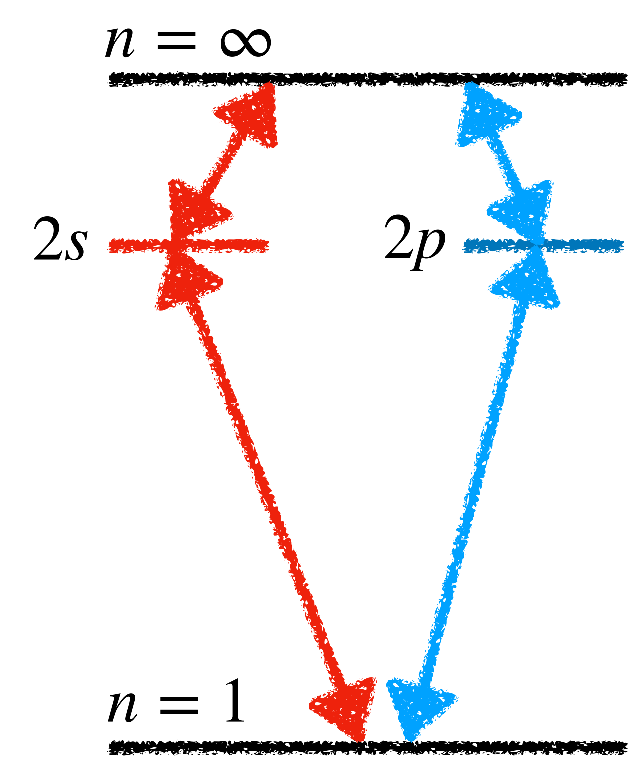
$$\dot{T}_m = -2HT_m + \Gamma_C(T_{\text{CMB}} - T_m)$$

ionization

$$\dot{x}_e = -\mathscr{C}\left[n_H x_e^2 \alpha_{\text{B}} - 4(1-x_e)\beta_{\text{B}} e^{-E_{21}/T_{\text{CMB}}}\right]$$







Peebles '68
Zeldovich+ '68

Hongwan Liu

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Temperature and Ionization Histories

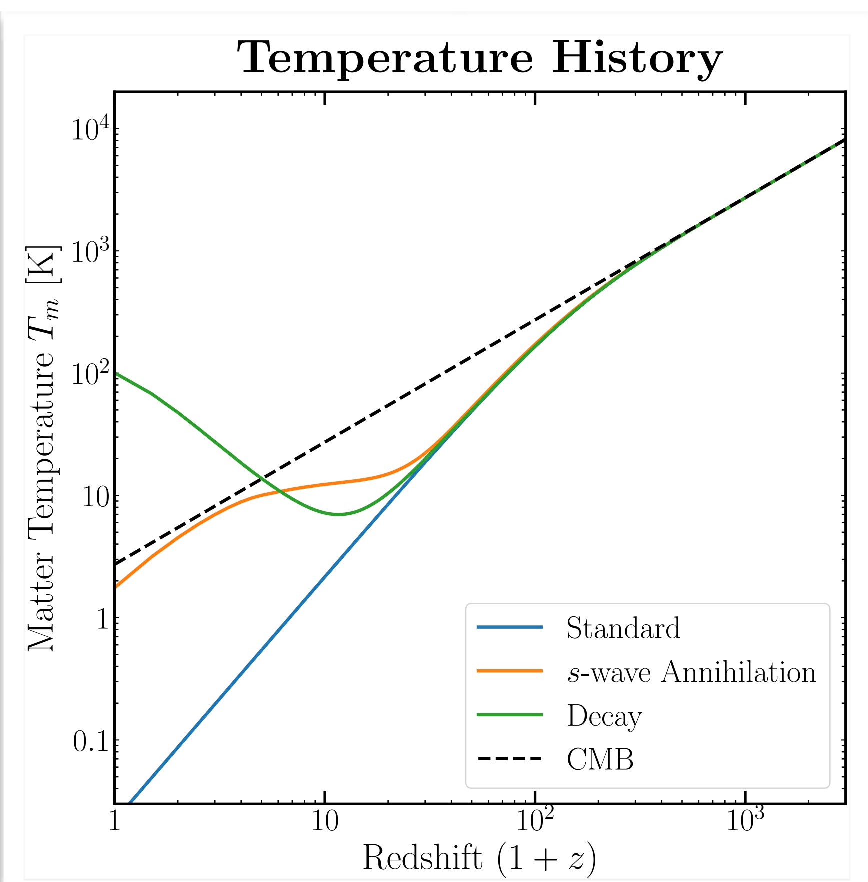
Energy injection from dark matter acts an additional source of ionization and heating.

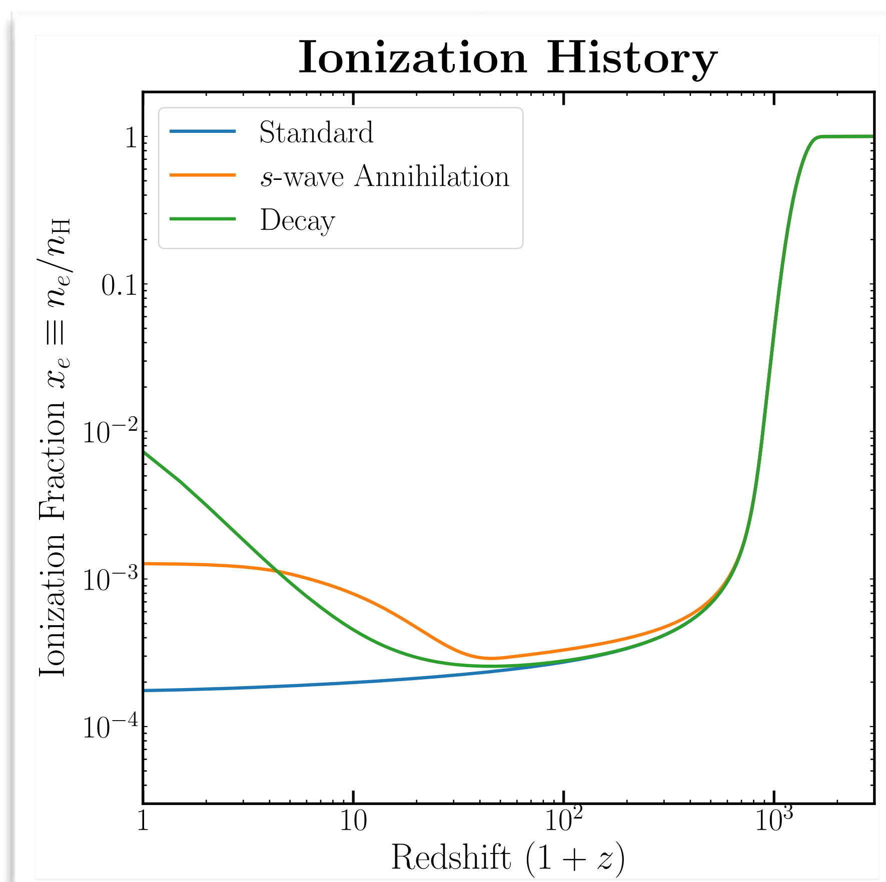
matter temperature

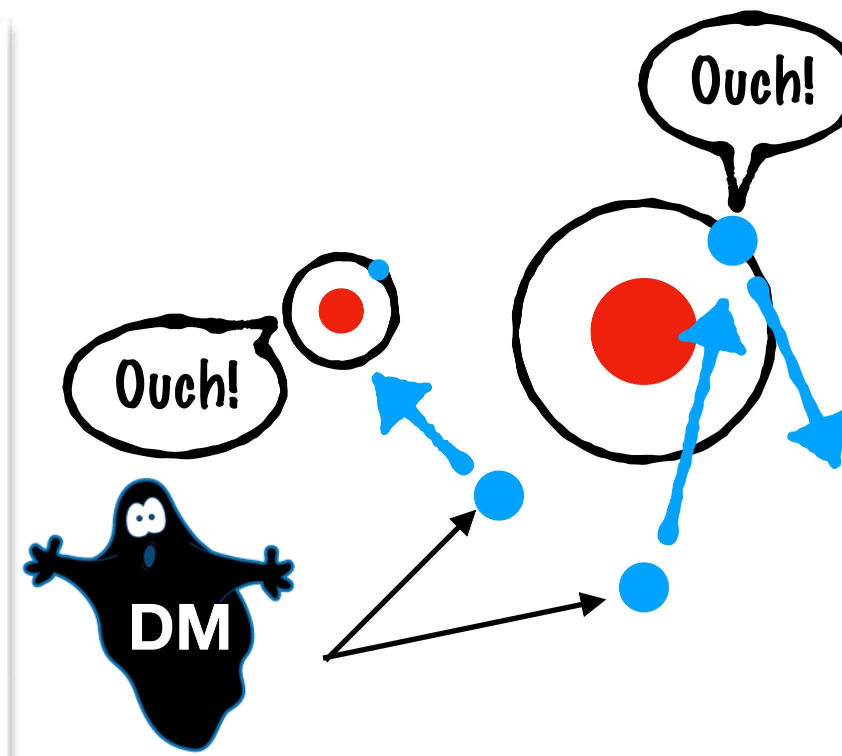
$$\dot{T}_m = -2HT_m + \Gamma_C(T_{\mathrm{CMB}} - T_m) + \frac{2f_{\mathrm{heat}}(z)}{3(1+f_{\mathrm{He}}+x_e)n_{\mathrm{H}}}\left(\frac{dE}{dV\,dt}\right)^{\mathrm{inj}}$$

ionization

$$\dot{x}_e = -\mathscr{C}\left[n_H x_e^2 \alpha_{\mathrm{B}} - 4(1-x_e)\beta_{\mathrm{B}} e^{-E_{21}/T_{\mathrm{CMB}}}\right] + \left[\frac{f_{\mathrm{ion}}(z)}{\mathscr{R} n_{\mathrm{H}}} + \frac{(1-\mathscr{C})f_{\mathrm{exc}}(z)}{0.75\mathscr{R} n_{\mathrm{H}}}\right]\left(\frac{dE}{dV\,dt}\right)^{\mathrm{inj}}$$







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Deposition Fractions

Energy injection ≠ Energy deposition. Some **fraction** gets deposited into **heating**, **ionization**, **excitation**.

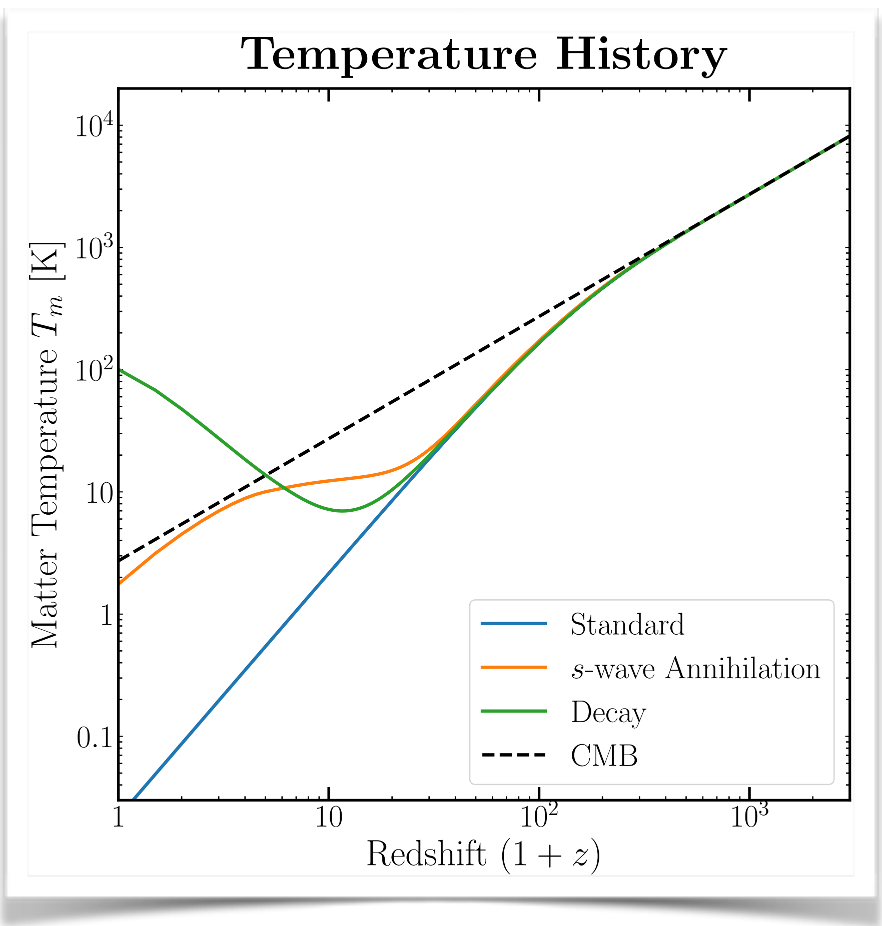
Nontrivial to calculate!
Slatyer 1506.03812

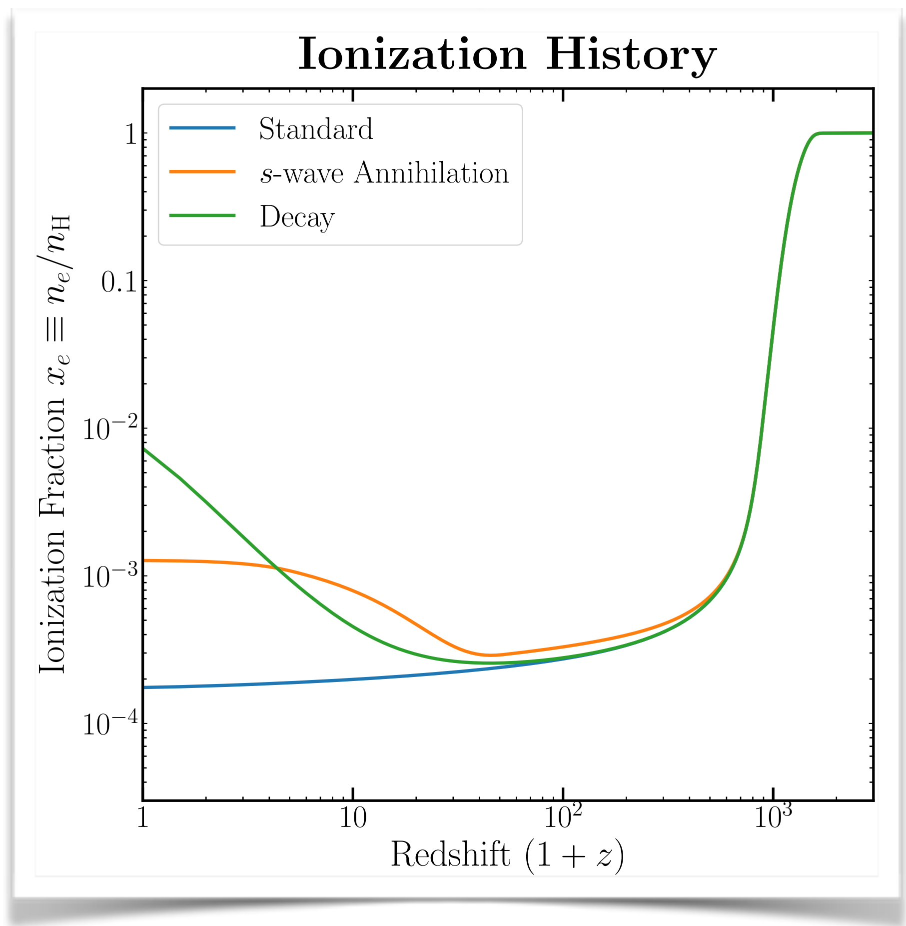
matter temperature

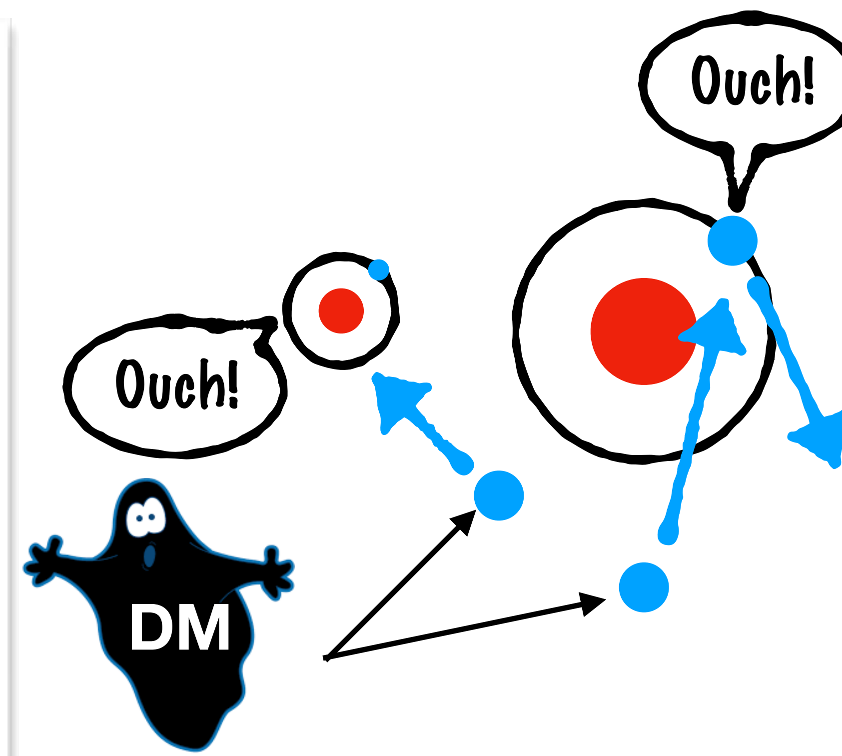
$$\dot{T}_m = -2HT_m + \Gamma_C(T_{\rm CMB} - T_m) + \frac{2 f_{\rm heat}(z)}{3(1+f_{\rm He}+x_e)n_{\rm H}}\left(\frac{dE}{dV\,dt}\right)^{\rm inj}$$

ionization

$$\dot{x}_e = -\mathscr{C}\left[n_H x_e^2 \alpha_{\rm B} - 4(1-x_e)\beta_{\rm B} e^{-E_{21}/T_{\rm CMB}}\right] + \left[\frac{f_{\rm ion}(z)}{\mathscr{R} n_{\rm H}} + \frac{(1-\mathscr{C}) f_{\rm exc}(z)}{0.75\,\mathscr{R} n_{\rm H}}\right]\left(\frac{dE}{dV\,dt}\right)^{\rm inj}$$







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Back-Reaction

These fractions are in fact dependent on **ionization**. Nontrivial **back-reaction**: energy deposition leads to increased ionization, affecting subsequent deposition.

matter temperature

$$\dot{T}_m = -2HT_m + \Gamma_C(T_{\mathrm{CMB}} - T_m) + \frac{2f_{\mathrm{heat}}(z, \mathbf{x_e})}{3(1 + f_{\mathrm{He}} + x_e)n_{\mathrm{H}}}\left(\frac{dE}{dV\,dt}\right)^{\mathrm{inj}}$$

ionization

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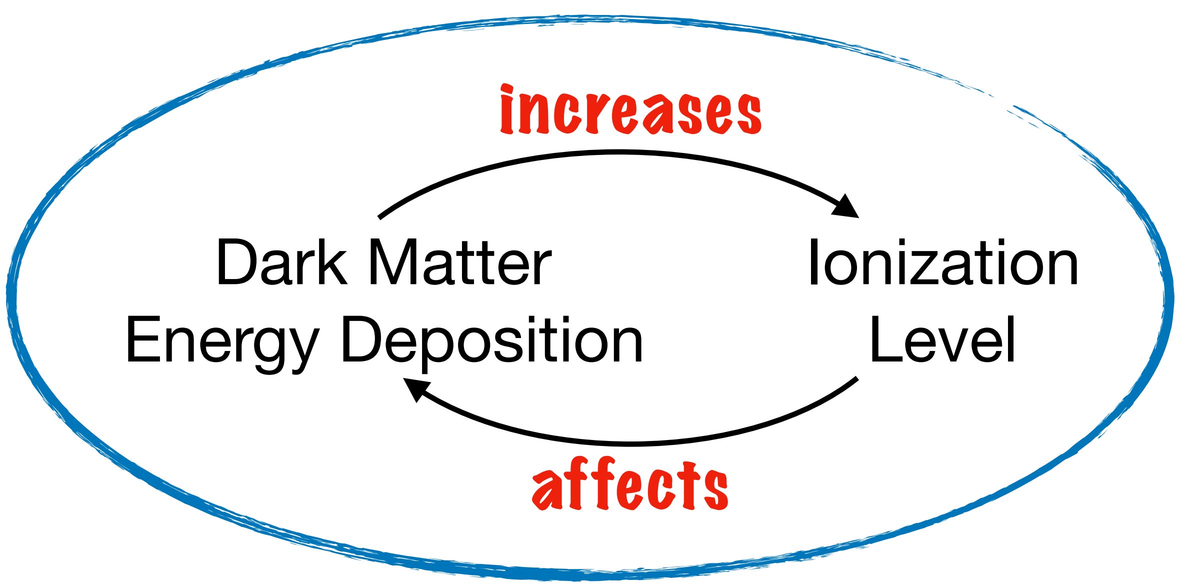
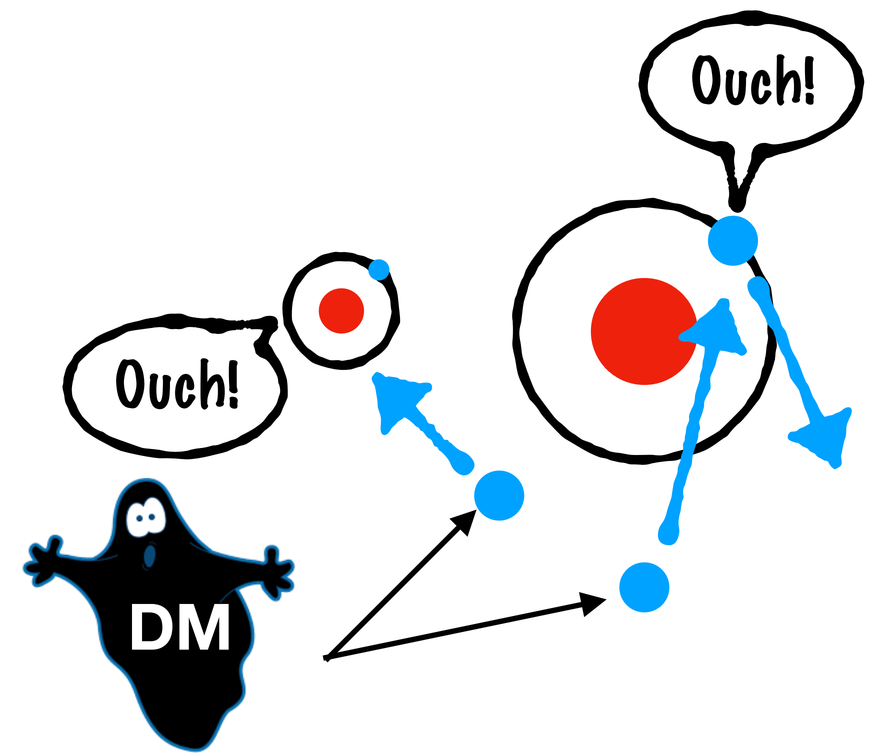
$f_c(z)$ previous computed using standard ionization history, **no reionization** and **no dark matter**.





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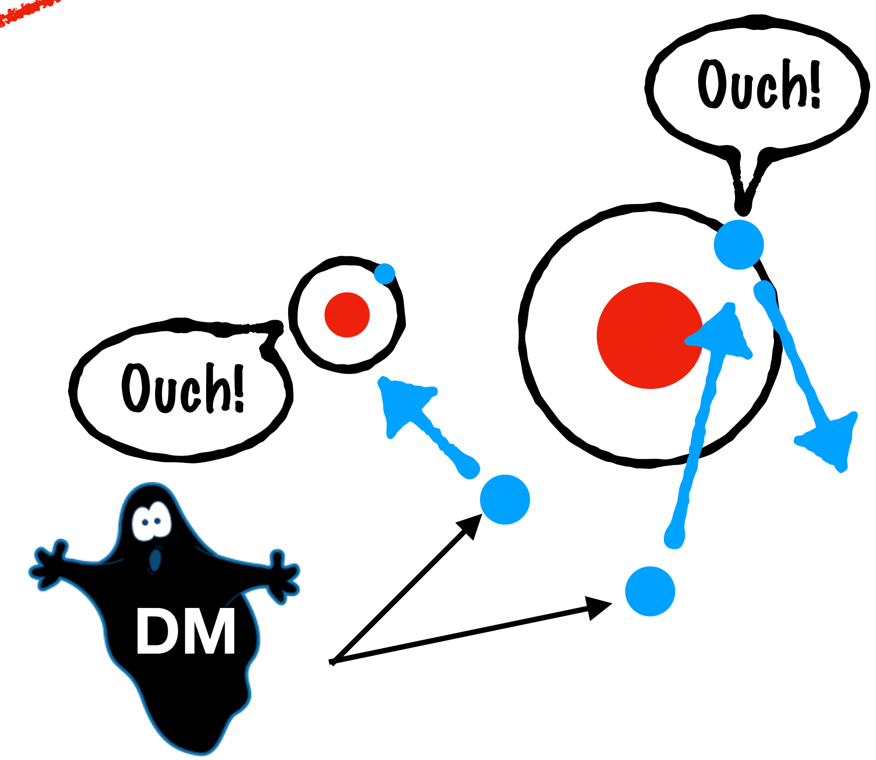
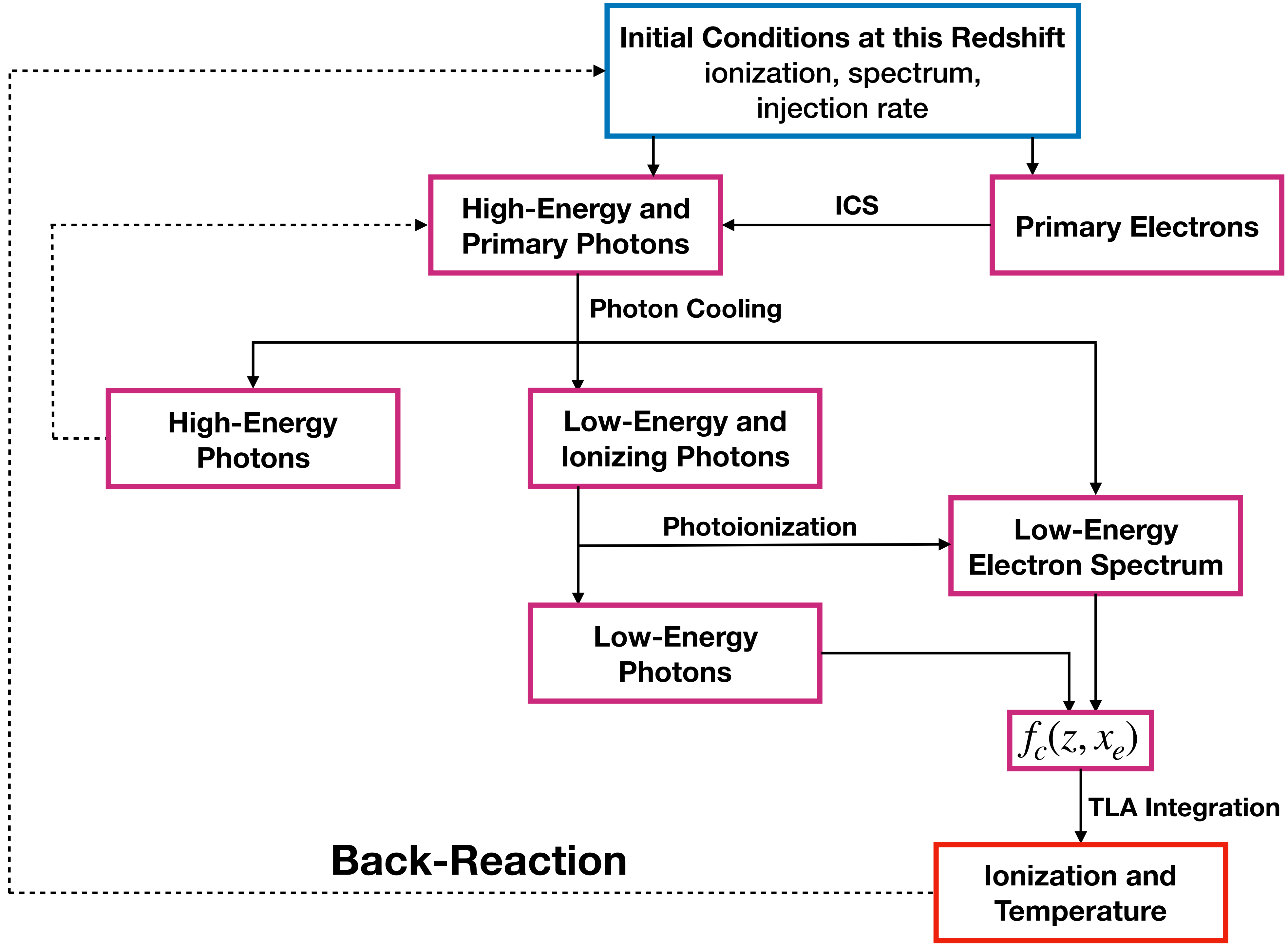
ionization

$$\dot{x}_e = -\mathscr{C}\left[n_H x_e^2 \alpha_{\rm B} - 4(1-x_e)\beta_{\rm B} e^{-E_{21}/T_{\rm CMB}}\right] + \left[\frac{f_{\rm ion}(z,\mathbf{x_e})}{\mathscr{R} n_{\rm H}} + \frac{(1-\mathscr{C})f_{\rm exc}(z,\mathbf{x_e})}{0.75\mathscr{R} n_{\rm H}}\right]\left(\frac{dE}{dV\,dt}\right)^{\rm inj}$$

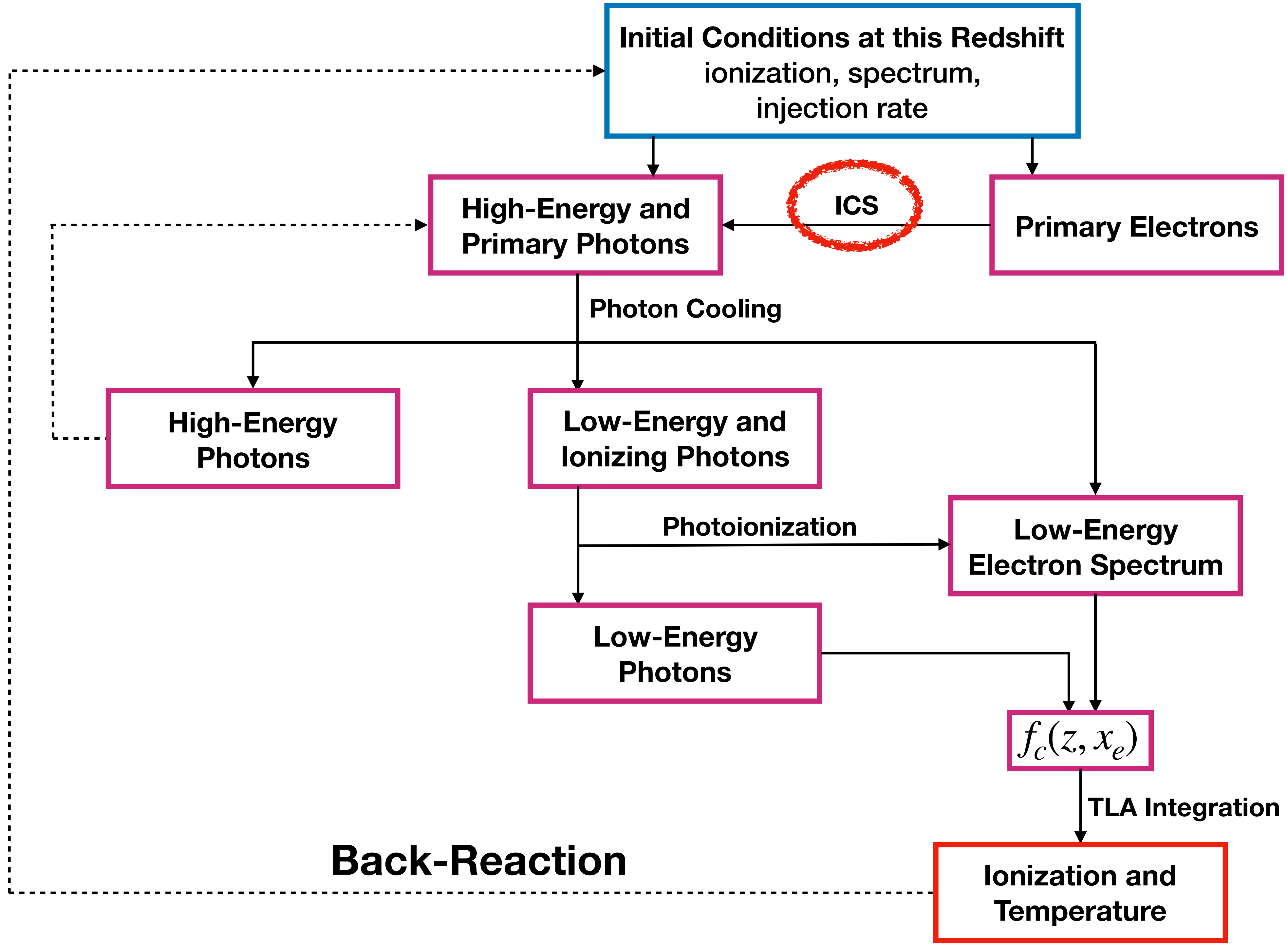
DarkHistory



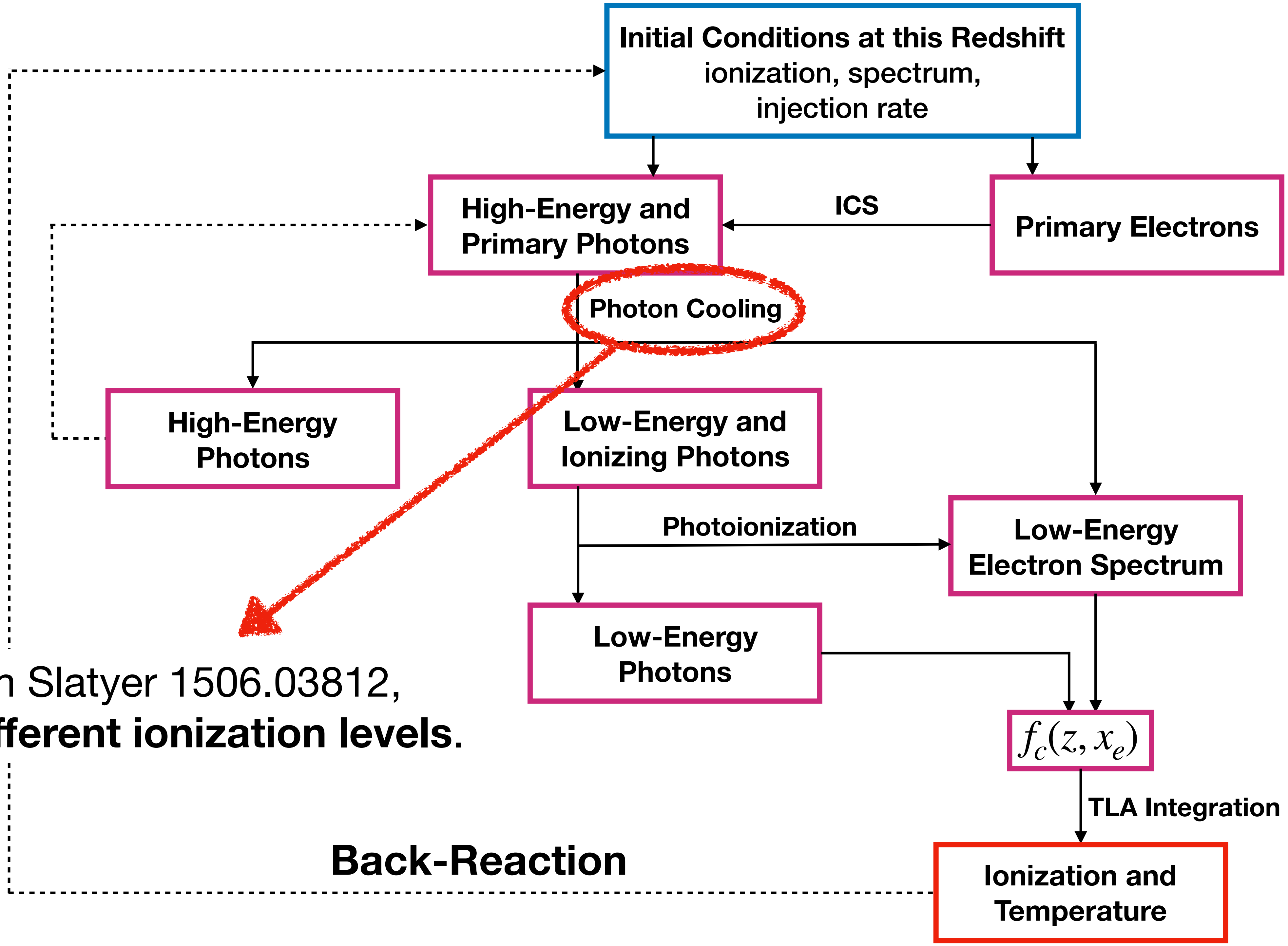
Code Structure



Code Structure

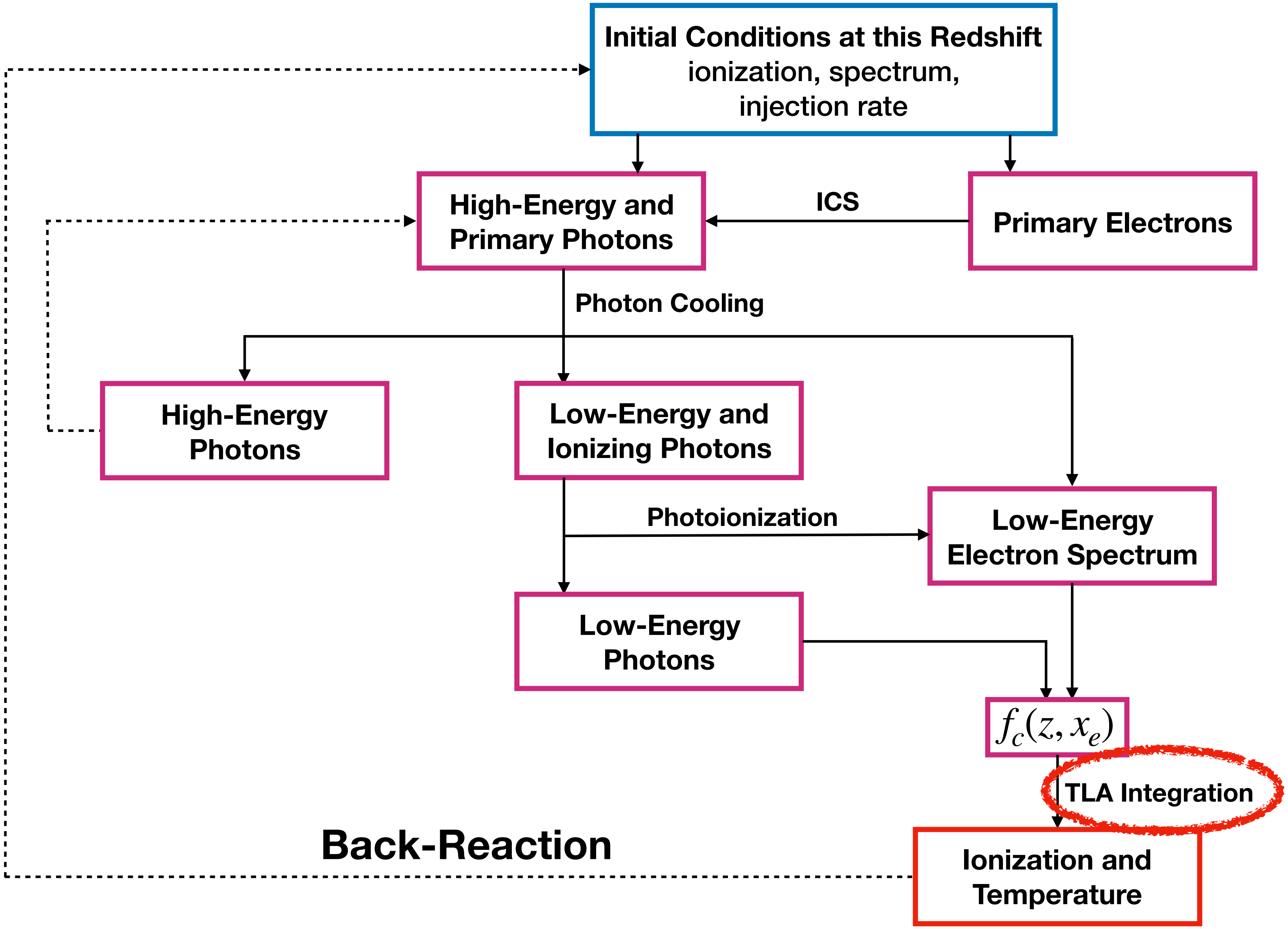


Code Structure

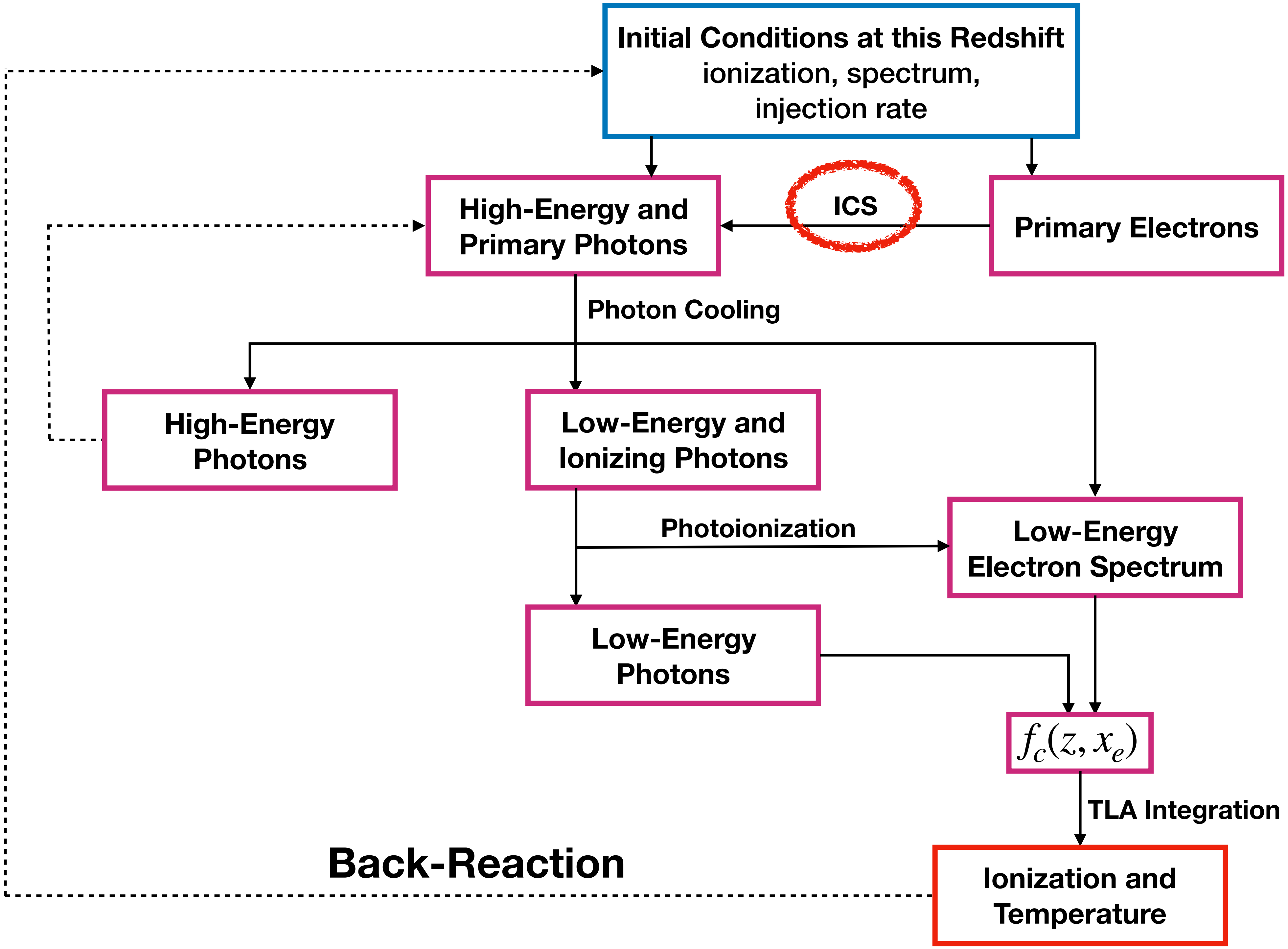


Results from Slatyer 1506.03812,
extended to **different ionization levels.**

Code Structure



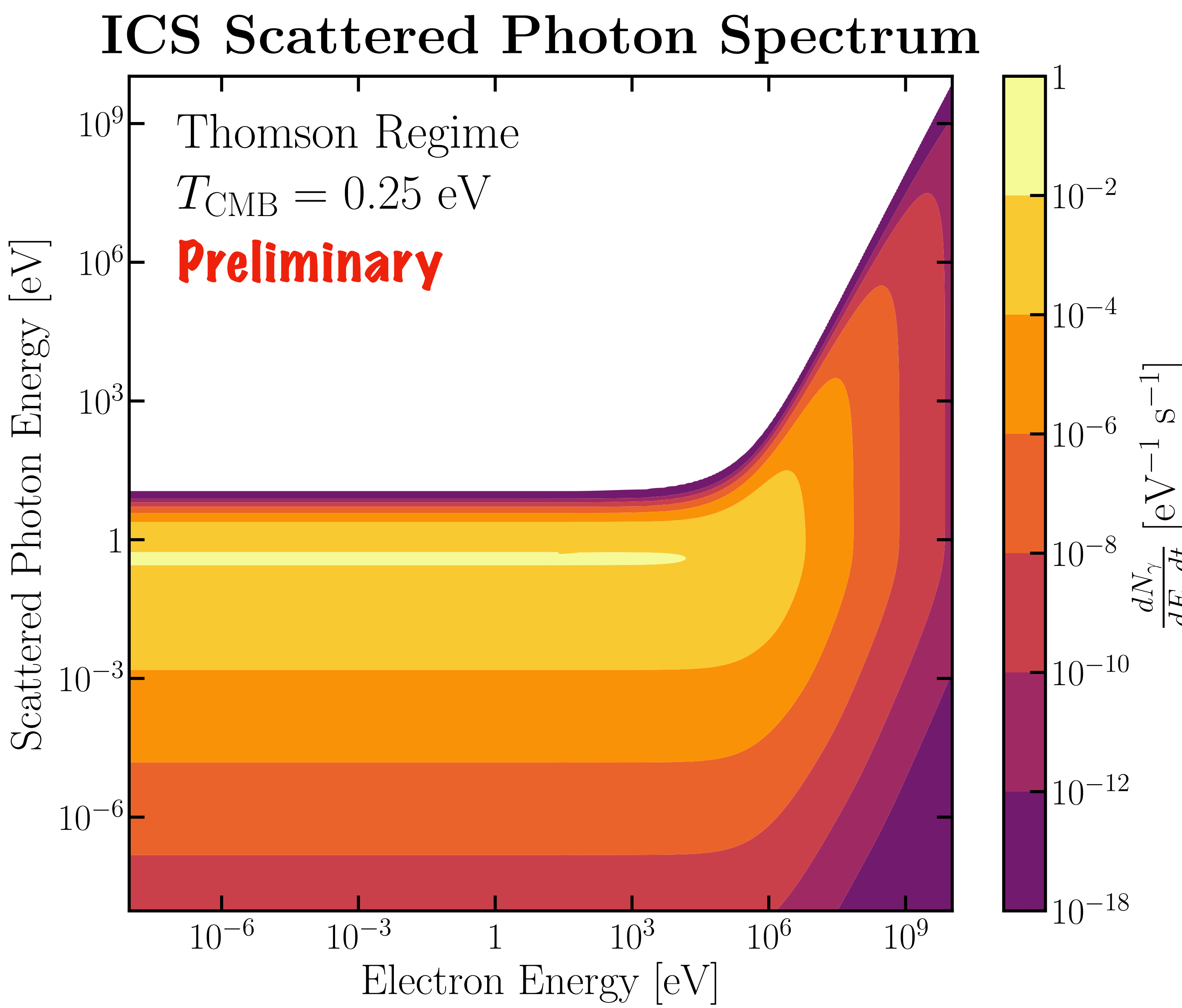
Code Structure



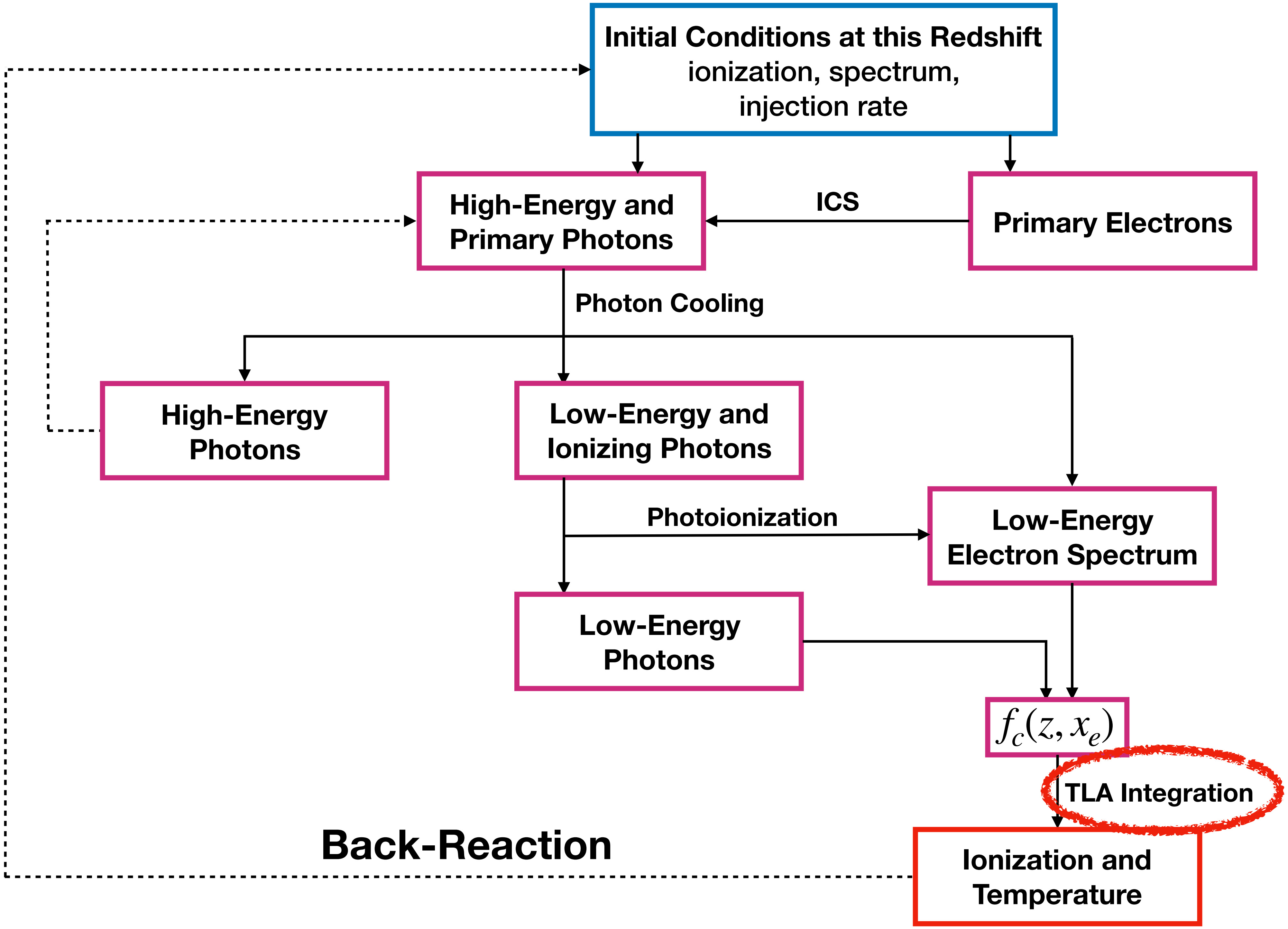
Inverse Compton

Inverse Compton off the CMB is **dominant process** by which high-energy electrons lose their energy.

Fast, **improved** calculation for secondary photon spectra in both **Thomson** and **relativistic** regimes.



Code Structure



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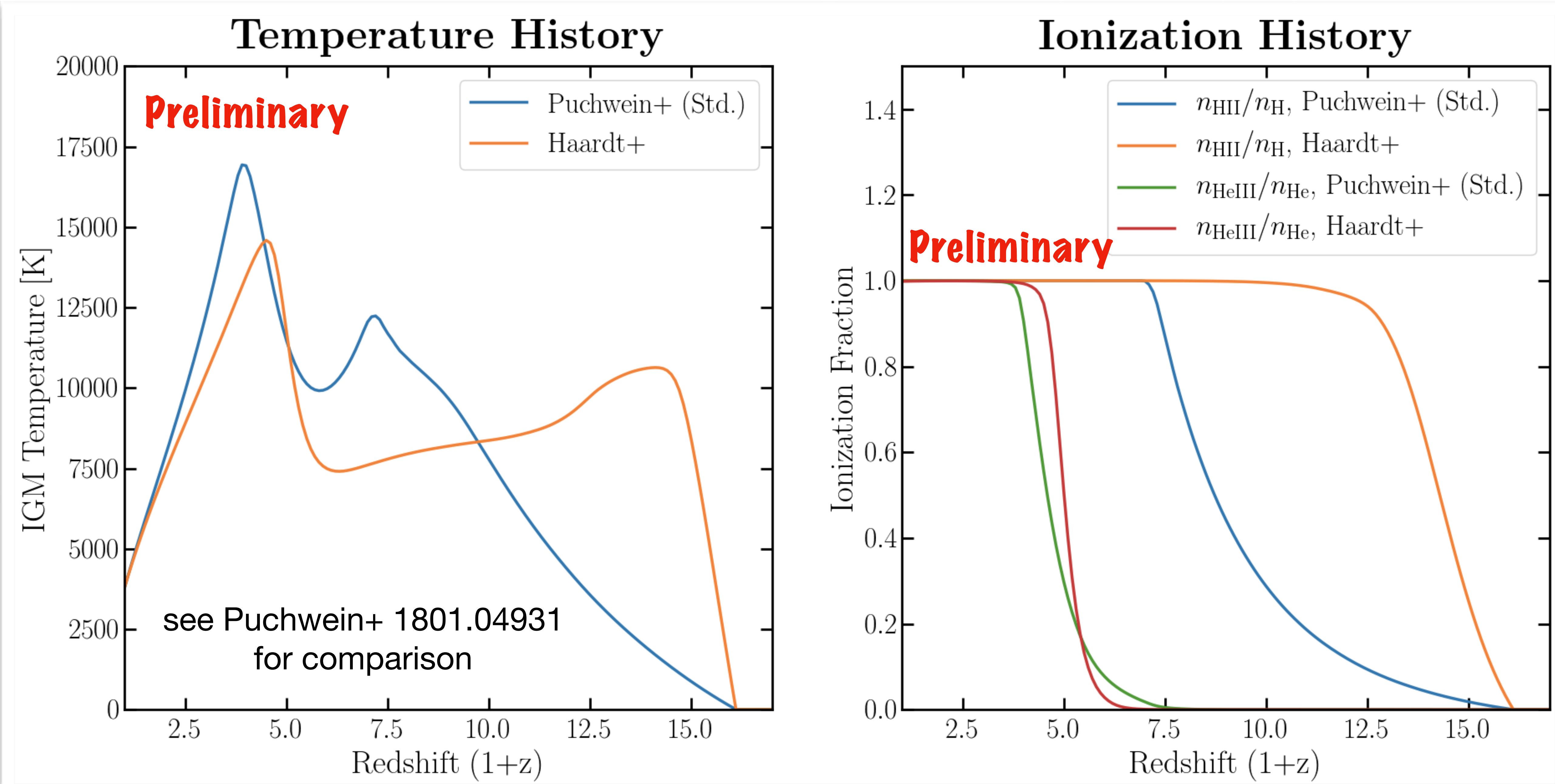
Reionization



Reionization models can be included. Default reionization model results **have good agreement** with state-of-the-art models.

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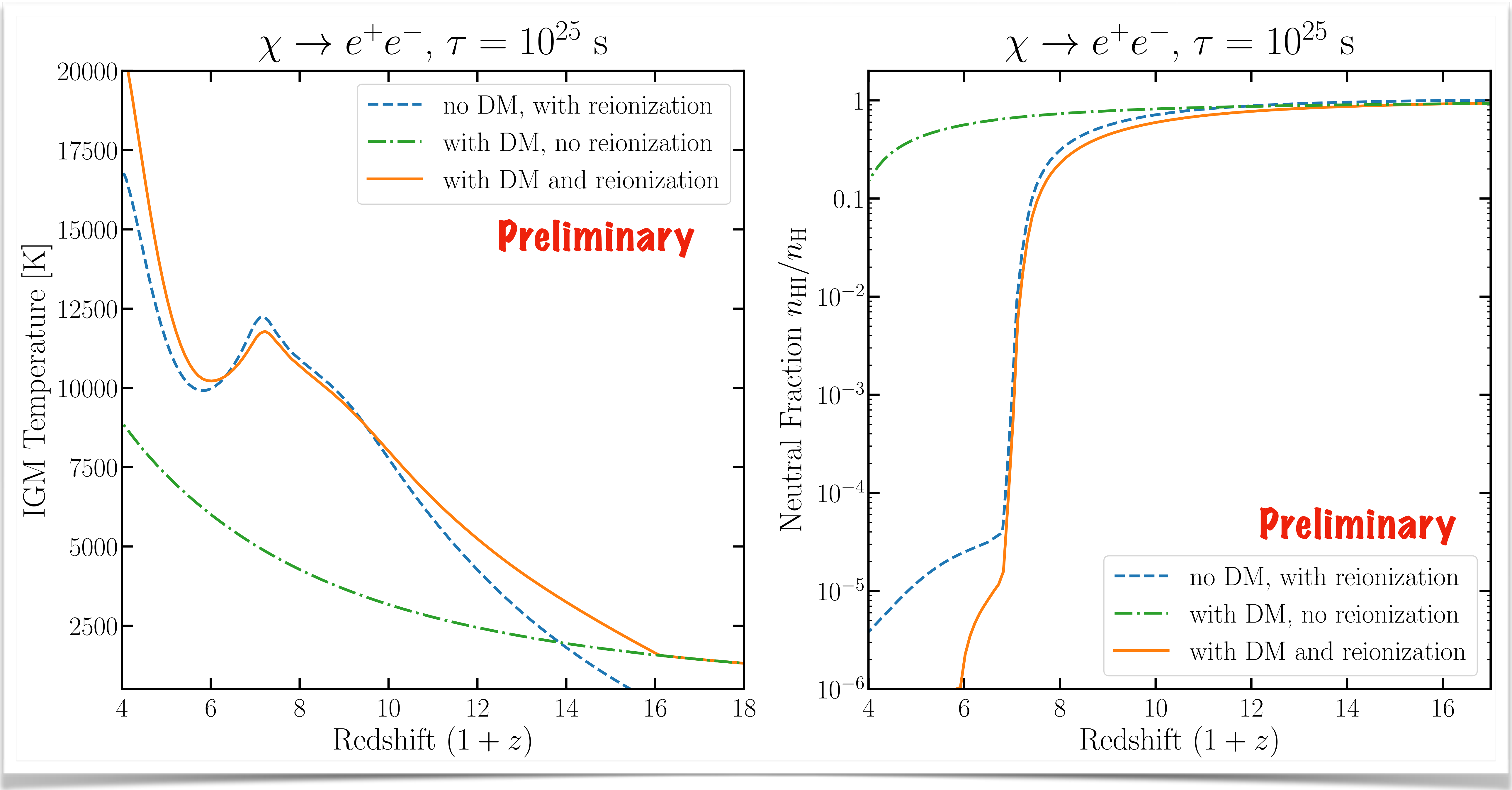
Reionization+DM



Ionization and thermal history can be integrated with the inclusion of **both DM and reionization**, with **back-reaction!**

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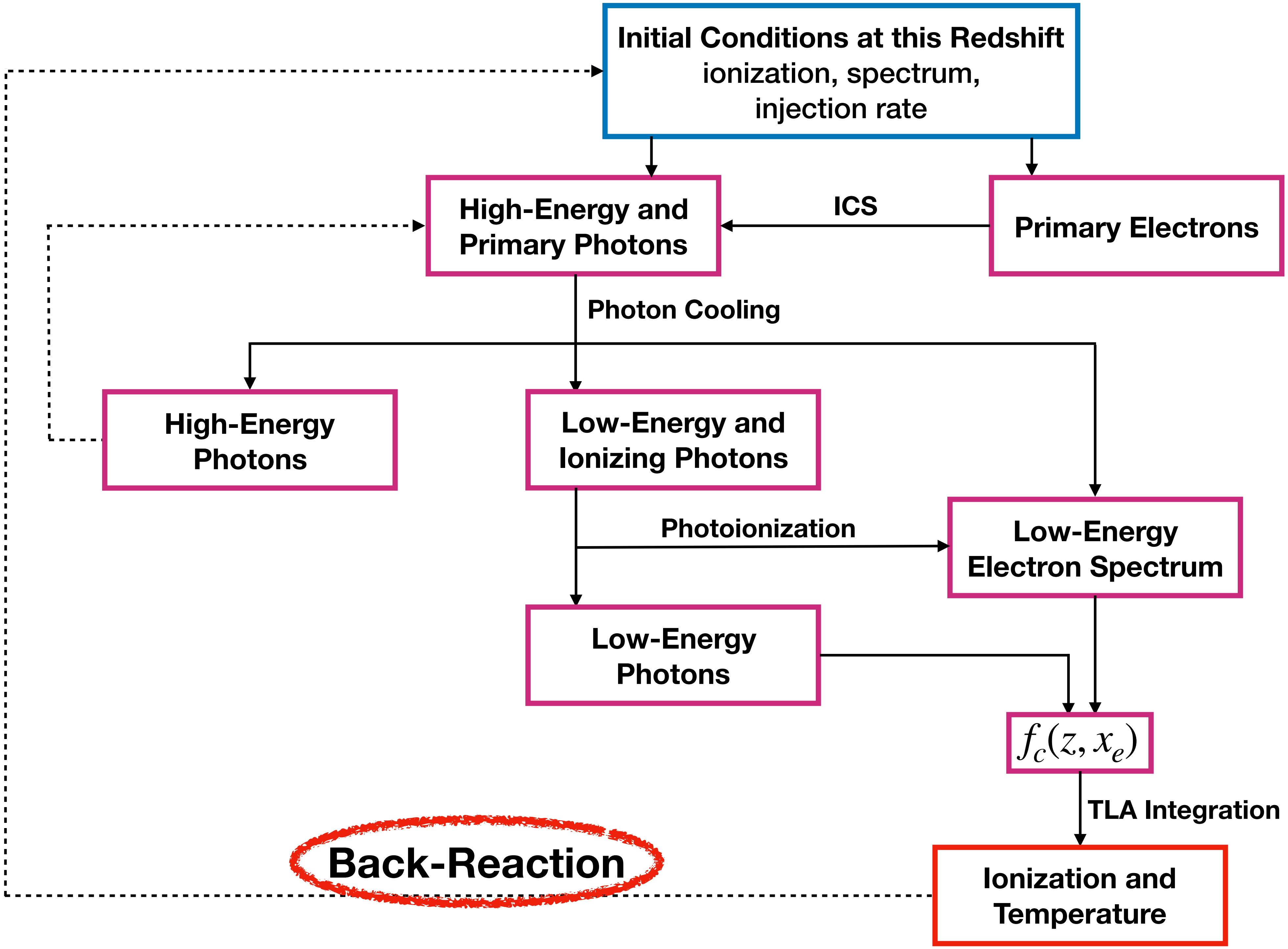
Code Structure



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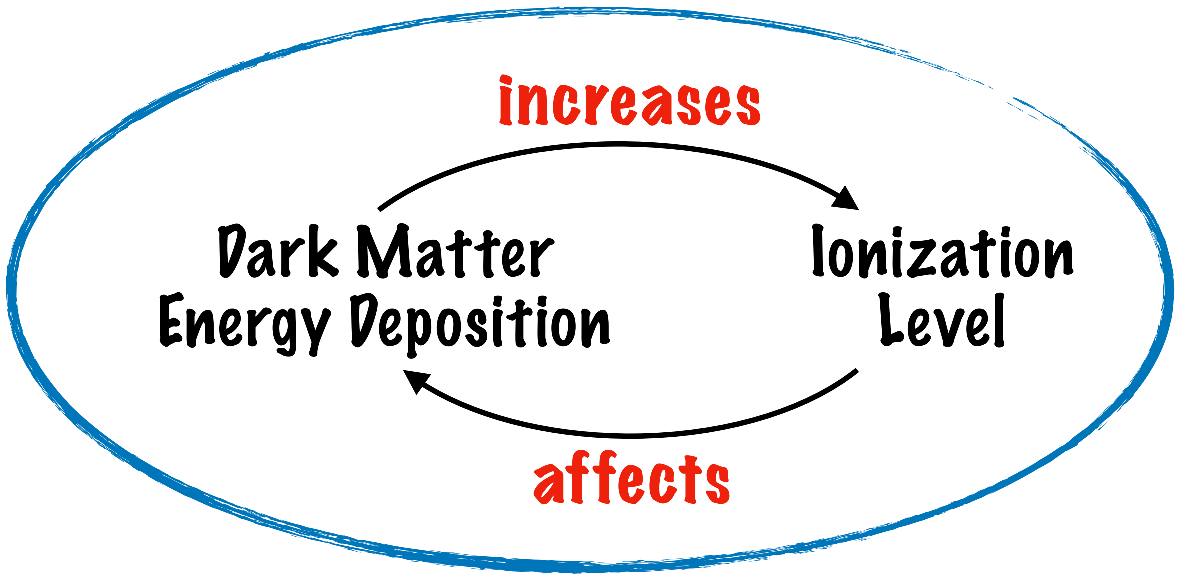
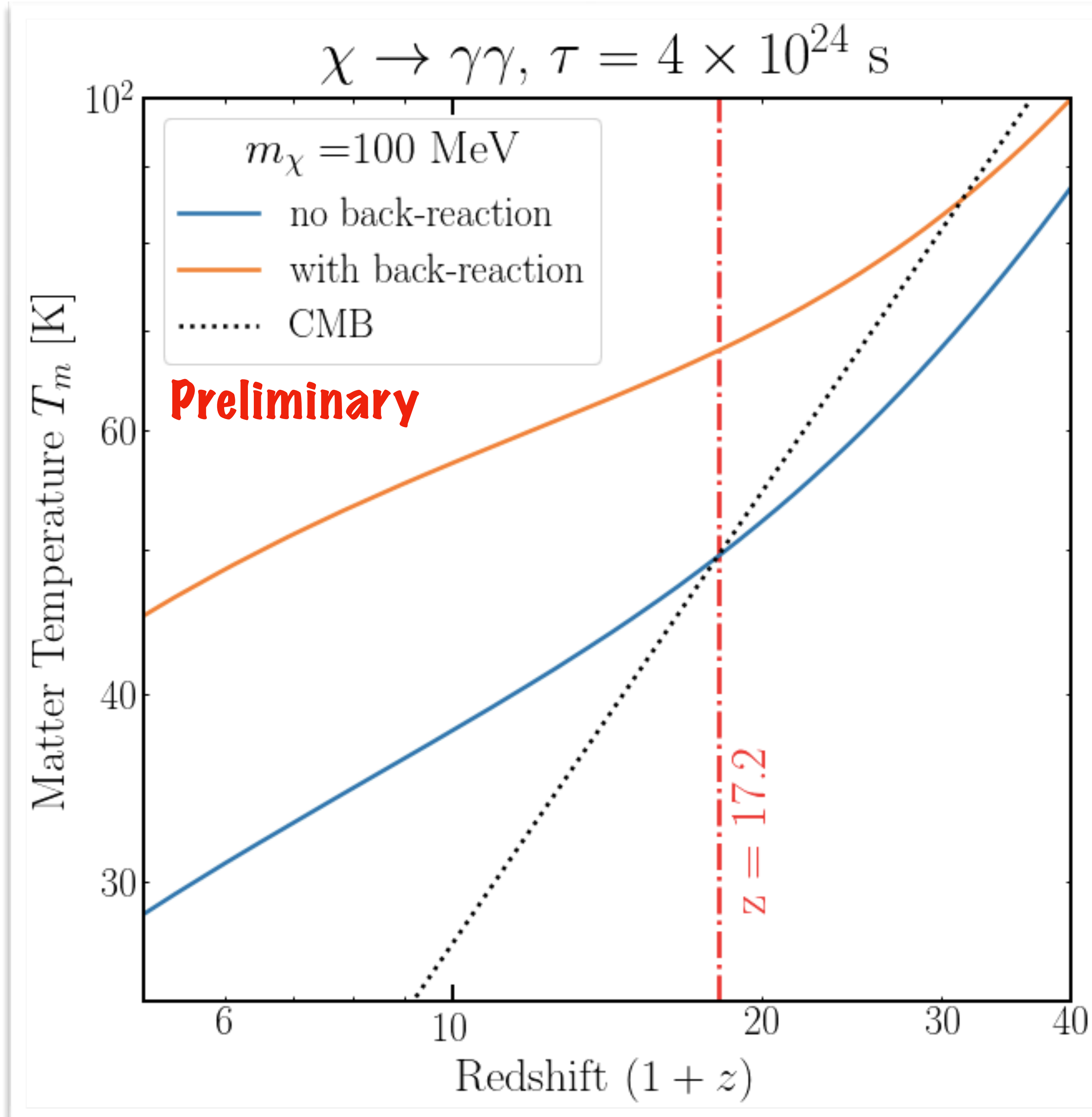
Back-Reaction





Back-reaction **increases heating**. Significant effect at **late times**, due to accumulation of this effect.

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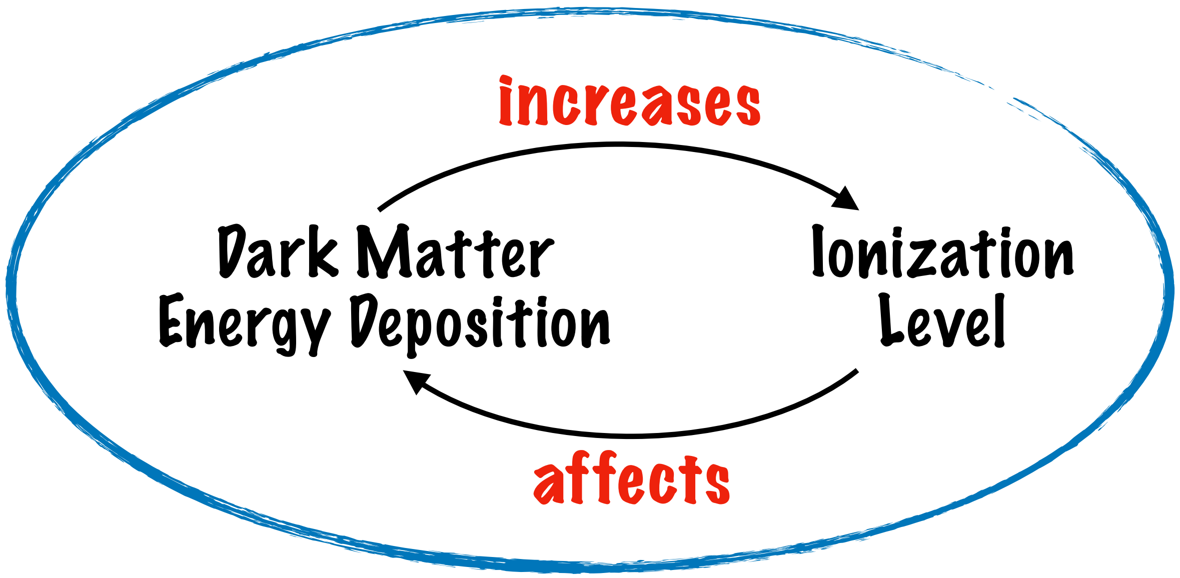
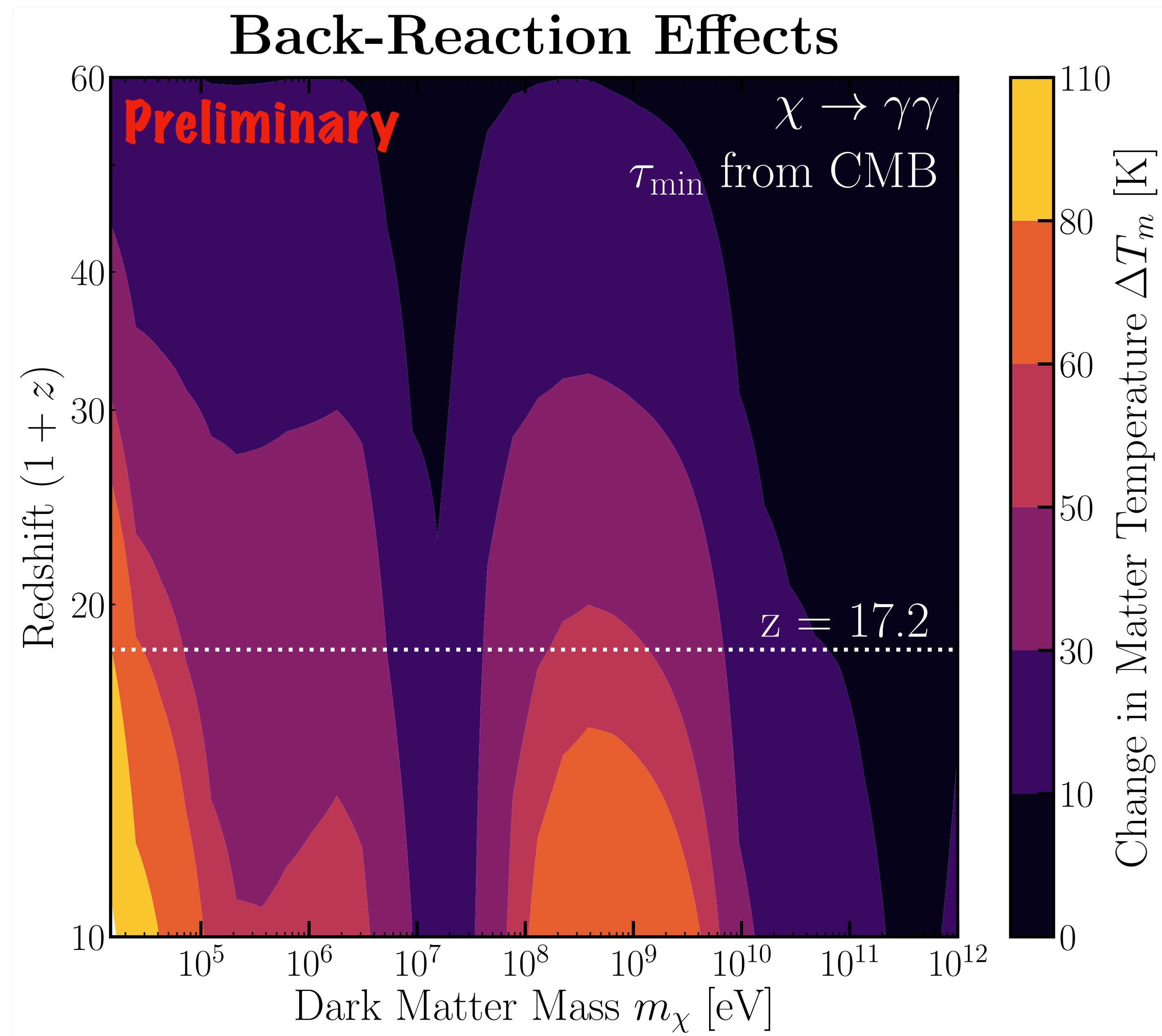
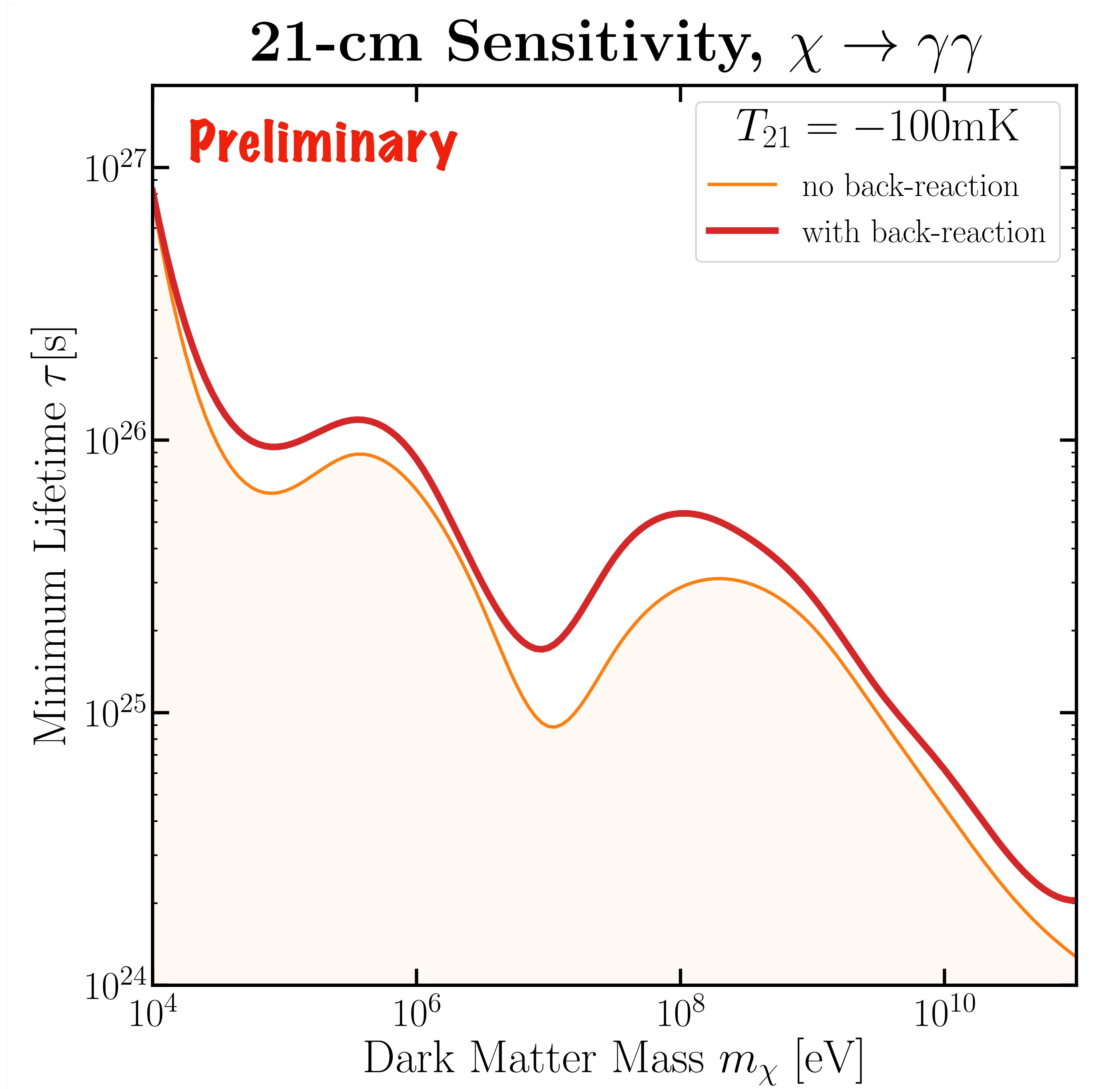
Back-Reaction





If we choose the minimum decay lifetime for $\chi \to \gamma\gamma$ allowable by CMB, **60 - 75% corrections** (~ **30–80 K**) across large mass range.

21-cm Sensitivity



21-cm sensitivity to $\chi \to \gamma\gamma$ increases by a factor of **2—3 with back-reaction.**

Conclusion

1. `DarkHistory`: a **public code** for calculating **thermal** and **ionization histories**.

2. Full treatment of **back-reaction**. Corrections at z ~ 20 of **60–75%** of the matter temperature. Critical for **21-cm constraints** on dark matter.

3. **Reionization** + **dark matter energy injection** can now be treated self-consistently.

Backup Slides