Radiative transfer of ionizing radiation through gas and dust: stellar source case

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Abstract

We present a new dust extension to the Monte Carlo radiative transfer code CRASH, which enables it to simulate the propagation of ionizing radiation through mixtures of gas and dust. The new code is applied to study the impact of dust absorption on idealized galactic H II regions and on small scale reionization. In general agreement with semianalytic predictions we find that H II regions are reduced in size by the presence of dust, while their inner temperature and ionization structure remain largely unaffected. In the small scale reionization simulation, dust hardens ionization fronts and delays the overlap of ionized bubbles. This effect is found to depend only weakly on the assumed abundance of dust in underdense regions. Grain charging is presented as a preview of future extensions focussing on the photo-electrons released by dust.

Implementation

CRASH [1; 5; 6] features:

- time dependent Monte Carlo radiative transfer scheme;
- ionization of hydrogen, helium and cosmologically abundant metals;
- point sources and background radiation;
- photon energies from 13.6 eV up to 10 keV;
- secondary ionization by high energy electrons;
- self consistent gas temperature computation;
- primary application in cosmic reionization.

The newly implemented **dust module**

- is dust model independent;
- supports an arbitrary number of dust species;
- tracks dust evolution per species in space and time;
- is easily extendable;
- at the moment accounts only for dust **absorption**.

Dust Model

For the time being, we adopt the **Silicate-Graphite-PAH dust model** [11; 8; 2-4] in CRASH:

- features two separate grain populations: carbon- and silicate-based respectively;
- grains are assumed to be spherical or Polycyclic Aromatic Hydrocarbons (PAHs);
- size distributions have simple functional form [11, eqs. (2)-(6)];
- it reproduces Milky Way dust extinction for different lines of sight.

From this we **expect dust absorption to be relevant at energies exceeding several 10^2 eV and when the gas is highly ionized.**

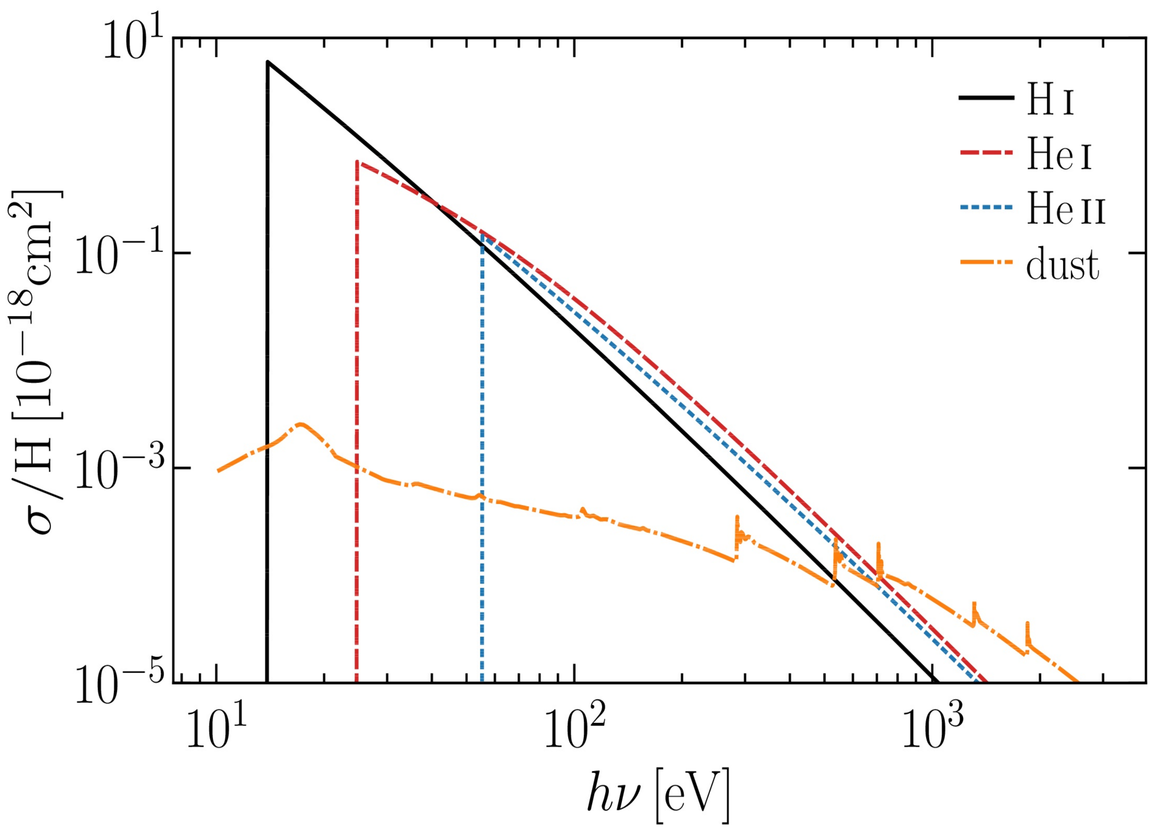

Fig. 1: Dust absorption cross section per H nucleus (dash-dotted orange) as function of photon energy for the $R_V = 3.1$ Silicate-Graphite-PAH dust mixture [11; 2-4] and ionization cross sections per H nucleus for neutral H (solid black), neutral He and singly ionized He (dashed red, dotted blue) [9].

Results

I Ideal Strömgren case:

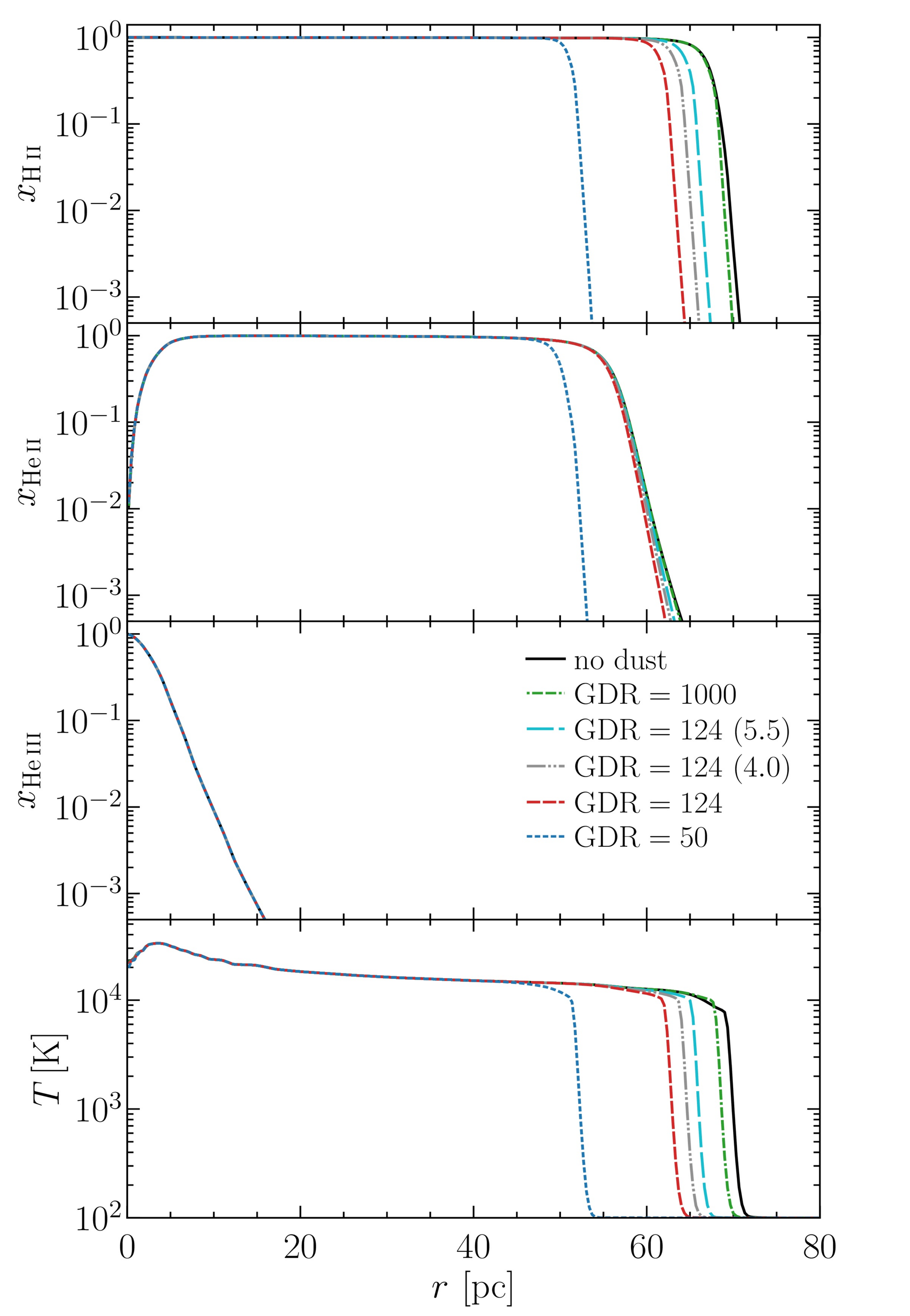

Fig. 2: Spherical averages (of, from top to bottom: H II, He II and He III fractions, and gas temperature) after 10^7 yr (equilibrium reached) for a Strömgren sphere as functions of distance from the stellar source. Different line styles correspond to different gas to dust mass ratios.

II Small cosmic web, for details see [7, Test 4]:

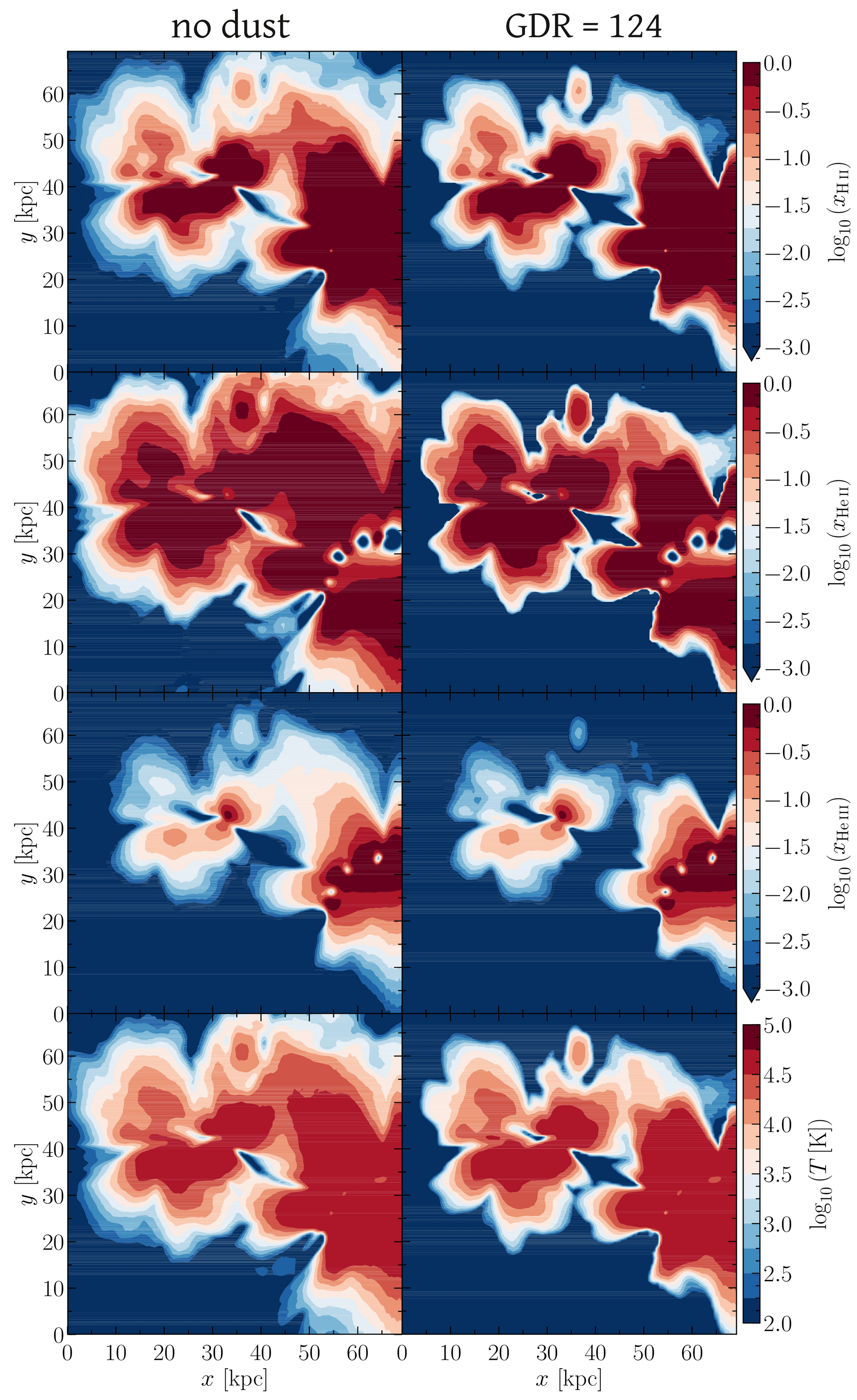

Fig. 3: Ionization and temperature structure of a small cosmic web (z~9) without dust (with a GDR of 124) on the left (right).

Grain charging implementation:

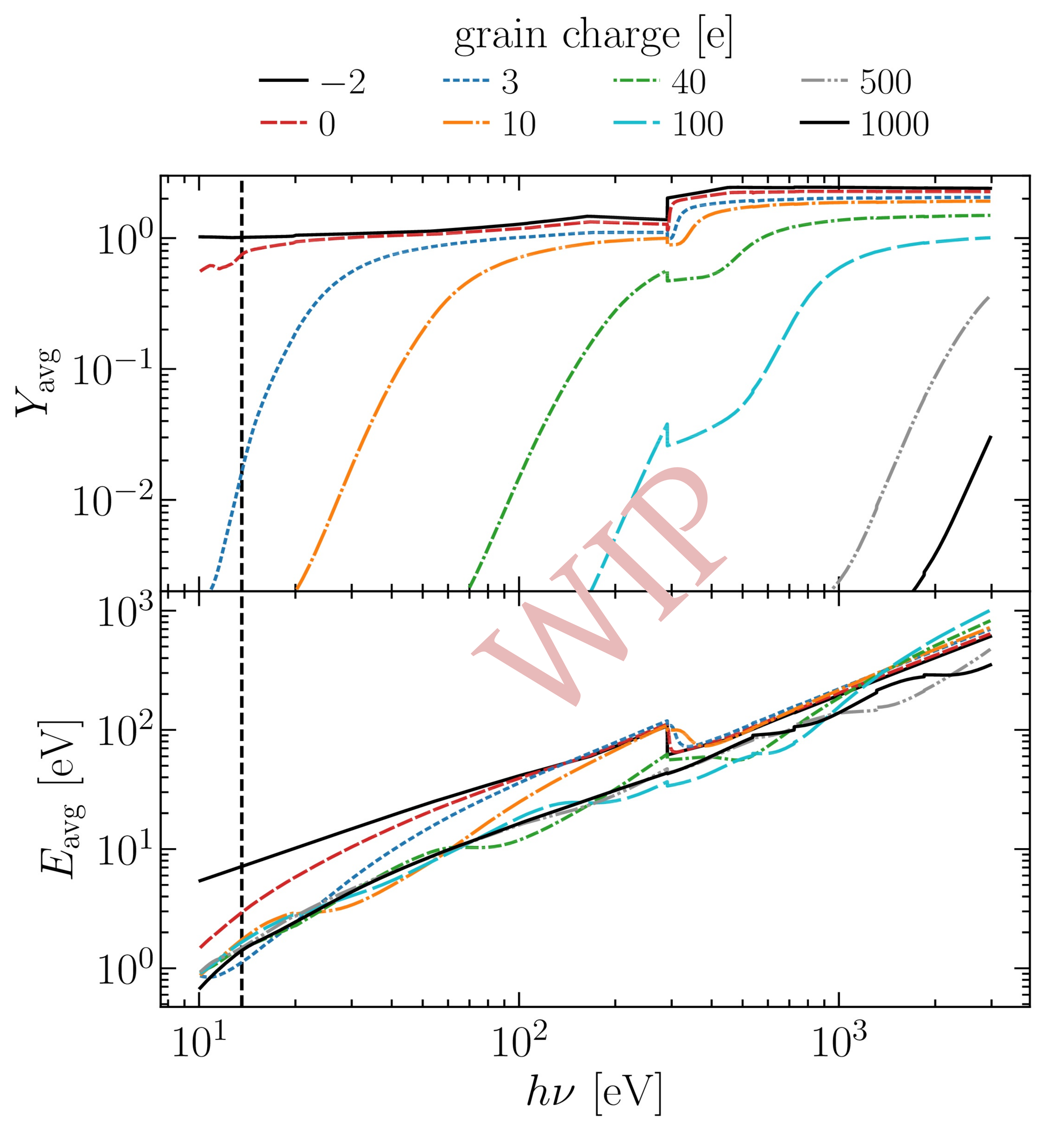

Fig. 4: Photo-electron yield (top) and average photo-electron energy (bottom) as functions of incident photon energy in the Silicate-Graphite-PAH R_V=3.1 model population average. Computed following [10; 12].

CONCLUSIONS I:

- Agreement with analytic predictions in wide range of conditions.
- Deviations at large optical depths.
- Dust absorption affects only profile fronts.

CONCLUSIONS II:

- In small scale cosmic web, absorption by dust primarily sharpens gas ionization fronts, since it is relatively more efficient at high photon energies.
- Stay tuned for more!

TAKE AWAY:

- Implementation of grain charging soon to be completed.
- Will allow studying interplay of dust evolution and gas ionization/temperature.
- Stay tuned for more!

Future Steps

We expect to complete the implementation of grain charging following [10, 12] soon, which will allow us to study the impact of gas photo-heating by dust self consistently and in arbitrary geometries.

In parallel we are working on galaxy evolution simulations with a custom version of GADGET that follows dust production, distribution and destruction. These results will allow us to study the impact of dust on reionization on different spatial scales in post-processing.

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