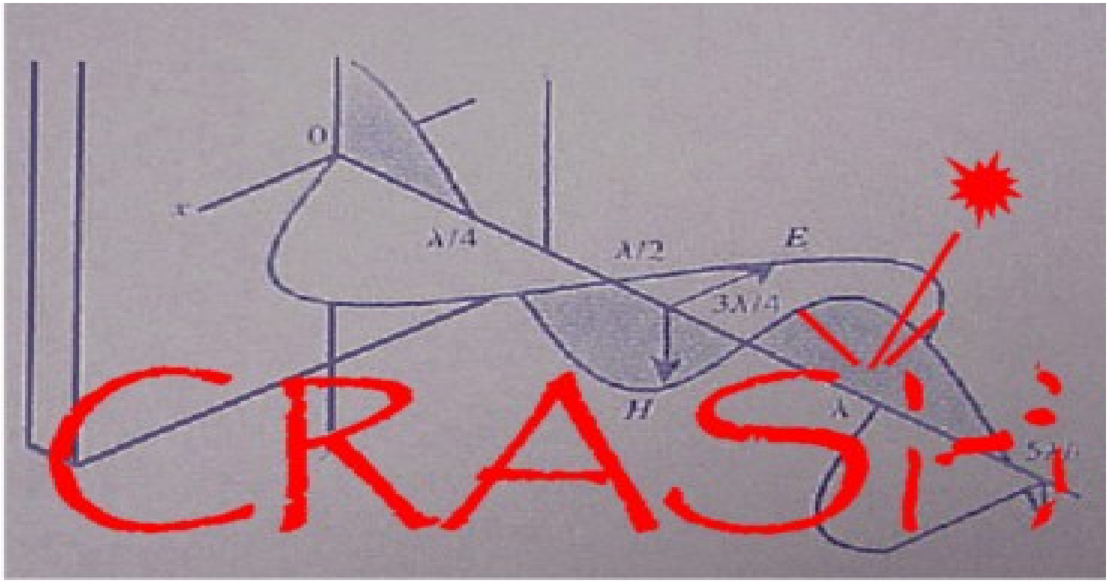
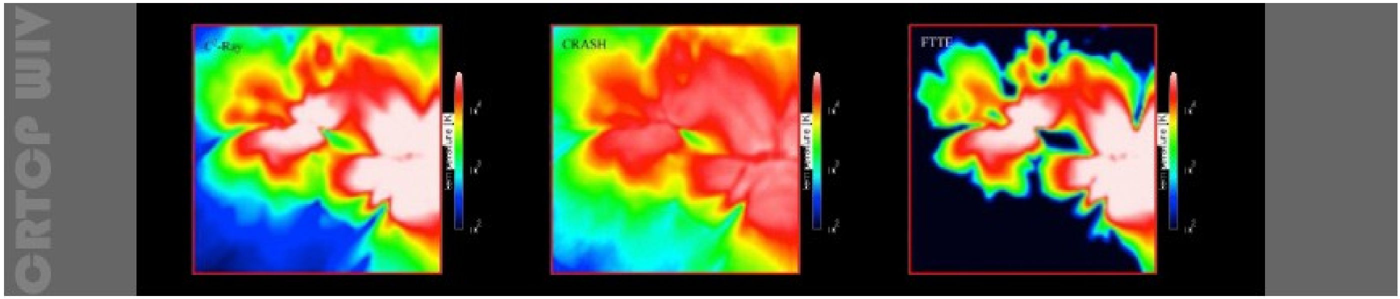


Radiative transfer through metals in CRASH3

Luca Graziani
B. Ciardi - A. Maselli

Max Planck Institute
for Astrophysics

- Cosmological RT with CRASH
- Metals in the IGM
- RT through metals



Cosmological Radiative Transfer Comparison Project Workshop IV

The University of Texas at Austin
December 12-14, 2012

C.R.A.S.H.

Cosmological RAdiative transfer Scheme for Hydrodynamics

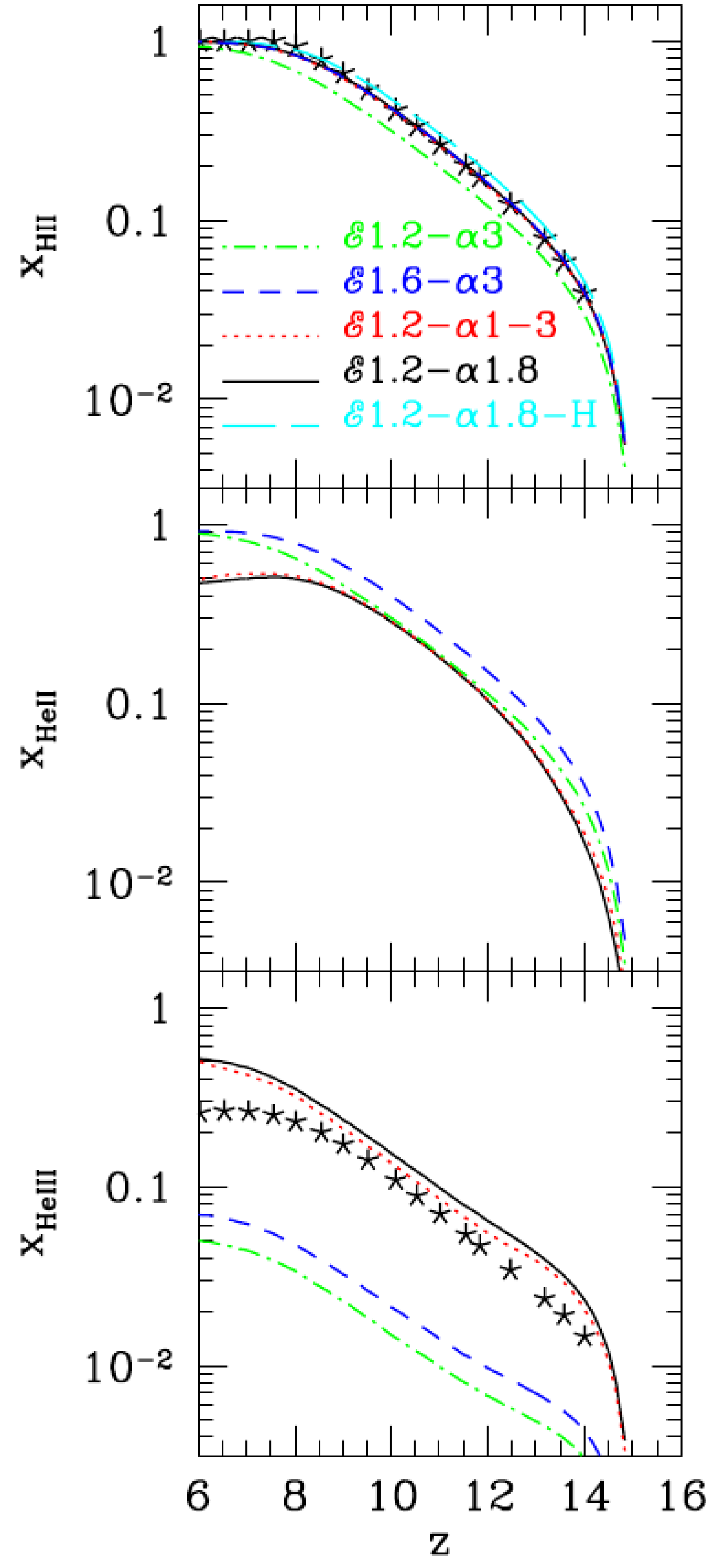
- RT code based on MC + Ray tracing.
- Describes ***3D*** RT cosmological scenarios.
- Solves ***time dependent*** RT on cosmological scales → Cosmic Reionisation.
- Implements ***detailed H,He physics + metal ions (in pipeline with other codes)*** .

B. Ciardi et al.,2001;A. Maselli et al., 2003, 2005, 2009; A. Partl, et al. 2011;

L. Graziani et al. 2012

C.R.A.S.H. Outputs

- Ionisation fractions of H, He, atomic metals.
- Gas temperature.
- Radiation intensity.
- Spectral shape on the same set of frequency bins describing the sources.
- Ionisation and heating rates.
- Reionisation history: x(z) ,T(z)



CRASH tested with CLOUDY

Maselli et al., 2003,2009. Partl et al. 2011 / Ferland, G. et al. 1999

- **CRASH: cosmological RT code**: Full 3D RT

1) **Photo-ionization+Coll. ionisation of H, He.**

2) **Arbitrary density fields and unlimited source types.**

3) **Time evolution of ionisation fronts**

4) **X-rays (soft, up to ~5keV) + Lyα photons → CRASH4**

- **Cloudy**

1) **Complex Chemistry: all the metals of the solar composition.**

2) **Limited to a 1D geometry + Background.**

3) **Full spectral range.**

4) **Very fast** ~50 secs for a single simplified run with H, He, C, O, Si and 1 source.

5) **Limited time evolution**

C.R.A.S.H.

Cosmological Applications I

- Radiative feedback from first stars

  B. Ciardi, A. Ferrara, S. Marri, and G. Raimondo, 2001 MNRAS, 324, 381.

- Cosmic reionisation of hydrogen

  B. Ciardi, A. Ferrara & S.D.M White, 2003, MNRAS, 344, L7-L11.

  B. Ciardi, F. Stoehr & S.D.M White, 2003, MNRAS, 343, 1101-1109.

- Effects of intergalactic helium on hydrogen reionisation

  B. Ciardi, J.S. Bolton, A. Maselli, L. Graziani, 2011, MNRAS, 344, L7-L11.

- 21-cm line with LOFAR

  B. Ciardi, P. Labropoulos, A. Maselli, R. Thomas, S. Zaroubi,

  L. Graziani, et al., 2012, MNRAS in press.

C.R.A.S.H.

Cosmological Applications II

- QSO regions

A. Maselli, A. Ferrara, S. Gallerani, 2009, MNRAS, 395, 1925

- Cosmic UV background fluctuations

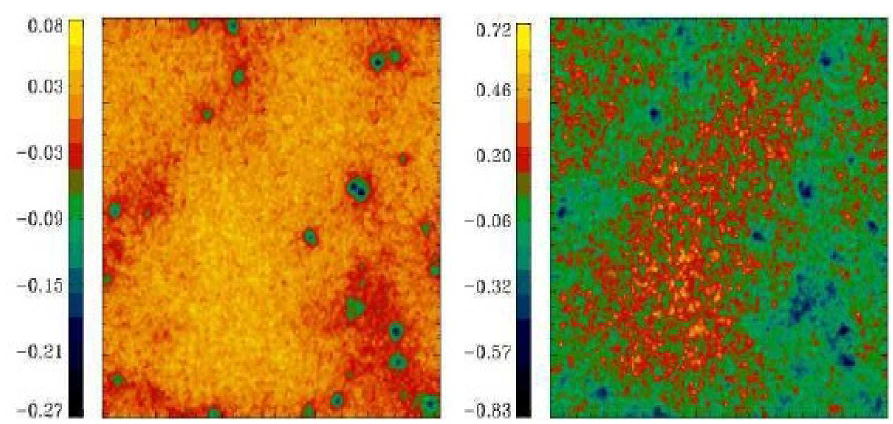
A. Maselli, A. Ferrara, 2005, MNRAS, 364, 1429-1440.

L. Graziani, B. Ciardi, A. Maselli, K.Dolag 2012, in prep.

RT through cosmic web induces fluctuations in the UVB

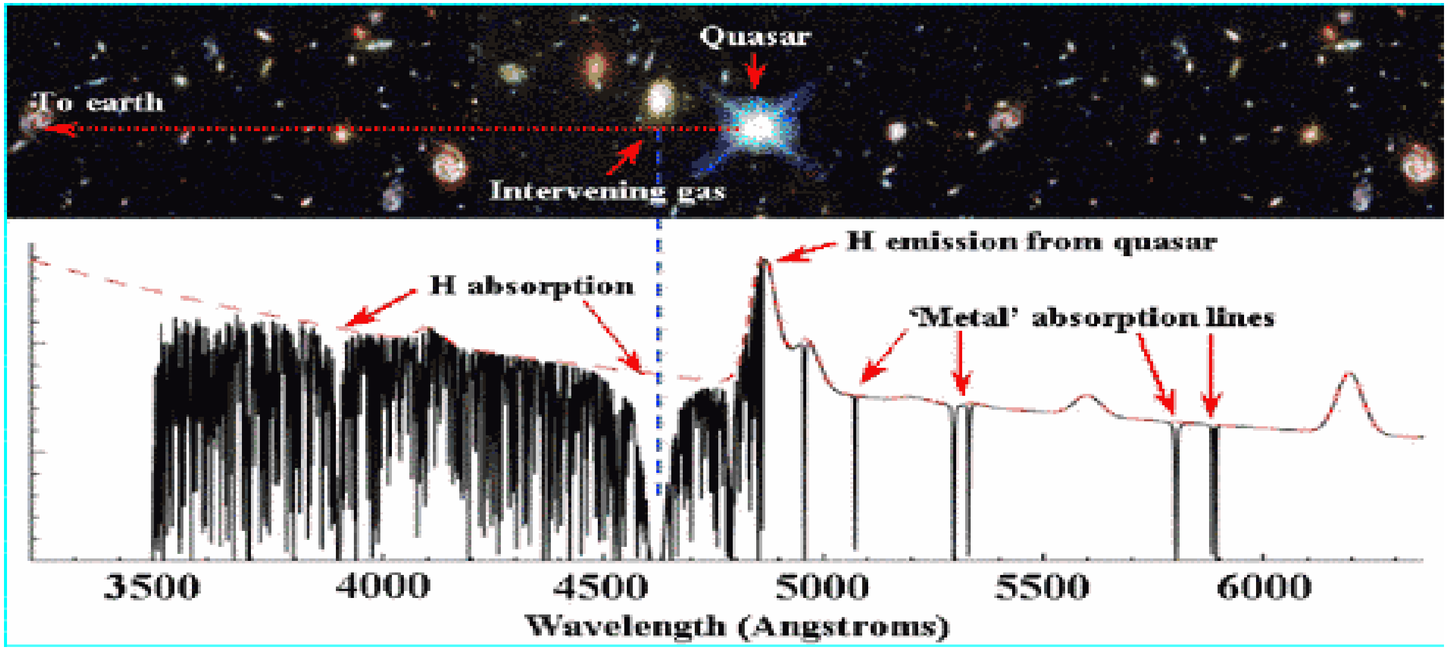
1) **Metals in the IGM can provide more constraints on the UVB spectral shape**

2) **Need to evaluate metal ions self-consistently with the RT.**



Spatial Fluctuations of HI (left) and HeII (right) Photoionization rates in a slice across the RT simulation of physical depth 27 Kpc.

Metal **ions** are observed in the spectra of QSOs(OVI CIV CIII SiIII CII SiII FeII MgII)

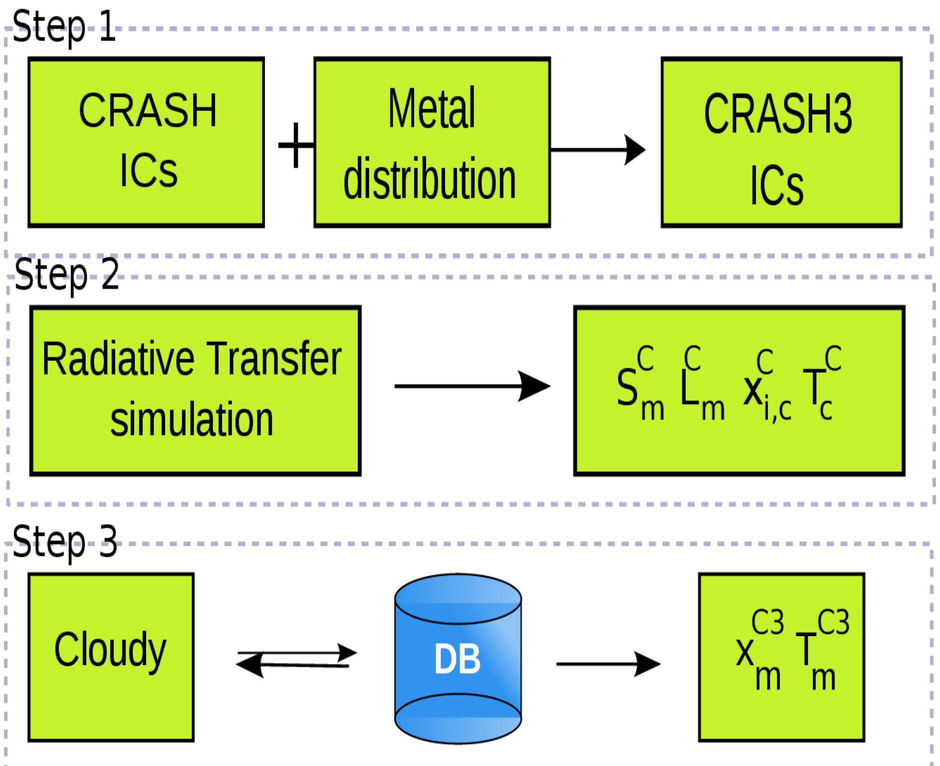


- **Metal atoms highly ionized**: Why? What radiation field at fixed z?

Ionisation model is needed: photo/coll ionisation

If photo, assumptions needed: radiation intensity and spectral shape

CRASH3: CRASH + Cloudy



STEP1: Where are the metals?
CRASH ICs + metal enriched subdomain (m-cells).

STEP2: RT in the full domain (c-cells).
Extracts spectra and luminosities in m-cell ($S_{m,}$ L_m)

STEP3: Compute Metal ions.
Uses (S_m,L_m) to derive metal ions in m-cell.

QUESTIONS: 1. x_{HII}, x_{HeII}, x_{HeIII} must remain consistent between steps.

2. Sensitivity of the method to fluctuations induced by the RT effects (cosmic web and source properties)?

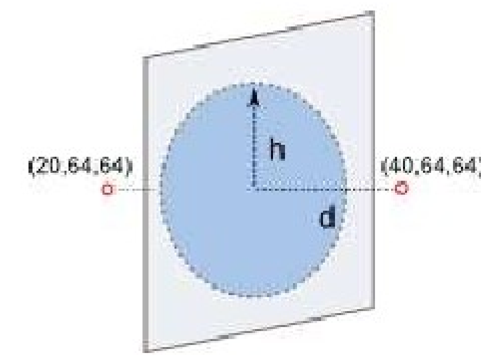
CRASH3 TESTS

TEST 1: Stroemgren sphere in uniform medium enriched by metals.

→ Evaluates the metal ionisation fractions inside the HII region, as function of the distance from the central star.

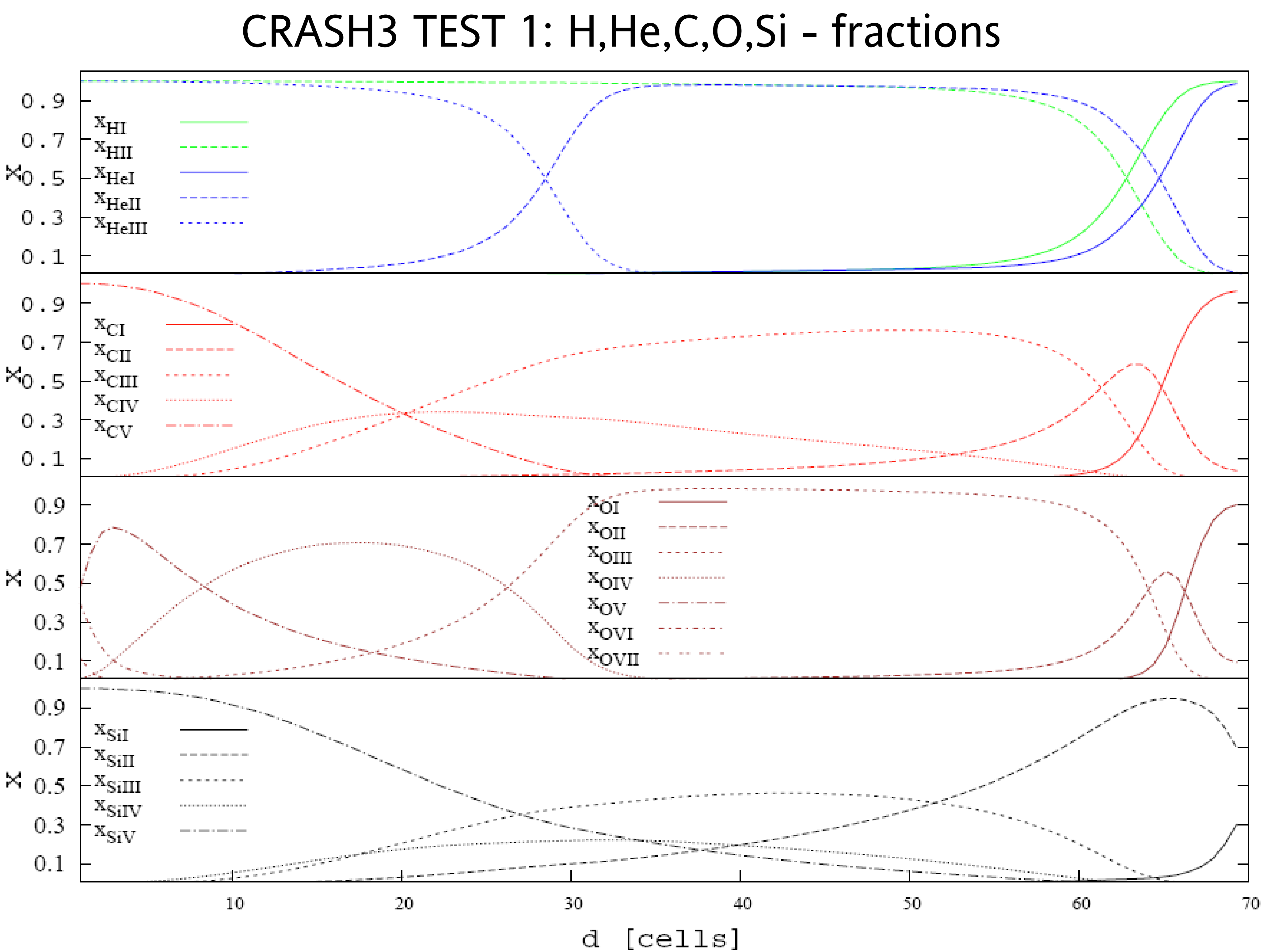
TEST 2: Overlap of two Stroemgren spheres.

→ By varying the source properties we test changes ionisation fractions.



TEST 3: Cosmic web with many sources as in TEST4 of the cosmological radiative transfer comparison project (Iliev et al. 2006).

→ Realistic RT scenario: cosmic web + many sources

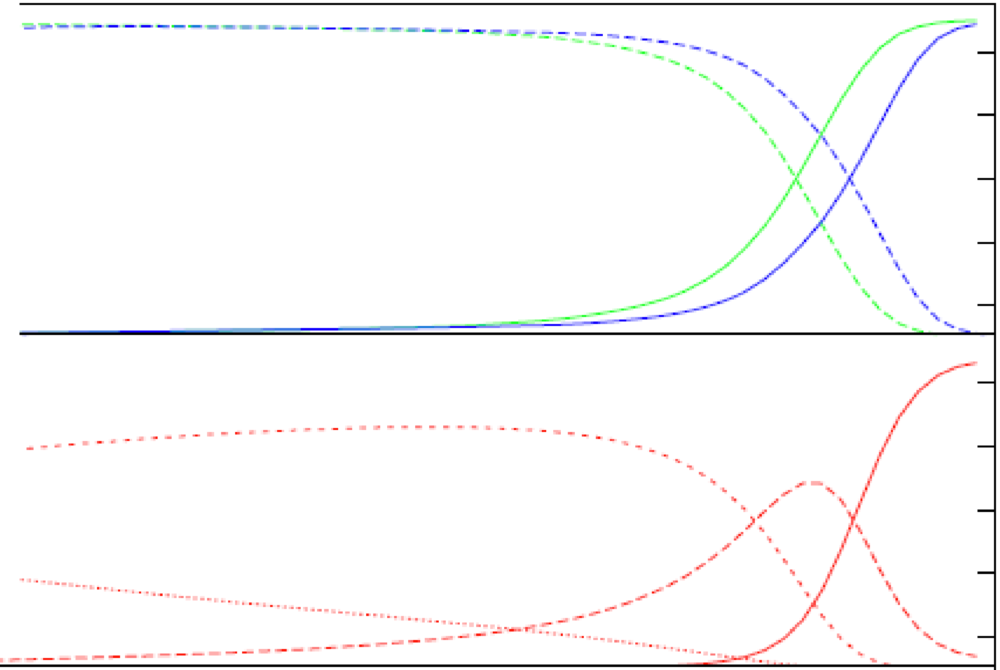


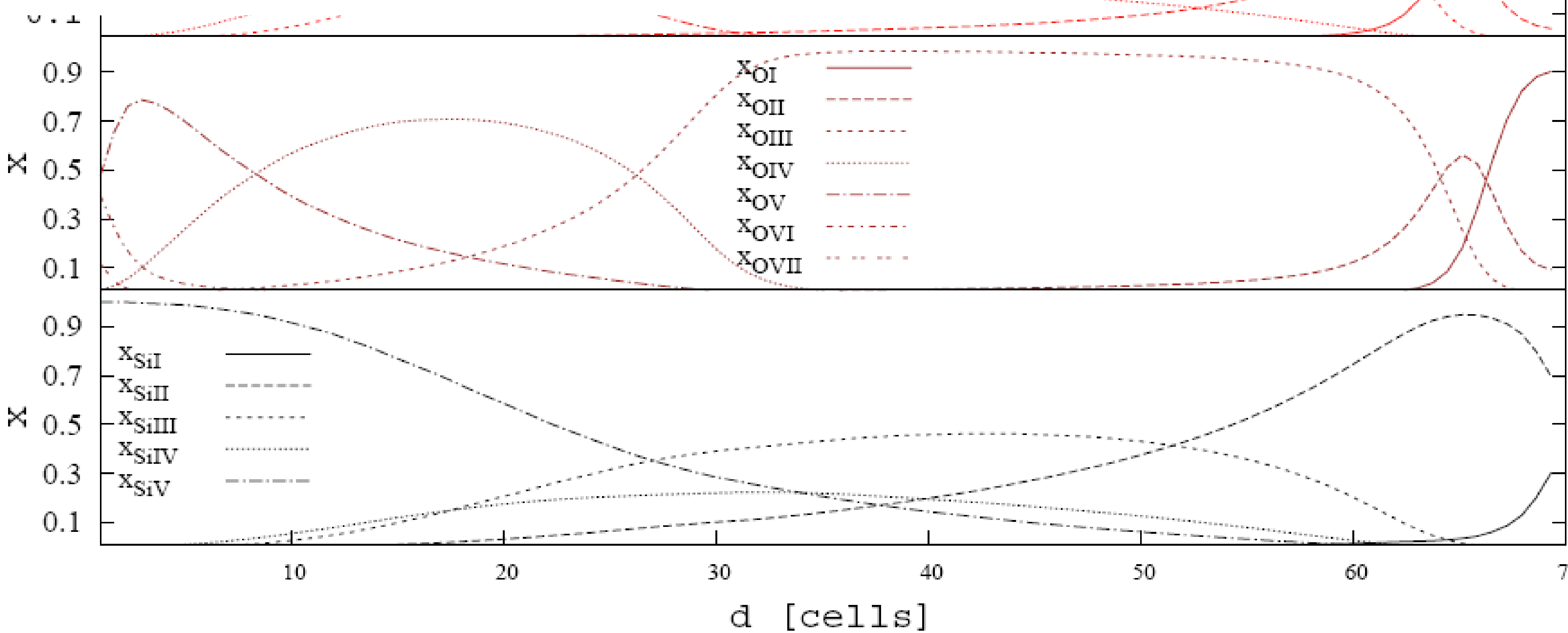
CRASH3 TEST 1: H,He,C,O,Si - fractions
x_{HI}
x_{HII}
x_{HeI}
x_{HeII}
x_{HeIII}
x_{CI}
x_{CII}
x_{CIII}
x_{CIV}
x_{CV}
x_{OI}
x_{OII}
x_{OIII}
x_{OIV}
x_{OV}
x_{OVI}
x_{OVII}
x_{SiI}
x_{SiII}
x_{SiIII}
x_{SiIV}
x_{SiV}
x
0.1
0.3
0.5
0.7
0.9
10
20
30
40
50
60
70
d [cells]

CRASH3 TEST 1: H,He,C,O,Si - fractions

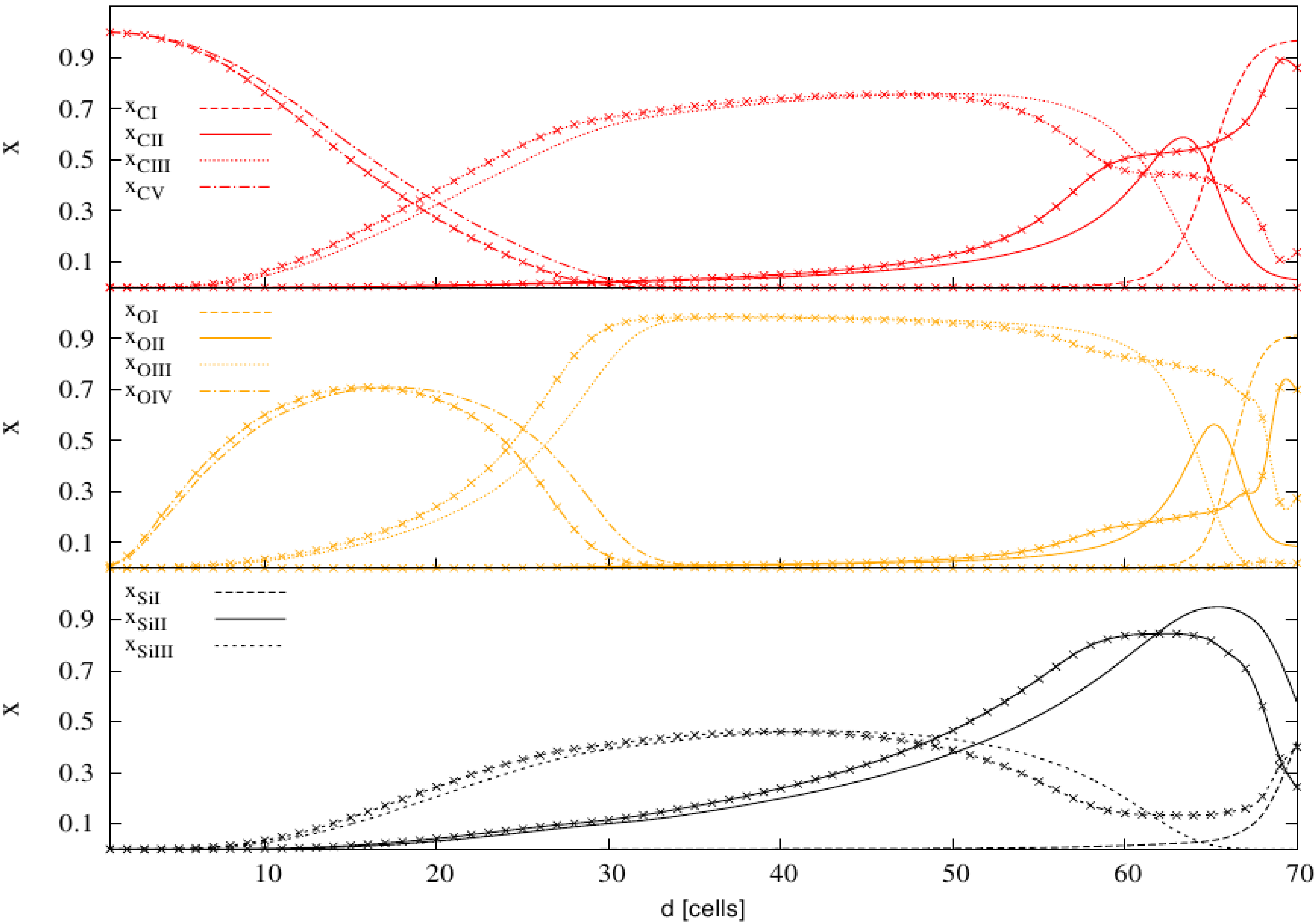
E_{ion} [eV]	H	He	C	O	Si
E_{xI}	13.598	24.587	11.260	13.618	8.152
E_{xII}		54.400	24.383	35.118	16.346
E_{xIII}			47.888	54.936	33.493
E_{xIV}			64.494	77.414	45.142
E_{xV}			392.090	113.900	166.770
E_{xVI}			489.997	138.121	205.060

Table 1. Ionisation potentials for H, He, C, O and Si up to the ionisation level VI as used in `Cloudy`.

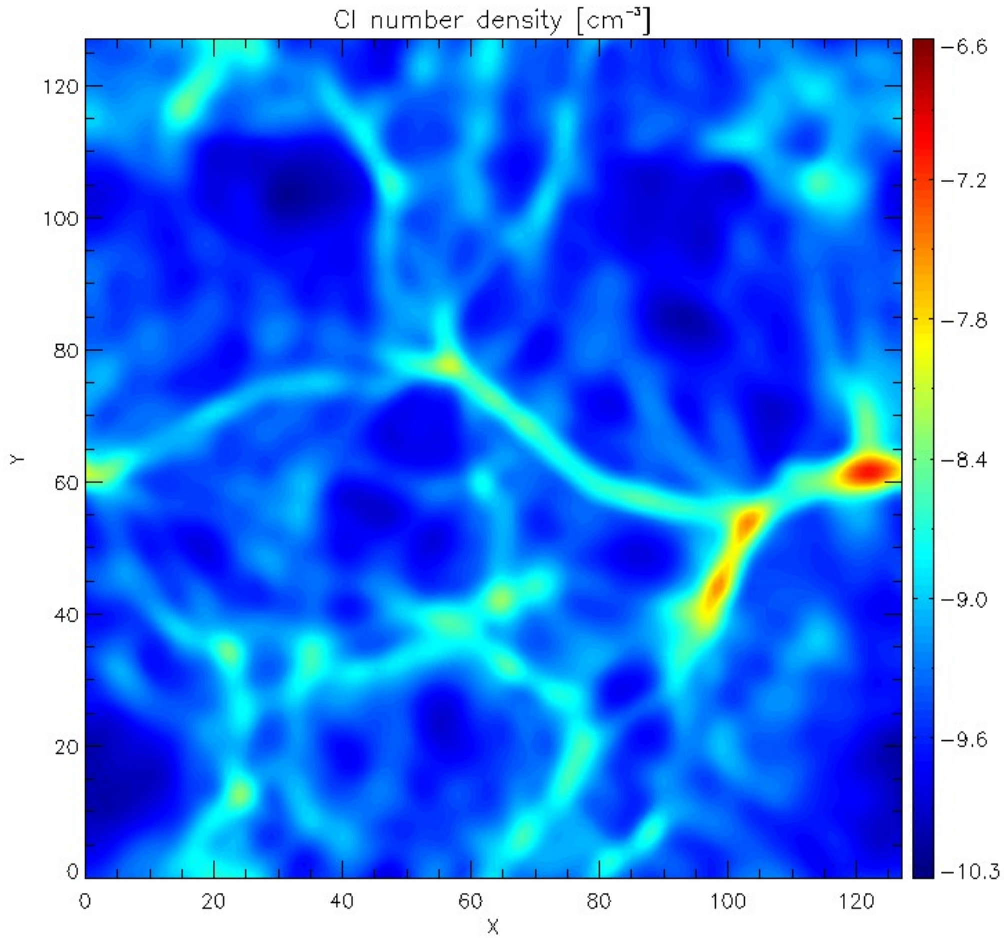




CRASH3 TEST 1: H,He,C,O,Si – fractions- ext. spectrum



CRASH3 TEST 3: 3D neutral Maps (ICs)



CI,OI,SiI created as separate maps.

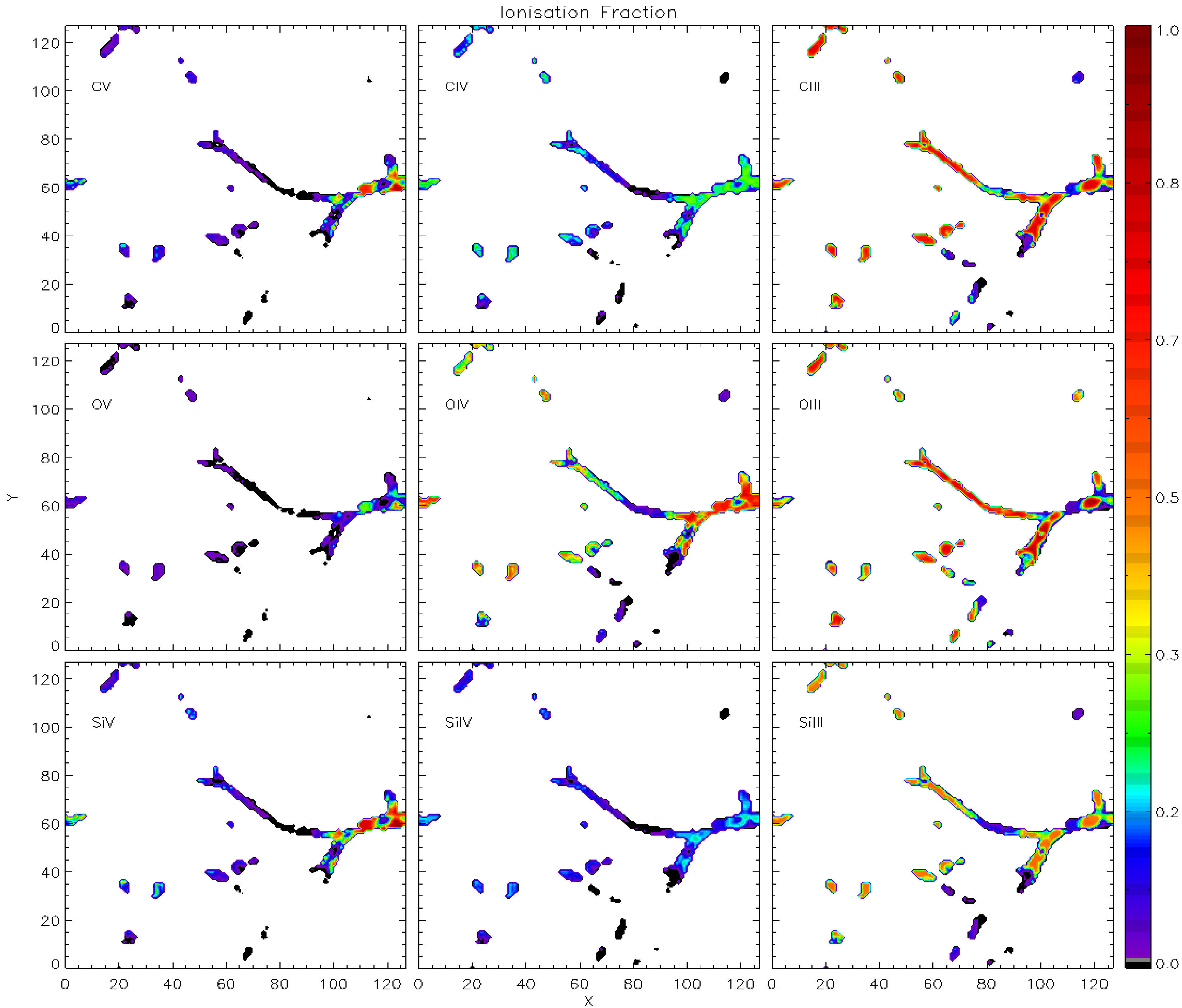
→ They provide the distribution of neutral metals in space.

Enriched regions can be obtained tracing the gas over-densities.
(e.g. Schaye 2003)

OR

Obtained self-consistently by Hydro-simulations accounting for metal production and spreading.
(e.g. Oppenheimer 2006, Maio 2010)

CRASH3 TEST 3: 3D ionised Maps



CRASH3
Conclusions and future steps

- CRASH3 includes ionisation states of C,O,Si evaluated self-consistently with the RT effects.

- Tested in simplified configurations and in more realistic RT scenarios involving point sources and UVB.

- Metal ions sensitive to small variations of the source properties and RT effects.

- The results of a first application of CRASH3 to constrain the UVB shape by using CIV /SiIV at the epoch of Helium Re-ionisation, will be available soon.