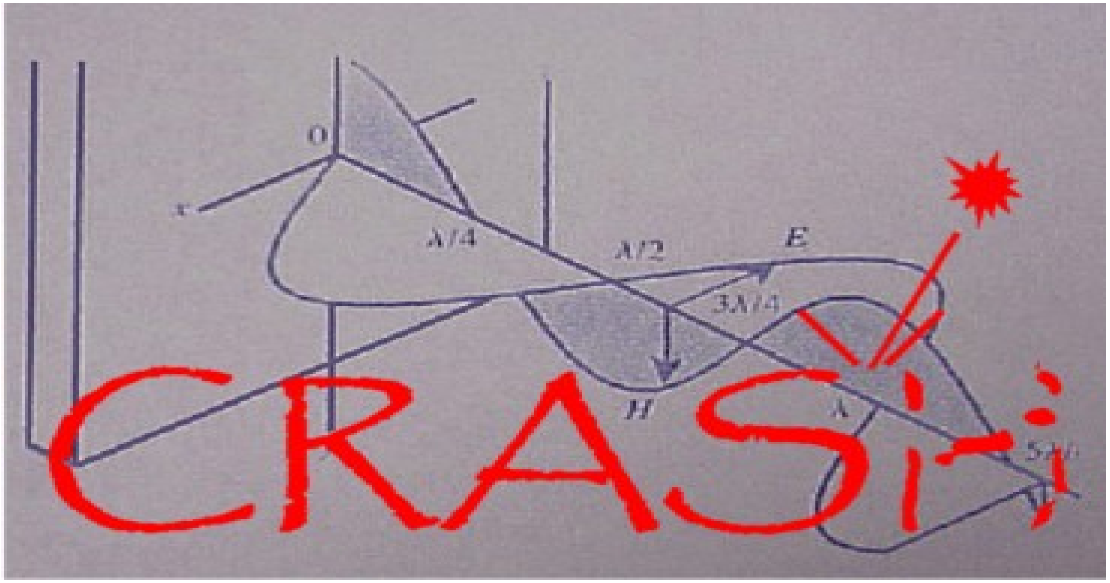


Cosmological radiative transfer through metals with CRASH

Luca Graziani
A. Maselli – B. Ciardi

Max Planck Institute
for Astrophysics

- CRASH software overview
- Current status
- MetalCRASH
- Some test with metals/ A first application
-

C.R.A.S.H.

Cosmological RAdiative transfer Scheme for Hydrodynamics

- ***Models the 3D*** RT in a cosmological context
- Implements ***detailed*** description of the ***H,He* microphysics** .

Advantages

- **Flexible:** describes realistic configurations
- **Accurate:** reproduces detailed radiative transfer effects
- **Additional physics** already **implemented** (LyAlpha, XRays)

Drawbacks

- **Problematic coupling with the gas dynamics** (reionisation still in post-processing)
- **Monte Carlo slow convergence** / Performance ~~**inefficient implementation**~~

The metal enrichment scenario

- Metal ions are observed in the spectra of QSOs
- Statistical detection of OVI in low density regions

IGM is metal polluted
we detect only few ions

- **Why metals are present in the IGM and not just in galaxies**?
- Galactic winds / Mixing
- Pollution topology / Pollution redshift (z-) evolution
- Metal atoms highly ionized: Why? What radiation field at various z?

Ionisation model is needed: photo/coll ionisation, chem. env.

If photo, assumptions needed: radiation field Intensity and Shape

Photoionisation codes CRASH vs. CLOUDY

Maselli et al., 2003 / Ferland, G. 1999, Hazy I Guide

- Cosmological RT codes (CRASH): Full RT

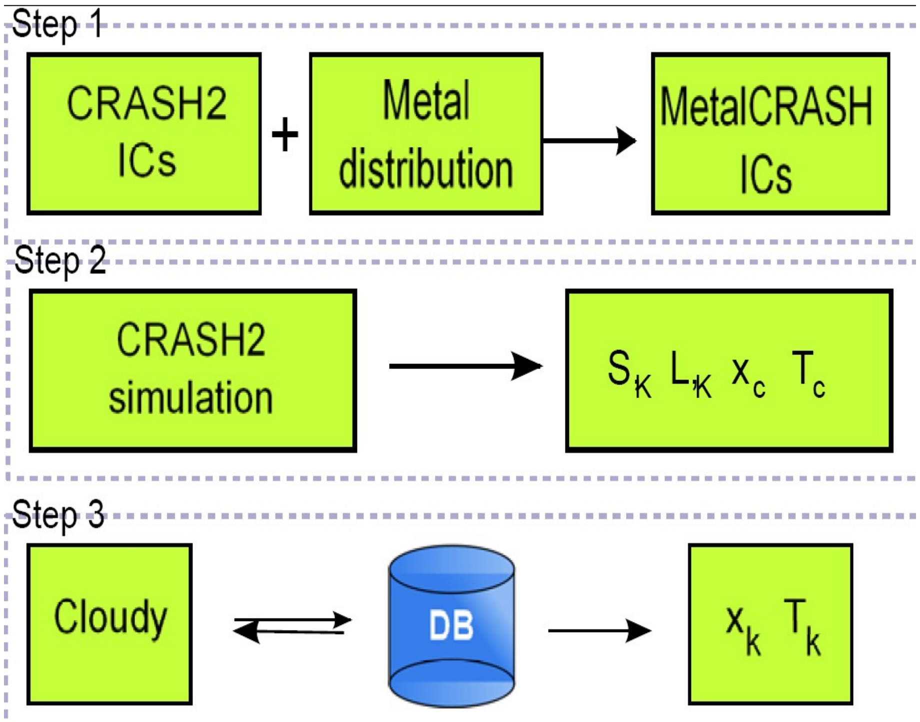
1) **Photoionization model is limited to H, He** micro-physics.
2) The **number of sources is unlimited**... if you can wait .. months!!
3) **Arbitrary density fields**

- Photoionization codes (Cloudy): Escape Probability/ On the spot

1) ***Complex Chemistry:* all the metals of the solar composition**. Includes a **self consistent treatment of the ions**.
2) Limited to a 1D illumination + Background.
3) **Very fast** ~50 secs for a single simplified run with H, He, C, O, Si and 1 source.

Extend the CRASH RT model to calculate **metal ionization fractions by using Cloudy**

MetalCRASH pipeline



IDEA: Integrate CRASH and Cloudy in a single, flexible pipeline.

STEP1. Extend CRASH ICs with metal distribution in space.

STEP2. Extract spectra per cell with a CRASH simulation

STEP3. Use a large DB of pre-calculated cases with Cloudy or integrate it with new spectra to derive metal ions.

PROBLEMS: 1. CRASH / Cloudy convergence for H,He ion. fractions.

2. Computationally intensive 10^5 computations per single redshift → we need a parallel asynchronous pipeline.

3. What is the sensitivity of the method? Can we see fluctuations due to the medium and the sources as with CRASH?

MetalCRASH TEST 1: single HII region

SETUP:

First Run: single point source with assigned Luminosity L [phot/sec] embedded in a uniform medium. Box: 6.6 Kpc, grid: 128^3
Second Run: First Run + metal pollution with $Z \sim 10^{-2} Z_{sol}$.

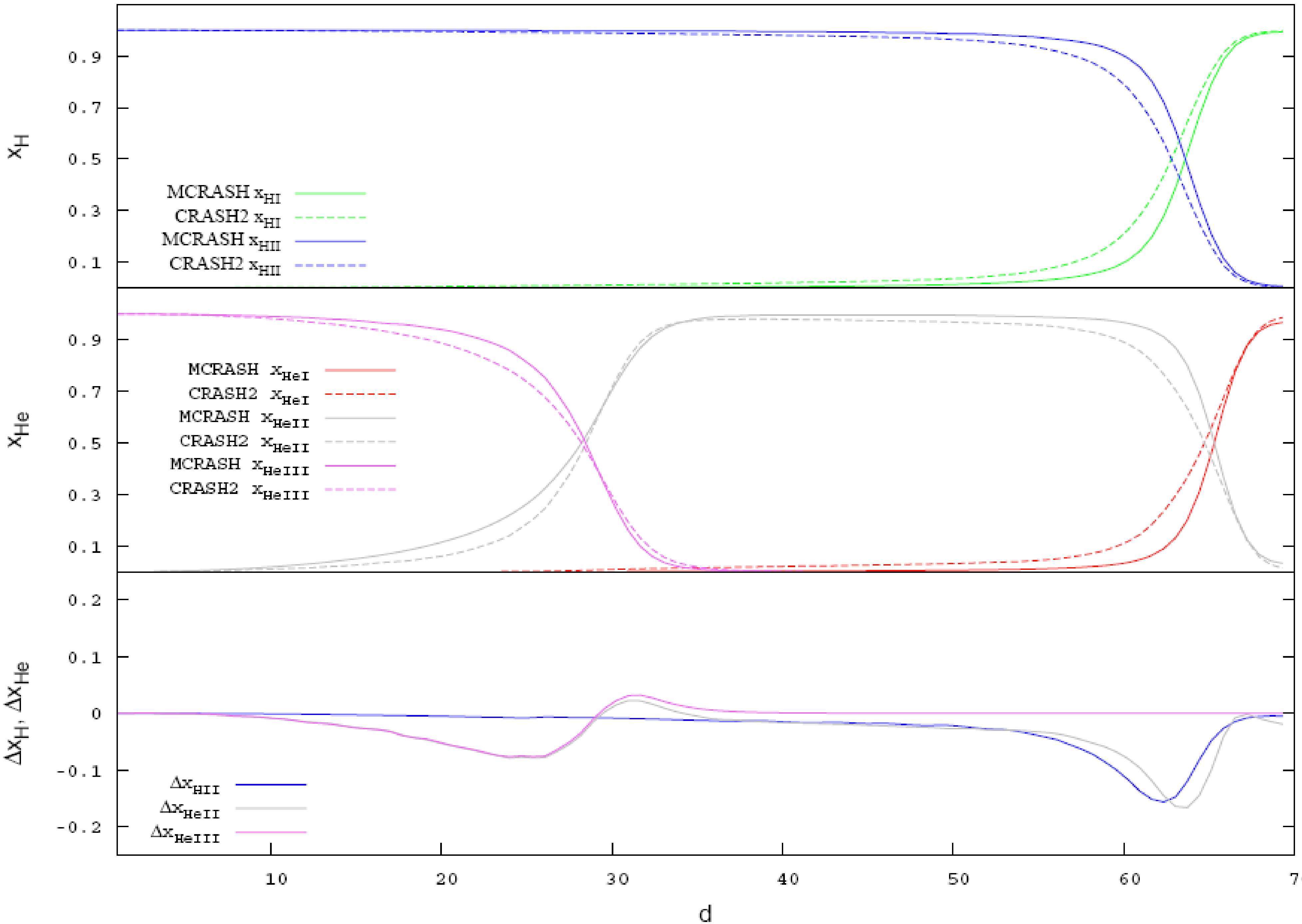
We expect:

1)To test the convergence between CRASH and MetalCRASH in xHII, xHeII, xHeIII, T.

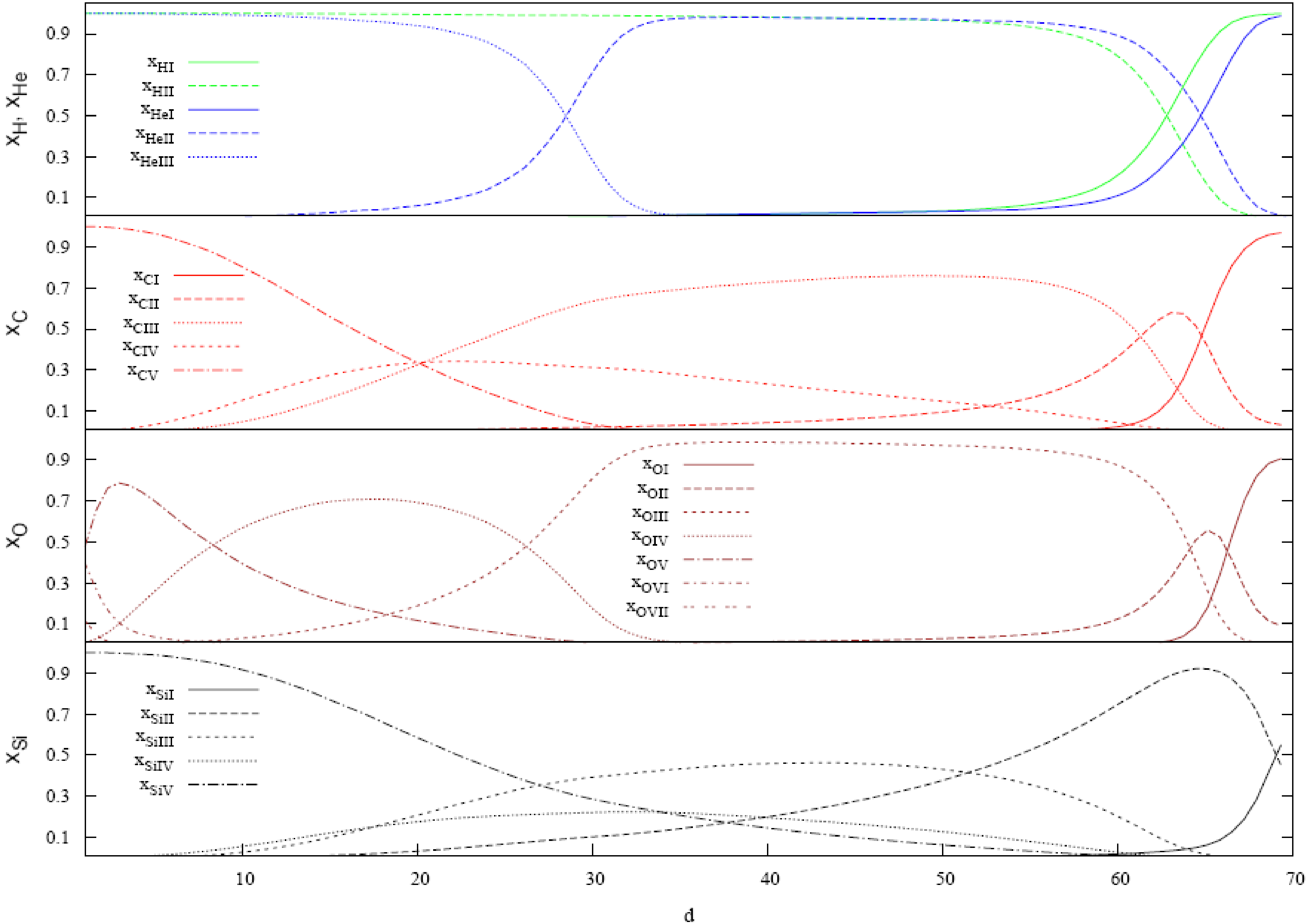
2)To derive the C, O, Si ionization states

3)To follow the time evolution of the metals.
4)
5)To study the gas cooling function and derive the metal cooling effects

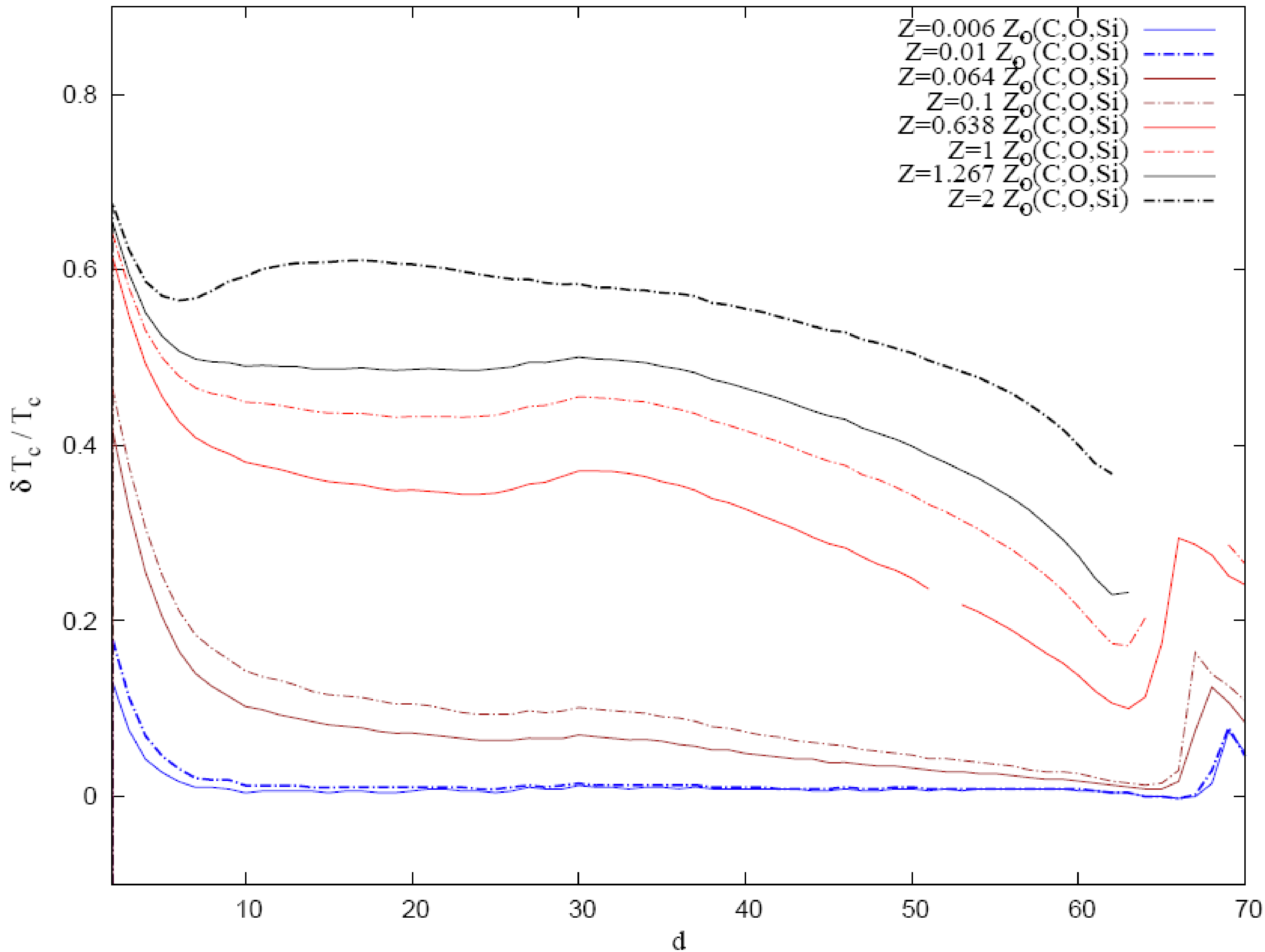
MetalCRASH TEST 1: xH, xHe convergence – no metals



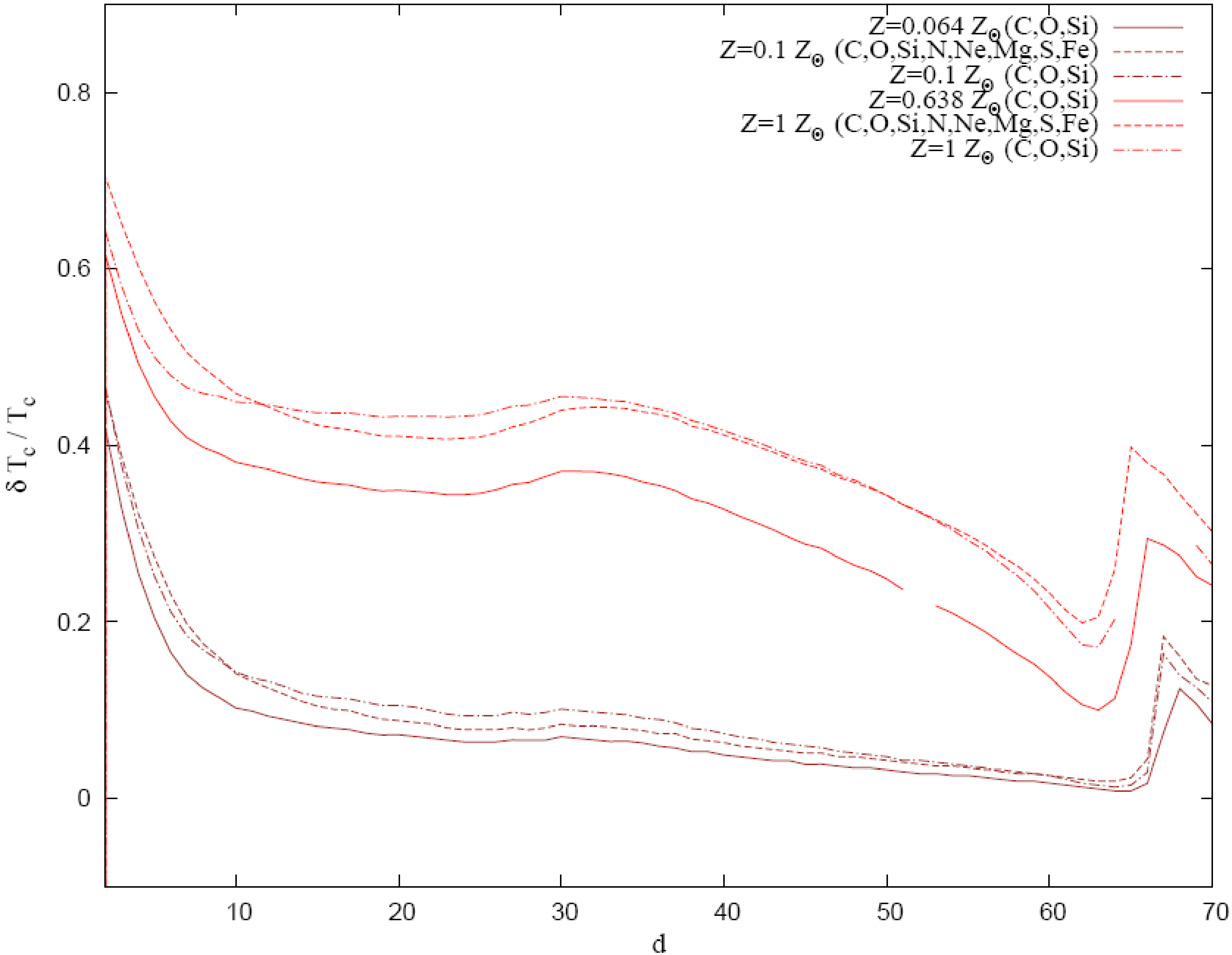
MetalCRASH TEST 1: H.He.C.O.Si - ions



MetalCRASH TEST 1: metal cooling vs Z



MetalCRASH TEST 1: metal cooling vs chem. env.



MetalCRASH TEST 1: single HII region

Conclusions:

1)Good agreement in a single bubble configuration. 20% errors in reproducing the fronts of the Helium but the mycro-physical treatment is different betw. codes: many transitions vs. single transition

2)Temperature problems around the source. Cloudy assumptions not correct

3)Regular metal ion evolution, in agreement with the spectra/ temporal evolution and with the temporal expansion of the HII fronts.

4)

5)Metal cooling and temperature correction needed if Z>0.1Zsol

6)

7)Chemical environment impacts if Z>1Zsol. C,O,Si is a good approx.

MetalCRASH TEST 2:
HII region overlap – 2 sources

SETUP:

First Run: 2 point sources with assigned Luminosity L [phot/sec] embedded in a uniform medium with, n_{gas}= 1 [cm^{-3}]. Box: 6.6 Kpc, grid: 128^3

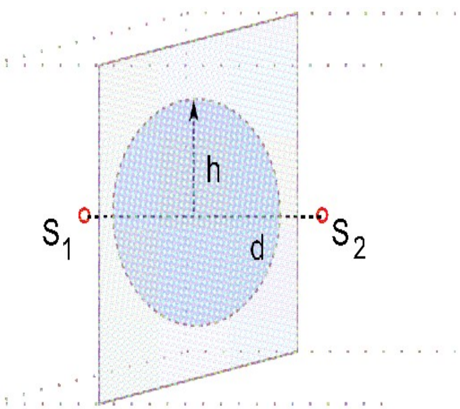
Second Run: First Run + metal pollution with $Z \sim 10^{-2} Z_{sol}$+ variation in source properties, L, BB spectrum temperature.

We expect:

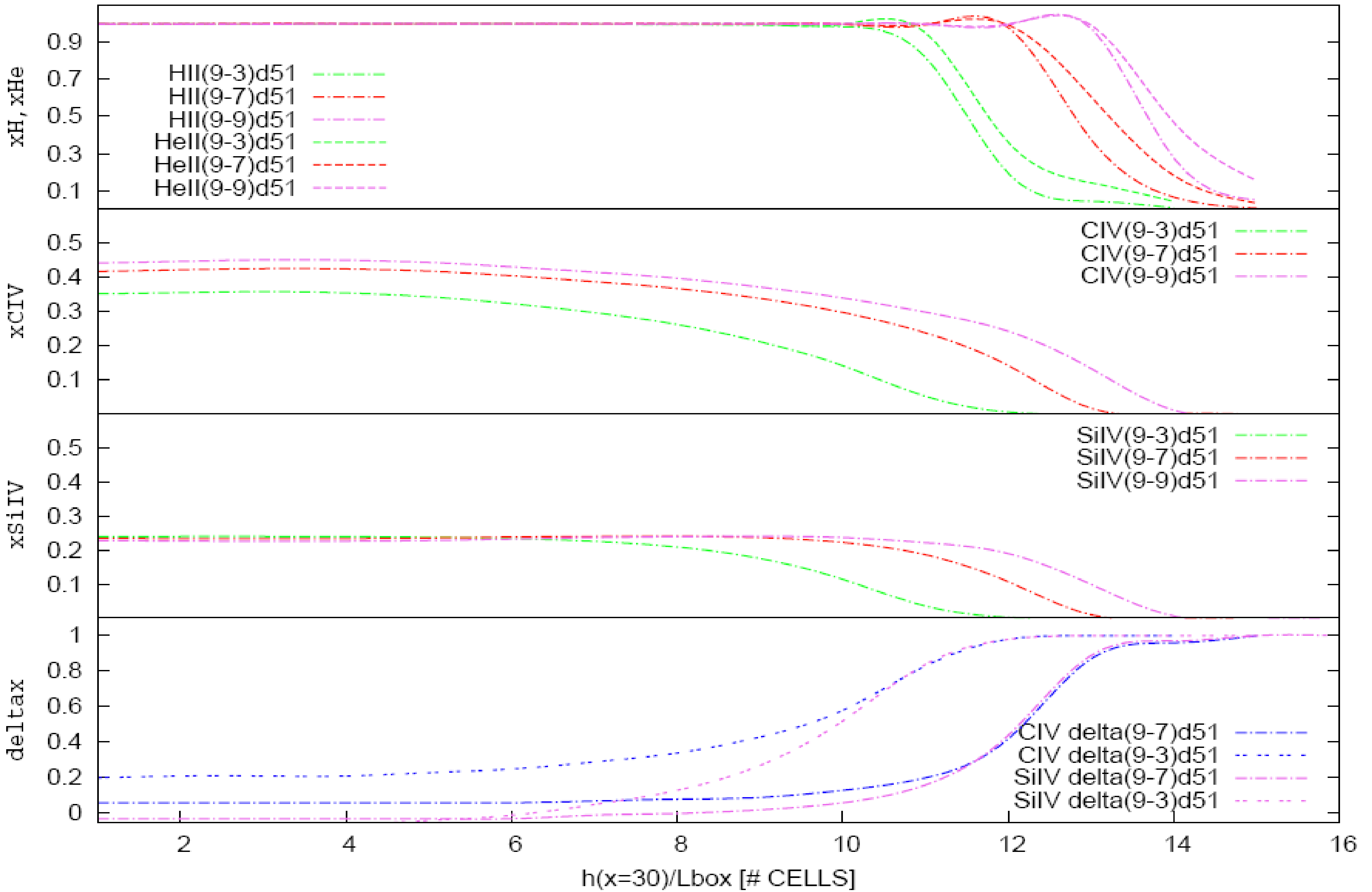
1)To test the front evolution when L_1,L_2 change.

2)To derive The C, O, Si ionization states and see if metals provide more info.

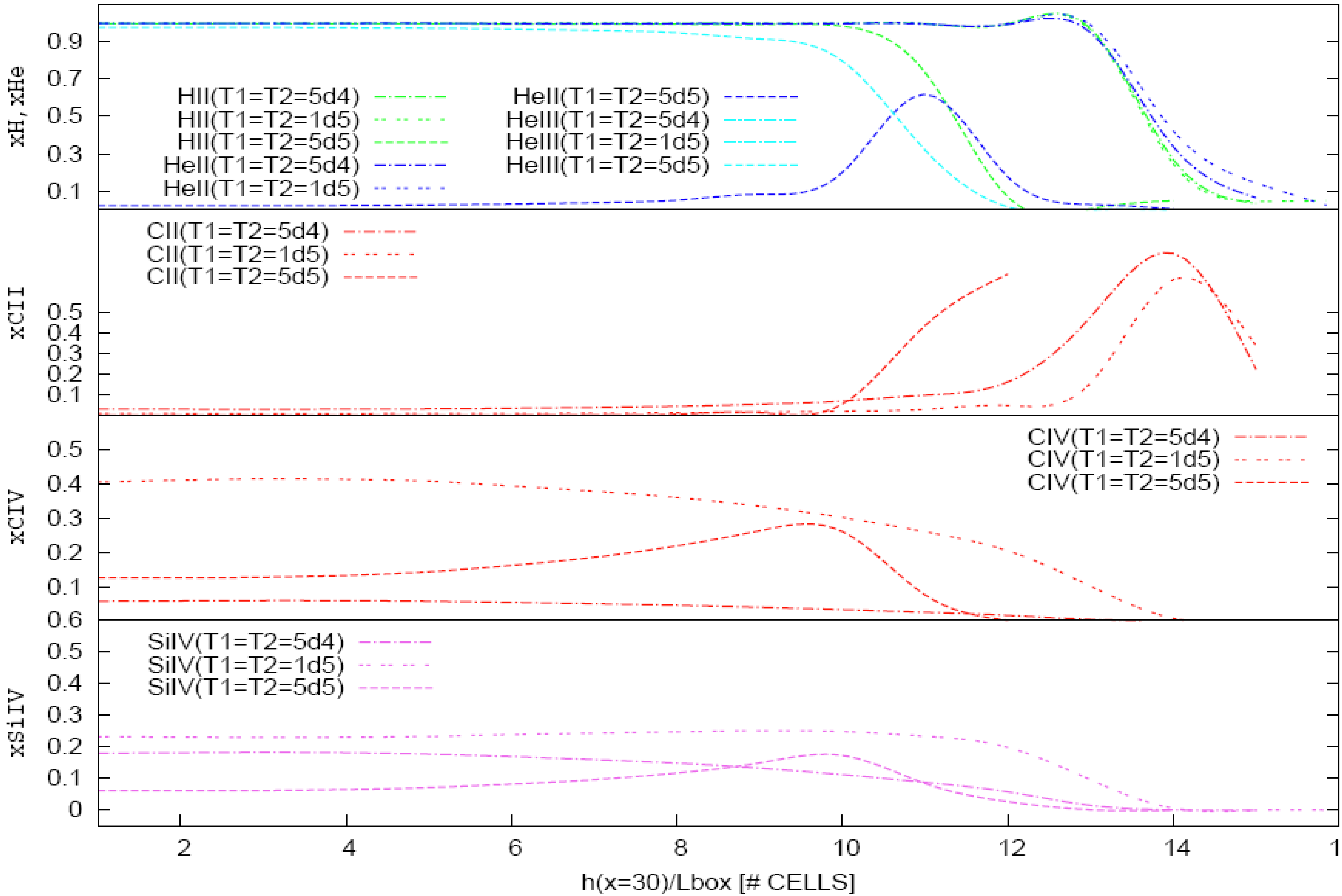
3)To trace the fluctuations induced by source type variations.



MetalCRASH TEST 2: Fluctuations by L_2



MetalCRASH TEST 2: Fluctuations by BBT_2



MetalCRASH TEST 3:
Small cosmological Box

SETUP:

First Run: 16 point sources with various luminosities L [phot/sec] embedded in a cosmic web. Box: $0.5h^{-1}$ Mpc, grid: 128^3
Second Run: First Run + artificial metal pollution $Z=\Delta\ 0.01Z_{\sigma o\lambda}$

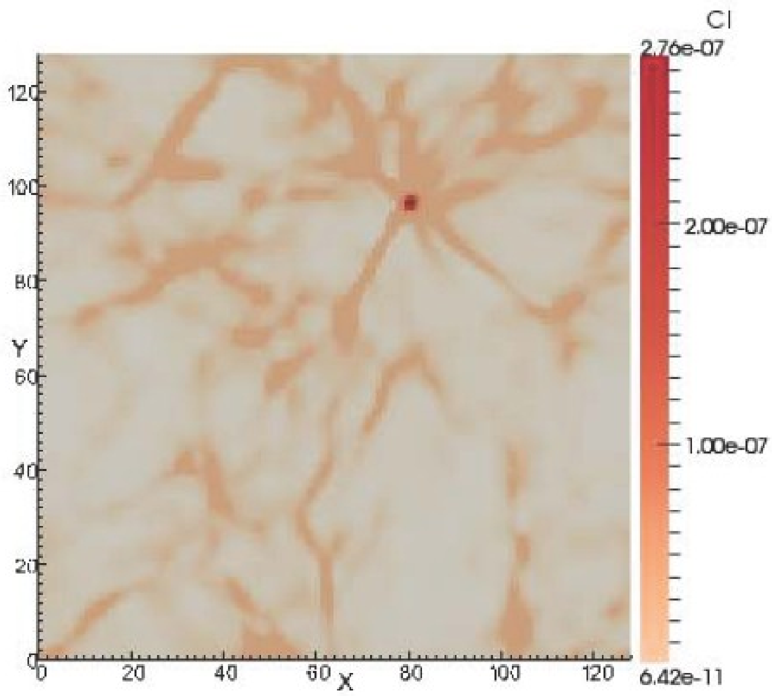
We want:

1)To show how to apply the pipeline in a full case .

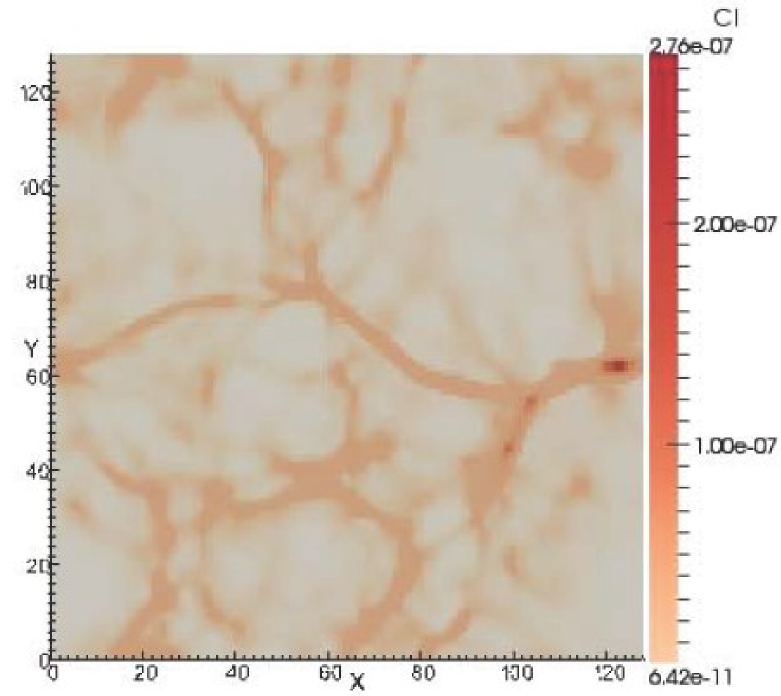
2)To derive The C, O, Si ionization states and compare the distribution in space of metal ions.

3) Discuss some limit of the pipe

MetalCRASH TEST 3: Metal Maps (ICs)



Slice @ Z=114



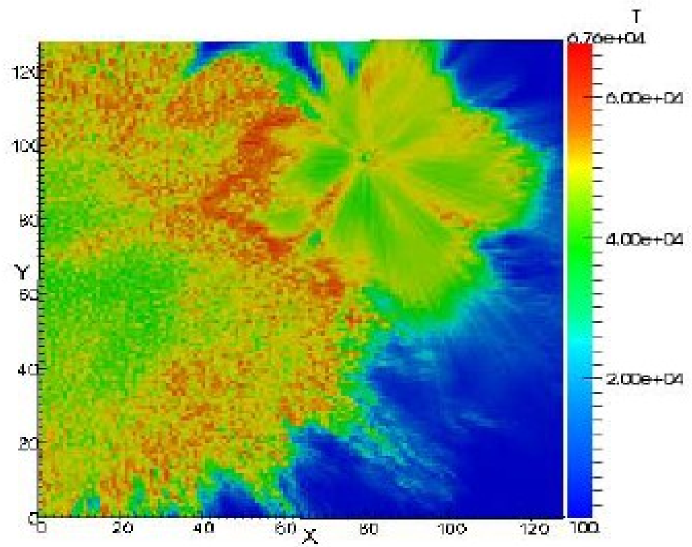
Slice @ Z=61

1) C,O,Si are created as separate maps. They provide the global distro of neutral metals.

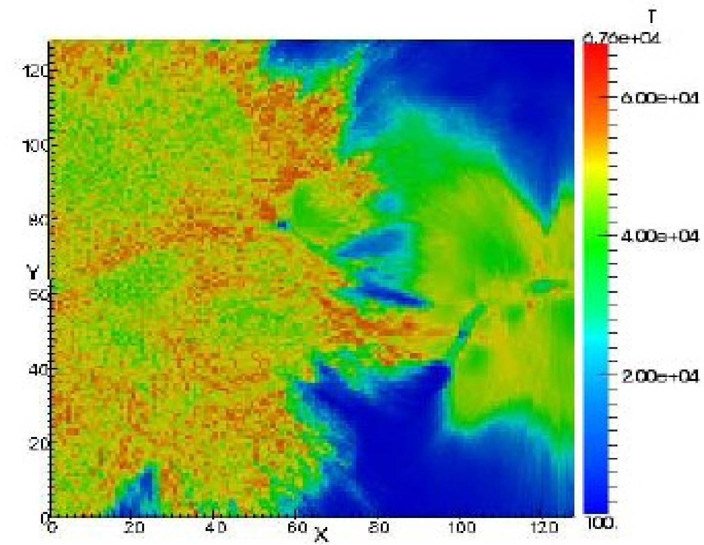
2) A mask is created intersecting the maps. The mask is used to track radiation in the cube.

3) Enriched regions ~5%. Computational principle respected. 0.012% supersolar, T correction not needed in large part of the domain.

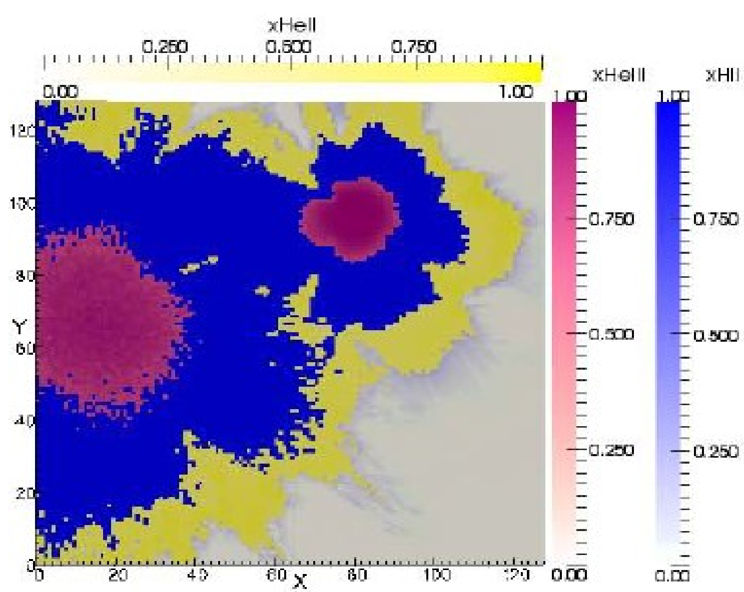
MetalCRASH TEST 3: standard CRASH results: H,He,T



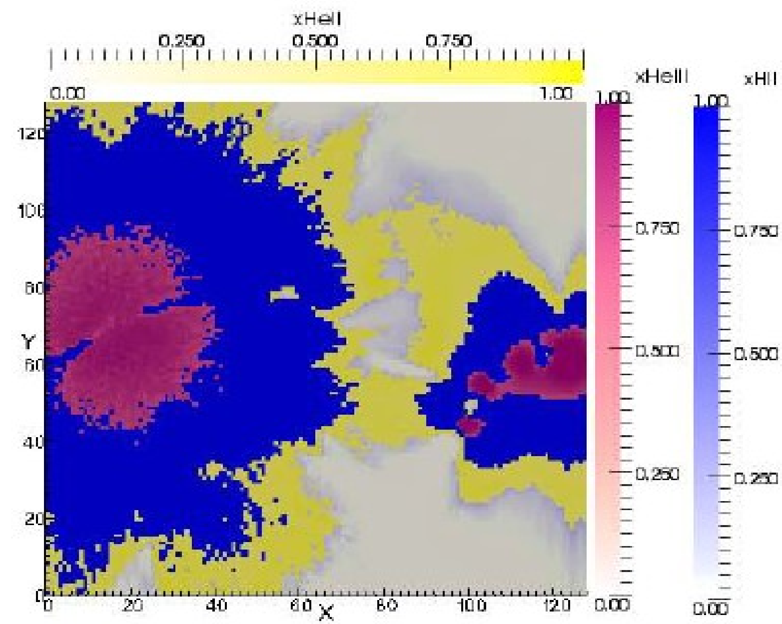
T (Slice @ Z = 114)



T (Slice @ Z=61)

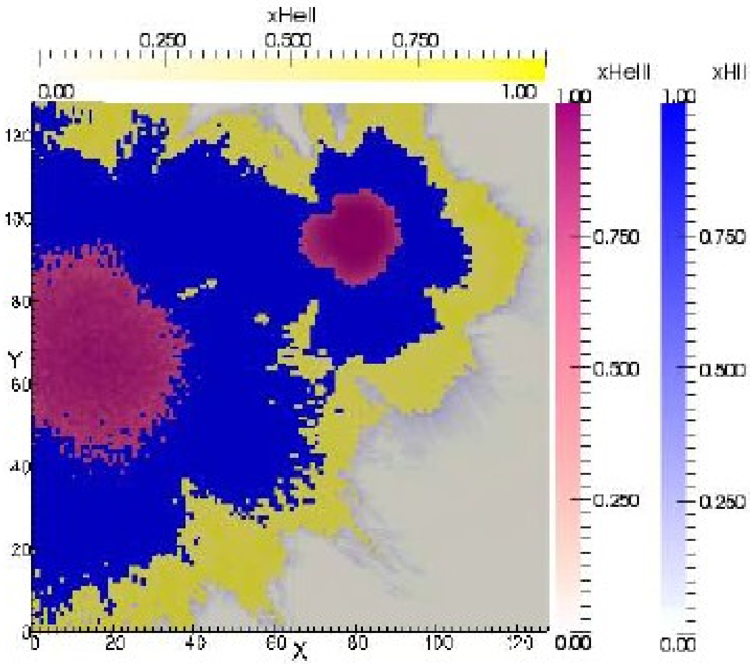


H,He ions (Slice @ Z=114)

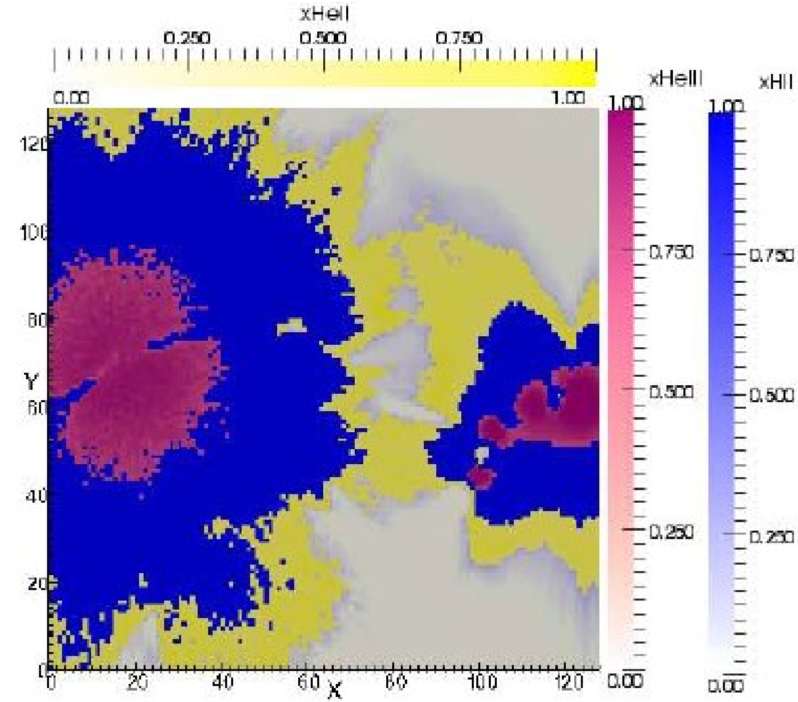


H,He ions (Slice @ Z=61)

MetalCRASH TEST 3: bubble topology, H,He,T



H,He ions (Slice @ Z=114)



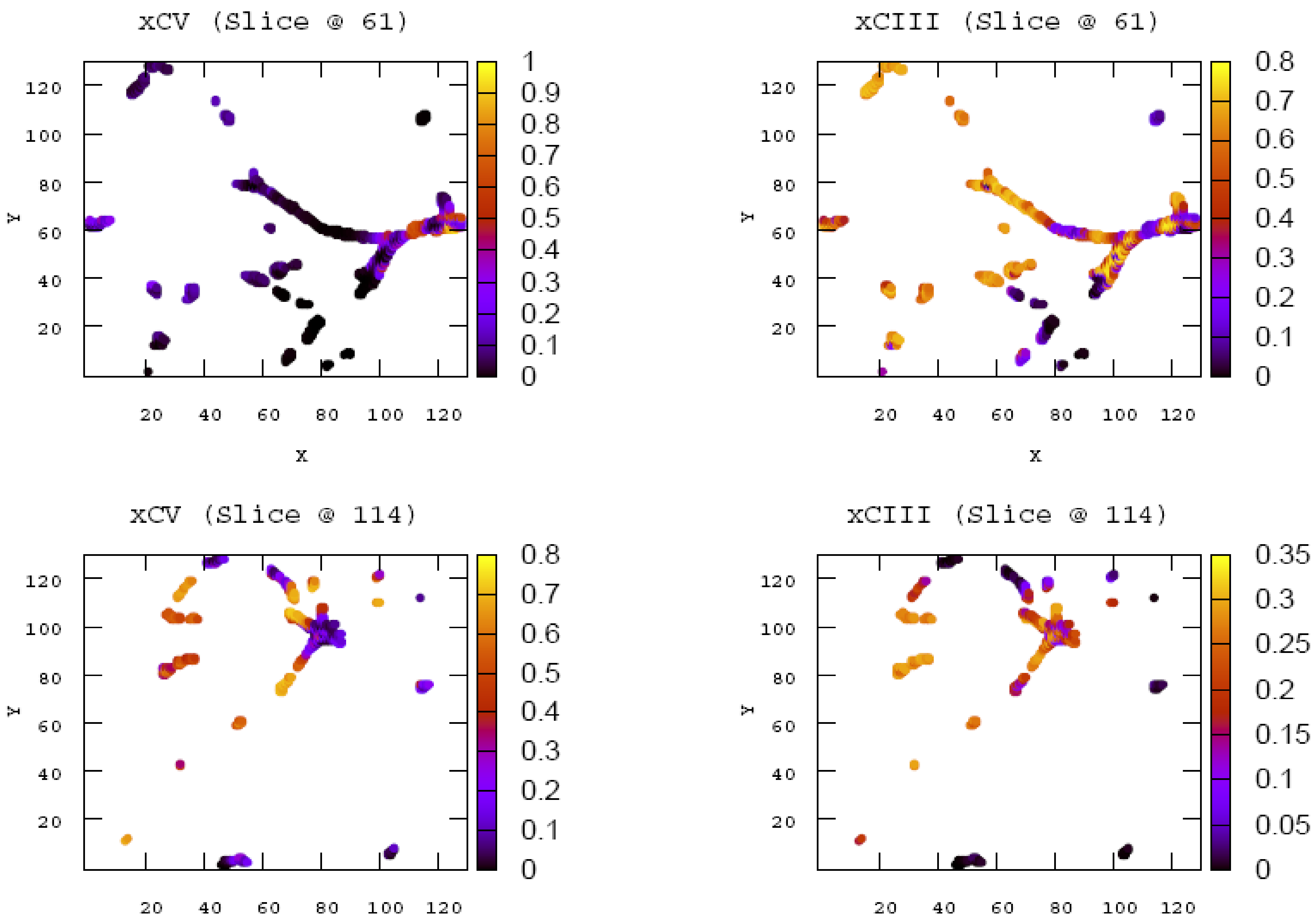
H,He ions (Slice @ Z=61)

1) HeIII traces the deep bubble overlap/regions around sources

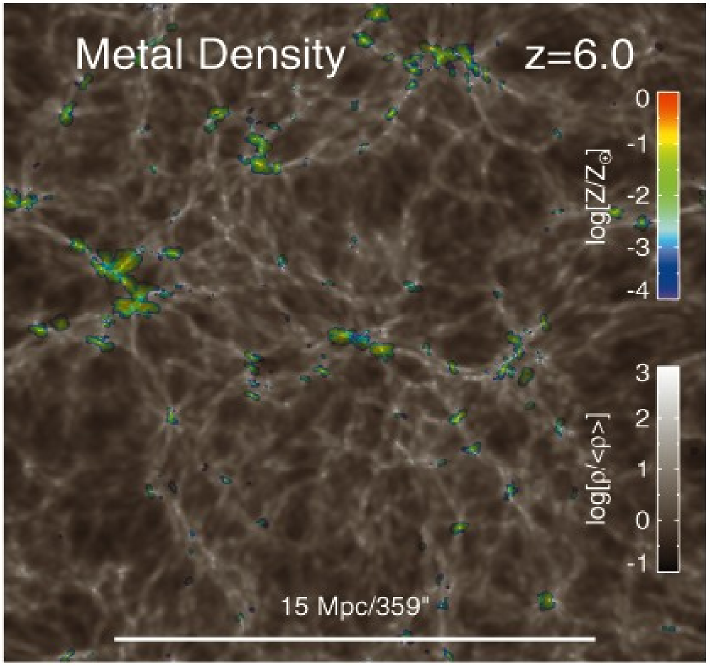
2) HII traces the bubble extent

3) HeII embeds any HII region

MetalCRASH TEST 3: Ions spatial distribution



UVB constrained by metal lines



Grey: Gas density distribution
Colored: Metal density distribution

Oppenheimer, et al., MNRAS 396, 729-758 (2009):

- **Metal enrichment** in cosmological simulations tracing C, O, Si abundances
- 3 different UVB models imposed on the density field **in post-processing**
- **Metal ionization fractions** calculated with **CLOUDY** (Ferland et al.) as function of density and temperature

Comparison between synthetic and observed spectral lines

1. Is this approach self-consistent ?
2. Are the effects of RT negligible?