BaBooNs:
Non-thermal neutron injection in BBN

Kaitlin Cook (parameters)
Justin Michael Brown (code)
Rob Almus (analysis)

Injecting stuff into BBN – Why?

- Dark matter decays during BBN may produce non-thermal particles (photons, leptons, hadrons).
- Will effect:
  - Expansion rate due to injection of relativistic species
  - Effect the abundances of light nuclei in BBN
- Has been done before!

  Cyburt et. al. 2009 (But he did it properly)

The Code

A reaction rat

- Written by F. Timmes
- Tabulates reaction “rats”
- Solves sparse matrix of ODEs
  - Isotopes
  - Energy
  - Temperature
  - Density

WIMP

- $2X \rightarrow 2n$ (not realistic)
- With some mass $M_X = 100$ GeV
- And some initial abundance N_x
- Self-annihilation cross section, canonically:

  $N_A\langle\sigma v\rangle = 1.81 * 10^{-2}\ cm^3\ s^{-1}\ mol^{-1}$

  Steigman, Dasgupta, Beacom (2012)
- Will vary $\langle\sigma v\rangle$ by 10 orders of magnitude

Reactions

$n + {}^4He \rightarrow n + {}^4He$

$3n + 2p$

$d + d + n$

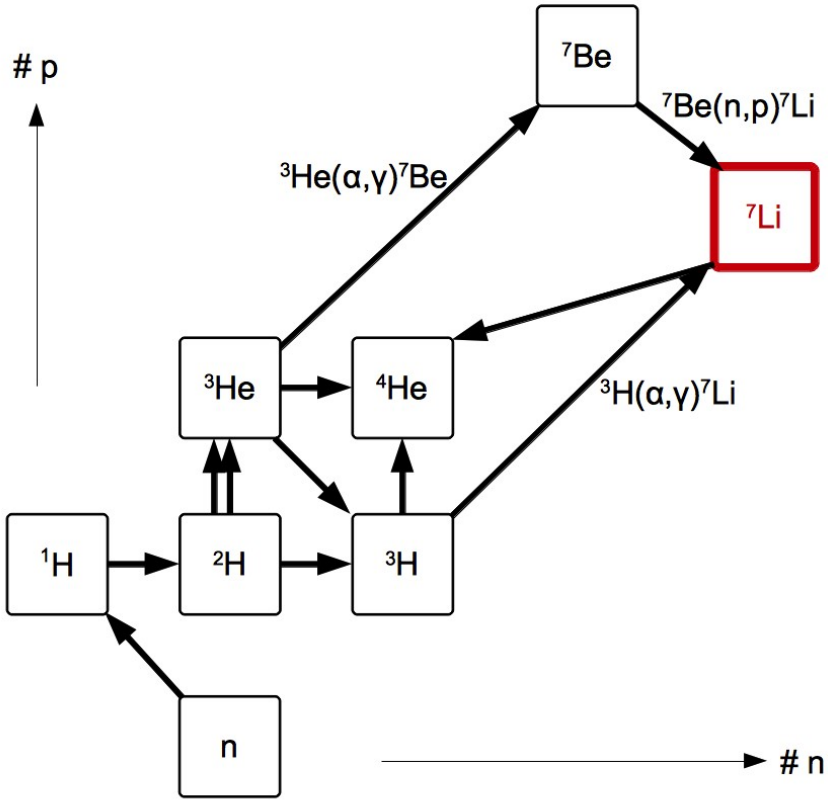
${}^3He + n$

${}^3H + p + n$

…

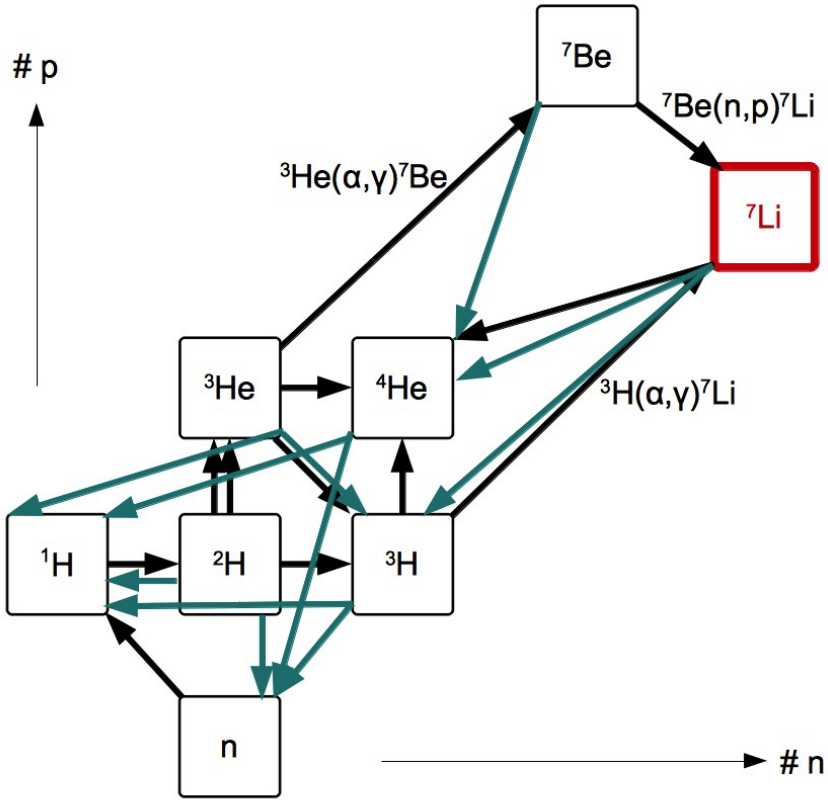
- Each reaction requires >12 changes to code
- Including every possible reaction not easy in three days!
- Choose one for each isotope in the network

A selection of neutron induced reactions – mostly dissociation.



- n + p $\rightarrow$ n + p
- n + d $\rightarrow$ 2n + p
- n + t $\rightarrow$ 3n + p
- n + ^{3}He $\rightarrow$ t + p
- n + ^{4}He $\rightarrow$ 3n +2p
- n + ^{7}Li $\rightarrow$ α + t + n
- n + ^{7}Be $\rightarrow$ 2α

A selection of neutron induced reactions – mostly dissociation.



- n + p $\rightarrow$ n + p
- n + d $\rightarrow$ 2n + p
- n + t $\rightarrow$ 3n + p
- n + ^{3}He $\rightarrow$ t + p
- n + ^{4}He $\rightarrow$ 3n +2p
- n + ^{7}Li $\rightarrow$ α + t + n
- n + ^{7}Be $\rightarrow$ 2α

Cross Sections – Ramsauer Model

$$\sigma_{tot} = 2\pi\,(R+\lambda)^2\,(1-\alpha\cos\beta)$$

$$\beta = \beta_x A^{\frac{1}{3}}(\sqrt{E+V}-\sqrt{E})$$

$$V = V_A + V_E\sqrt{E}$$

$$V_A = V_0 + V_1(N-Z)/A + V_2/A$$

$$\alpha = \alpha_0 + \alpha_A\sqrt{E}$$

$$\alpha_A = \alpha_1\ln(A) + \alpha_2/\ln(A)$$

$$R = r_0 A^{\frac{1}{3}} + r_A\sqrt{E} + r_2$$

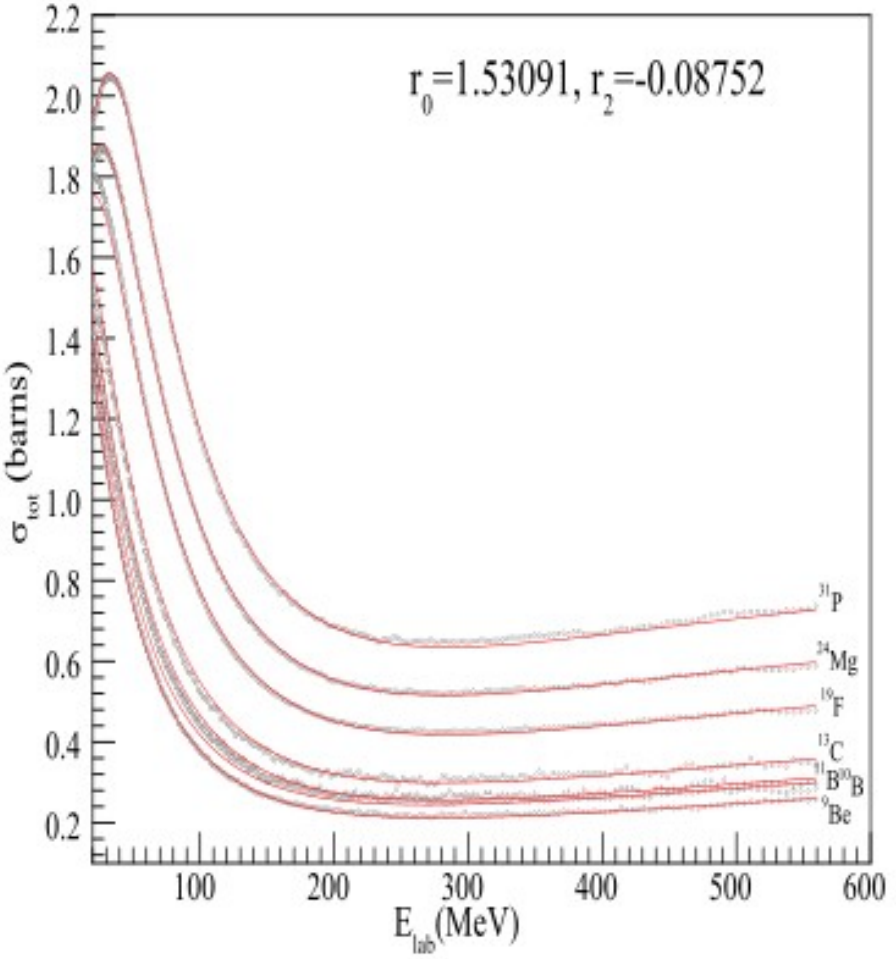
$$r_A = r_{10}\ln(A) + r_{11}/\ln(A)$$

$$r_0 = 1.42988,\quad r_{10} = -0.02298,\quad r_{11} = 0.10268$$

$$r_2 = 0.23216,\quad V_0 = 46.51099,\quad V_1 = 6.73833$$

$$V_2 = -117.52082,\quad V_E = -3.21817,\quad \beta_x = 0.592$$

$$\alpha_0 = 0.02868,\quad \alpha_1 = -0.00274,\quad \alpha_2 = 0.13211$$



Gowder R.S. et. al. 2005

Cross Sections

- Ramsauer model gives σ_{Tot}
- Require $\sigma_{Destruction}$
- For $^{3}He(n,n)^{3}He$, $^{3}He(n,total)$ data at ~10 MeV

  $(\sigma_{tot} - \sigma_{el})/\sigma_{tot} \sim 0.1$
- Handwave: $\sigma_{Destruction} = 0.1\ \sigma_{Total}$

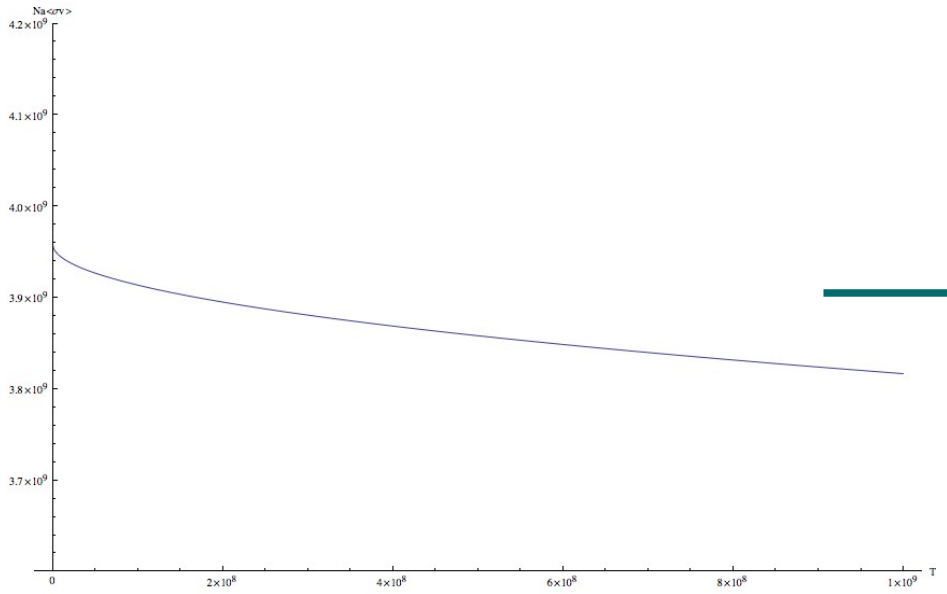
Cross Sections → Reaction rates

$$N_A \langle \sigma v \rangle (T) = \int_0^\infty \int_0^\infty N_A \phi_1(v_1, T) \phi_2(v_2, T) \sigma(v_1 - v_2)(v_1 - v_2) dv_1 dv_2$$

$$\phi_1(v_1, T) = \delta(v1 - v_N)$$

$$\phi_2(v_2, T) = 4\pi v_2^2 (\frac{m_i}{2\pi k_b T})^{3/2} exp(\frac{-m_i v_2^2}{2k_b T})$$

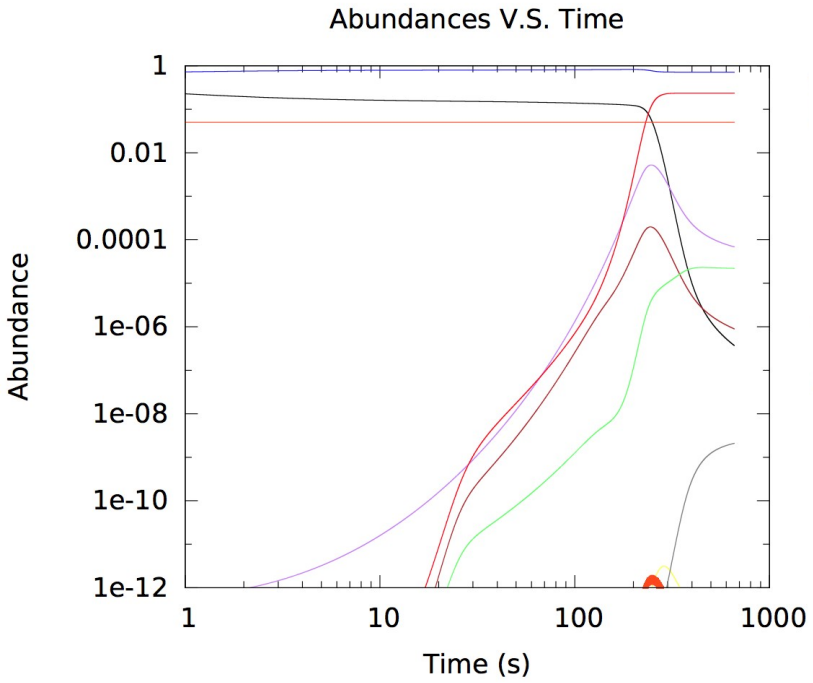
$$N_A \langle \sigma v \rangle (T) = 4\pi N_A (\frac{m_2}{2\pi k_b T})^{3/2} \int_0^\infty v_2^2 exp(\frac{-m_2 v_2^2}{2k_B T}) \sigma(v_N - v_2)(v_N - v_2) dv_2$$



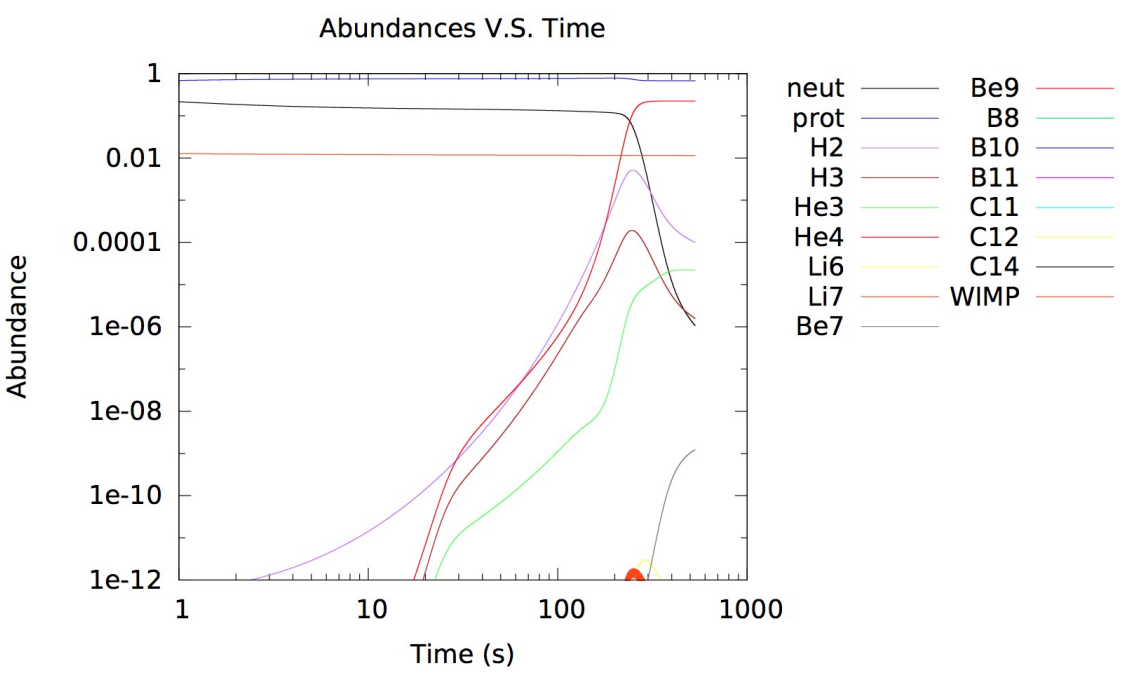
Basically flat.

SBBN vs
BBN with 100 MeV neutron

No WIMP Decay

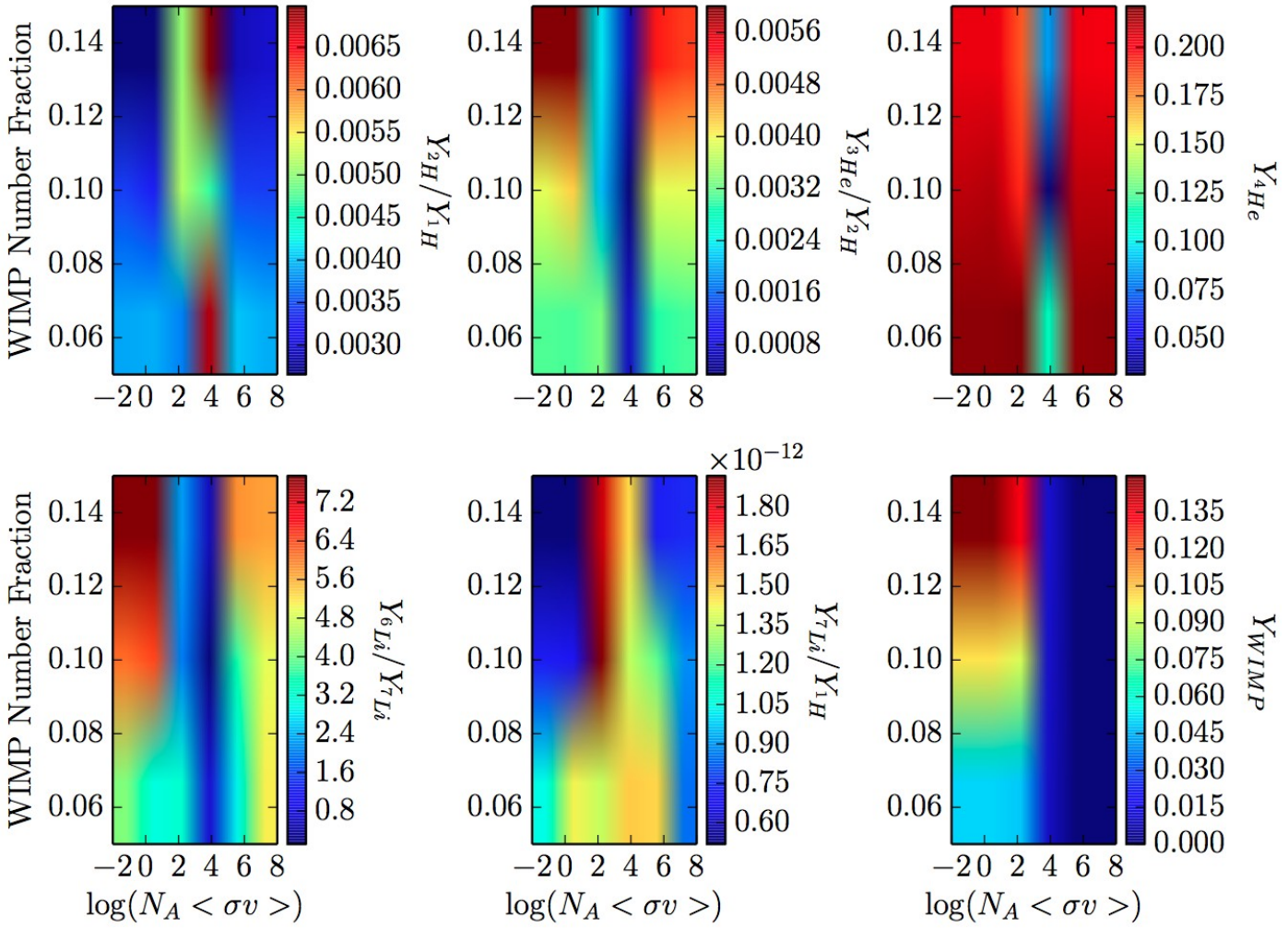


(fast) WIMP Decay

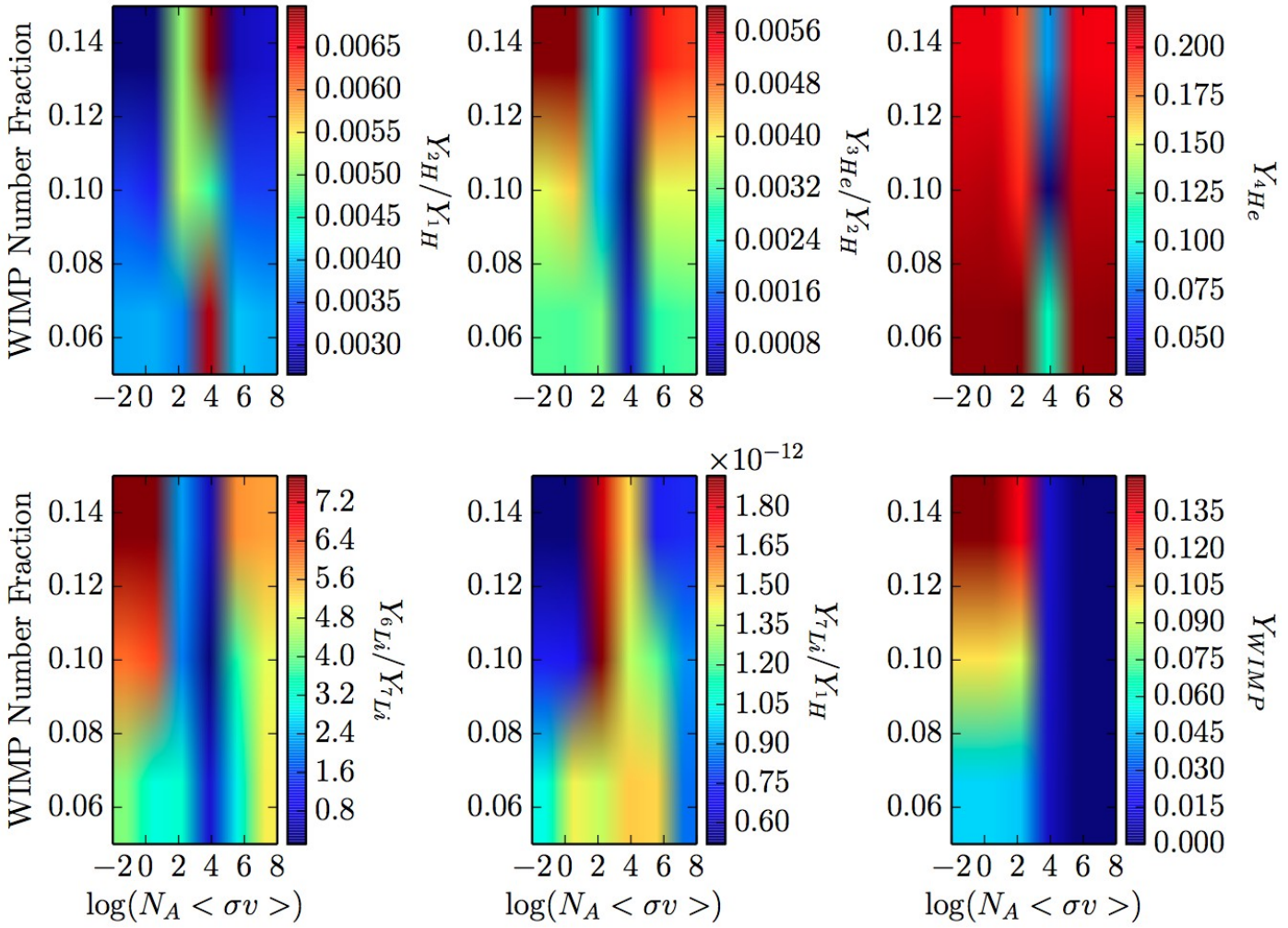


The differences are subtle!

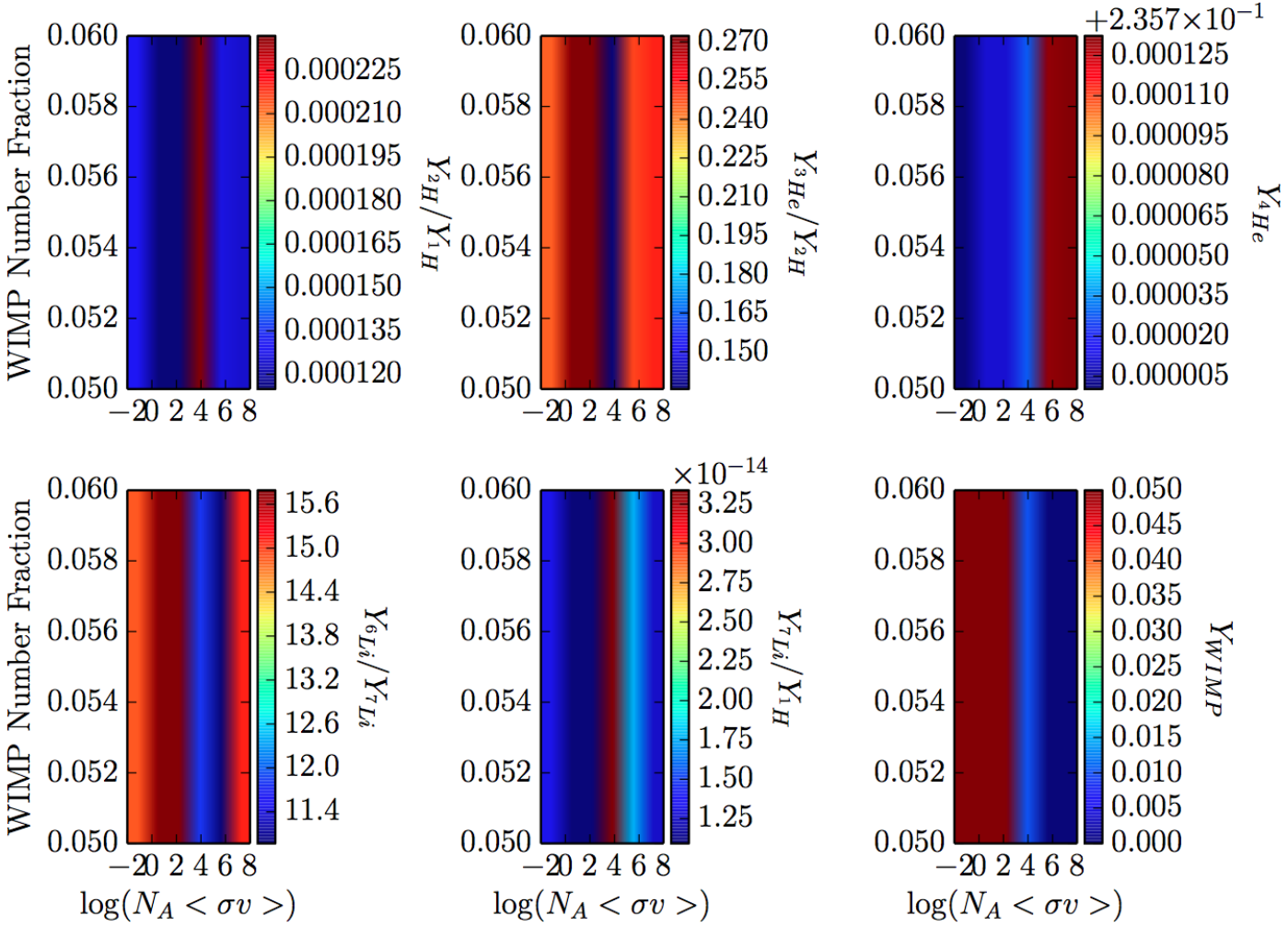
Varying <σv> and N_x



Varying <σv> and N_x – at 200s



Varying <σv> and N_x – to 600 s. Smaller parameter space



With more time:

- Longer evolution time
- Better (and more) cross sections. (TALYS?)
- Thermalisation of non-thermal neutrons
- Creation of secondary non-thermal particles
- Better treatment of WIMP decay.
- Other hadronic WIMP decay channels.
- EM decay channels.
- More thorough exploration of the parameter space.