Online Tools for Understanding the Equation of State

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Nuclear Statistical Equilibrium (NSE)

- Condition of complete equilibrium among nuclear species under exchange of neutrons and protons
- Achieved in late stages of stellar evolution or in supernova explosions

$$\mu(Z, A) = Z\mu_p + (A - Z)\mu_n$$

Nuclear Statistical Equilibrium (NSE)

- Our assumptions about the nuclei:
  - Boltzmann particles (except at low temperature where they can be bosons)
  - Incompressible, but finite volume
- Our assumptions about the nucleons (and electrons and positrons):
  - Non-interacting
  - Fully relativistic and degenerate

Nuclear Statistical Equilibrium (NSE)

- The nuclei:

$$\mu(Z,A) = m(Z,A)c^2 + kT \ln\left(\frac{\rho N_A Y(Z,A)}{G(Z,A)} \left[\frac{h^2}{2\pi m(Z,A)kT} \right]^{3/2} \right)$$

- We thus require:
  - Masses: m(Z,A)
  - Ground state spins: J(Z,A)
  - Nuclear partition functions: G(Z,A), which we take to be a multiple of 2J(Z,A)+1

Nuclear Statistical Equilibrium (NSE)

- NSE codes are fairly straightforward to write and run
- However, one must write or obtain the code, compile it, test it, and then data mine the output
- This may be a barrier to those who would like to use such codes but do not have the time to undertake these steps

http://nucleo.ces.clemson.edu/pages/nse

- Online tool for calculating NSE
  - User inputs in a straightforward way nuclear properties (masses, spins, partition functions) or uses default values.
  - Computer at Clemson calculates NSE for the user-input set of temperatures, densities, and electron fractions.
  - Interfaces allow user to explore results of the calculation, including abundances and thermodynamic properties of the matter

We have chosen W3C standards or recommendations

- Input data upload from client to server is via XML (eXtensible Markup Language)
  - Validation via Schema checking
  - Formatting via XSLT
- Form: <tag>data</tag>

Example XML file

```
<nuclear_data>

<!--  Neutron -- >

<nuclide>
   <z>0</z>  <a>1</a>
   <mass_excess units="MeV">8.071</mass_excess>
   <spin>0.5</spin>
</nuclide>

<!– Proton -- >

</nuclide>
   <z>1</z>  <a>1</a>
   <mass_excess> 7.289 </mass_excess>
   <spin>0.5</spin>
</nuclide>

.
.
.

</nuclear_data>
```

Formatted Input

Z	A	Mass Excess (MeV)	Spin
0	1	8.07100	0.500000
1	1	7.28900	0.500000
1	2	13.1360	1.00000
1	3	14.9500	0.500000
2	3	14.9310	0.500000
2	4	2.42400	0.00000
3	6	14.0850	1.00000
3	7	14.9070	1.50000
3	8	20.9450	2.00000

Output

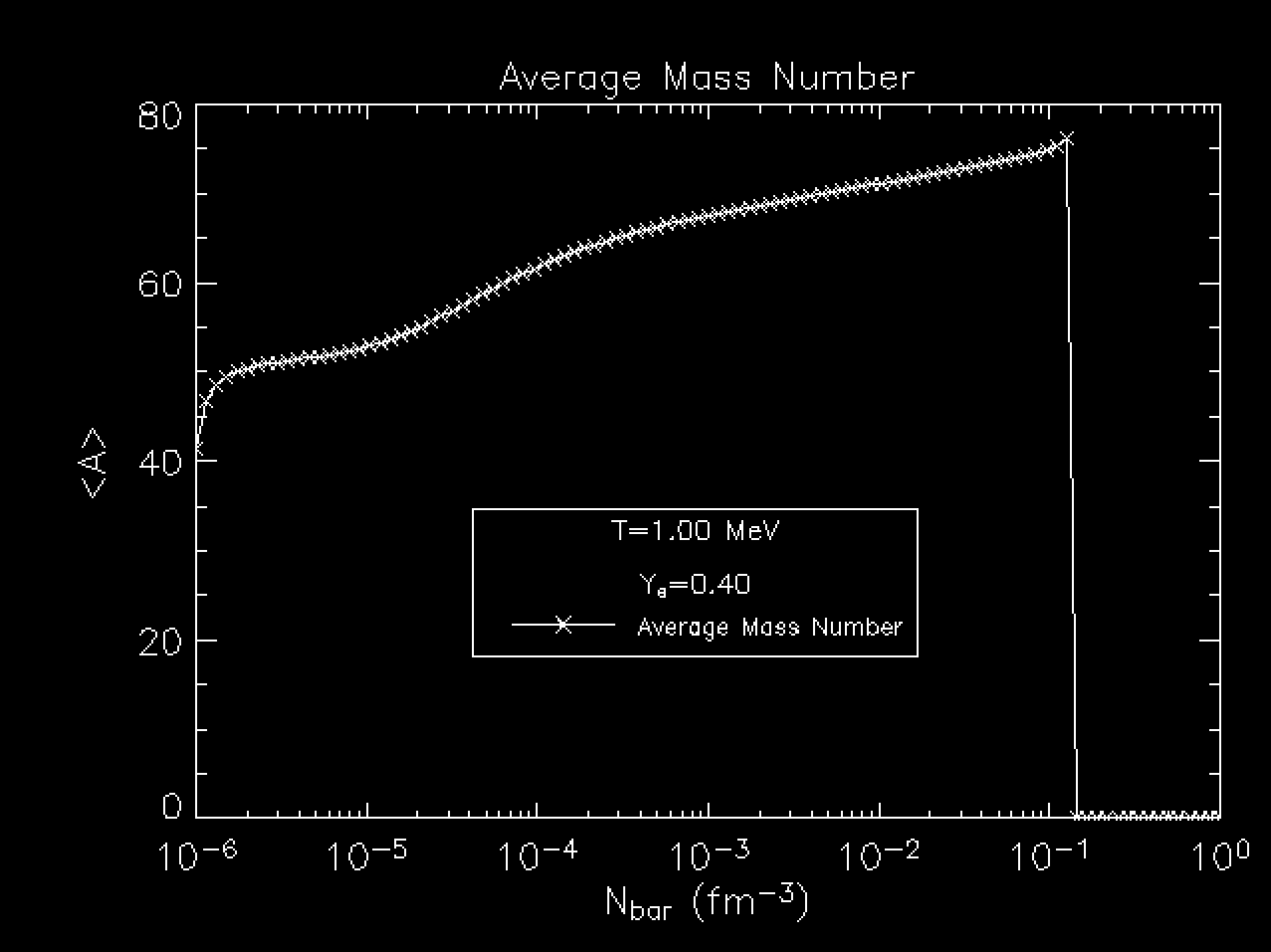
- Output format is binary or FITS file
- User may data mine the output as soon as it is available or download it. Downloaded output files may be uploaded again.
- Data mining and graphics are through IDL on the Net (ION).

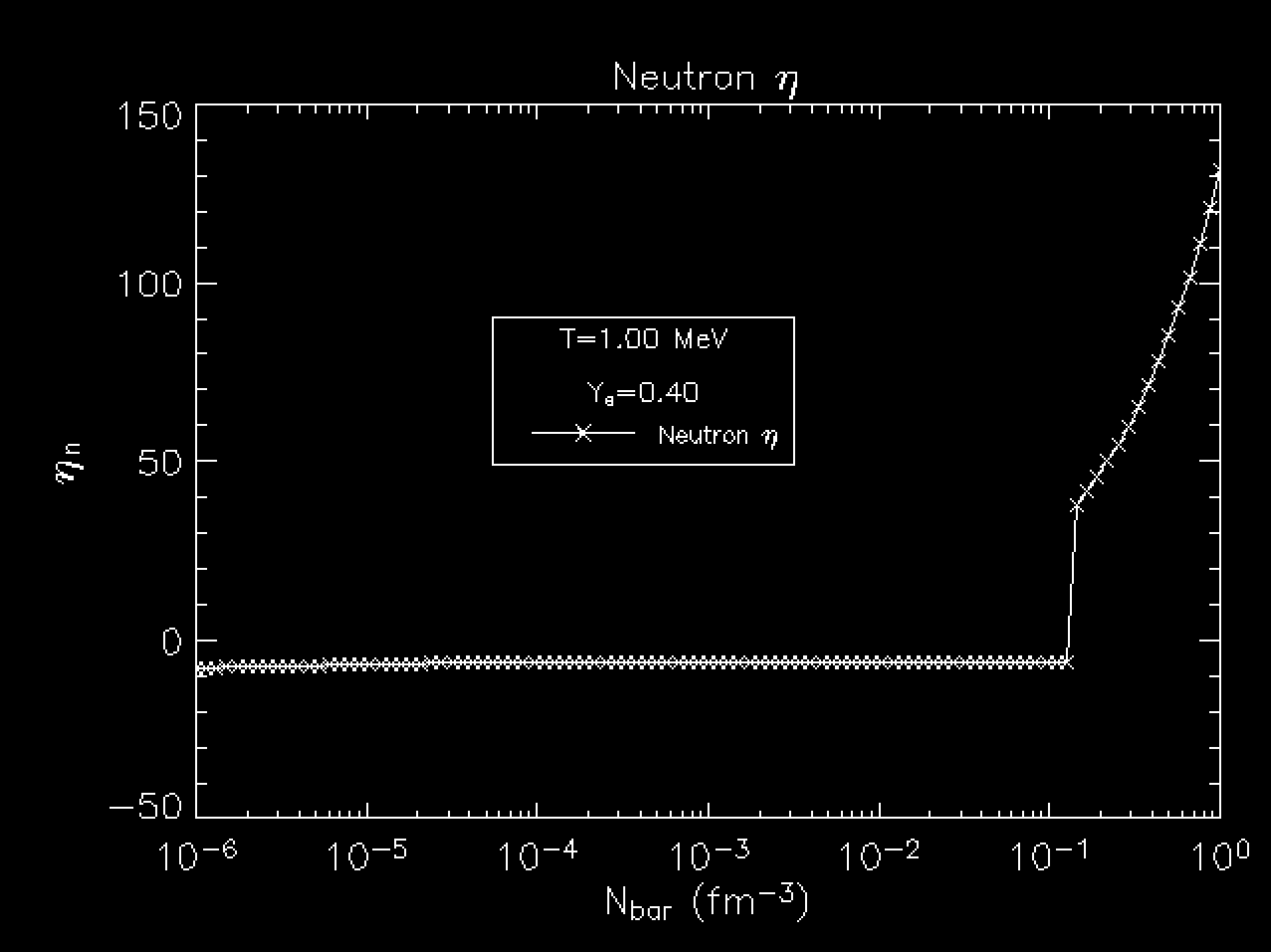
Calculations

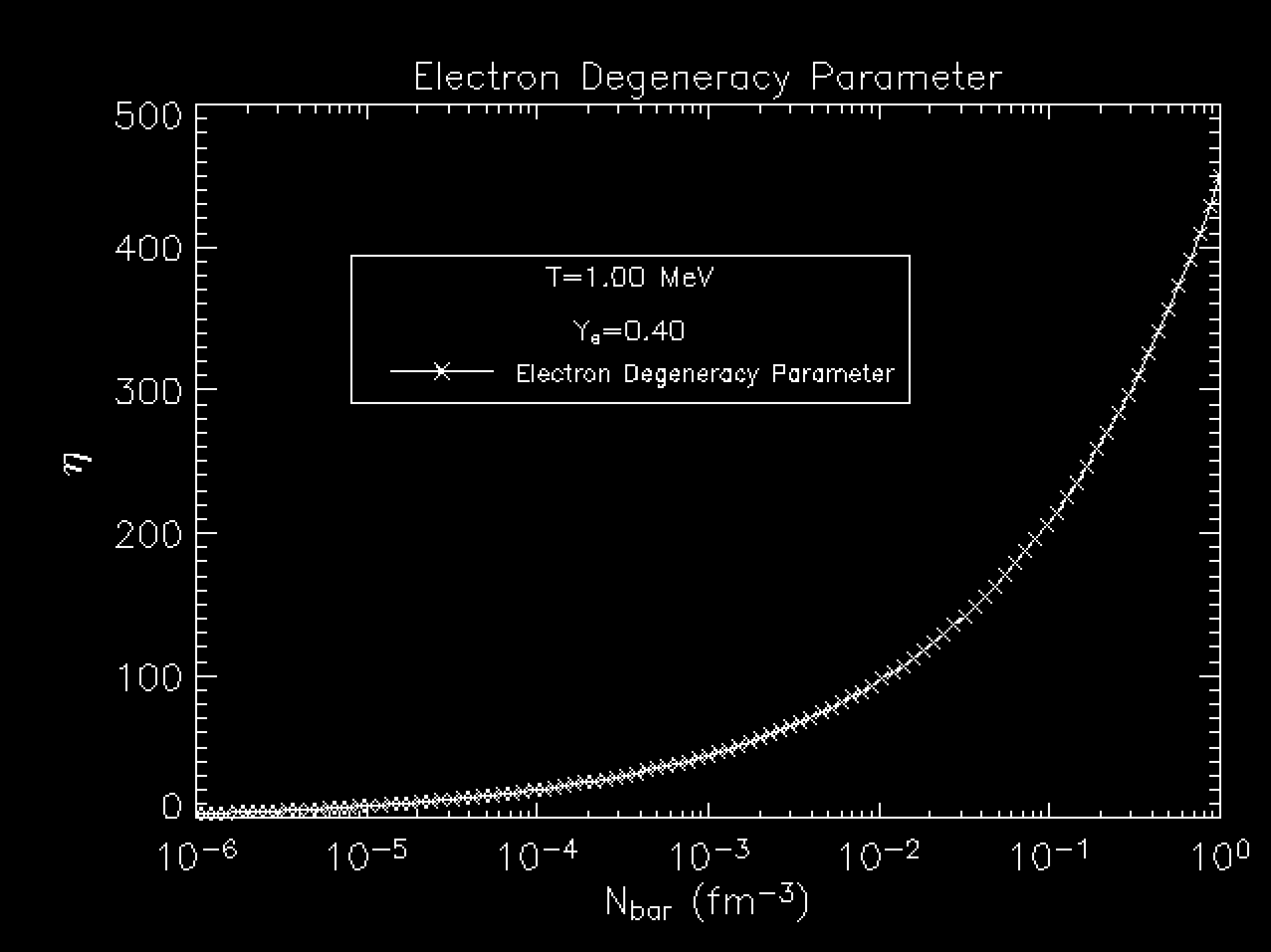
- Single calculations: user inputs T, density, Y_e
  - These calculations usually take < 1 minute
- Multiple calculations: user inputs range of T, density, or Y_e or enters an NSE trace
  - These calculations can take a while
  - The computer puts the calculation in the background and then emails the user with information on how to access the data when the calculation is done

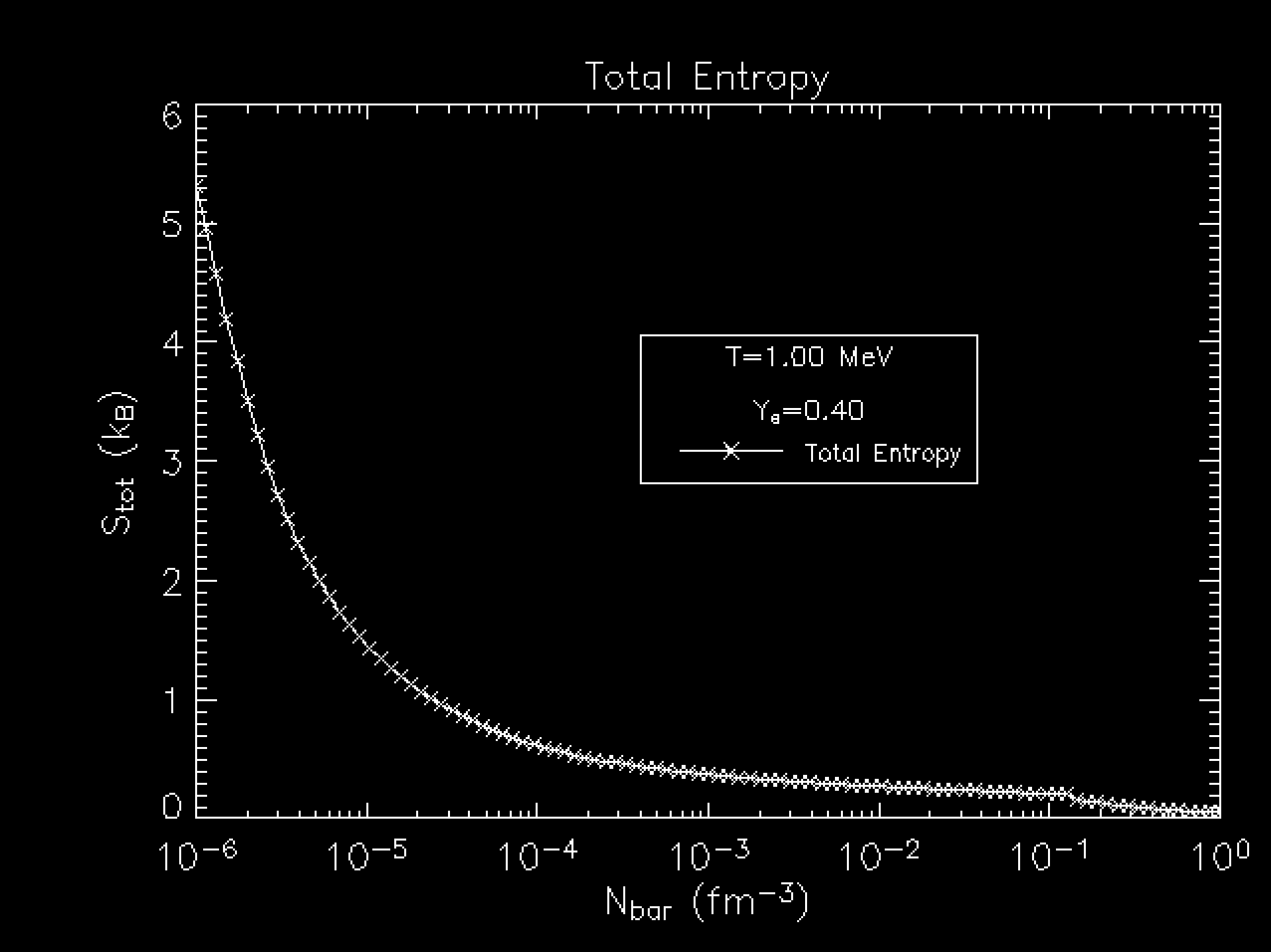
Example calculation

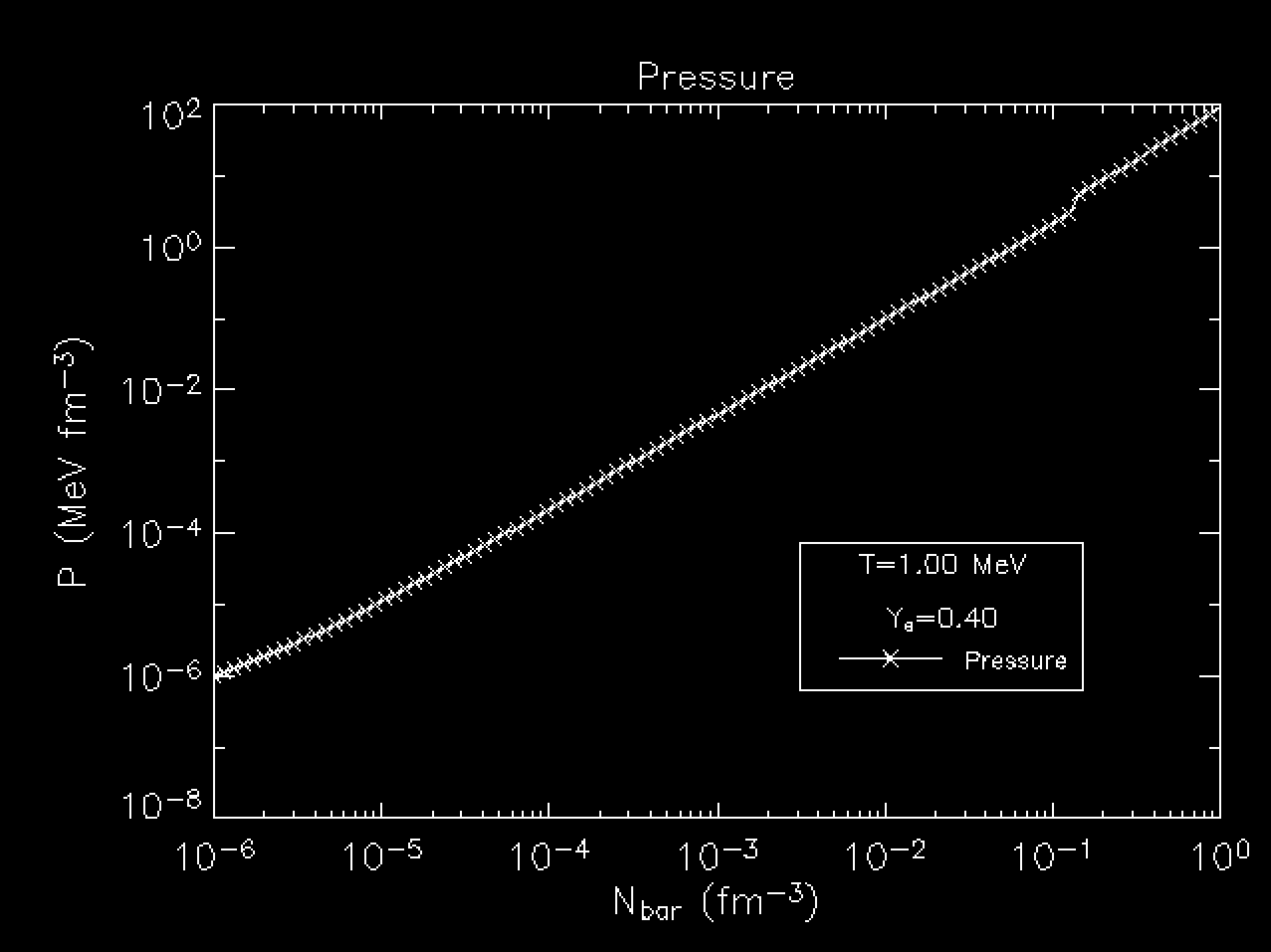
- T = 1 MeV
- $Y_e = 0.4$
- Density = 1.0e-6 to 1 fm^{-3}

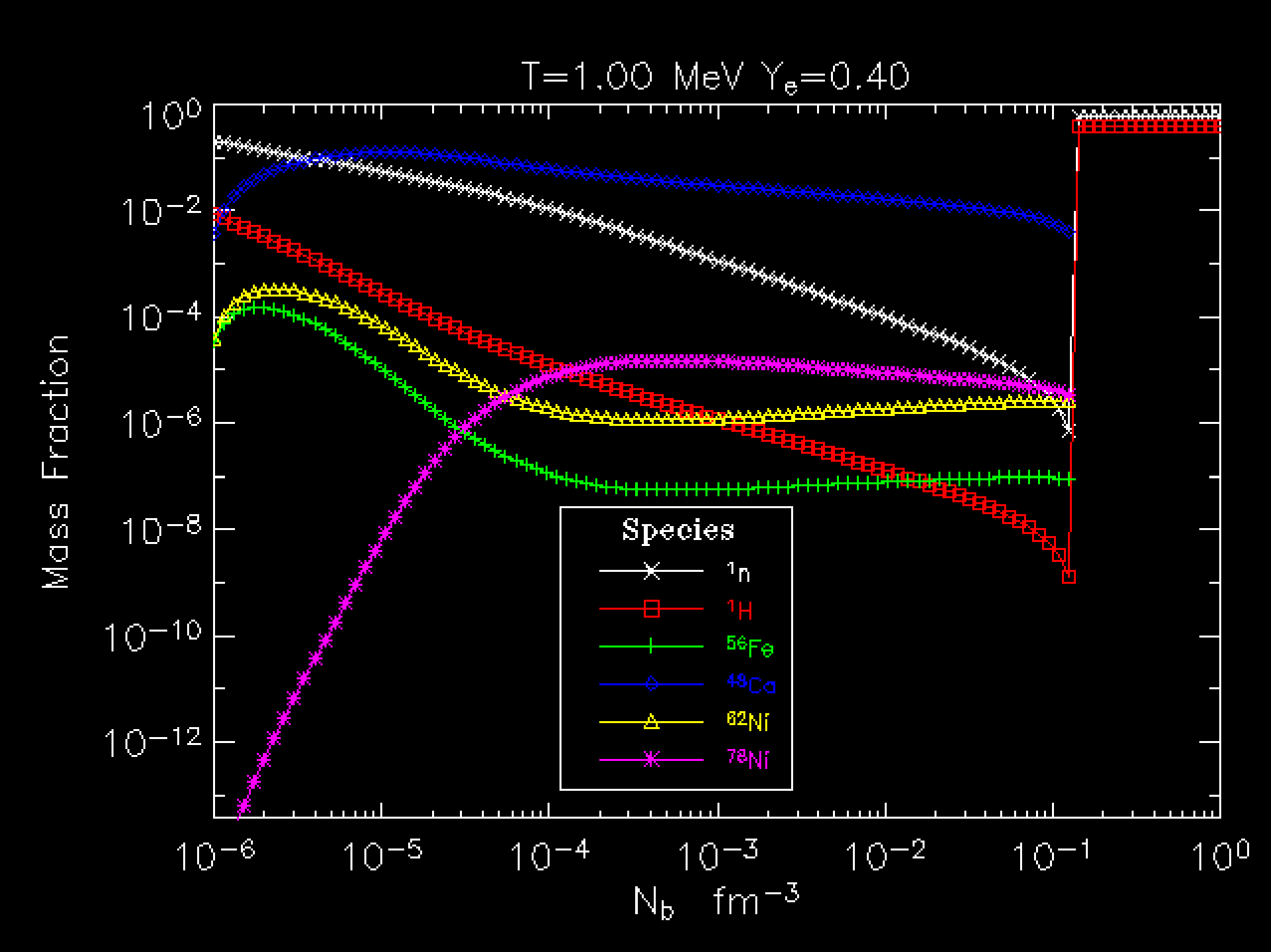

Average Mass Number
80
60
40
20
0
<A>
T=1.00 MeV
Y_e=0.40
Average Mass Number
10^-6
10^-5
10^-4
10^-3
10^-2
10^-1
10^0
N_bar (fm^-3)

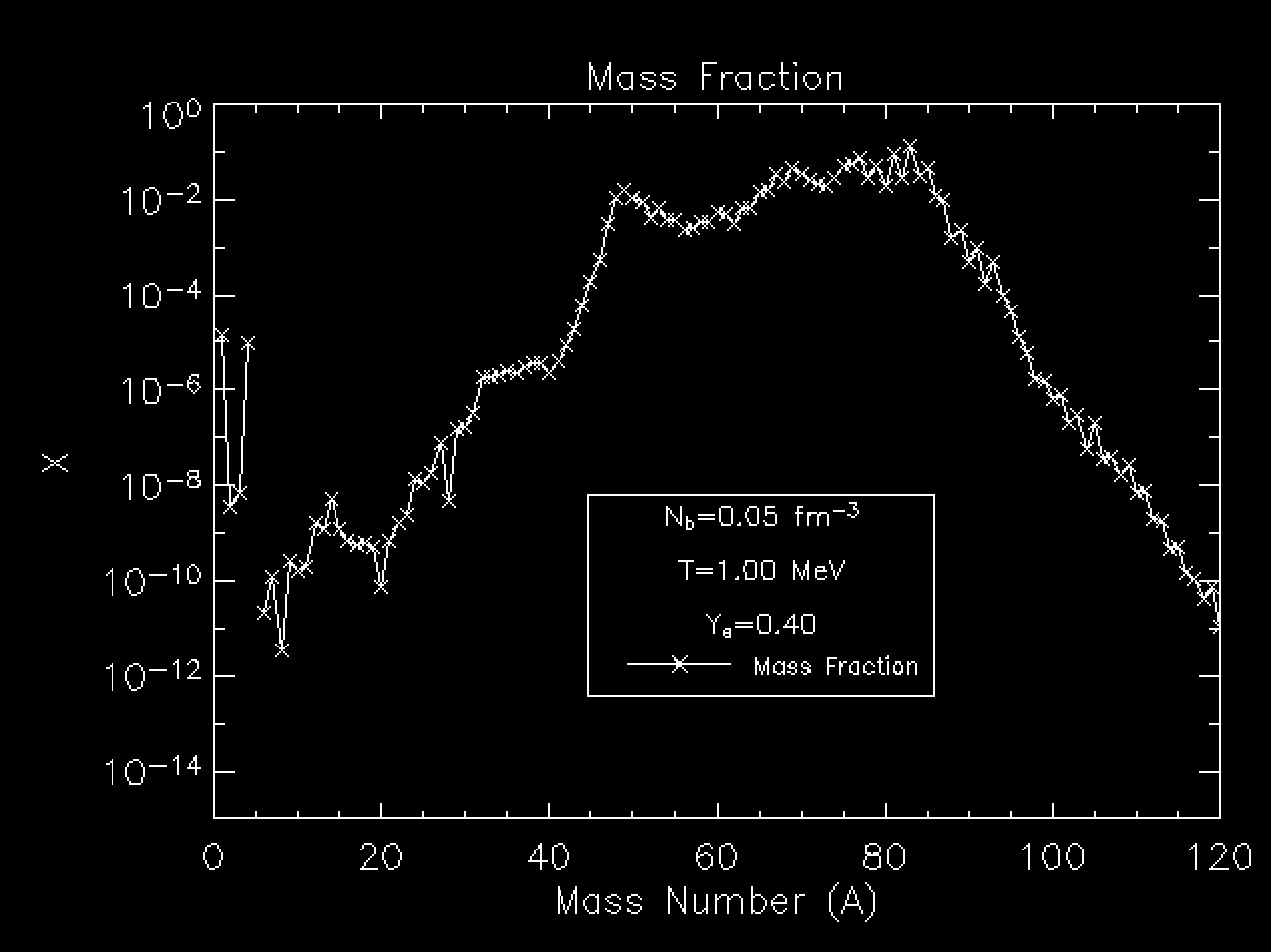

Neutron η
150
100
50
0
−50
ηn
T=1.00 MeV
Ye=0.40
Neutron η
10−6
10−5
10−4
10−3
10−2
10−1
100
Nbar (fm−3)

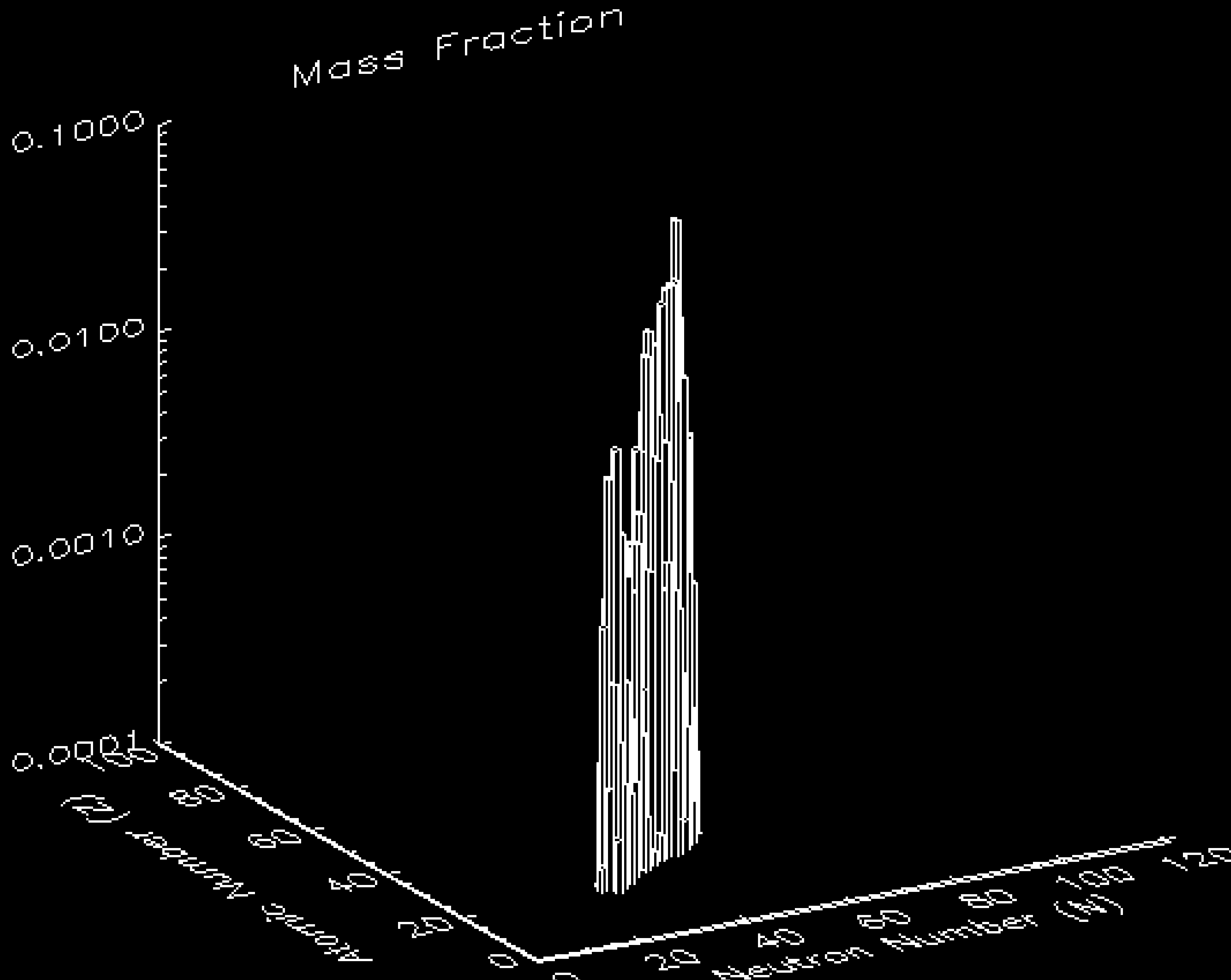

Electron Degeneracy Parameter
T=1.00 MeV
Y_e=0.40
Electron Degeneracy Parameter
η
500
400
300
200
100
0
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
N_{bar} (fm^{-3})


Total Entropy
T=1.00 MeV
Y_e=0.40
Total Entropy
S_{tot} (k_B)
N_{bar} (fm^{-3})
0
1
2
3
4
5
6
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}


Pressure
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
P (MeV fm^{-3})
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
N_{bar} (fm^{-3})
T=1.00 MeV
Y_e=0.40
Pressure


T=1.00 MeV Ye=0.40
Mass Fraction
Nb fm-3
Species
1n
1H
56Fe
48Ca
82Ni
72Ni


Mass Fraction
X
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
0
20
40
60
80
100
120
Mass Number (A)
N_b=0.05 fm^{-3}
T=1.00 MeV
Y_e=0.40
Mass Fraction



Mass Fraction
0.1000
0.0100
0.0010
0.0001
Atomic Number (Z)
0
20
40
60
80
100
Neutron Number (N)
0
20
40
60
80
100
120

Pages available

- Ideal gas calculator
  - Computes thermodynamics of an ideal fermionic or bosonic gas for any degree of degeneracy or relativity
  - Available:
    - http://nucleo.ces.clemson.edu/pages/ideal_gas/0.1
- NSE calculator
  - Computes abundances and thermodynamics of matter in nuclear statistical equilibrium
  - Available:
    - http://nucleo.ces.clemson.edu/pages/nse/0.1
- Galactic Chemical Evolution calculator
  - Computes simple models of one-zone galactic chemical evolution
  - Available:
    - http://nucleo.ces.clemson.edu/pages/cugce/

Purposes

- Research
- Education
- Code Archiving

Acknowledgments

- SUN Microsystems (Academic Equipment Grant)
- Computer Support Services College of Engineering and Science at Clemson (especially Corey Ferrier and the Unix Team)
- NASA, DOE, and NSF for support


Sun

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