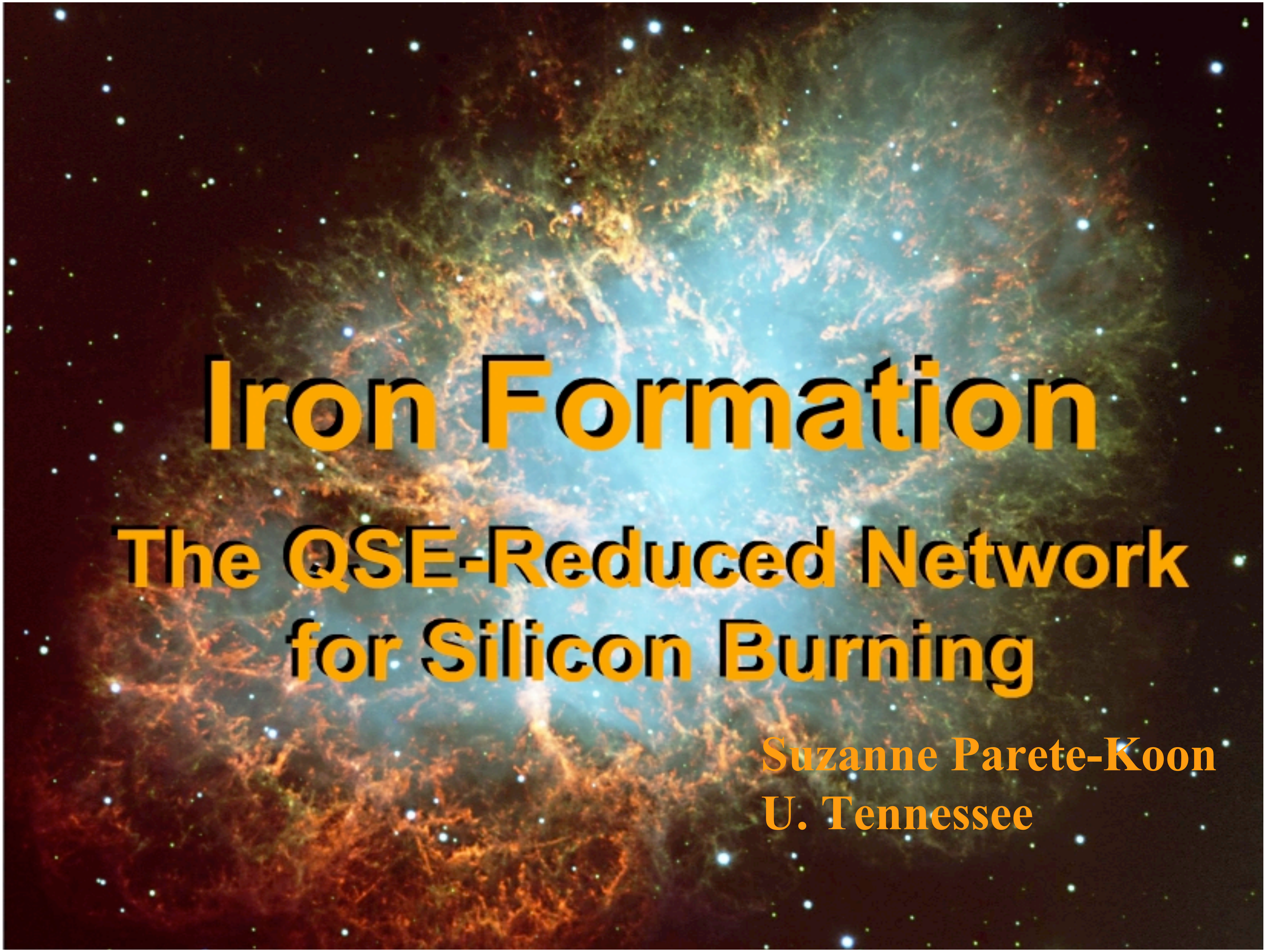
Iron Formation
The QSE-Reduced Network
for Silicon Burning
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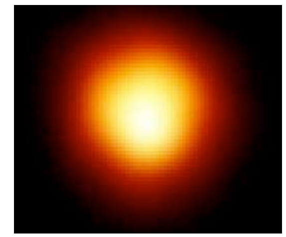
U. Tennessee

Challenges of Modeling Iron Formation



- Iron is formed by explosive silicon burning in supernovae and in the end stage of hydrostatic burning for stars that are more massive that 8 M_{Solar}
- Iron formation is computationally expensive to model because of the wide range of nuclei involved ~300 different coupled nuclear isotopes.
- Iron is the product of NSE.

Networks and Supernova Models

- Main functions of a nuclear reaction network:
  - Calculate the nuclear energy generation
  - Determine the abundances of nuclei produced
- Current Supernovae models use a 2 level scheme or an α-network to get the composition to NSE.
  - Missing important reaction channels for iron formation.
- Post Processing with a full network
  - Dependant on success of limited scheme used for energy generation
  - Can not take into account mixing of the different layers of fuel
- Needed- methods that allow reaction flows away from N=Z, without the cost of the full network

Quasi-Statistical Equilibrium QSE

Isolated groups of nuclei are in equilibrium with protons, neutrons and each other.

$$\mu_i = \mu_{\,^{28}\mathrm{Si}} + (Z\text{-}14)\,\mu_p + (N\text{-}14)\,\mu_n$$

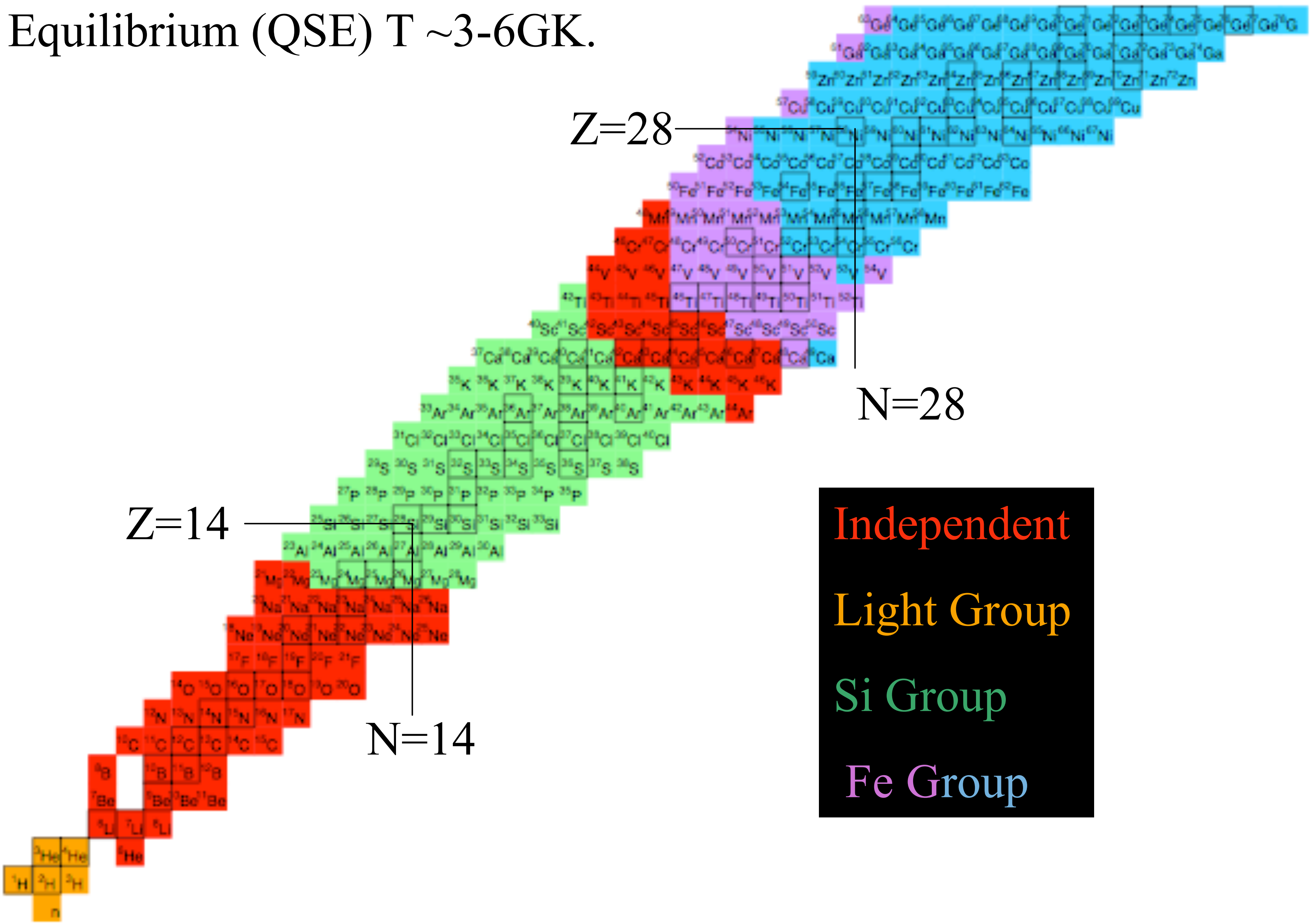
$$\mu_i = m_i c^2 + k_{\mathrm{B}} T \ln\left[\frac{Y_i \rho N_a}{G_i}\left(\frac{2\pi\hbar^2}{m_i k_{\mathrm{B}} T}\right)^{2/3}\right]$$

$$Y_{\mathrm{QSE,Si}}(^AZ) = \frac{C(^AZ)}{C(^{28}\mathrm{Si})} Y(^{28}\mathrm{Si}) Y_p^{Z-14} Y_n^{N-14} \;,$$

$$C(^AZ) = \frac{G(^AZ)}{2^A}\left(\frac{\rho N_A}{\theta}\right)^{A-1} A^{\frac{3}{2}} \exp\left(\frac{B(^AZ)}{k_{\mathrm{B}} T}\right) \;,$$

$$\theta = \left(\frac{m_u k_{\mathrm{B}} T}{2\pi\hbar^2}\right)^{3/2} \;.$$

BCF (1968) Quasi-Statistical Equilibrium (QSE) T ~3-6GK.



QSE-Reduced Network

- The heart of a reaction network is a matrix solution
- Speed scales as N^3
- Full Network N=299
- QSE reduced Network N=82

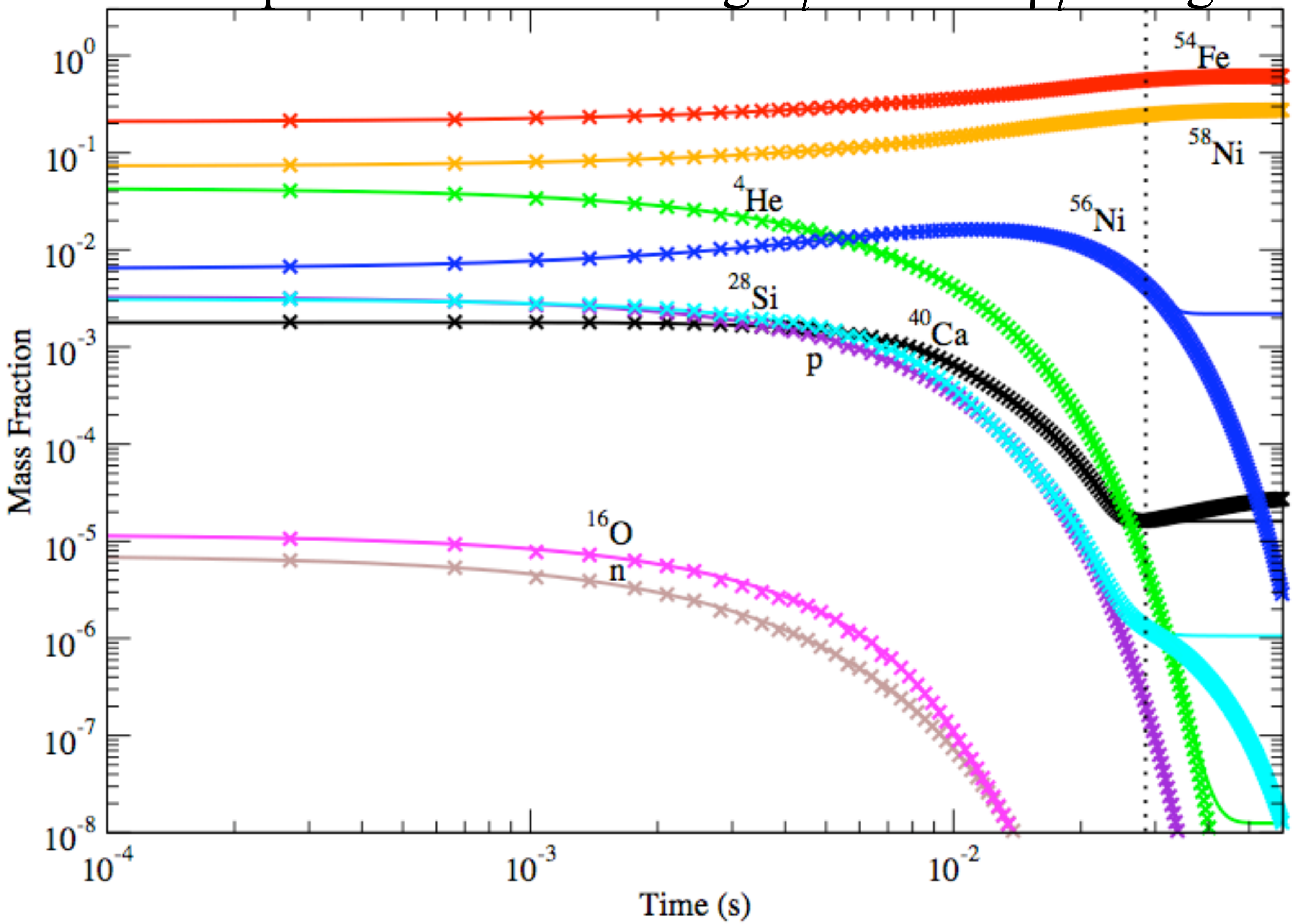
Table 4. Network Speed for Silicon Burning α-rich Freezeout

Network	Opteron cpu time (s)	Opteron matrix time (%)	Opteron Iteration count	Itanium2 cpu time (s)	Itanium2 matrix time (%)	Itanium2 Iteration count	Core Duo cpu time (s)	Core Duo matrix time (%)	Core Duo Iteration count	Pentium4 cpu time (s)	Pentium4 matrix time (%)	Pentium4 Iteration count
Vendor Supplied Solver												
LQSE	1.99	12	1640	2.41	13	1640	1.96	27	1381	4.88	12	1640
SQSE	4.11	18	2210	4.06	23	2184	4.23	42	1877	9.49	18	2186
Full	16.26	85	2174	17.04	89	2266	31.78	97	1414	39.77	77	2115
Compiled Solver												
LQSE	2.20	21	1647	3.06	34	1646	2.29	30	1369	5.15	16	1642
SQSE	5.06	37	2264	6.69	49	2241	5.12	49	1833	11.09	28	2246
Full	32.21	95	1980	39.36	97	1892	33.56	95	1487	200.85	96	1981

The most reduced network is 8-15 times faster than the full network

Initial Results

Incomplete Silicon Burning $T_i = 5$ GK $\rho_i = 10^9$ g cm^{-3}



Initial Results
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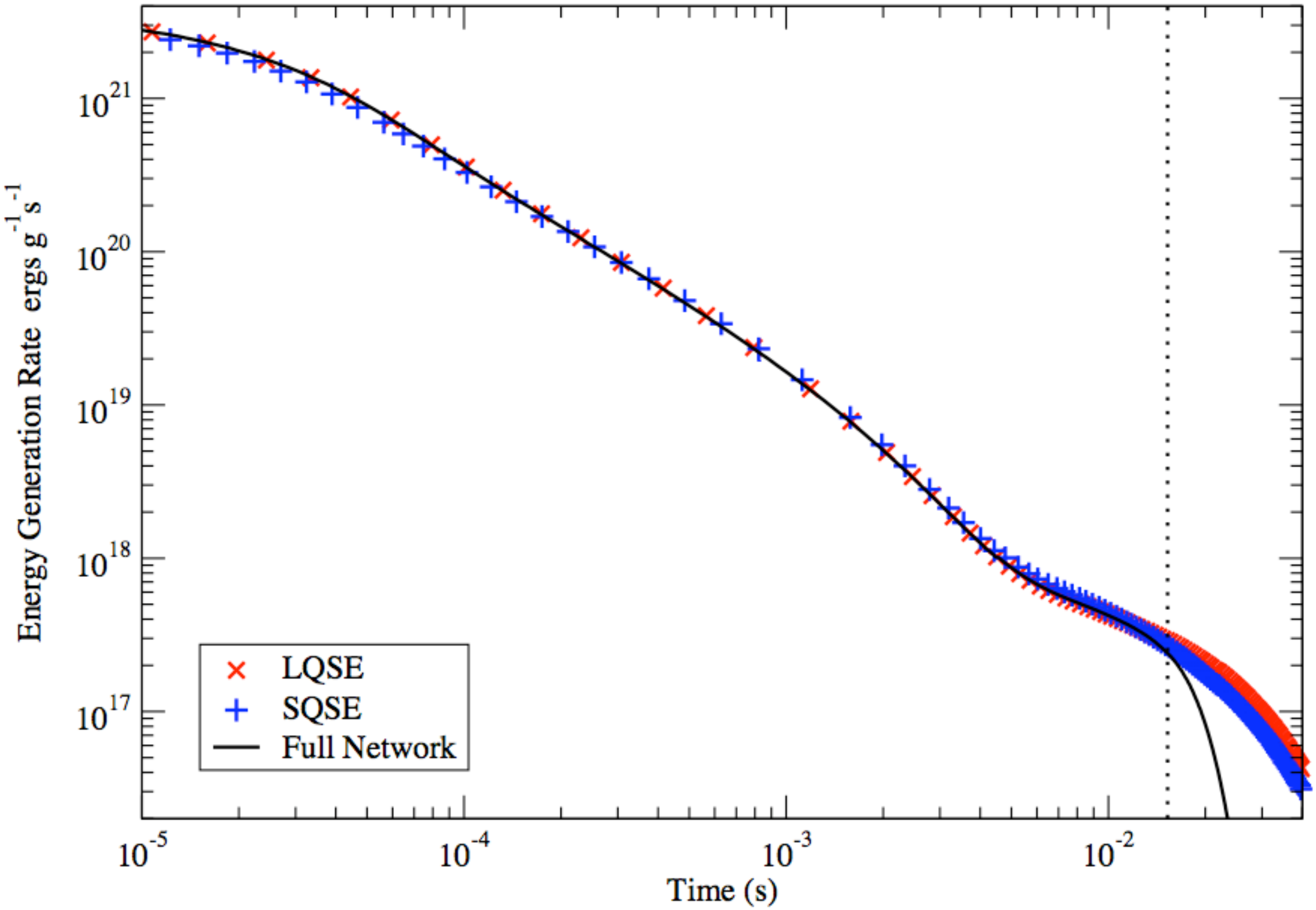

Initial Results
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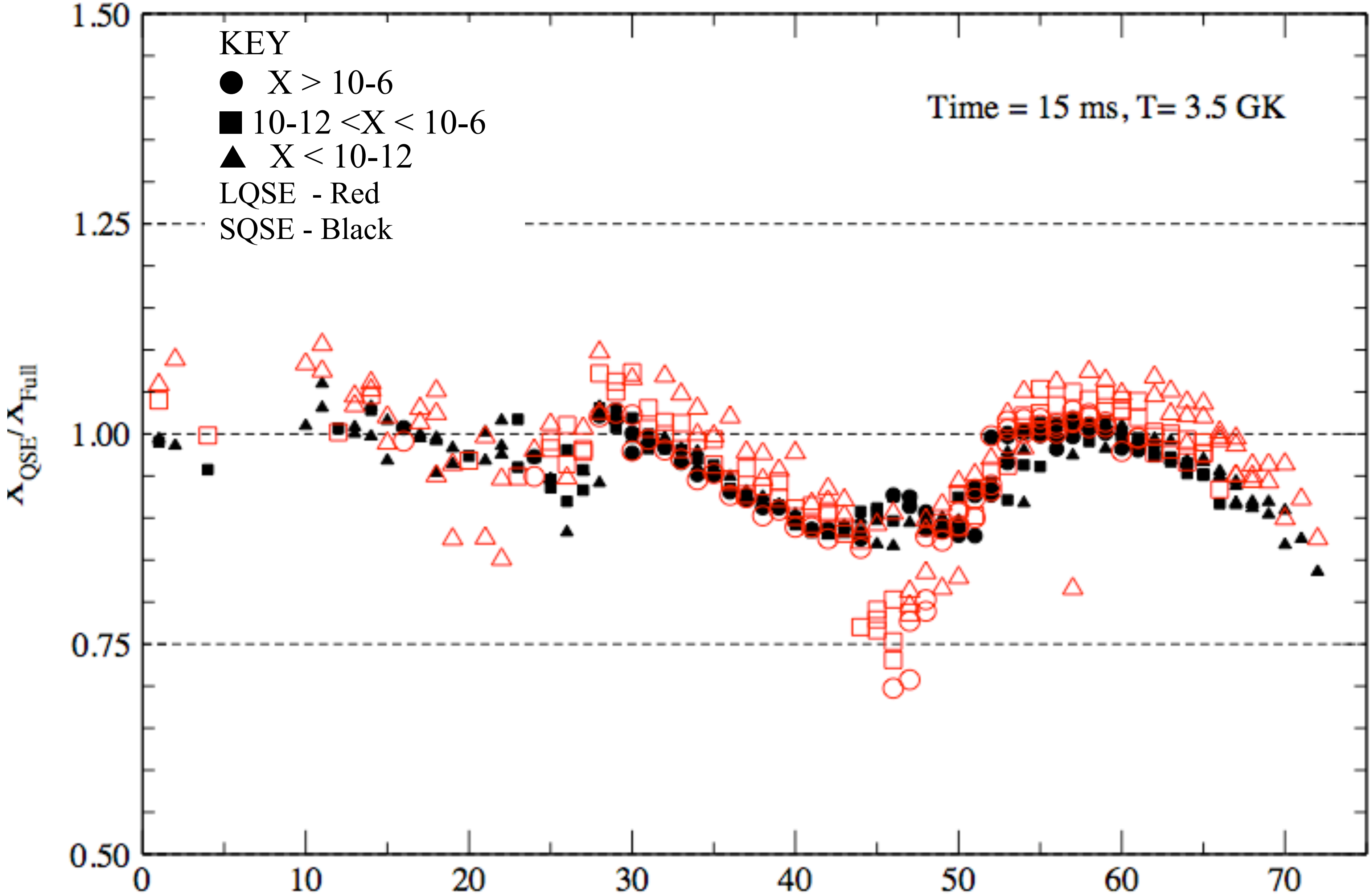

Conclusions

- **QSE-Reduced network runs an order of magnitude faster than the full network and**
- **matches the full network to 10% down to 3.5 GK for most isotopes.**

Future Work

- Build a dynamic QSE group algorithm.
- Test this dynamic QSE network in thermonuclear and core-collapse supernovae simulations

Thank You

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