A New View of the Approach to Core Collapse

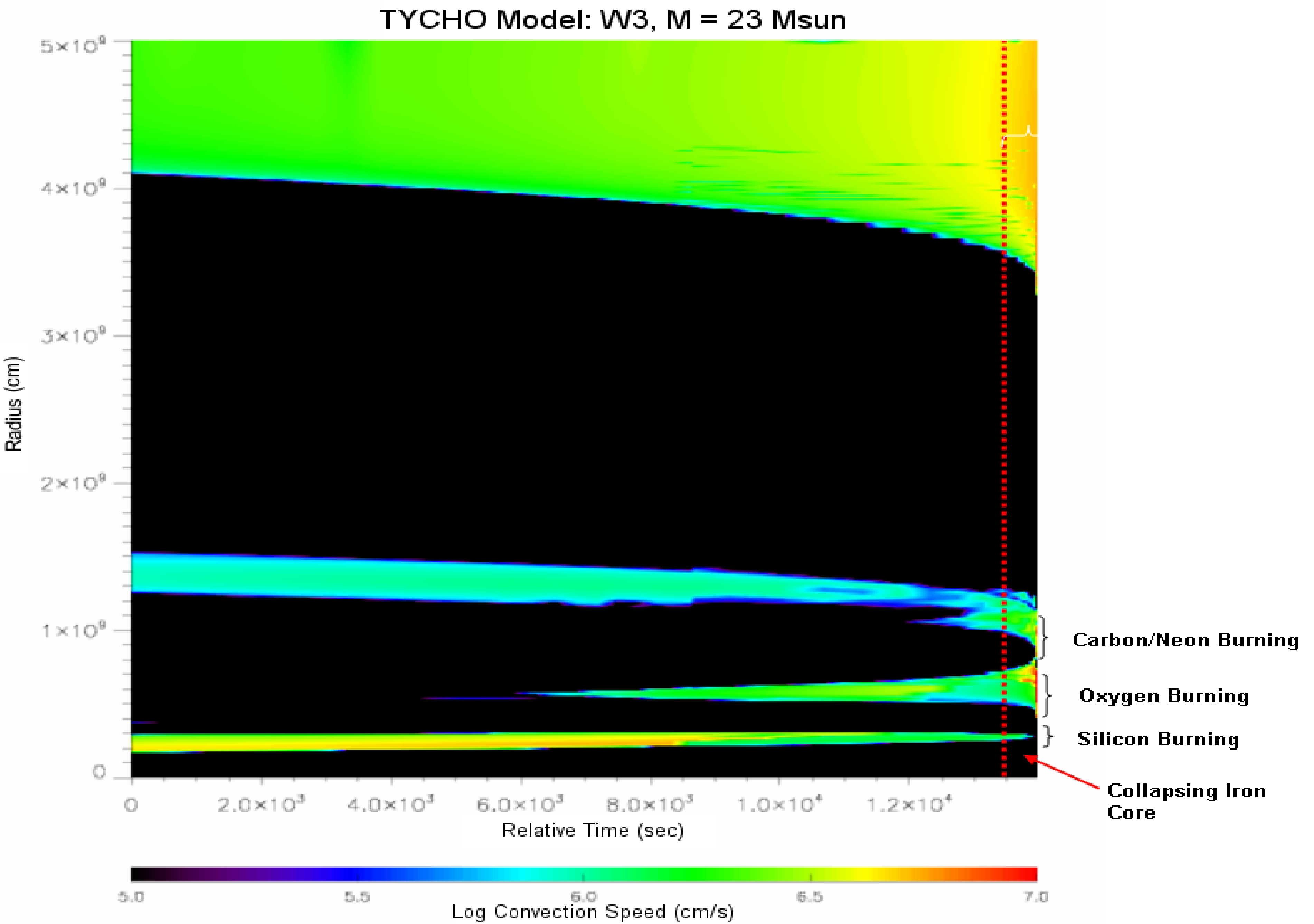
D. Arnett

and C. Meakin

Steward Observatory

1 D simulation of massive star evolution

- Convection is approximated by diffusive mixing
- Spherical symmetry is enforced
- Hydrostatic behavior is assumed
- Each of these assumptions is seriously wrong



TYCHO Model: W3, M = 23 Msun
Radius (cm)
5×10⁹
4×10⁹
3×10⁹
2×10⁹
1×10⁹
0
0
2.0×10³
4.0×10³
6.0×10³
8.0×10³
1.0×10⁴
1.2×10⁴
Relative Time (sec)
Carbon/Neon Burning
Oxygen Burning
Silicon Burning
Collapsing Iron Core
5.0
5.5
6.0
6.5
7.0
Log Convection Speed (cm/s)

2D versus 3D Hydrodynamics

- Two dimensional flow has absolute vortex pinning (like large cyclonic systems on Earth)
- Three dimensional flow is unstable toward vortex tilting (giving less ordered flow)
- Two dimension simulations are a hundred times less demanding of computer resources

2D vs 3D Hydrodynamics

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

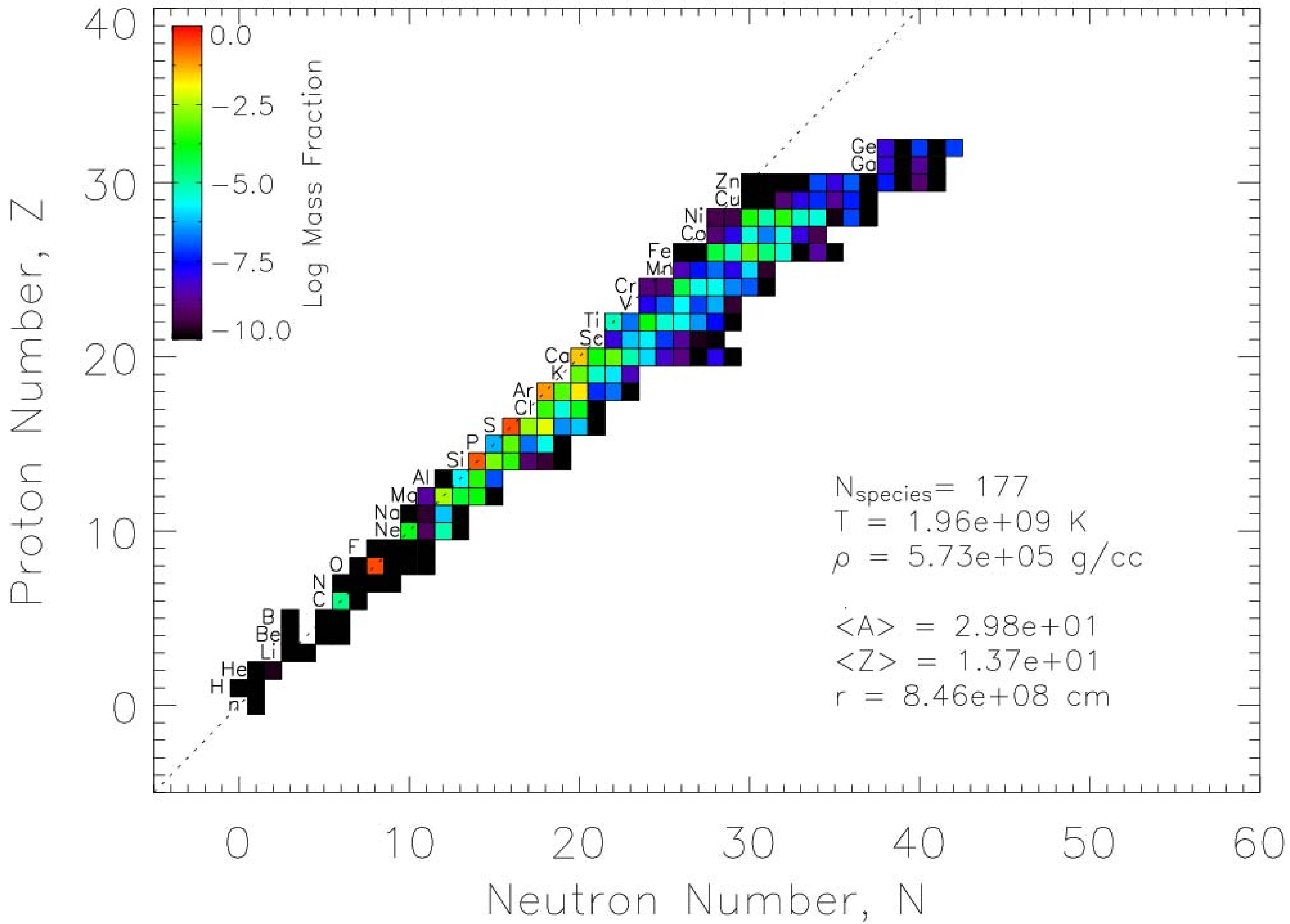
QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Implications

- Convection generates waves in neighboring radiative regions
- 2D convection is about 10 times more extreme than 3D convection
- Convective velocities are similar to MLT for alpha=2

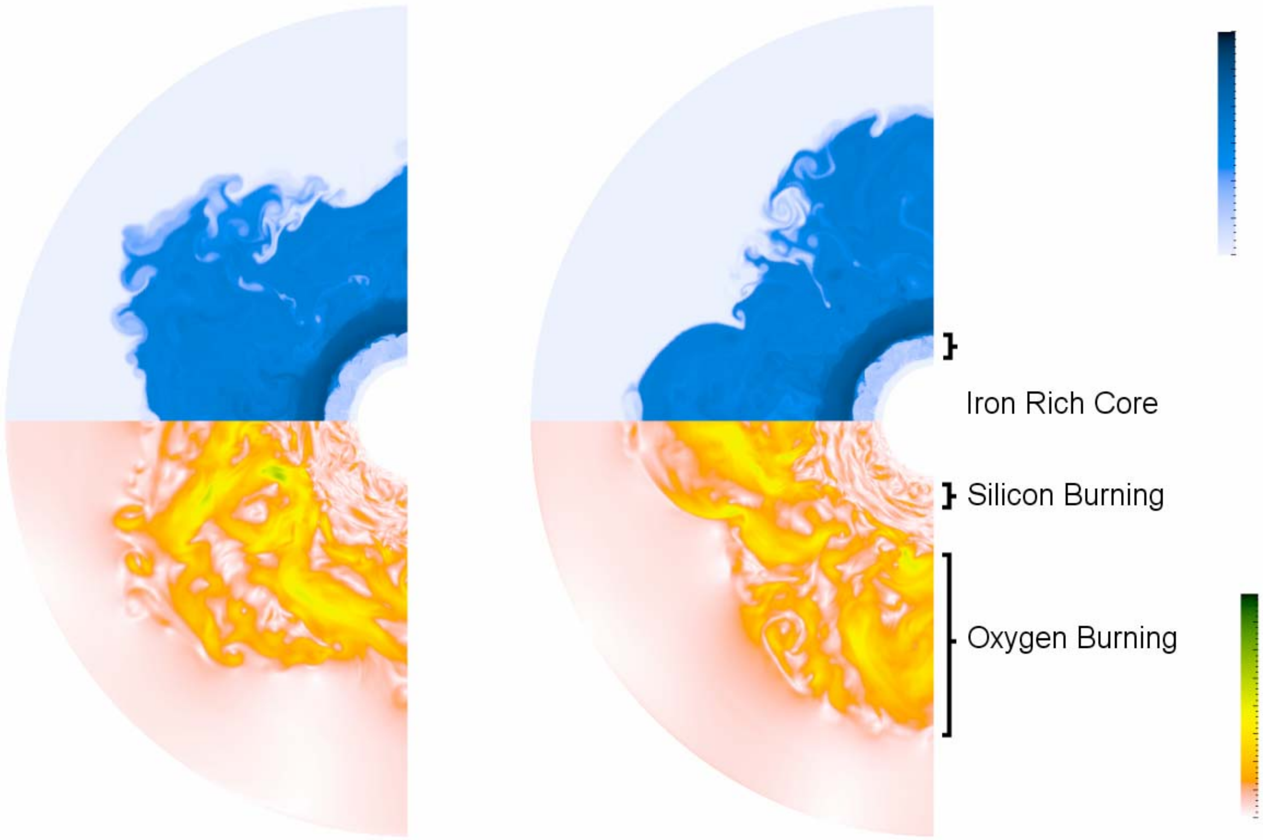
Oxygen burning

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.



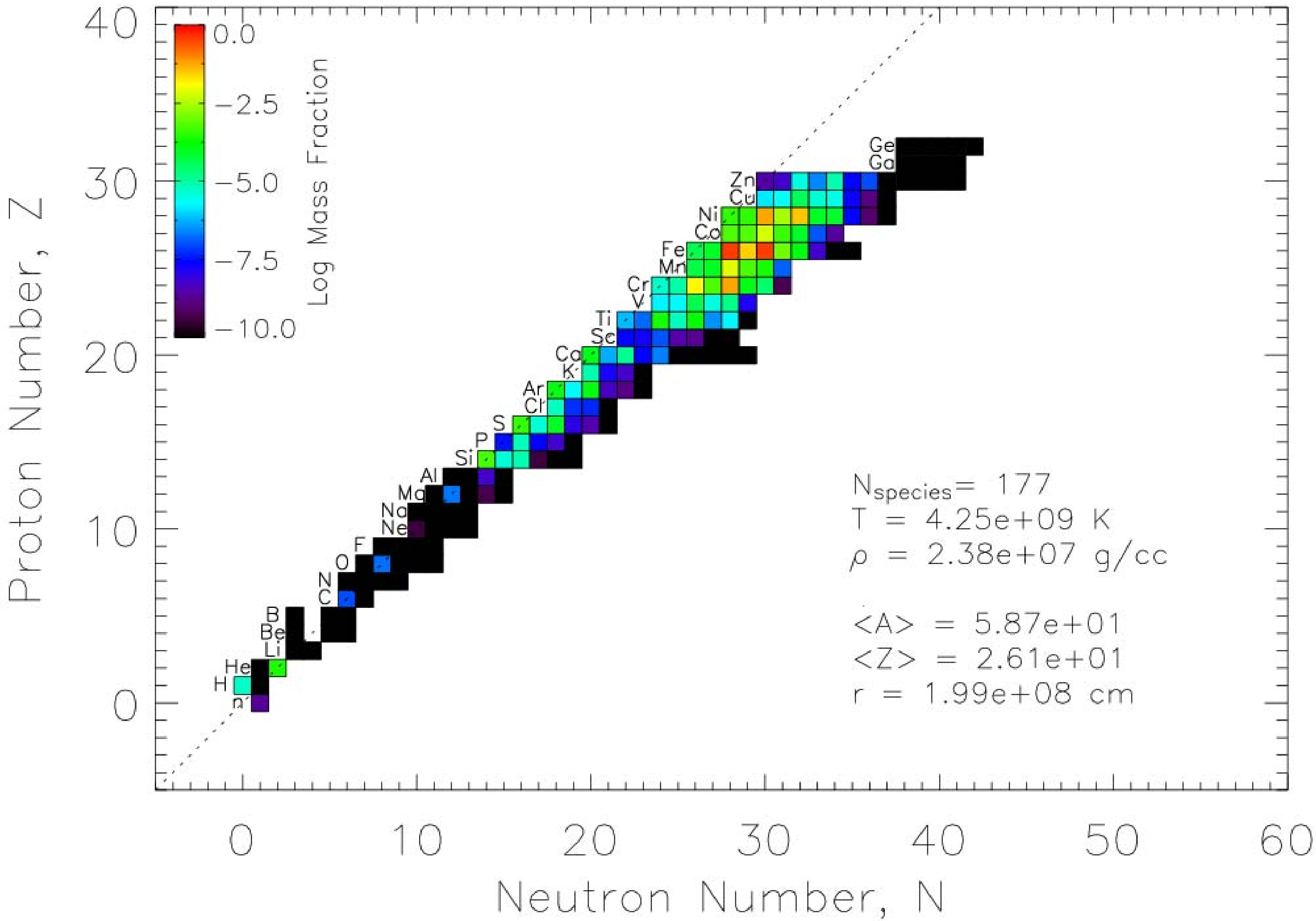
0.0
−2.5
−5.0
−7.5
−10.0
Log Mass Fraction
Proton Number, Z
Neutron Number, N
n
H
He
Li
Be
B
C
N
O
F
Ne
Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
$N_{species}$ = 177
T = 1.96e+09 K
ρ = 5.73e+05 g/cc
<A> = 2.98e+01
<Z> = 1.37e+01
r = 8.46e+08 cm

Multiple Burning Shells



C, Ne, O, and Si Shells (2D)

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.



0.0
−2.5
−5.0
−7.5
−10.0
Log Mass Fraction
Proton Number, Z
Neutron Number, N
n
H
He
Li
Be
B
C
N
O
F
Ne
Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
N_{species}= 177
T = 4.25e+09 K
ρ = 2.38e+07 g/cc
<A> = 5.87e+01
<Z> = 2.61e+01
r = 1.99e+08 cm

What do we conclude?

- Late stages (C,Ne,O,SI) are dynamic
- Late stages are non-spherical
- Late stages have strong shell interactions
- Late stages are significantly and qualitatively different from even the best 1D simulations
- These differences grow with approach to core collapse
- Rotation will couple to wave physics

Where do we go from here?

- “URCA” processes in Si burning (reduced networks)
- Approach to Collapse (2D is feasible)
- 3D multiple shells (computationally demanding)
- Project 3D physics back to 1D models