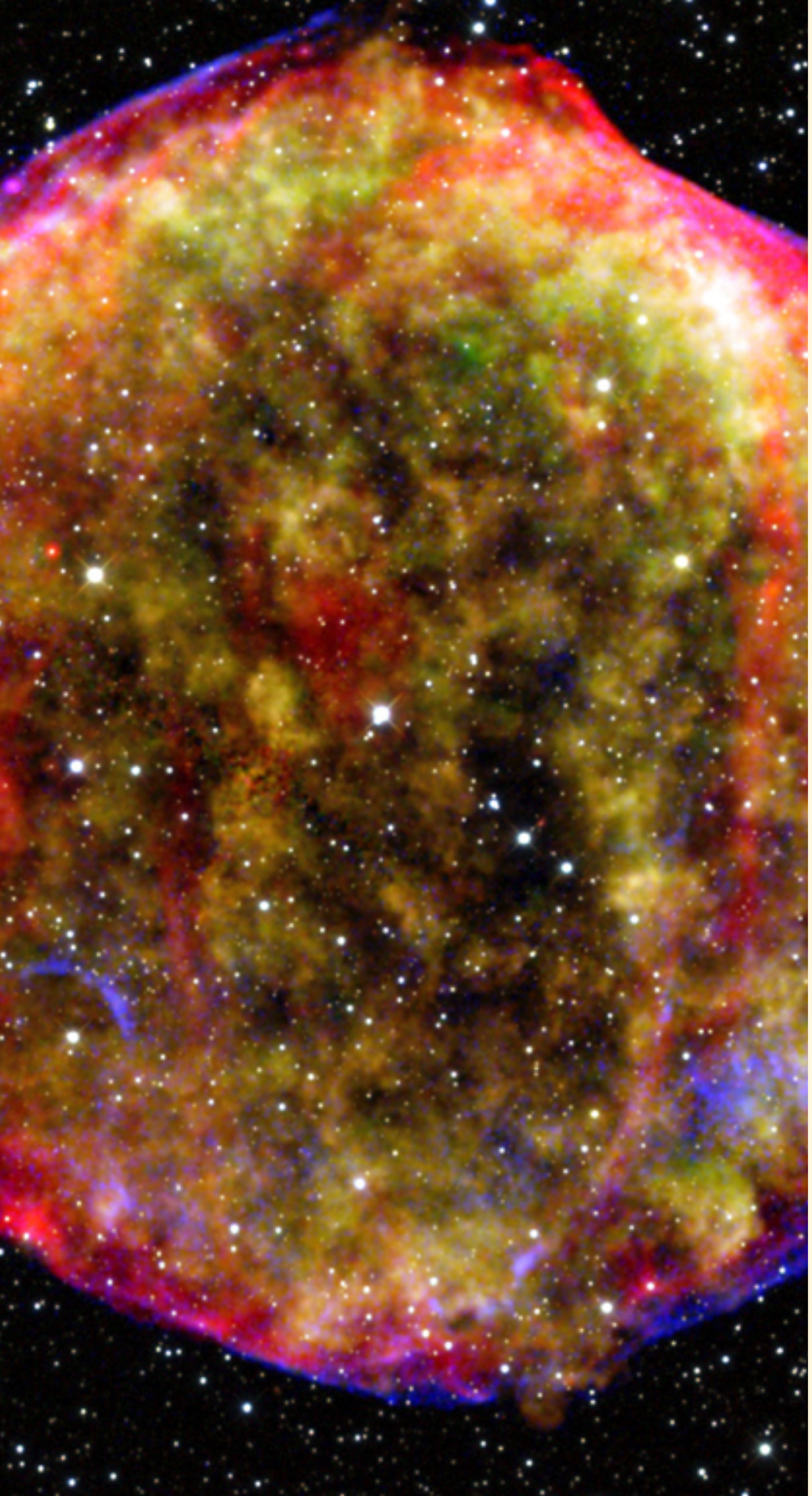


Neutronization and weak reactions in SNe Ia

Edward Brown
Michigan State University

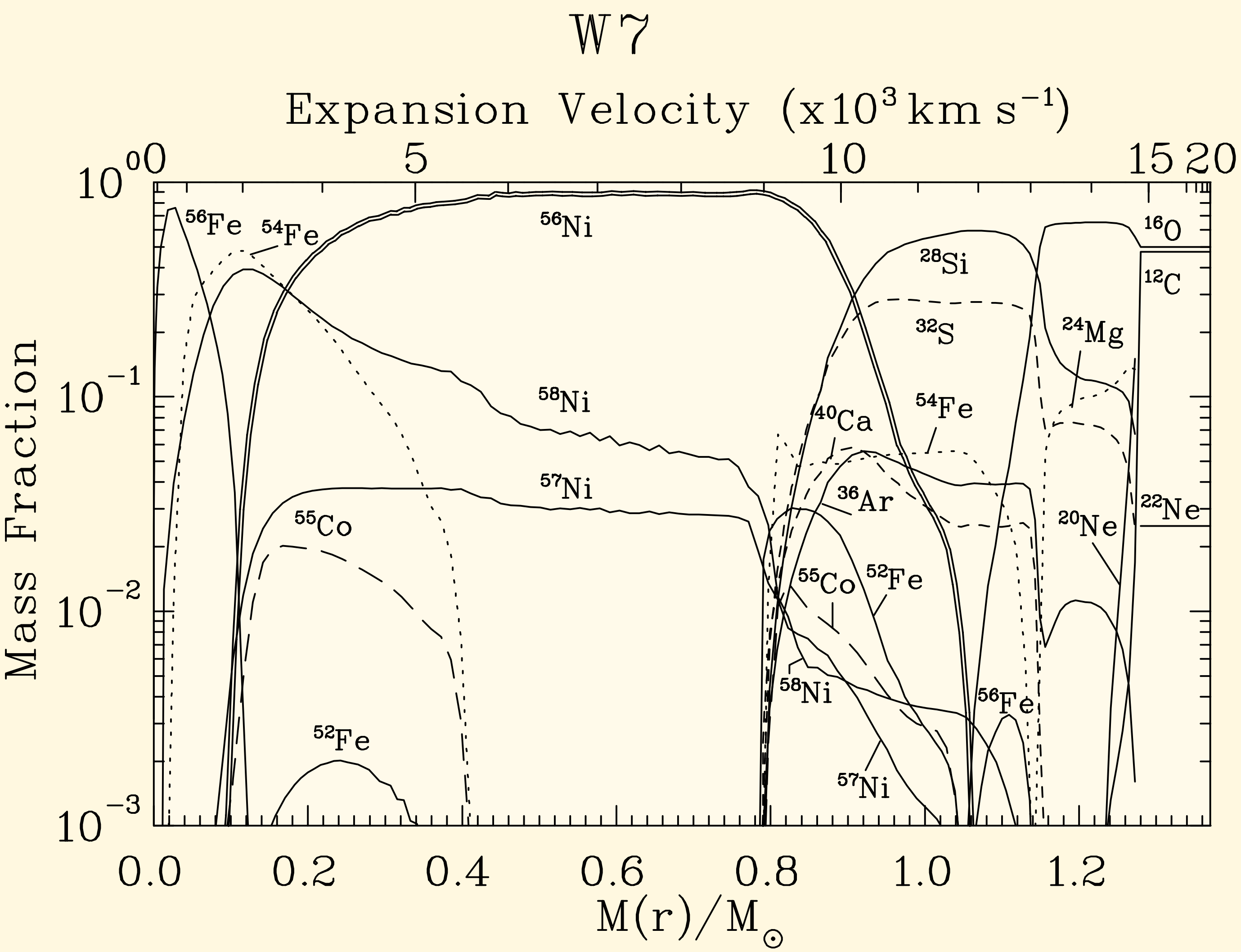
In this talk:

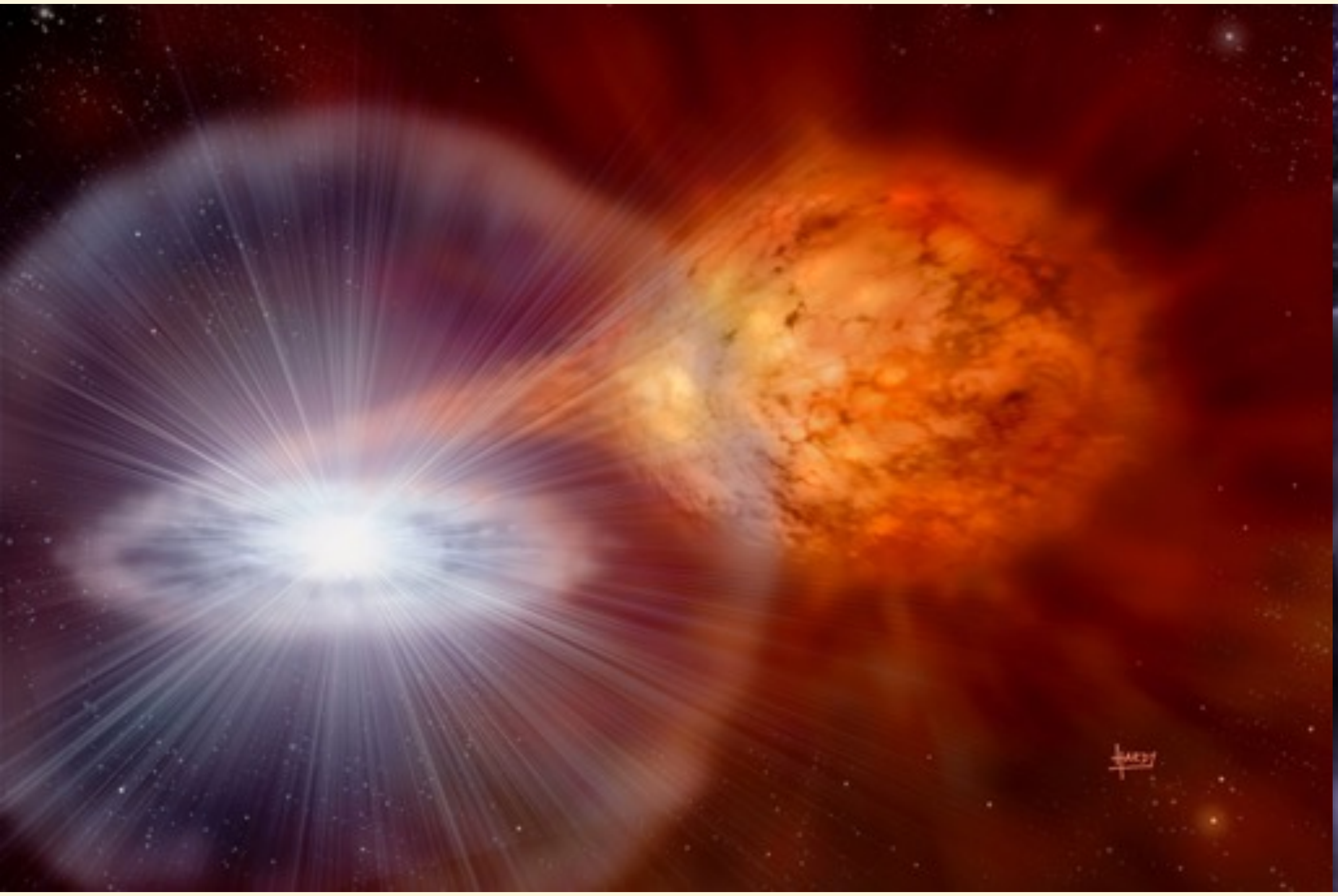
1. when and where do electron captures occur, and how they affect the explosion
2. how to look for their effects
3. nuclear physics inputs

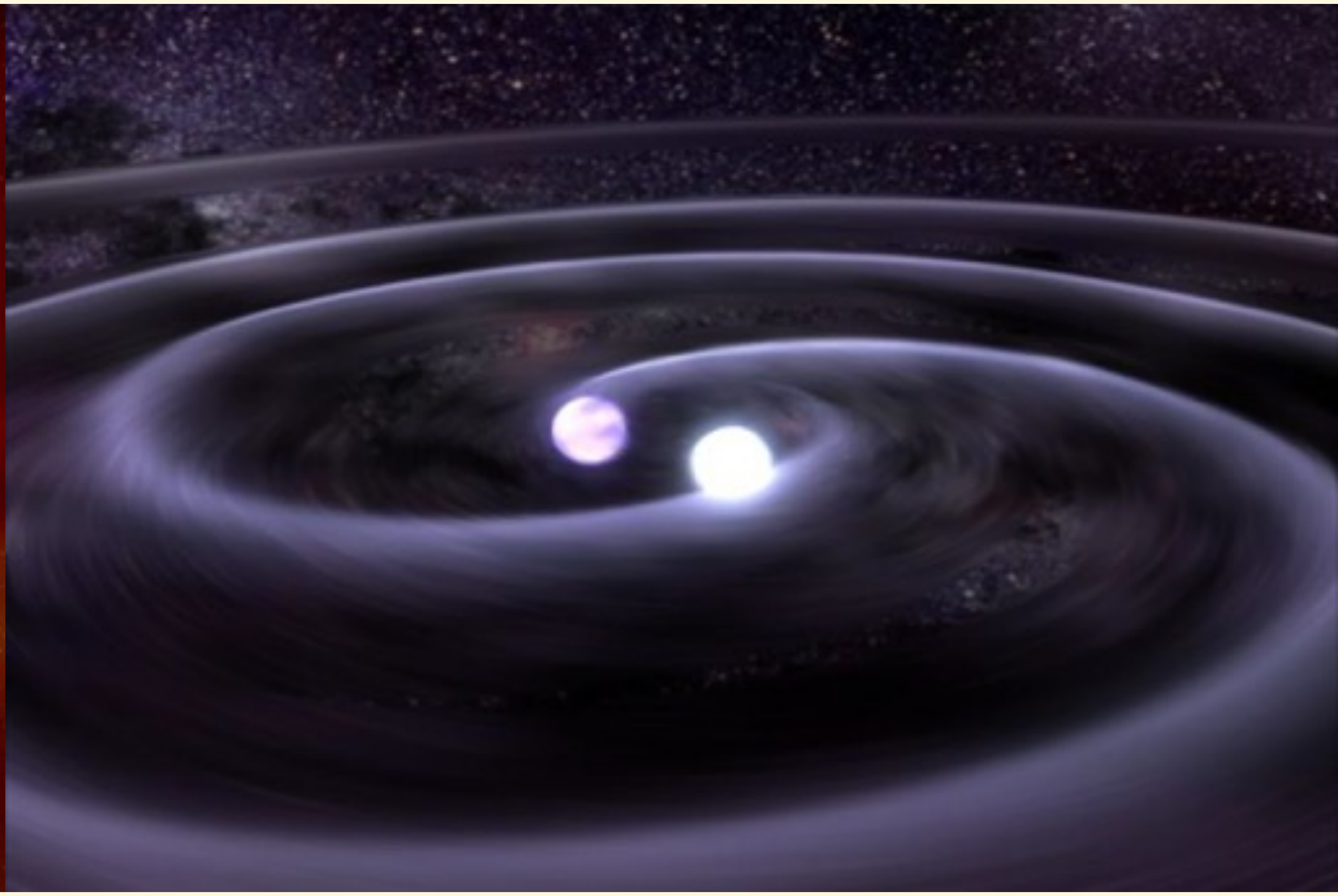
to get an explosion to look (superficially) like a Ia…

…detonate ≈ $1 M_{sun}$ C-O WD with a central density $\approx 10^8$ g cm^{-3} (Woosley, yesterday)

There are potentially many ways to do this.





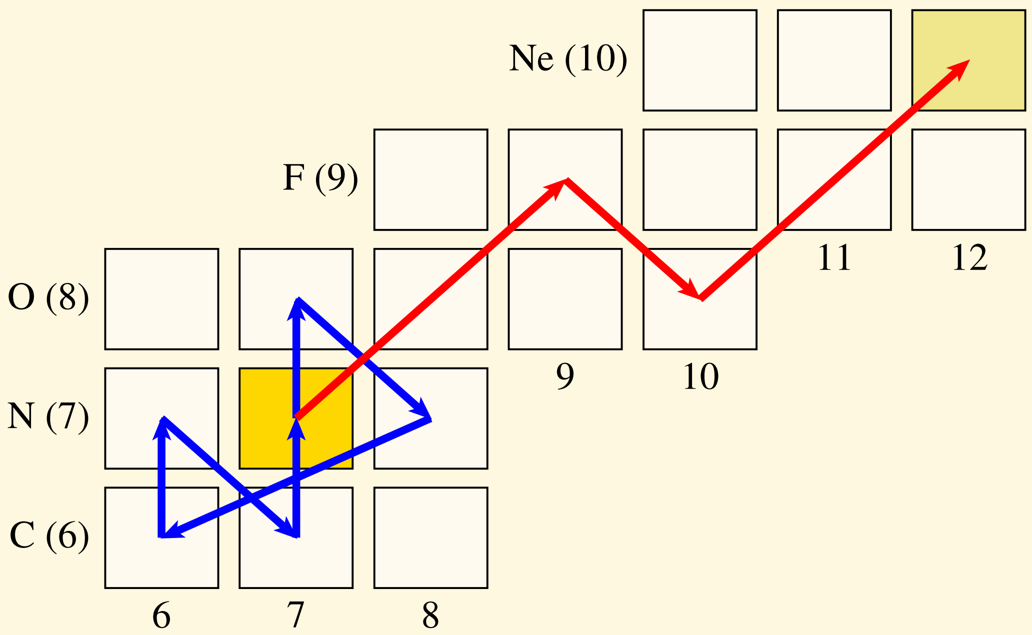


Evidence that at least some SNe Ia come from near M_{Ch} WDs with high central densities

Abundance of ^{55}Mn (Seitenzahl ’13; next talk)

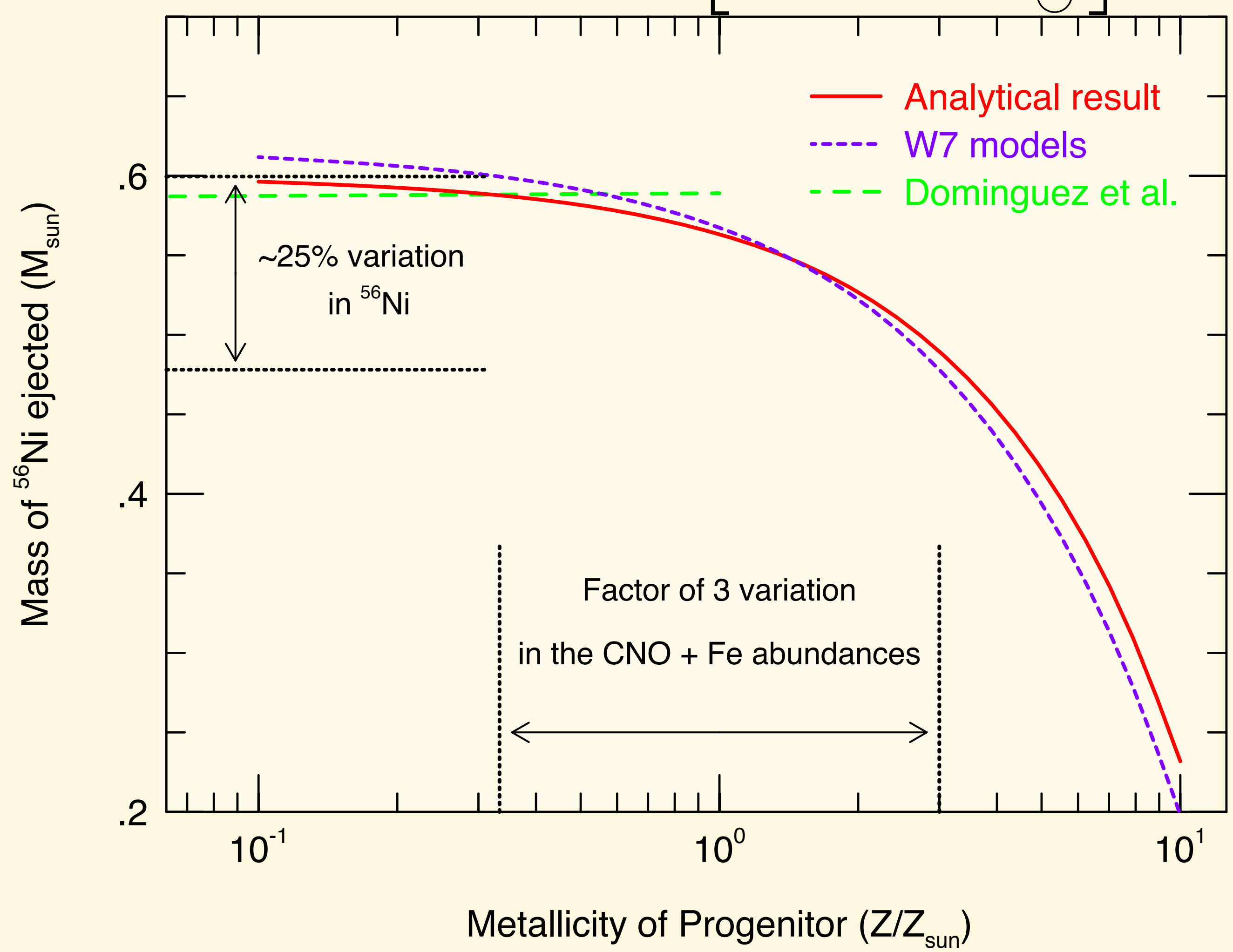
late-time NIR spectroscopy of 2005df suggests $\rho \approx 10^9$ g cm^{-3} (Diamond et al. ’15)

MS CNO abundance sets starting neutron-to-proton ratio



For a solar distribution of metals,

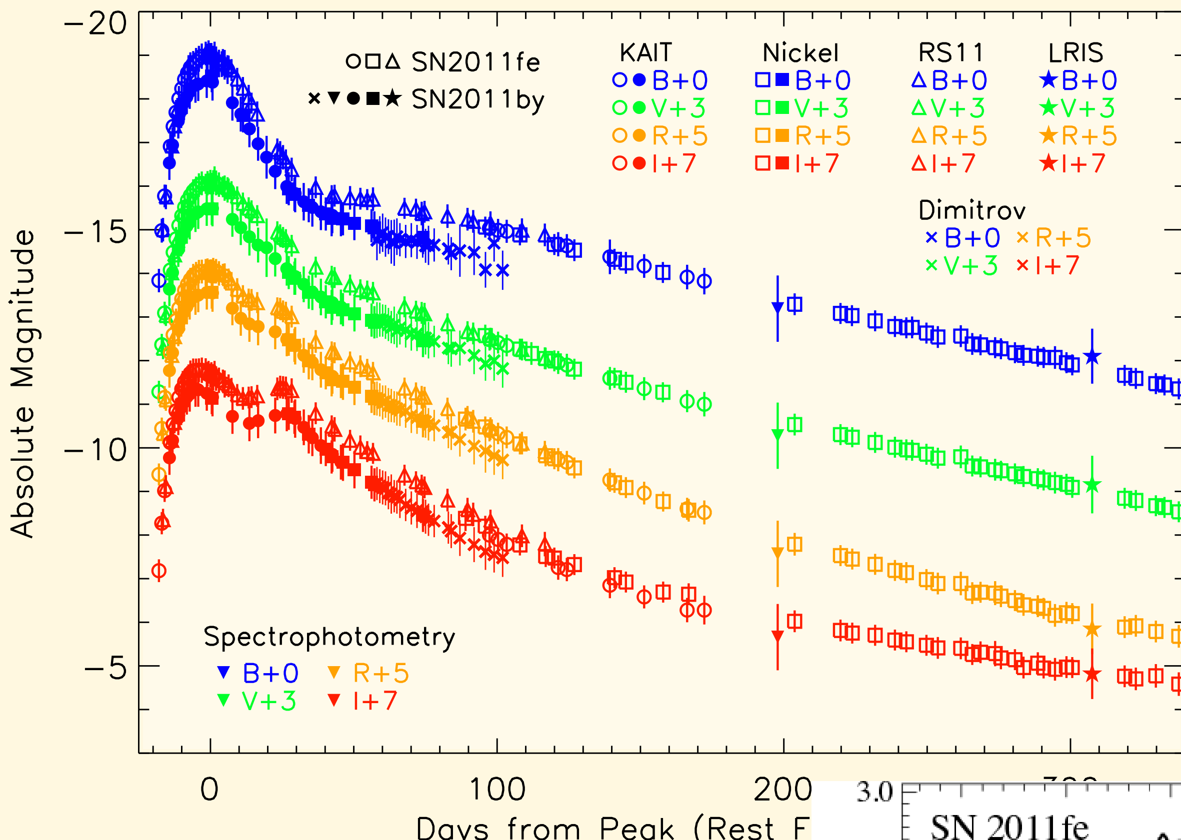
$$M(^{56}\mathrm{Ni}) = M_0(^{56}\mathrm{Ni})\left[1 - 0.057\frac{Z}{Z_\odot}\right]$$



Explosion dynamics insensitive to ^{22}Ne abundance; Townsley et al. '09

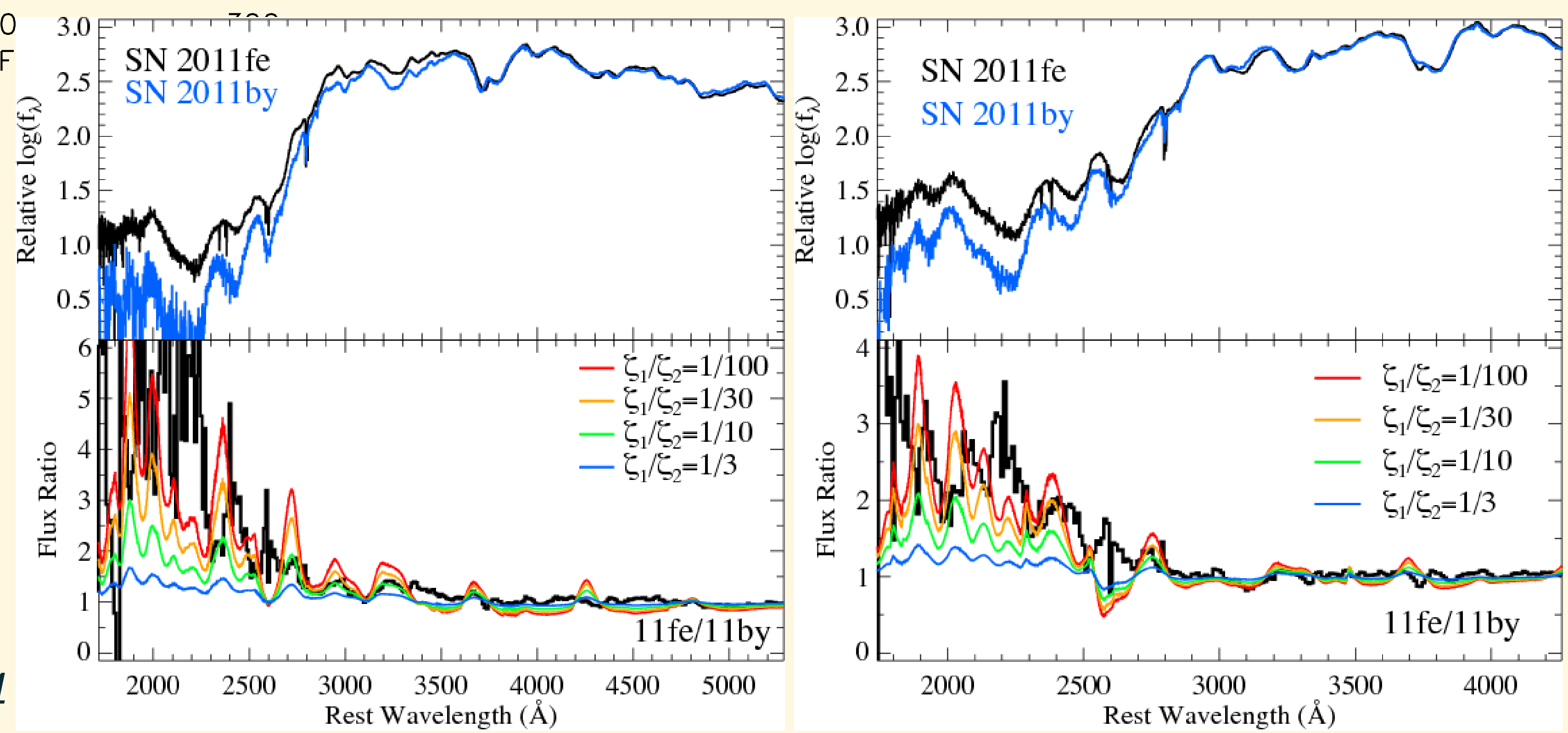
Can account for ≈10% of ^{56}Ni variation (Howell et al. '09)

Testing this relation with the “twins” 2011fe, 2011by (see talk by Graham)



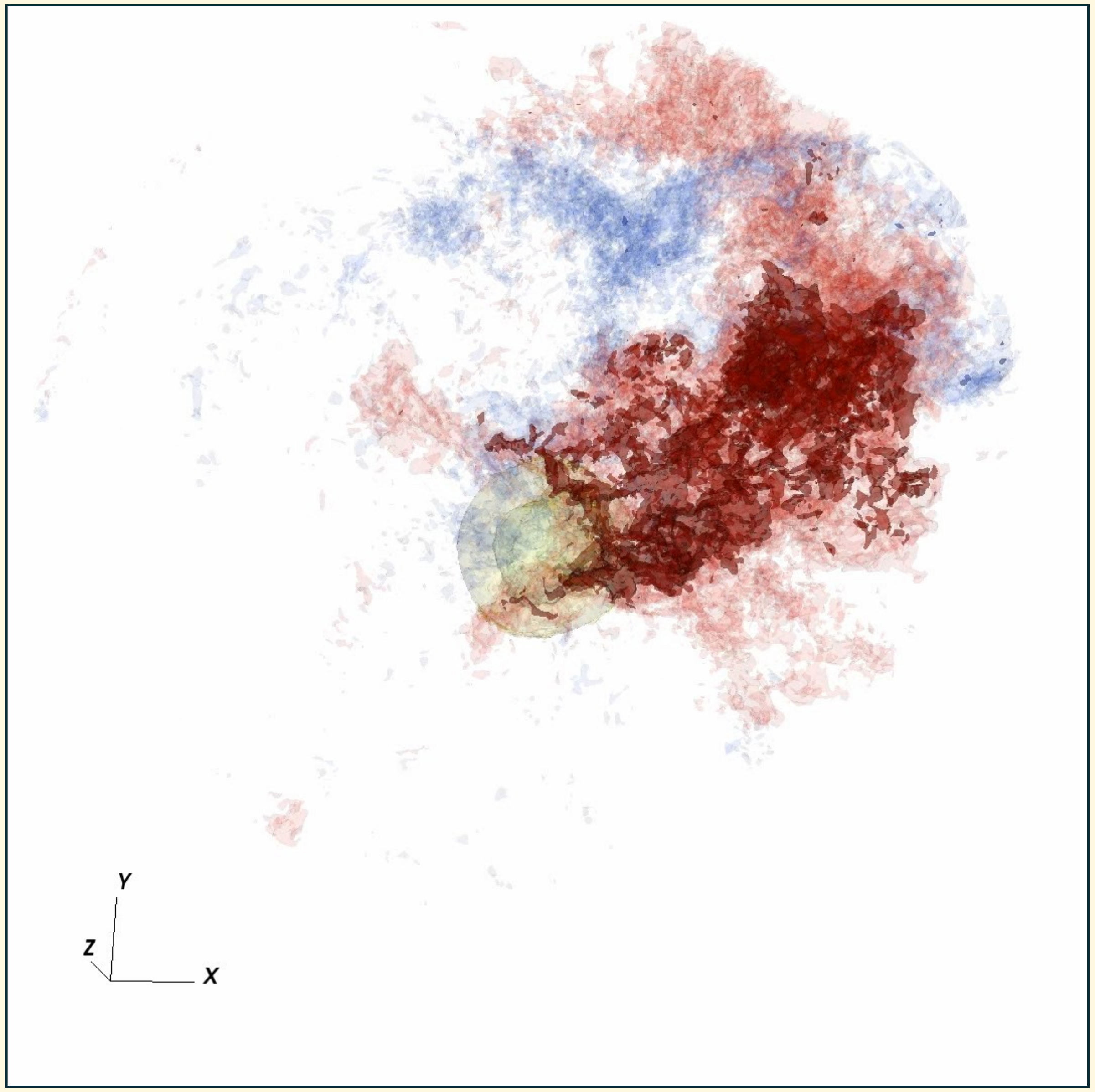
Production of stable ^{58}Ni, ^{54}Fe affects NUV (Lentz et al., Sauer et al.)

Foley & Kirshner ’13, Graham et al. ‘14



simmering

Nonaka et al. 2012; image courtesy M. Zingale

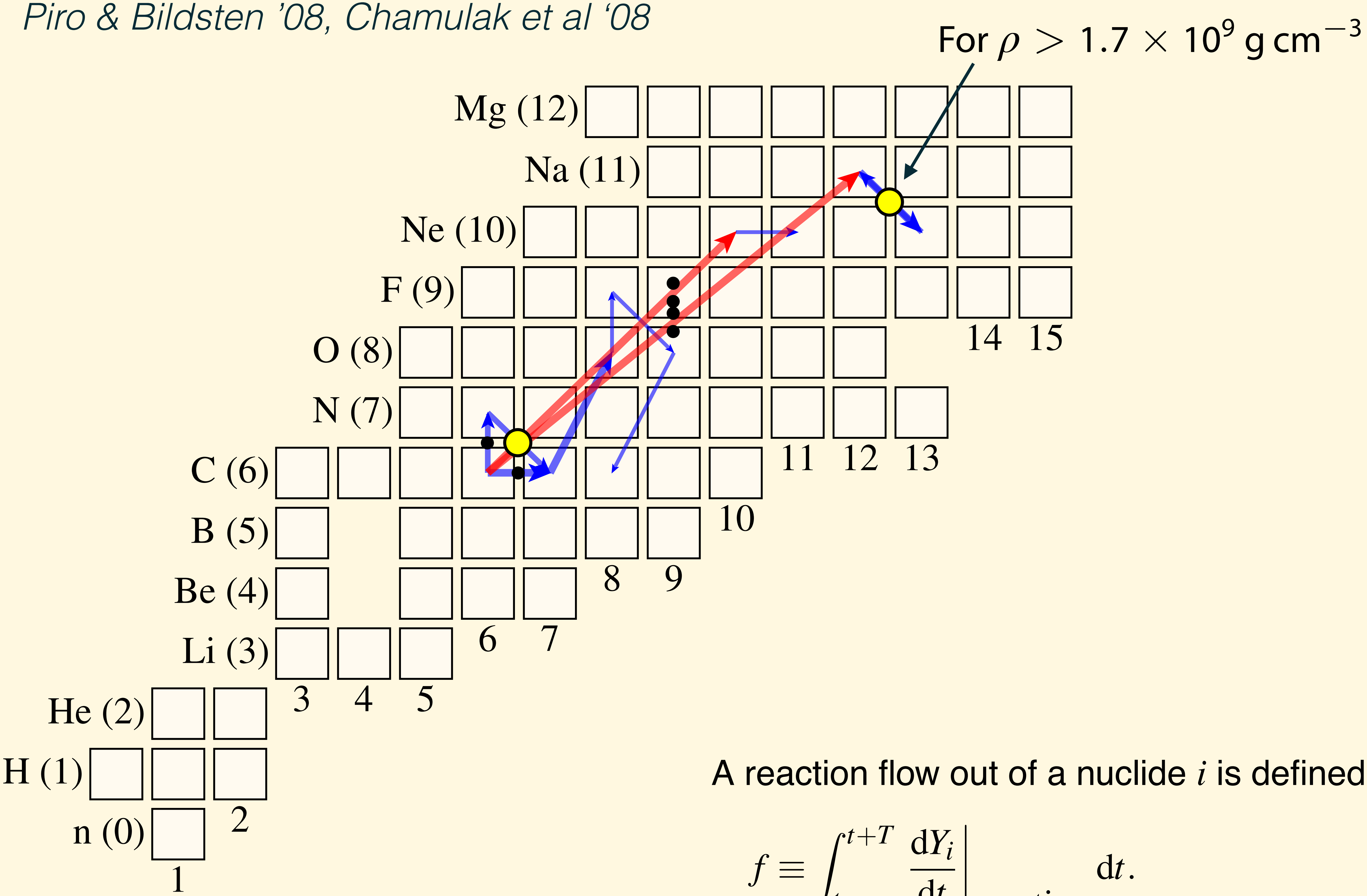


Thermal instability begins with $T \approx 3 \times 10^8$ K. Over $(100\text{–}1000)$ yr the core temperature rises to $\approx 8 \times 10^8$ K at which point the heating timescale is $\sim$ 10 s and the flame is launched. This heating requires $\sim$ 10^{49} erg.

Woosley et al. (04)

neutronization during simmering

Piro & Bildsten '08, Chamulak et al '08

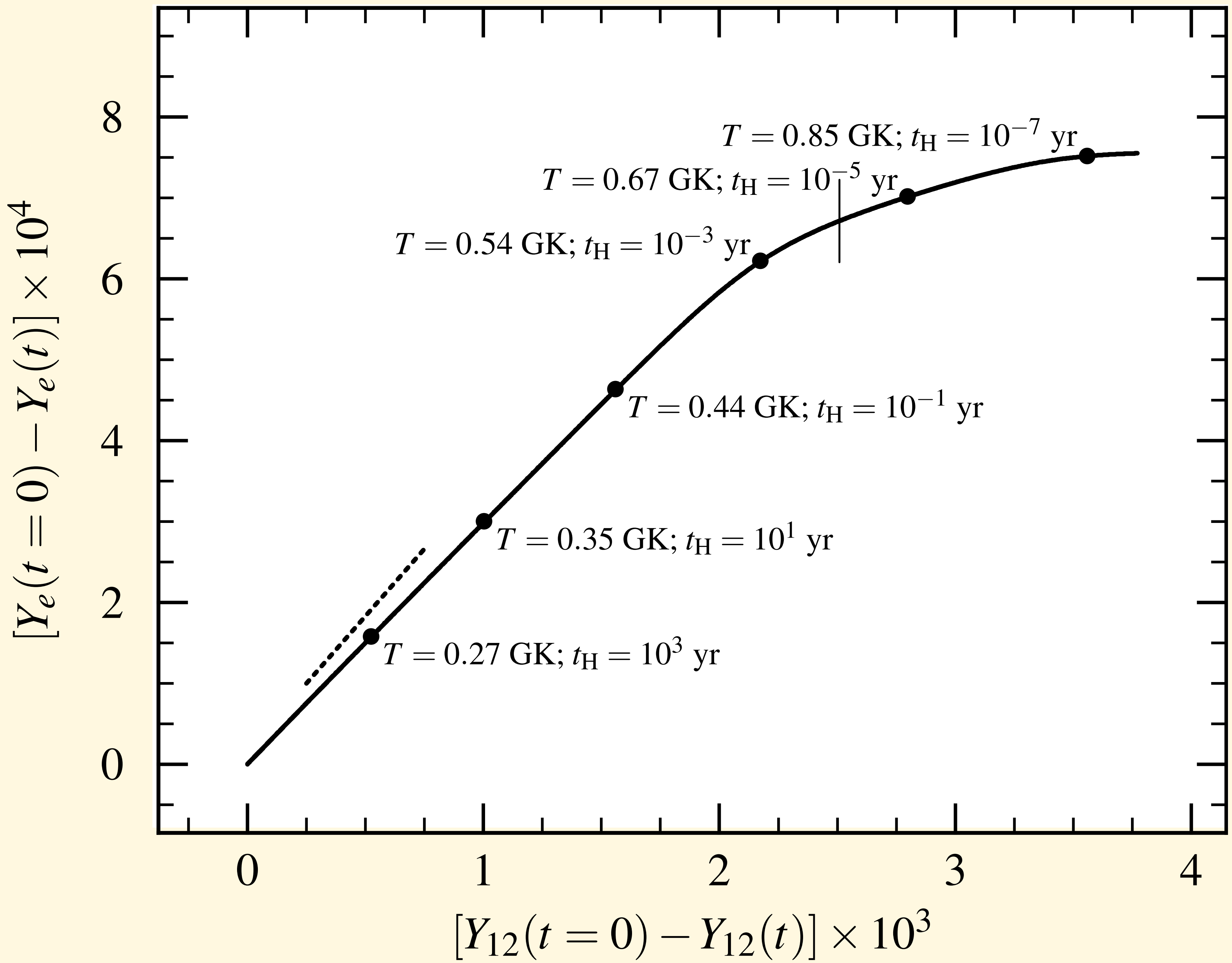


A reaction flow out of a nuclide i is defined by

$$f \equiv \int_t^{t+T} \left.\frac{dY_i}{dt}\right|_{\text{reaction}} dt.$$

decrease in e- abundance (equivalent to $X(^{22}\mathrm{Ne})$ from $Z \approx 2/3\ Z_{\mathrm{sun}}$)

Piro & Bildsten '08; Chamulak et al. '08



QSE products are sensitive to Y_e

In burn to intermediate mass elements, charge and mass conservation, and assuming clusters are in equilibrium gives

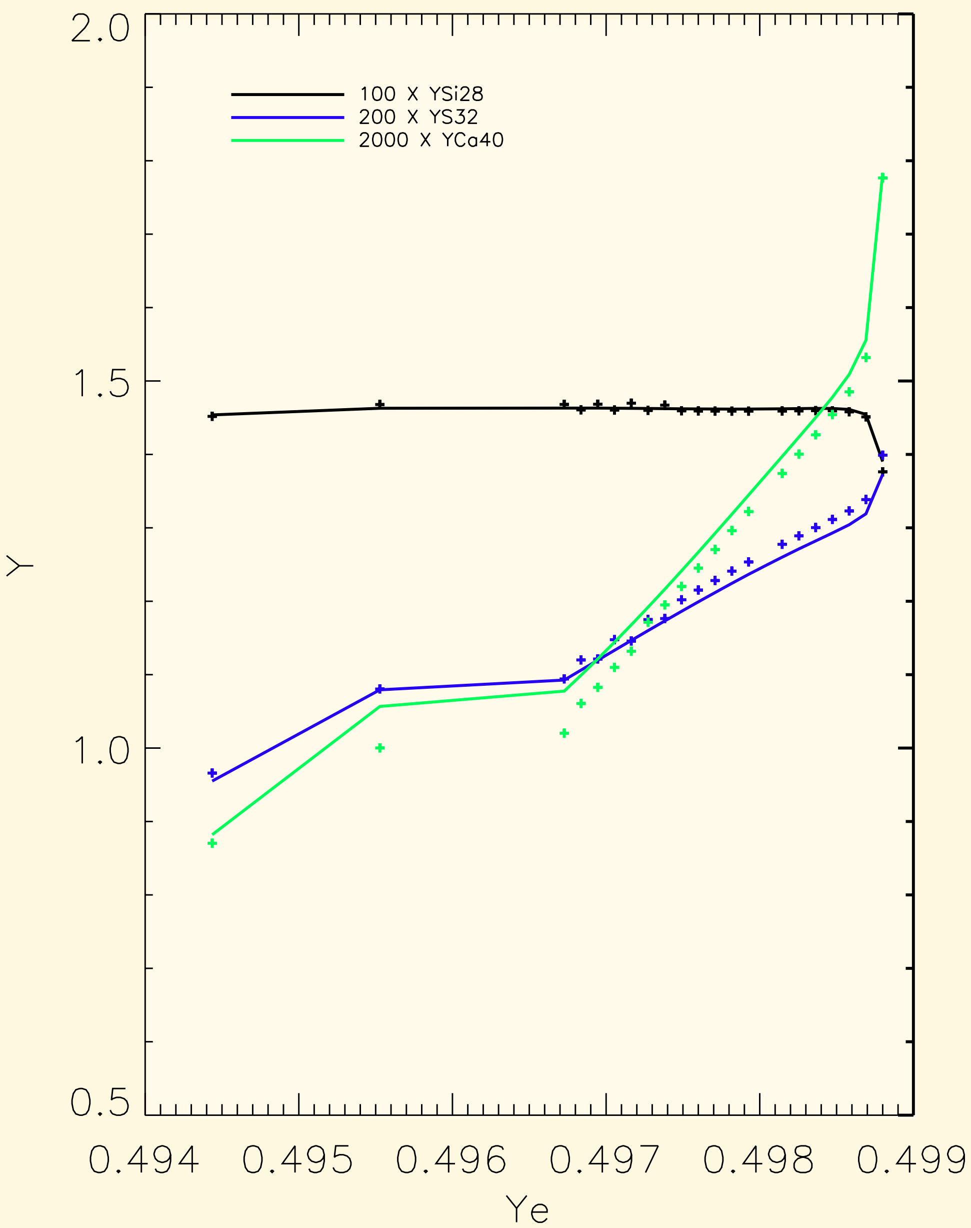
$$Y_e = Y_{28Si}\left[14 + 16\frac{Y_{32S}}{Y_{28Si}} + 20\frac{Y_{40Ca}}{Y_{32S}}\frac{Y_{32S}}{Y_{28Si}} + 26\frac{Y_{54Fe}}{Y_{28Si}} + 28\Psi\frac{Y_{32S}}{Y_{28Si}}\frac{Y_{54Fe}}{Y_{28Si}}\right],$$

where

$$\Psi \approx \exp\left(\frac{6.36}{T_9}\right)$$

A more comprehensive study (post-processing DDT) is in preparation (Miles, van Rossum, Townsley et al.)

De et al. '14




R. São Clemente
Urca
R. Barata Ribeiro
Av. Ns. de Copacabana
Freitas
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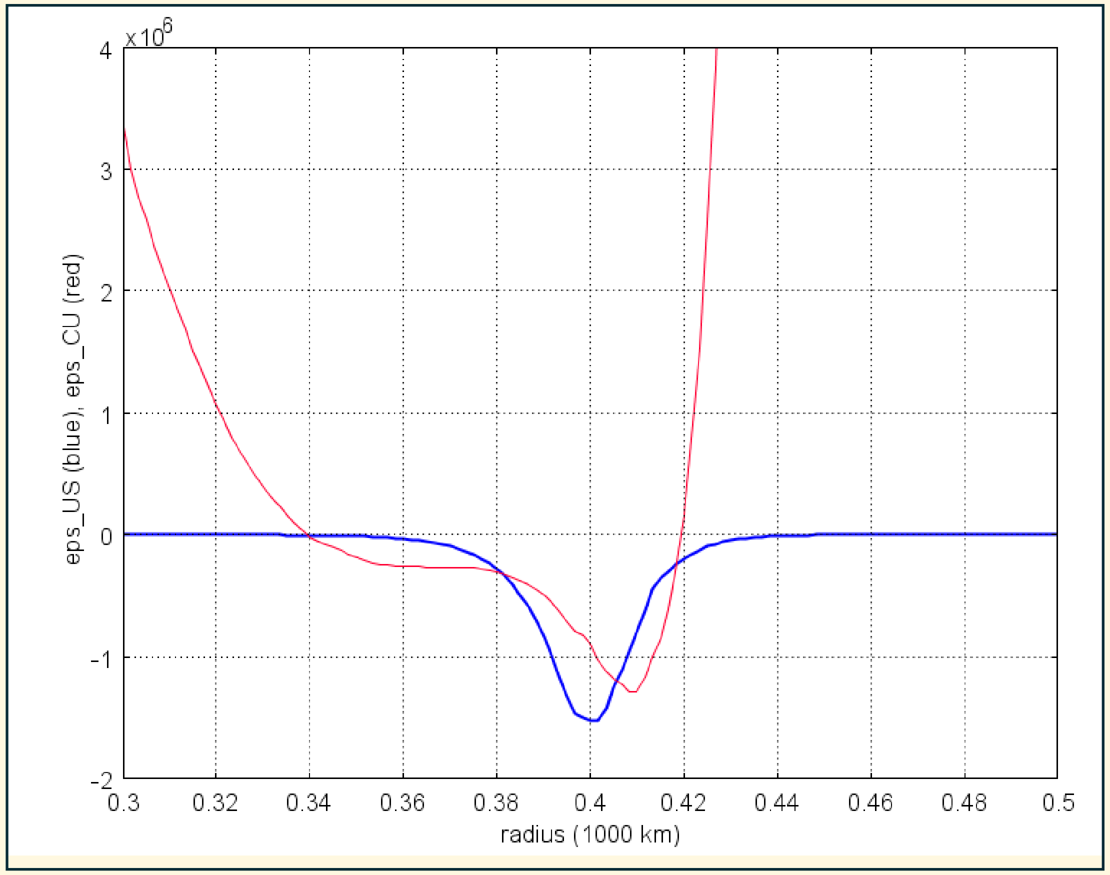
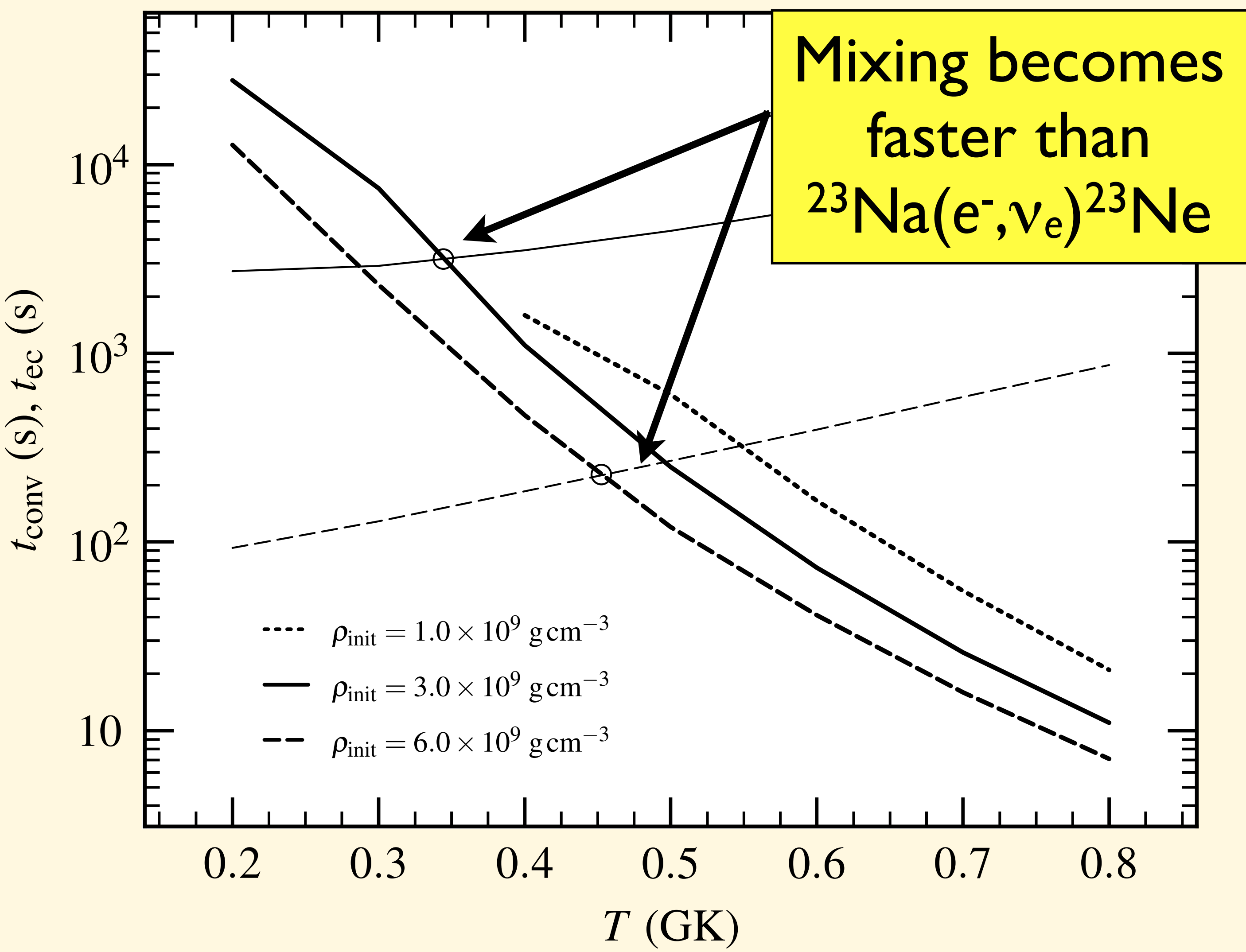
convective Urca

Denissenkov et al. '15



electron captures/beta decays on ^{23}Na, ^{25}Mg affect the convective flow (Paczynski, Barkat & Wheeler, Iben, Mochkovitch, Stein & Wheeler)

Chamulak et al. '08



Energy loss via neutrinos acts as a bulk viscosity (Bisnovatyi-Kogan '01); confines convective zone. This is not accounted for in MLT (Lesaffre et al. '05; Denissenkov et al. '15)

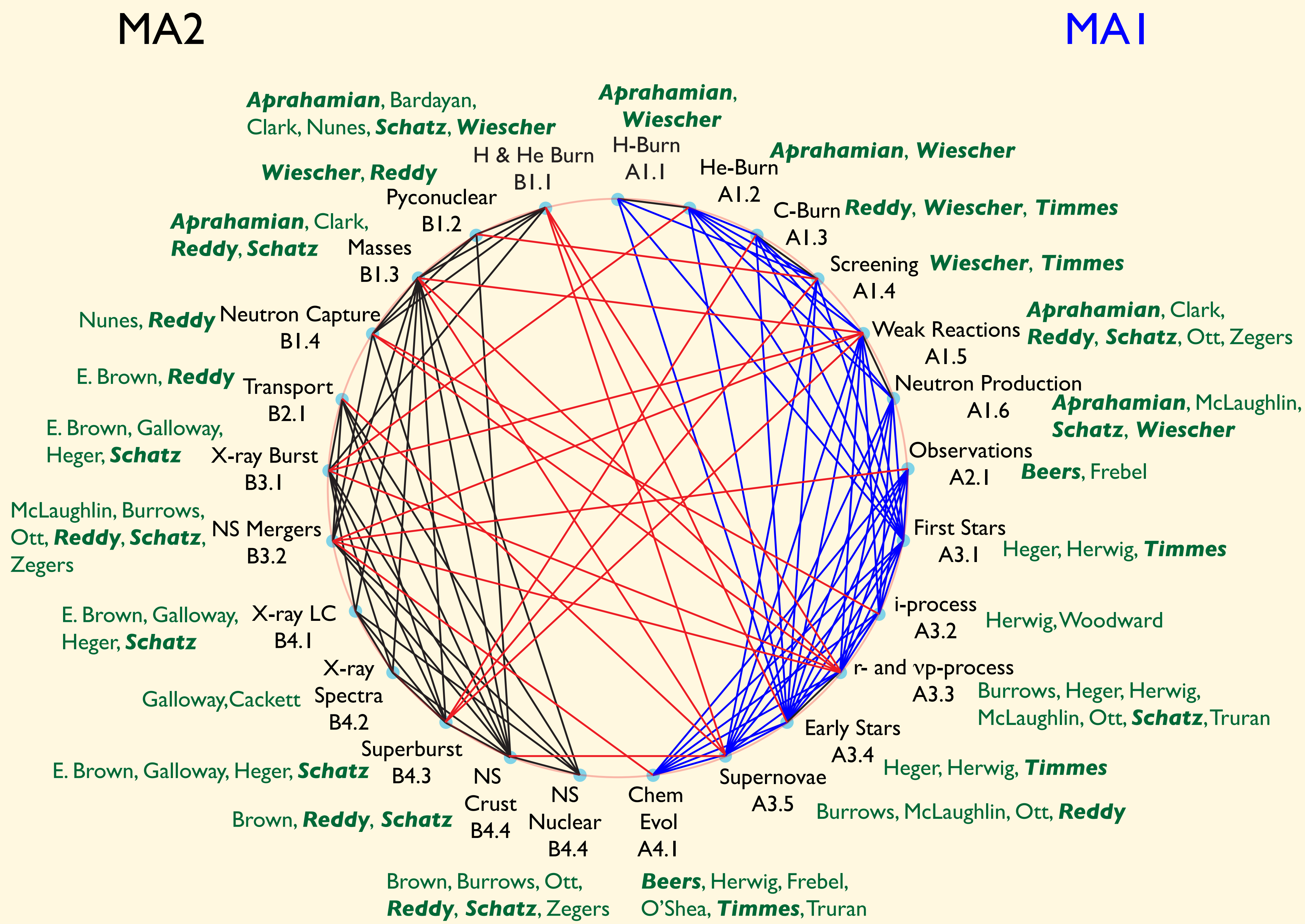
Nuclear physics input

"Despite experimental and theoretical progress, lack of knowledge of relevant or accurate weak-interaction data still constitutes a major obstacle in the simulation of some astrophysical scenarios today."

Langanke & Martinez-Pineado 2003, RMP

- Supernovae (both core-collapse and white dwarf)
- Accreting neutron stars
- Nucleosynthesis (r-, s-process)

Joint Institute for Nuclear Astrophysics—Center for the Evolution of the Elements

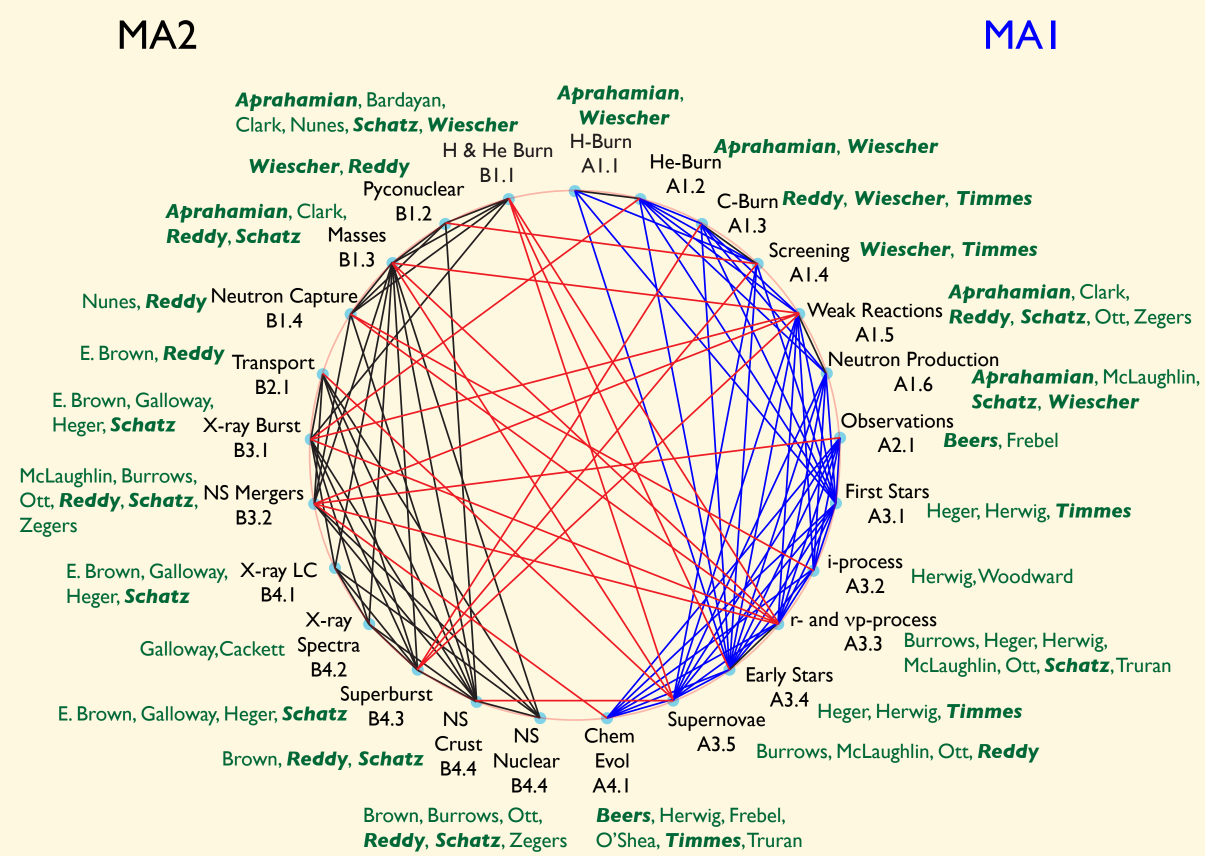


JINA-CEE
NSF Physics Frontier Center

Charge-exchange group at NSCL (R. Zegers)

1. perform charge-exchange experiments (for example, $^{56}Ni(p,n)^{56}Cu$ measures transition rates in β- direction; $^{46}Ti(t,^{3}He+\gamma)^{46}Sc$ at intermediate energies to benchmark and test theoretical rate calculations

2. work together hand-in-hand with nuclear theorists and astrophysicists to develop improved weak-rate sets and perform improved astrophysical simulations

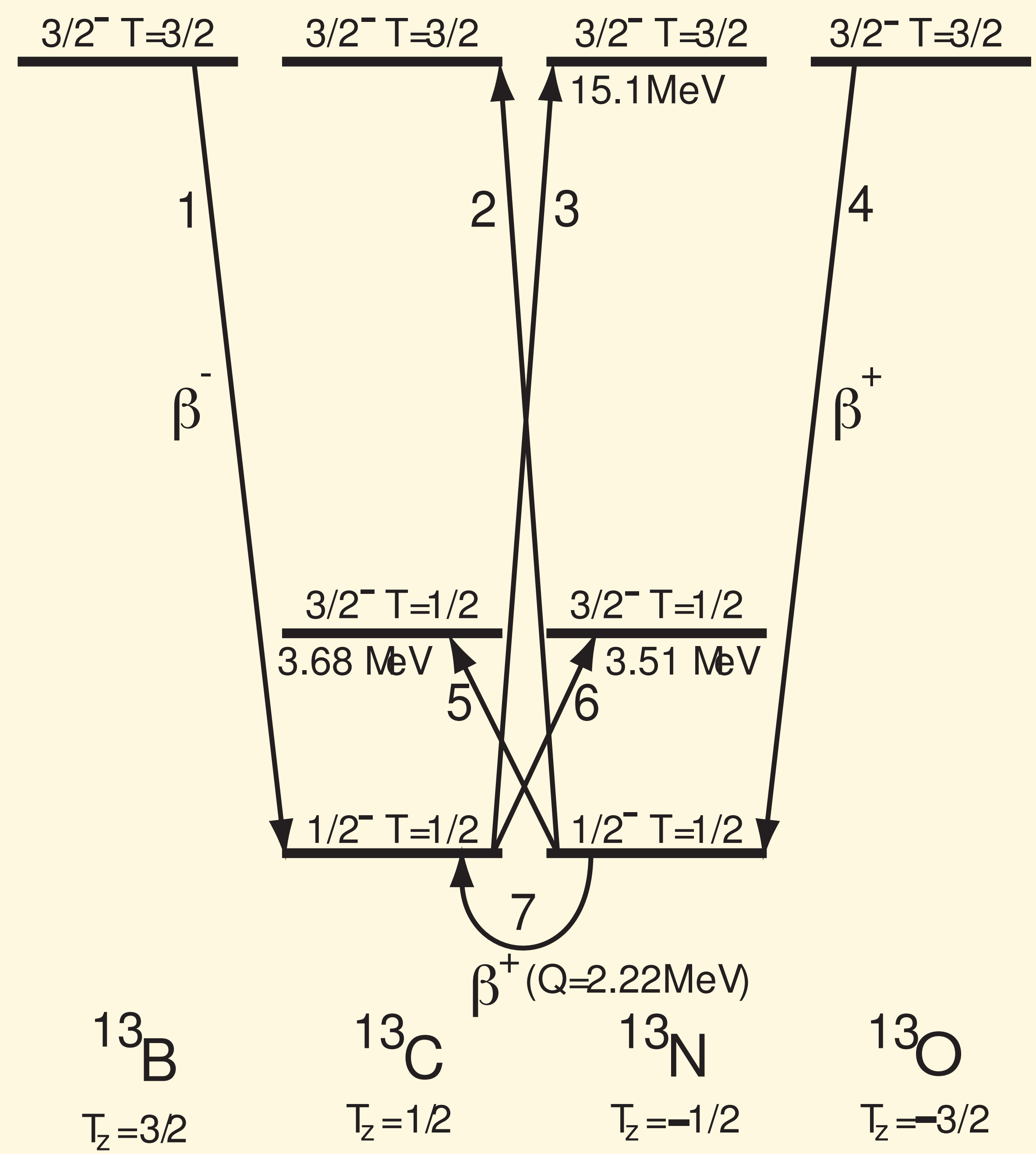


PHYSICAL REVIEW C **77**, 024307 (2008)

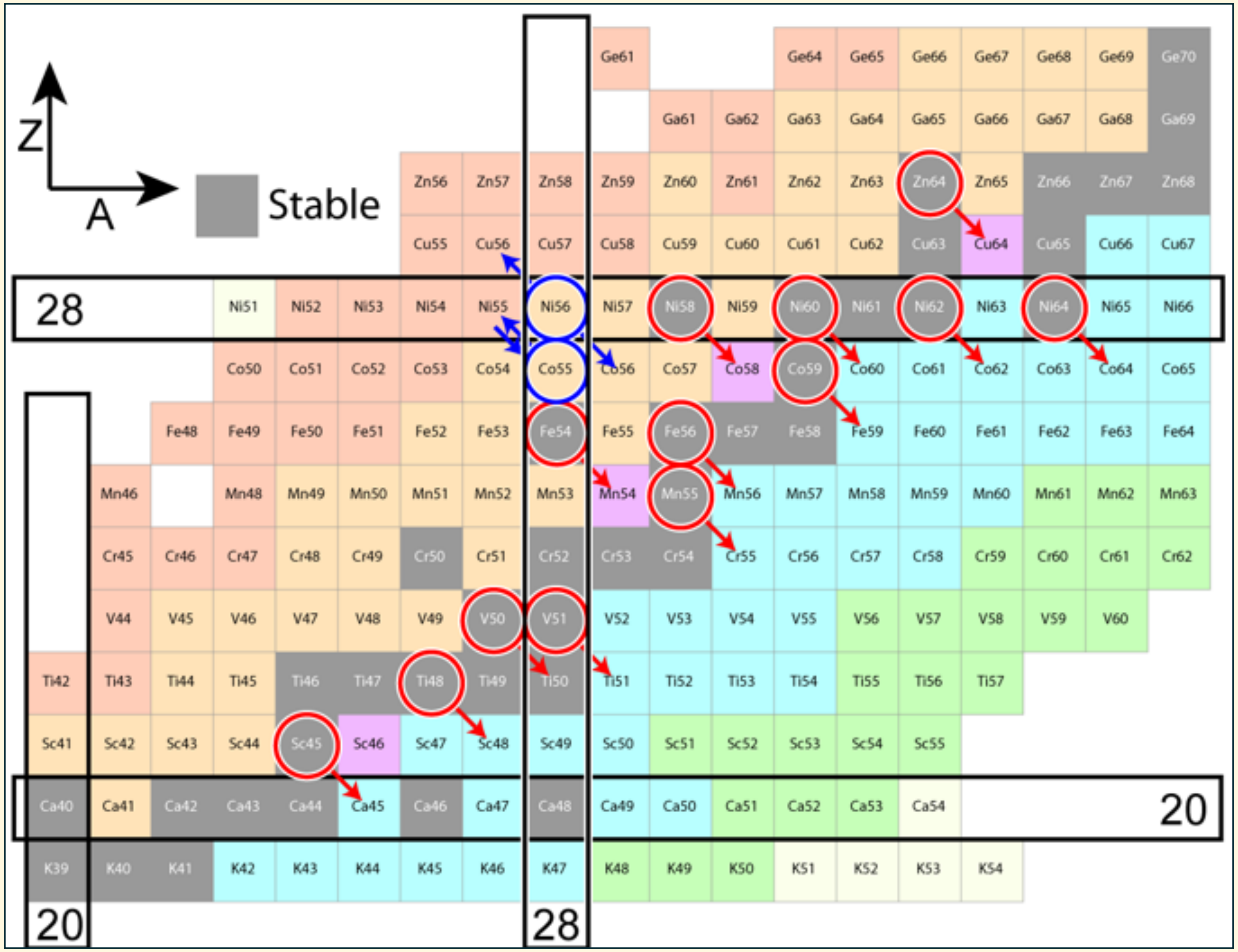
Gamow-Teller strength for the analog transitions to the first $T = 1/2$, $J^\pi = 3/2^-$ states in ^{13}C and ^{13}N and the implications for type Ia supernovae

R. G. T. Zegers,[1,2,3,*] E. F. Brown,[1,2,3] H. Akimune,[4] Sam M. Austin,[1,3] A. M. van den Berg,[5] B. A. Brown,[1,2,3] D. A. Chamulak,[2,3] Y. Fujita,[6] M. Fujiwara,[7,8] S. Galès,[9] M. N. Harakeh,[5] H. Hashimoto,[8] R. Hayami,[10] G. W. Hitt,[1,2,3] M. Itoh,[11] T. Kawabata,[12] K. Kawase,[8] M. Kinoshita,[4] K. Nakanishi,[8] S. Nakayama,[10] S. Okumura,[8] Y. Shimbara,[1,3] M. Uchida,[13] H. Ueno,[14] T. Yamagata,[4] and M. Yosoi[8]

- Normally, ^{13}N decays via β+ (Q = 2.22 MeV)
- Electron Fermi energy is 5.1 MeV, so capture into excited state (*E* = 3.68 MeV) of ^{13}C is possible
  - Increases capture rate
  - Increases heat deposition



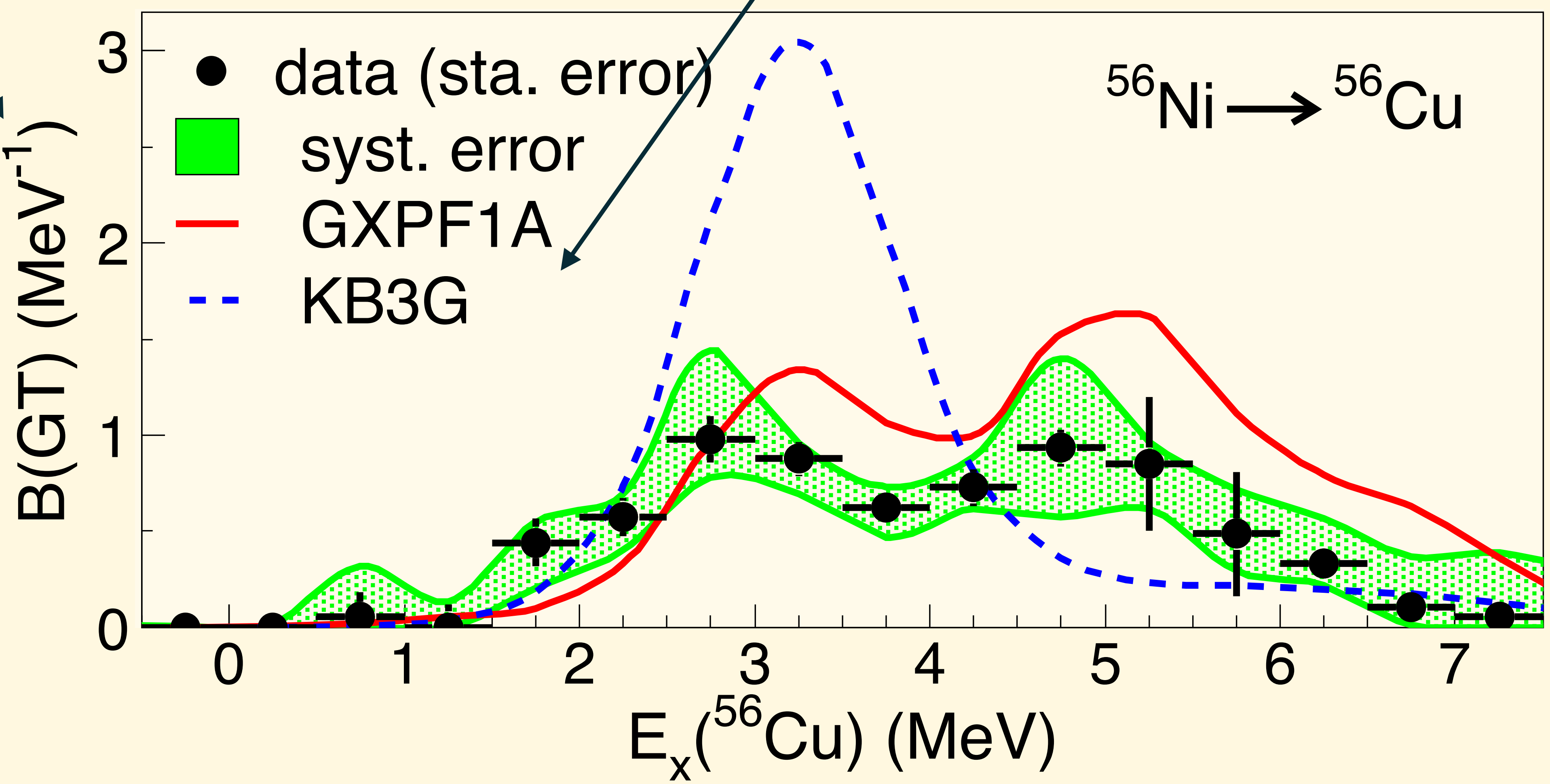
Completed: Comprehensive evaluation of theoretical electron-capture rates in pf-shell near stability.



Gamow-Teller transitions from ^{56}Ni (Sasano et al., 2011, PRL)

GXPF1A, KB3G are different nuclear interaction models used to calculate EC rates

∝cross-section



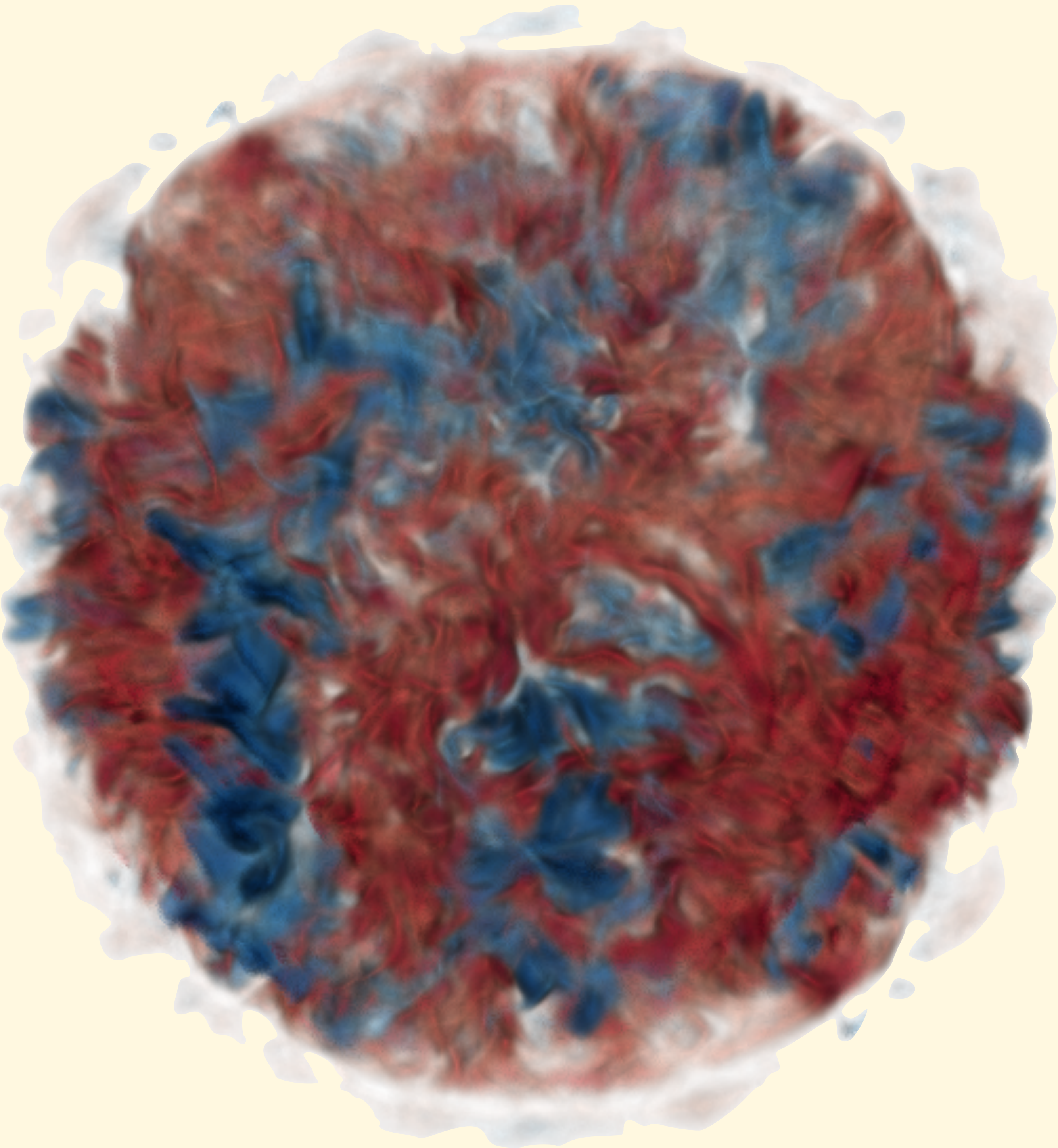
Facility for Rare Isotope Beams, MSU—1 year ago

Facility for Rare Isotope Beams, MSU—yesterday

NEW Computational Mathematics, Science, and Engineering at MSU

Offers both
graduate and undergraduate programs in computational science. Astronomy faculty Brian O'Shea and Sean Couch have joint appointments.

We are looking for talented graduate students interested in computational modeling!



3D simulation of a massive star just prior to collapse and explosion as a supernova. Couch et al. (2015)

Discussion

1. What important physics haven't we included in the simmering phase? Is the convective Urca important? What could derail "ignition at only one point"?

2. What is the greatest impediment to improving determinations of metallicity?