

# The Nuclear Data Archive for Nucleosynthesis Studies

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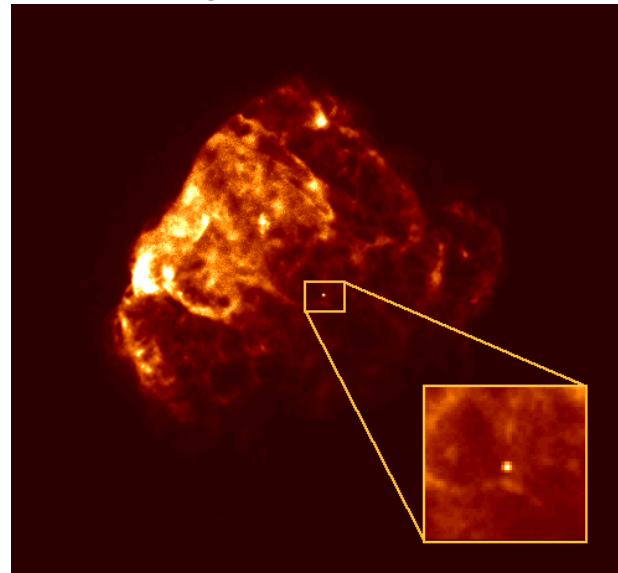


Galactic 1809 keV  $\gamma$ -ray intensity from  $^{26}\text{Al}$  decay

# Why study nucleosynthesis in supernovae?



- **Supernovae provide the requisite conditions for production and ejection of newly formed nuclei into the interstellar medium**
- **Nucleosynthesis - the goal:**
  - To develop a complete understanding of the origin of the chemical elements in terms of their nuclear properties and to identify the conditions in which they were assembled
- **This yields:**
  - Chemical history of stars in our own and distant galaxies
  - Chemical evolution of the Galaxy
- **Diagnostics of:**
  - Stellar evolution
  - Novae
  - SN Ia, Ib, II
  - Hypernovae
  - $\gamma$ -ray bursts



SNR Puppis A  
and its neutron star  
in X-rays

# Reaction Rates Important for Astrophysics



- $^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$  **Most important for nucleosynthesis**
- $3\alpha$ ,  $^{12}\text{C}+^{12}\text{C}$ ,  $^{12}\text{C}+^{16}\text{O}$ ,  $^{16}\text{O}+^{16}\text{O}$  - energy generation
- $p$ ,  $n$ ,  $\alpha$  induced reactions on C – Si ( $Z < 14$ )  
especially rates influencing  $^{17,18}\text{O}$ ,  $^{22}\text{Ne}$  and neutron production  
for s-process
- Reactions affecting  $^{22}\text{Na}$ ,  $^{26}\text{Al}$ ,  $^{44}\text{Ti}$ ,  $^{60}\text{Fe}$  - gamma-line candidates
- There are a **LOT** of nuclei and important reactions on them  
roughly 4600 bound nuclei (H-Pb)  
roughly 25,000 reaction rates

# Nucleosynthesis – Needed Information: 1



$3\alpha$ ,  $^{12}\text{C}+^{12}\text{C}$ ,  $^{12}\text{C}+^{16}\text{O}$ ,  $^{16}\text{O}+^{16}\text{O}$

- **Importance:**  
Main line burning reactions for helium, carbon, oxygen burning
- **Current source:**  
Caughlan and Fowler 1988
- **Status:**  
Probably adequate except perhaps for  $^{12}\text{C}+^{12}\text{C}$  (and its screening rate)

# Nucleosynthesis – Needed Information: 2



- $^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$
- **Importance:**  
Determines C/O after helium burning. Affects stellar structure and all subsequent nucleosynthesis
- **Current source:**  
CF88, Azuma 94, Buchmann 96, Tischhauser 99, Brune 99
- **Status:**  
Inadequate knowledge of E1 and especially E2 component, need total to better than 20%, presently known to about 50%  
WW93 indicate CF88\*1.7 ok, NEEDS WORK!

# Nucleosynthesis – Needed Information: 3



- $(\alpha, n)$  and  $(\alpha, \gamma)$  reactions on  $8 < Z < 14$  and  $(n, \gamma)$  on  $Z > 10$
- **Importance:**  
crucial for s-process neutron production (and poisons  $Z < 14$ ?)
- **Current source:**  
Variety of experiments on  $(\alpha, n)$ ,  $(\alpha, \gamma)$   
Bao et al. 2000 (ADNDT 76, 70)
- **Status:**  
 $^{22}\text{Ne}(\alpha, n)^{25}\text{Mg}$  633 keV res highly uncertain – measurements needed!  $(n, \gamma)$  on stable species good, still using HF for unstable species

# Nucleosynthesis – Needed Information: 4



- $(p,\gamma)$ ,  $(\alpha,p)$ ,  $(p,\alpha)$ ,  $(\alpha,\gamma)$  reactions on  $Z < 14$
- **Importance:**  
Determines energy generation in CNO hydrogen burning and nucleosynthesis of  $^{13}\text{C}$ ,  $^{14,15}\text{N}$ ,  $^{17,18}\text{O}$ ,  $^{21}\text{Ne}$ , and  $^{23}\text{Na}$ . Also determine synthesis of radioactive nuclei  $^{22}\text{Na}$  and  $^{26}\text{Al}$  and breakout of hot CNO cycle.
- **Current source:**  
Variety of experiments, CF88, NACRE, etc.
- **Status:**  
Variable: Needs work!

# Nucleosynthesis – Needed Information: 5



- $(p,\gamma)$ ,  $(\alpha,\gamma)$ ,  $(p,n)$ ,  $(\alpha,p)$ ,  $(\alpha,n)$  and inverses on  $Z > 14$
- **Importance:**  
Nucleosynthesis up to  $A=100$  and beyond. Particularly important are  $(\alpha,\gamma)$ , and  $(\alpha,p)$   $(p,\gamma)$  reactions on self-conjugate nuclei
- **Current source:**  
Inadequate experimental data, mostly Hauser-Feshbach (Woosley, Thielemann, NOW: Rauscher & Thielemann 2000, ADNDT, 75, 1
- **Status:**  
Variable: Need more experiments to calibrate HF models, especially  $T_\gamma$ ,  $\alpha$ -potential, charged particle reactions on  $A>60$

# Nucleosynthesis – Needed Information: 6



- **Ground state lifetimes, binding energies, excited levels**
- **Importance:**  
Nucleosynthesis of unstable progenitors and their freeze out (also rp-process and r-process nuclei up to  $A=100$ )
- **Current source:**  
Experiment (ENSDF)
- **Status:**  
In general good shape except for  $^{44}\text{Ti}$  and near proton drip-line (r-process needs not included here)

# Nucleosynthesis – Needed Information: 7



- **Weak reaction rates at high temperatures and densities**
- **Importance:**  
Determines the stellar structure after oxygen burning. Affects nucleosynthesis, several cases, e.g.  $^{14}\text{N}(e^-, \nu)^{14}\text{C}$ , electron capture on Ne, Na, Mg.
- **Current source:**  
FFN, Langanke, Matinez-Pinedo 2000, Nuc Phys A 673, 481
- **Status:**  
Needs work, especially for  $A > 60$ . In select cases, laboratory measurements can help.

# Nucleosynthesis – Needed Information: 8



- **Neutrino cross sections and branching ratios**
- **Importance:**  
Neutrino nucleosynthesis of  ${}^7\text{Li}$ ,  ${}^{11}\text{B}$ ,  ${}^{15}\text{N}$ ,  ${}^{19}\text{F}$ ,  ${}^{26}\text{Al}$ ,  ${}^{138}\text{La}$ ,  ${}^{180}\text{Ta}$
- **Current source:**  
Haxton (WHHH90), Kolbe, Langanke, et al. (1992-2000)
- **Status:**  
Needs experimental work, electro-excitation and spallation matrix elements, polarized inelastic proton scattering.

# Evaluated Nuclear Data Archive



- **Where alternate sources of reaction rate data exist guidance is needed – ideal would be an evaluated archive**
- **Importance:**  
Allows for a recognized panel of experts (experiment and theory) to determine a standard
- **Current source:**  
None –
- **Status:**  
With NSF funding JINA could serve as a coordinator for such a panel – collaborative effort needed

# Nuclear Astrophysics Data Needs - Summary



- $3\alpha$  and heavy-ion reactions
- Reaction rates for all isotopes having n,p, $\alpha$  or  $\gamma$  in entrance or exit channel, from experiment where possible (RIA?)
- CNO spallation cross sections for Li, Be, B production
- Lifetimes and binding energies up to p-drip line for all species
- Weak interaction rates (temp dependent) for all nuclei  $A < 80$
- Neutrino spallation cross sections for  $A < 60$
- ALL ACCURATELY FIT AS ANALYTIC FUNCTIONS OF  $(T_9, \rho)$ !

# 15, 20, & 25 Solar Mass stars

