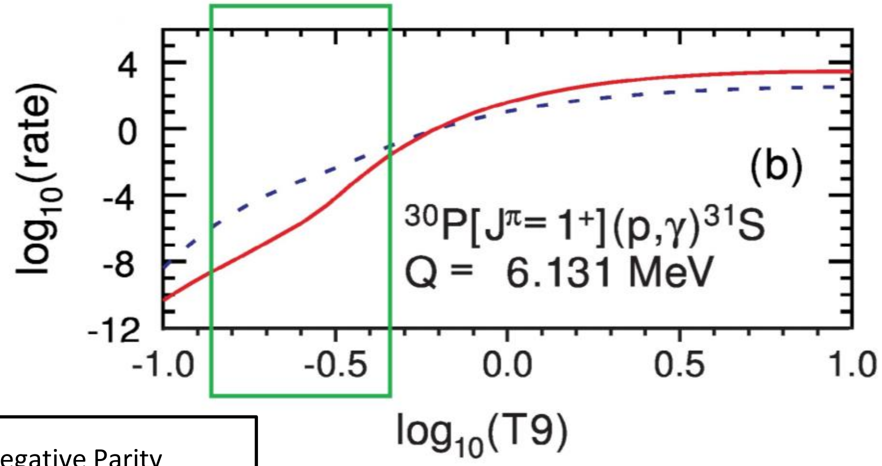
Shell Model Studies of the Astrophysical Rapid-Proton-Capture Reaction $^{30}P(p,\gamma)^{31}S$

B. Alex Brown, W. A. Richter, and C. Wrede, Phys. Rev. C 89, 062801 June, 2014

How did the elements come into existence?

- Open question in Nuclear Astrophysics, 2013 National Research Council Report

- The $^{30}P(p,\gamma)^{31}S$ reaction and is a potential bottleneck for nucleosynthesis toward heavier nuclei via rapid proton capture in nova outbursts.
- The reaction rate remains uncertain
- Negative-parity states in ^{31}S that have not been treated by past theoretical calculations.



Main Results:

- First time calculations in a full p-f model space for negative-parity states in ^{31}S.
- The reaction rate is dominated by these newly calculated negative-parity states (by an order of magnitude)

Negative Parity
Positive Parity

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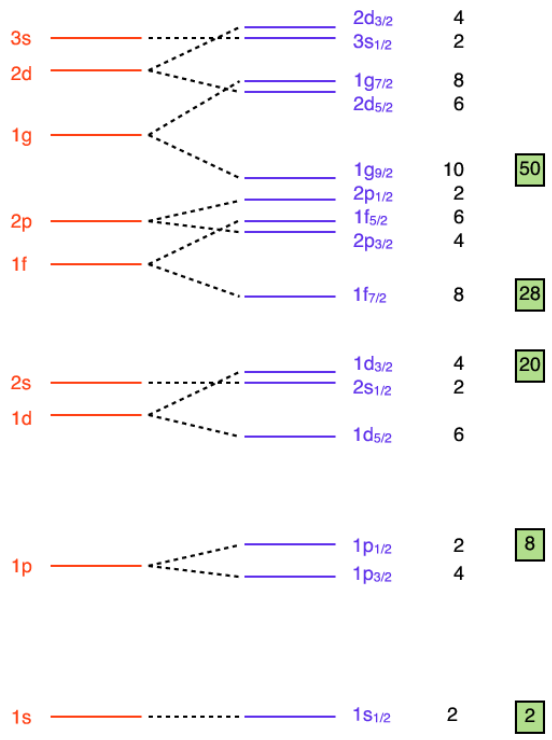
Experiment			
Energy$_x$ (KeV)	(2J)π		
	Wrede(2014)	Doherty et al. (2012)	Parikh et al. (2011)
6160		7+	5
6327		3[-]	1+
6377	9	9[-]	9[-]
6542		3[-]	7,9
6583	7	3,5,7[-]	7
6636	9	5,9	9[-]
6833			11[-]

- Contradictions between experiments for negative parity spin state assignments (red)

- No previous theory calculations to compare with experiment



- Full calculation of one particle excitation from 1p to 2s/1d or from 2s/1d to 2p/1f shell
- Was not previously calculated because of computational limits

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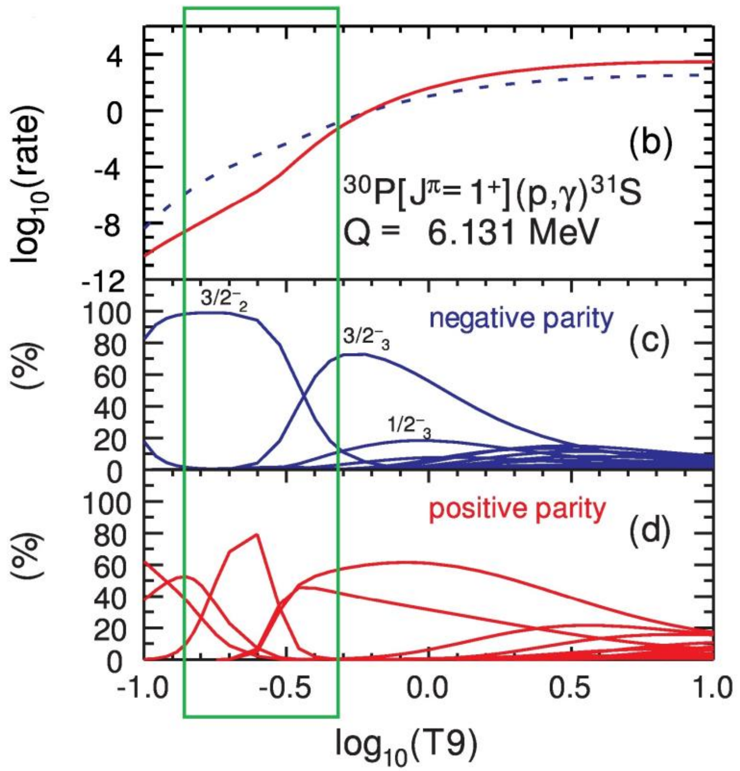
Experiment				Theory	
$Energy_x$ (KeV)	(2J)π			$Energy_x$ (KeV)	(2J)π
	Wrede(2014)	Doherty et al. (2012)	Parikh et al. (2011)	Shell Model	
6160		7+	5	5825	5-
6327		3[-]	1+	6327	3-
6377	9	9[-]	9[-]	6313	9-
6542		3[-]	7,9	6757	3-
6583	7	3,5,7[-]	7	6792	5-
6636	9	5,9	9[-]	6682	9-
6833			11[-]	6833	11-
				6247	1-
				6602	1-

- Calculated energies normalized to 6833 KeV state (red)
- Reaction rate dominated by 6327 KeV state (blue)



- Reaction rate depends on resonance energy, decay widths, and spin
- Large uncertainties in these results
  - Energy shift of ½⁻ state by 200 keV
- 2013 experiment at MSU with the GRETINA detector will further reduce the uncertainty in this reaction.

Backup

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Reaction Rate

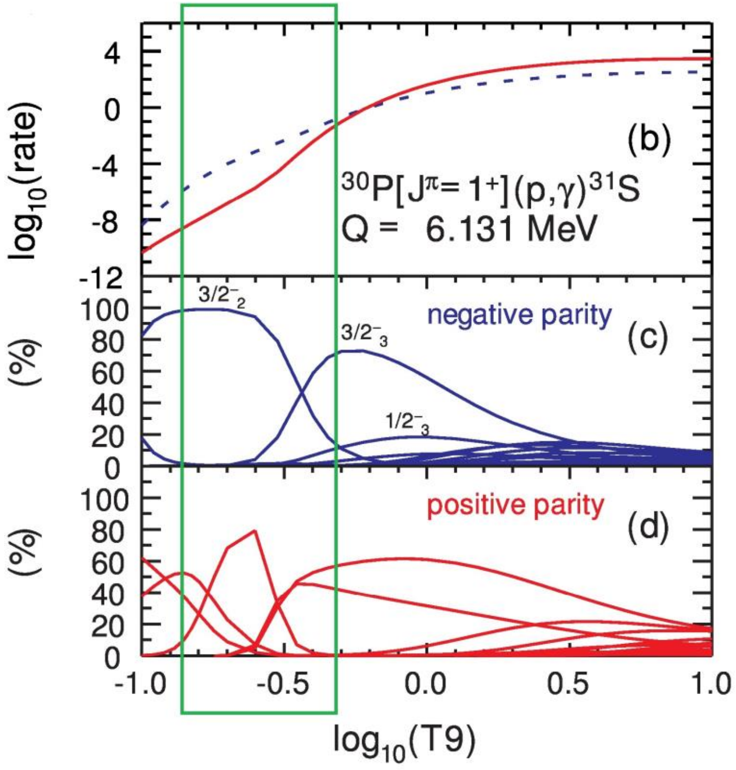
- $N_A\langle\sigma v\rangle \propto (\mu T_9)^{-\frac{3}{2}} \cdot \sum_f \omega\gamma e^{-\frac{E_{x-Q}}{(kT)}} \quad cm^3 s^{-1} mole^{-1}$ [1]

Resonance Strength

- $\omega\gamma_{^{30}P,^{31}S} = \frac{(2J_{^{31}S}+1)}{(2J_p+1)(2J_{^{30}P}+1)}\frac{\Gamma_p\Gamma_\gamma}{\Gamma_p+\Gamma_\gamma}$

- $T_{\frac{1}{2}} = Ln\left(2\frac{\hbar}{\Gamma}\right)$

- Reaction rate depends on resonance energy, decay widths, and spin



[1] C. Wrede, AIP Advances 4, 041004 (2014)