Investigating the $^{38}K(p,\gamma)^{39}Ca$ Reaction Rate for Classical Novae

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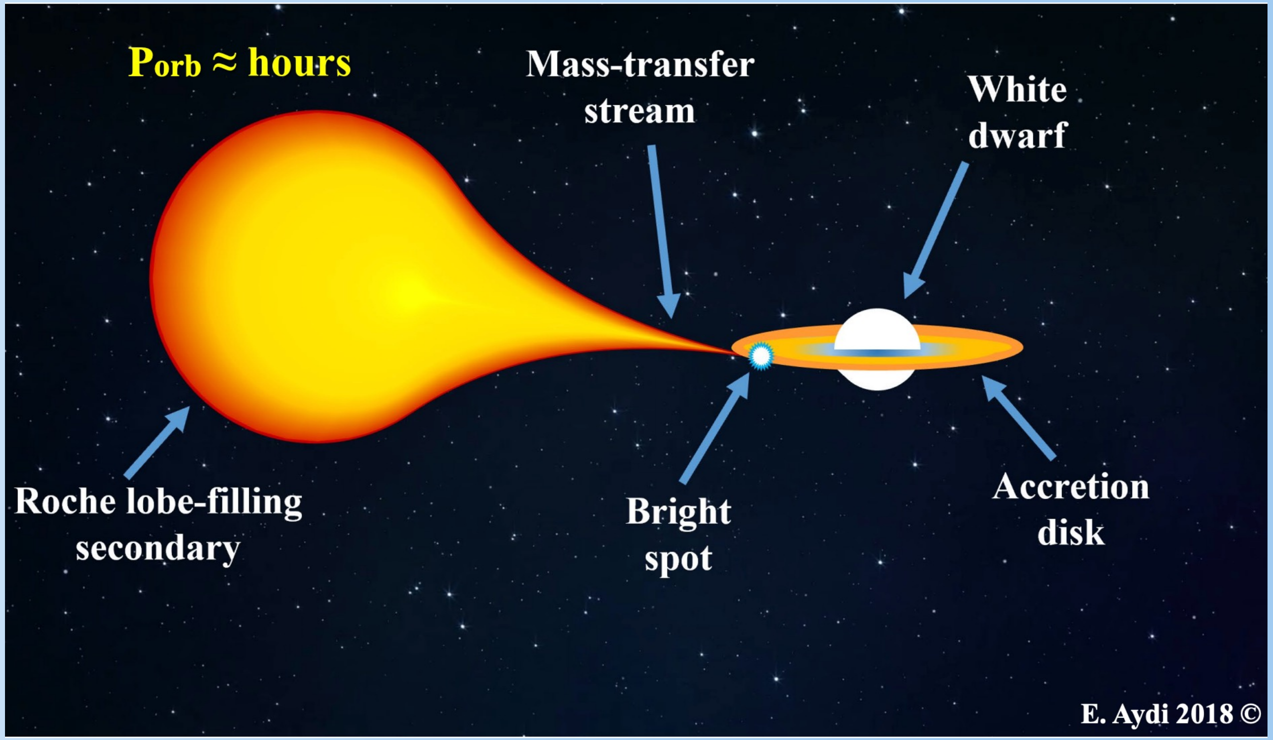
Nova Persei 1901

(Chandra)

Background

- What is a classical nova?
- They are partially responsible for the galactic synthesis of various nuclides
- The structure of these novae are relatively well understood
- There are discrepancies between calculated and observed abundances
- Specifically, Ar and Ca

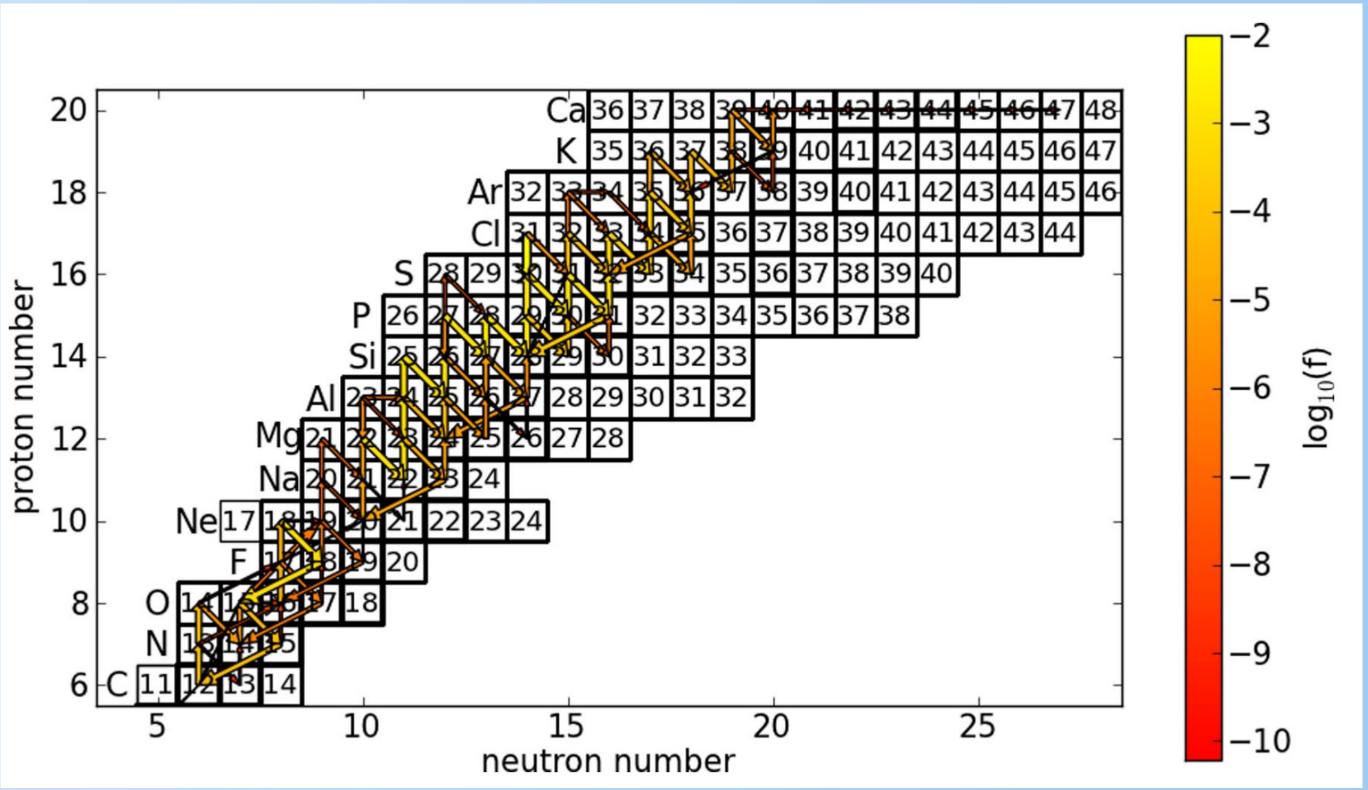


Goal

- $^{38}K(p,\gamma)^{39}Ca$ could account for these discrepancies
- Significant influence on Ar, Ca and K production
- Update the reaction rate using nucleosynthesis simulations and a new resonance, measured by Liang et al.
- The new resonance was measured at MLL in Munich and TUNL
- Observe the implications of this ‘new’ reaction rate

Classical Novae Nucleosynthesis

- Nucleosynthesis pathway, endpoint A~40
- Ca-39 decays into K-39 through β^+ decay
- Which can affect Ca-40 through $^{39}K(p,\gamma)^{40}Ca$
- K-38 decays into Ar-38 through β^+ decay



Denissenkov et. al., MNRAS 442 3, 2014

Importance of $^{38}K(p,\gamma)^{39}Ca$

- $^{38}K(p,\gamma)^{39}Ca$ can affect Ar-38 by a factor of 25, K-39 by a factor of 136, Ca-40 by a factor of 58
- Could account for 1/3 of nova-produced Ar
- Could account for all nova-produced Ca

Reaction	Isotope i	Reaction Rate Multiplied By					
		100	10	2	0.5	0.1	0.01
^{37}K(p, γ)^{38}Ca	^{37}Ar	0.42	0.79	0.94	1.0	1.0	1.0
	^{37}Cl	0.41	0.79	0.96	1.0	1.0	1.0
	^{38}Ar	1.4	1.1	1.0	1.0	1.0	1.0
	^{39}K	1.6	1.3	1.1	0.96	0.92	0.90
	^{40}Ca	1.7	1.4	1.1	0.94	0.86	0.84
^{38}K(p, γ)^{39}Ca	^{38}Ar	0.057	0.35	0.81	1.1	1.4	1.4
	^{39}K	3.4	2.6	1.5	0.63	0.19	0.059
	^{40}Ca	2.4	2.0	1.4	0.66	0.20	0.042
^{39}K(p, γ)^{40}Ca	^{39}K	0.030	0.26	0.74	1.2	1.5	1.6
	^{40}Ca	2.4	2.2	1.4	0.66	0.19	0.026

(Iliadis et al., 2002)

Previous Research

- E_x refers to the excitation energy
    - Energy required to transition an atom from its ground state to an excited state
- E_r refers to the resonance energy
    - The energy at which a reaction is most likely to occur
- $\omega\gamma$ refers to resonance strength
    - The measure of the probability of a specific nuclear reaction occurring at a particular energy level

Ref.	E_x (keV)	E_r (keV)	$\omega\gamma$ (meV)
Christian *et al.*	6157(10)	386(10)	$\leqslant$2.54
	6286(10)	515(10)	$\leqslant$18.4
	6450(2)	679(2)	120(25)
Setoodehnia *et al.*	6154(5)	383(5)	$\leqslant$2.6
	6286(10)	515(10)	$\leqslant$18.4
	6472.2(24)	701.3(25)	126(39)
Hall *et al.*	6156.7(16)	386(2)	$\leqslant$2.54
	6269.3(22)	498(2)	2.47–24.7
	6471.4(19)	701(2)	126(39)

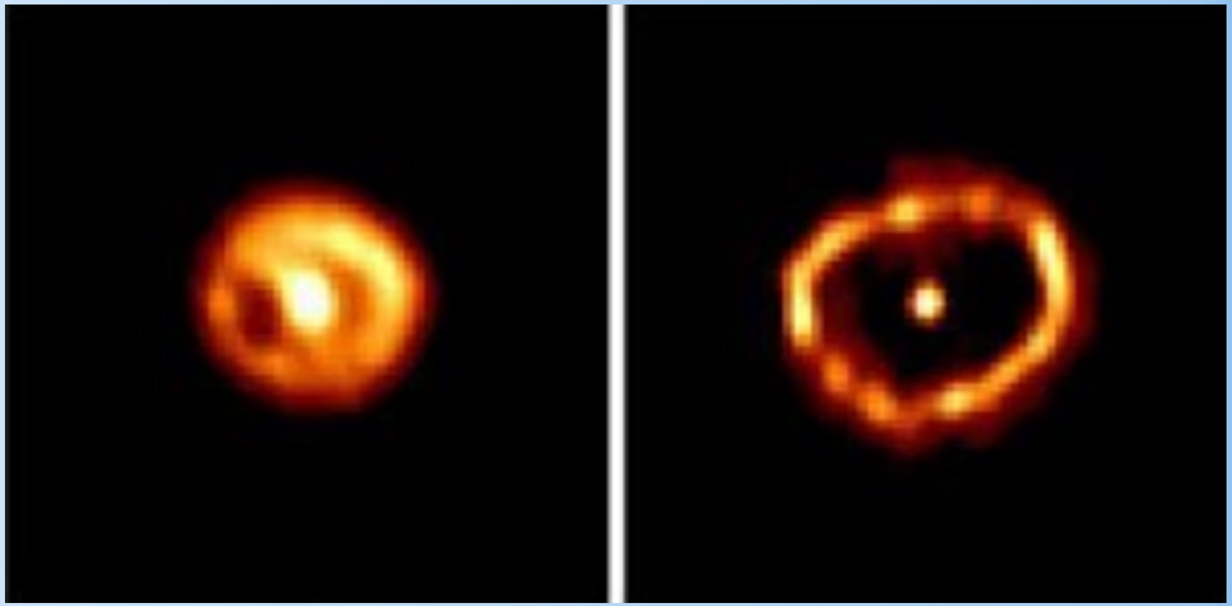
Updates

- A new resonance with E_r = 675 keV with an unknown resonance strength
- 5 different cases to see the effect of this new resonance
- Christian et al. and Setoodehnia et al. both used DRAGON
- Hall et al. used unobserved γ-ray transitions for $^{40}Ca(\,^{3}He,\alpha\gamma)^{39}Ca$

Cases	Er (keV)	$\omega\gamma$ (meV)
Case 1	386	2.54
	515	18.4
	679	120
	675	120
Case 2	386	0.254
	515	1.84
	679	120
	675	120
Case 3	386	0.254
	515	1.84
	679	120
	675	1200
Case 4	386	0.0254
	515	0.184
	679	120
	675	1200
Case 5	386	0.0254
	515	0.184
	675	120
	701	126

Methods

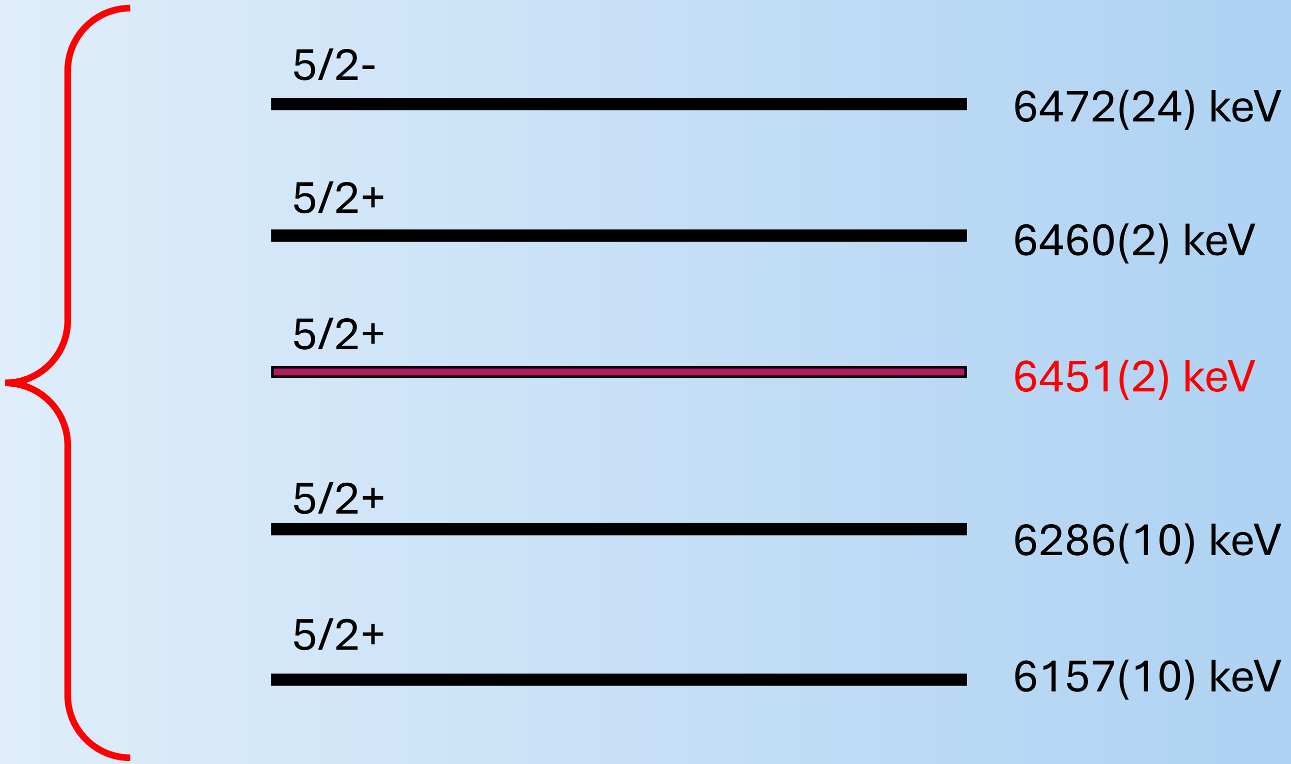
- Find the Gamow window and peak
- Use Quantum Mechanical Selection Rules to find spin parities
- Calculate the reaction rate
- Use the CaNPAN simulations to observe elemental abundances



Nova Cygni 1992
(F. Paresce, R. Jedrzejewski (STScI) NASA/ESA)

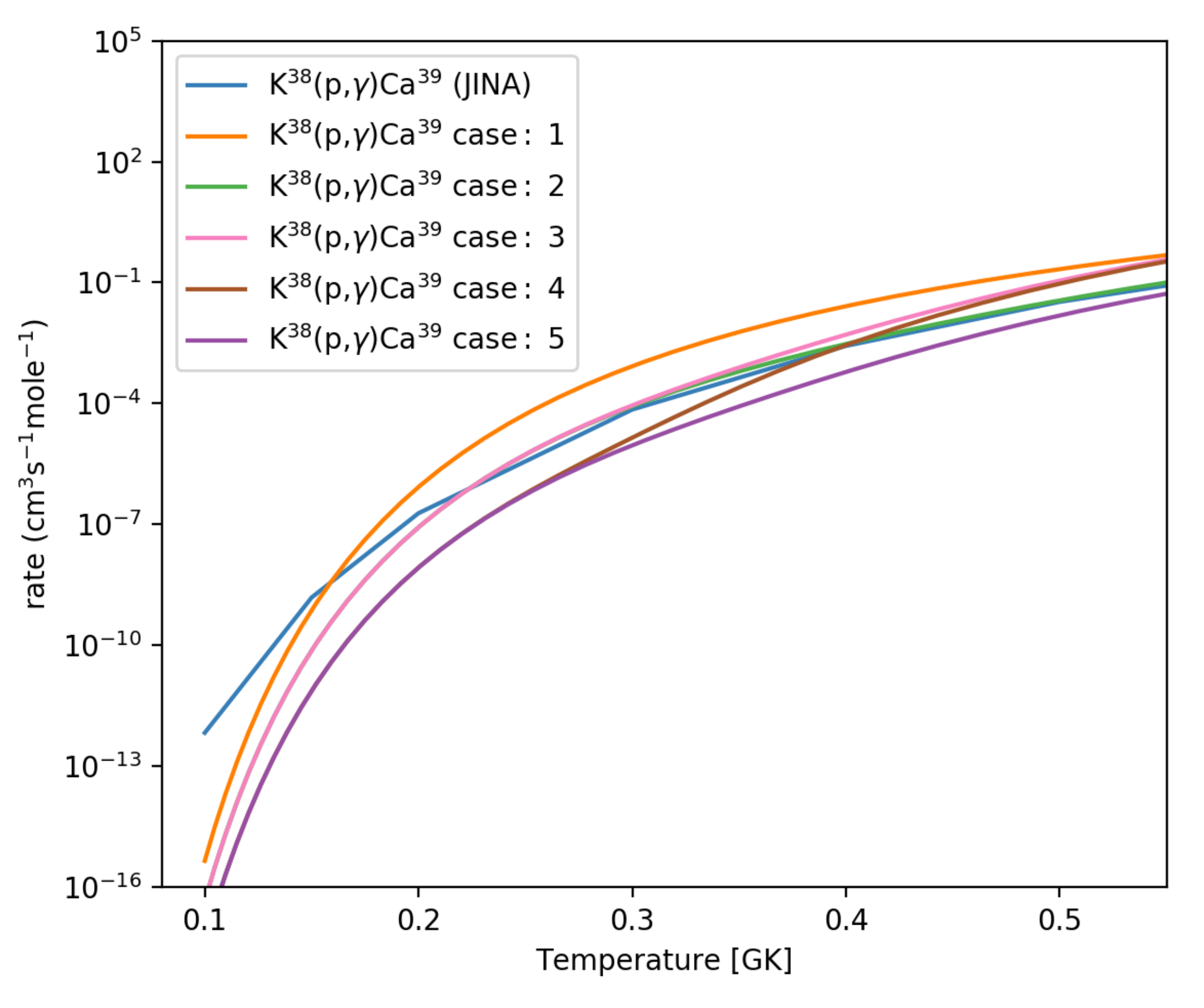
^{39}Ca Energy Levels

Gamow Window is
Approx. 6.0 - 6.4 MeV



Results

- The reaction rate was calculated using the formula: $N_A\langle\sigma v\rangle_r = \frac{1.5399\times10^{11}}{\mu T_9^{3/2}} \times \sum_i(\omega\gamma)_i \ \exp\left(\frac{-11.605E_i}{T_9}\right)$
- Simulations used an oxygen-neon nova model
- White dwarf has a mass of $1.3M_\odot$, with initial central temp. of 7 MK
- Peak temperature around 436 MK



Elemental Abundances

- Case 1 has the highest impact on Ca-40 and K-39 abundances
- Ca-40 differs by a factor of 5.4
- K-39 differs by a factor of 9.2
- Case 5 has the highest impact on Ar-38 abundances
- Ar-38 differs by a factor of 3.7
- But the lowest on Ca-40 and K-39

Cases	Ca-40 Abundances	K-39 Abundances	Ar-38 Abundances
Default Case	0.003	0.009	0.03
Case 1	0.0065	0.024	0.0095
Case 2	0.0031	0.0091	0.027
Case 3	0.0039	0.010	0.025
Case 4	0.0028	0.0057	0.031
Case 5	0.0012	0.0026	0.035

Conclusion

- There are significant discrepancies between observed and predictions for Ca and Ar in Nova ejecta
- An updated reaction rate for $^{38}K(p,\gamma)^{39}Ca$ could account for these discrepancies over the nova temperature ∼0.1-0.4 GK
- More experiments on the $^{38}K(p,\gamma)^{39}Ca$ reaction rate are needed, specifically at DRAGON
- Studying these reaction rates sheds light on the formation of elements, energy production in stars, and serves as a basis for comprehending the intricate processes of stellar evolution

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