

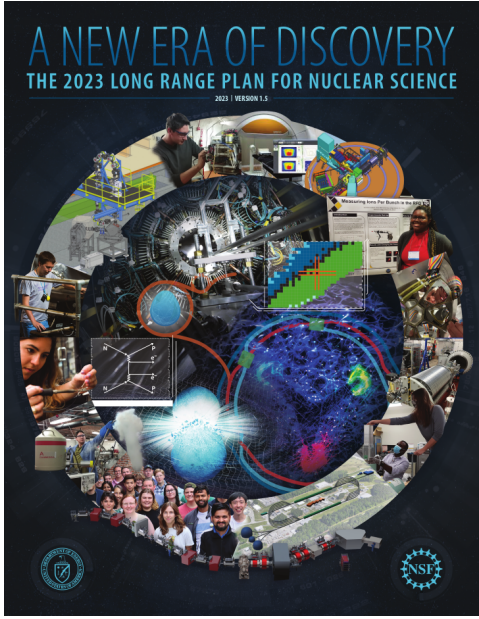
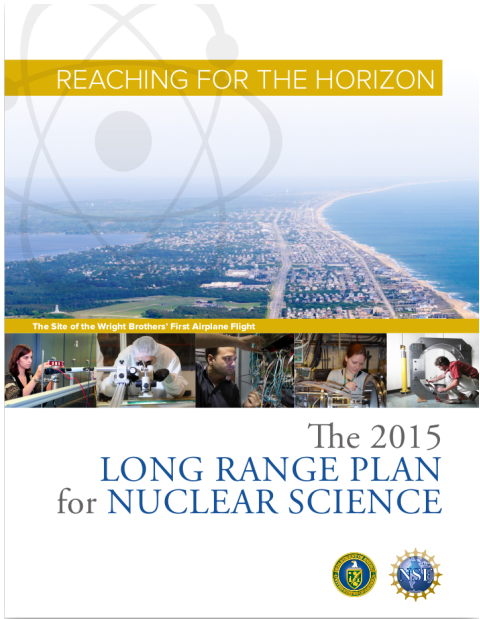
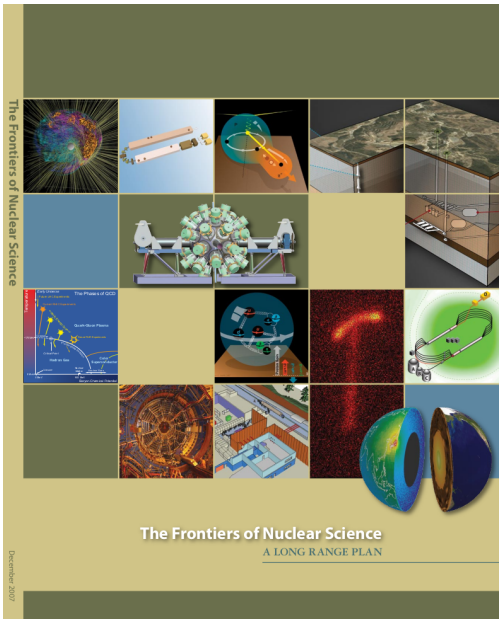
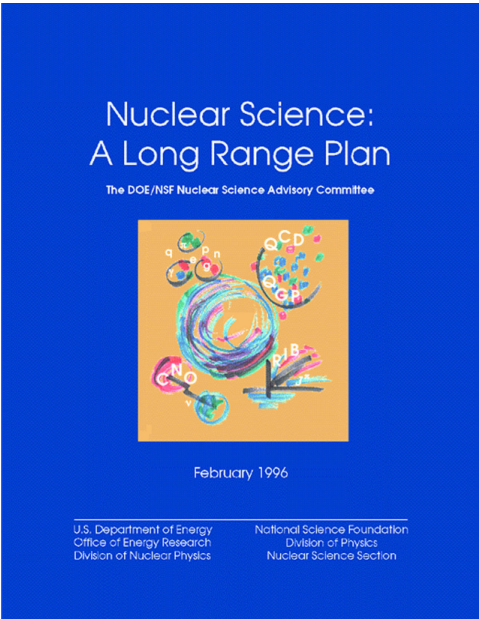
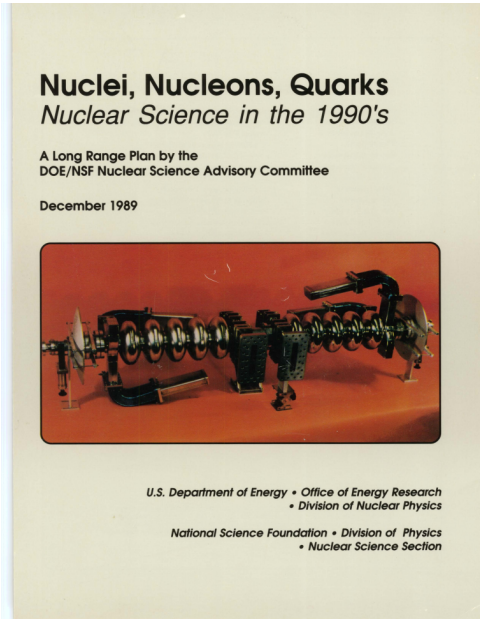
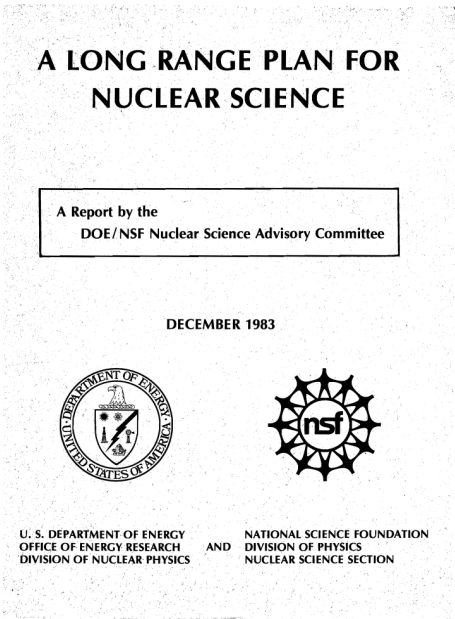
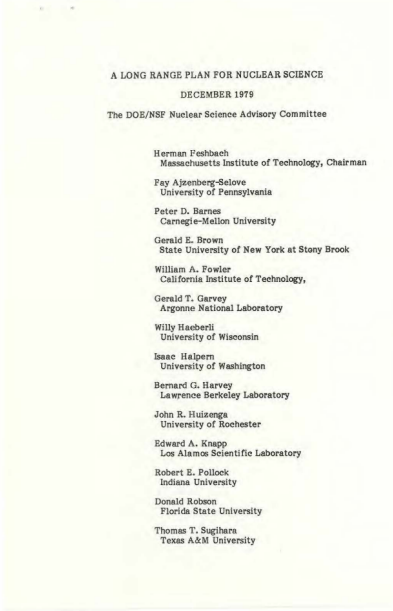
Spectroscopy for Astrophysics in the Janssens Era (and Beyond!)

K.A. Chipps

Oak Ridge National Laboratory

ORNL is managed by UT-Battelle LLC for the US Department of Energy

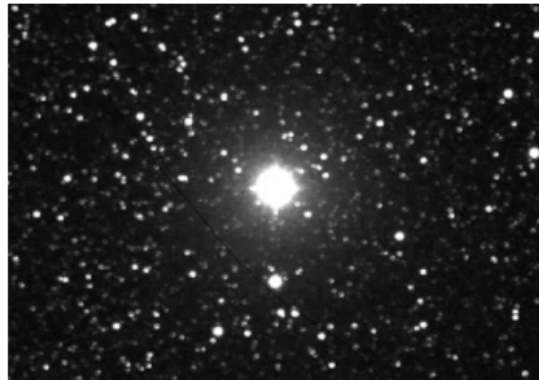
RVFJ career spans 1981-present. In that time, we determined the r-process is universal and then determined it isn't



Explosive Astrophysical Environments are Unique and Fascinating Multi-Physics Laboratories

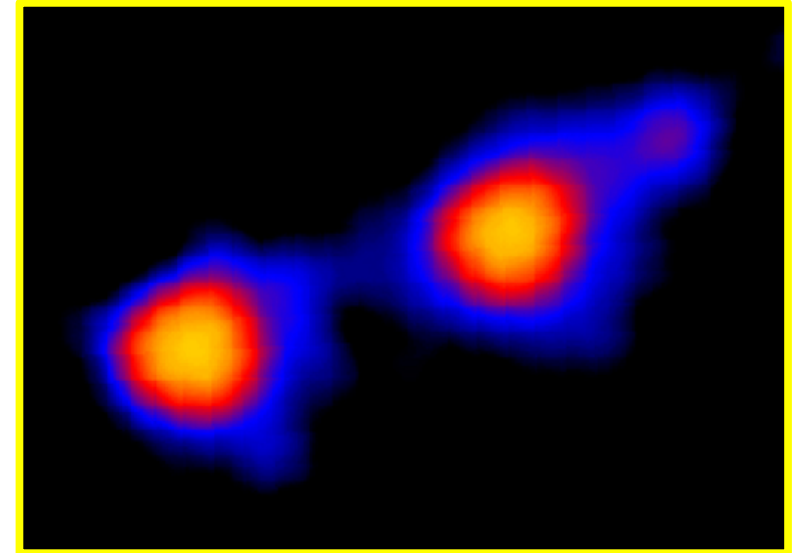
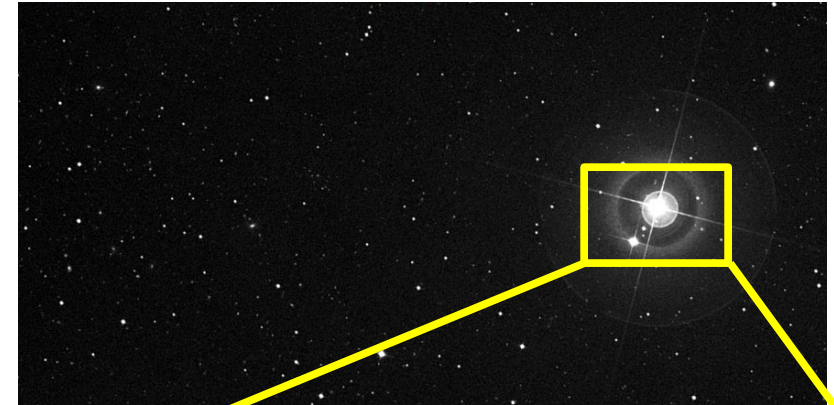
Novae, X-Ray Bursts, Supernovae, Mergers...

The recurrent nova RS Ophiuchi just went into outburst — its first burst in 15 years — and it's bright enough to see with the naked eye.

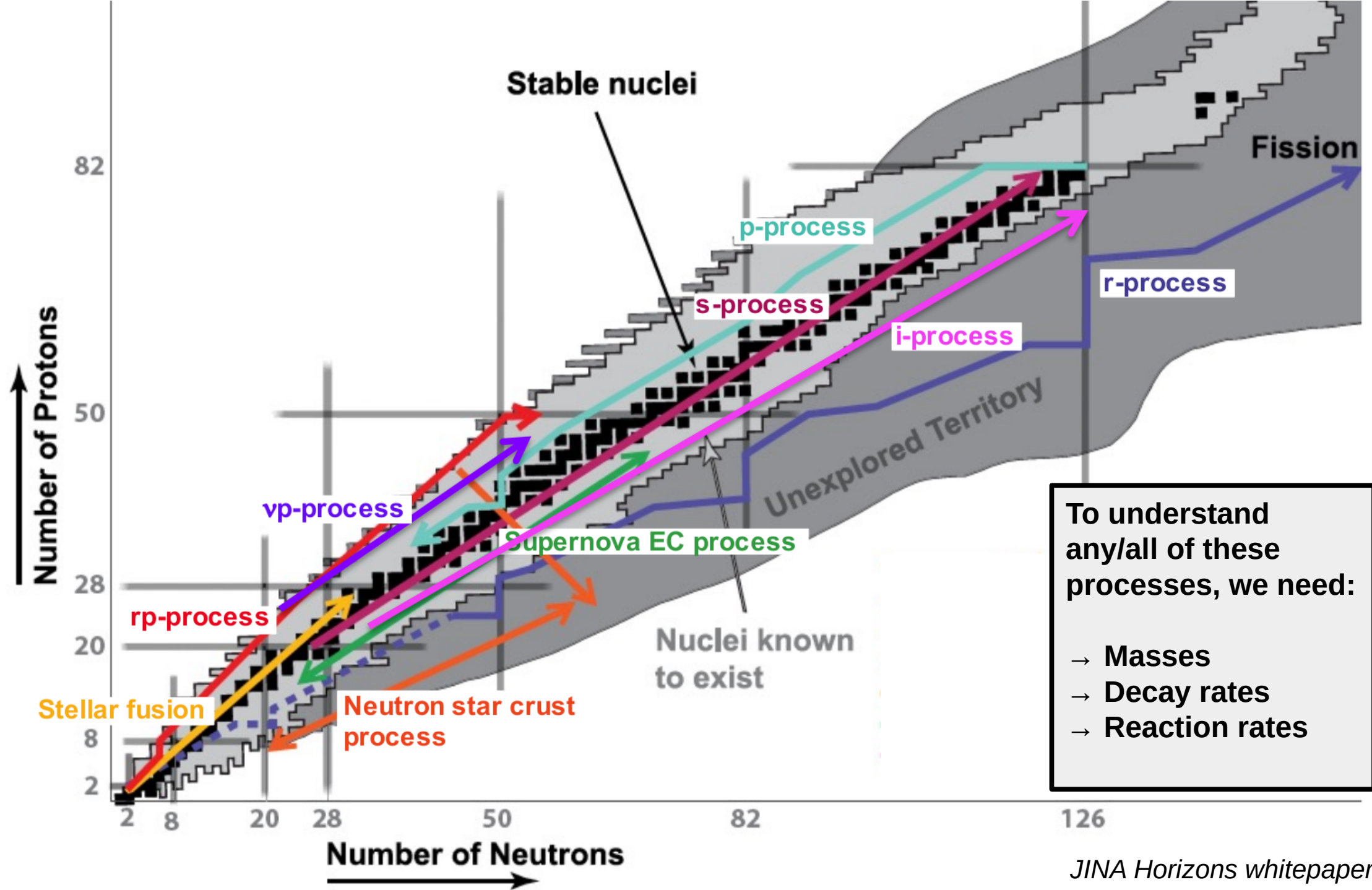


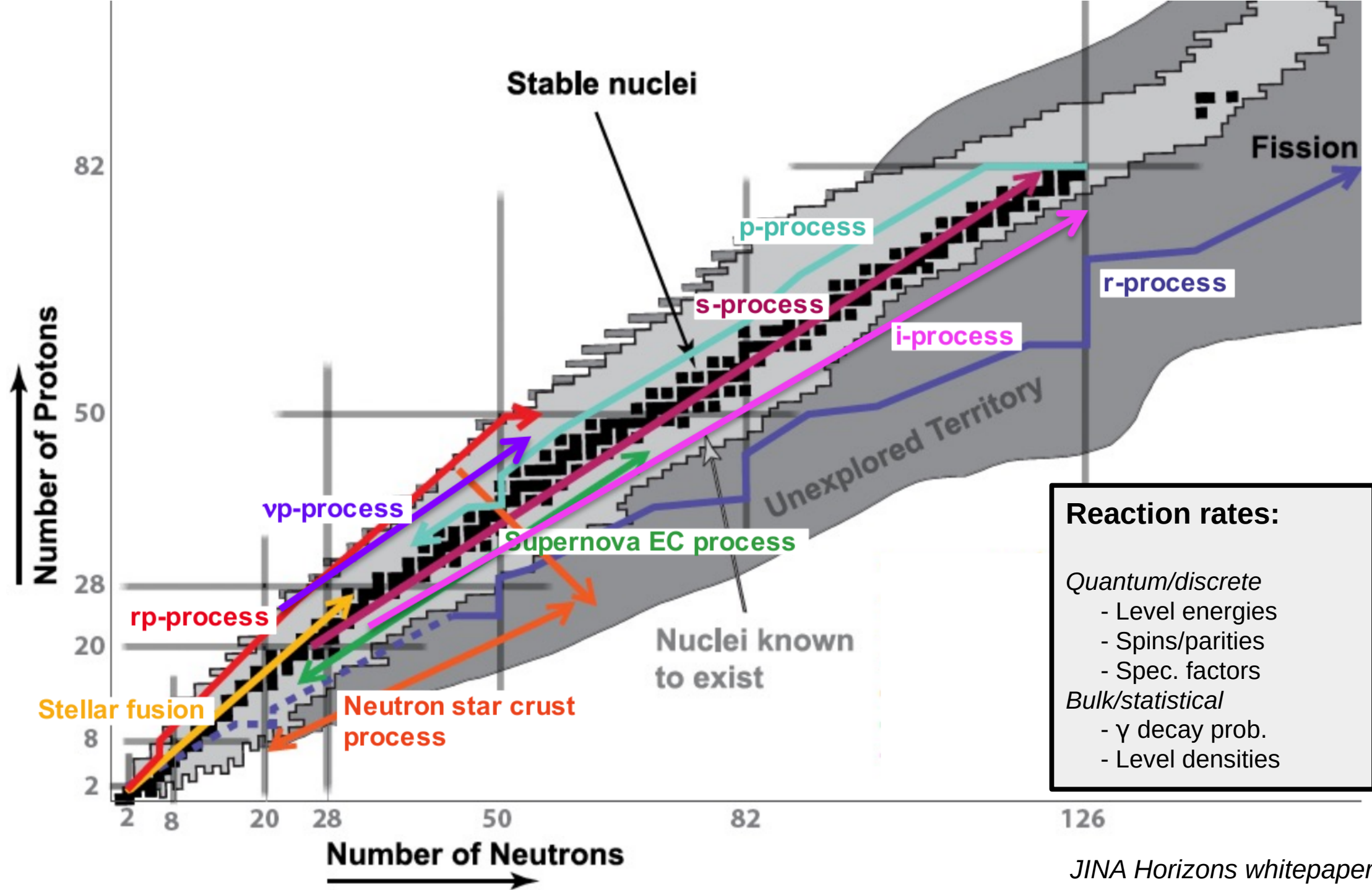
The recurrent nova RS Ophiuchi dramatically brightened from magnitude 11.2 to 4.8 over August 8-9, 2021. The outburst image was taken on August 9.42 UT and paired with an older photo from the Palomar Observatory Sky Survey (POSS) from July 1989 when the star was at minimum. Ernesto Guido, Marco *Rocchetto & Adriano Valvasori / telescope.live*

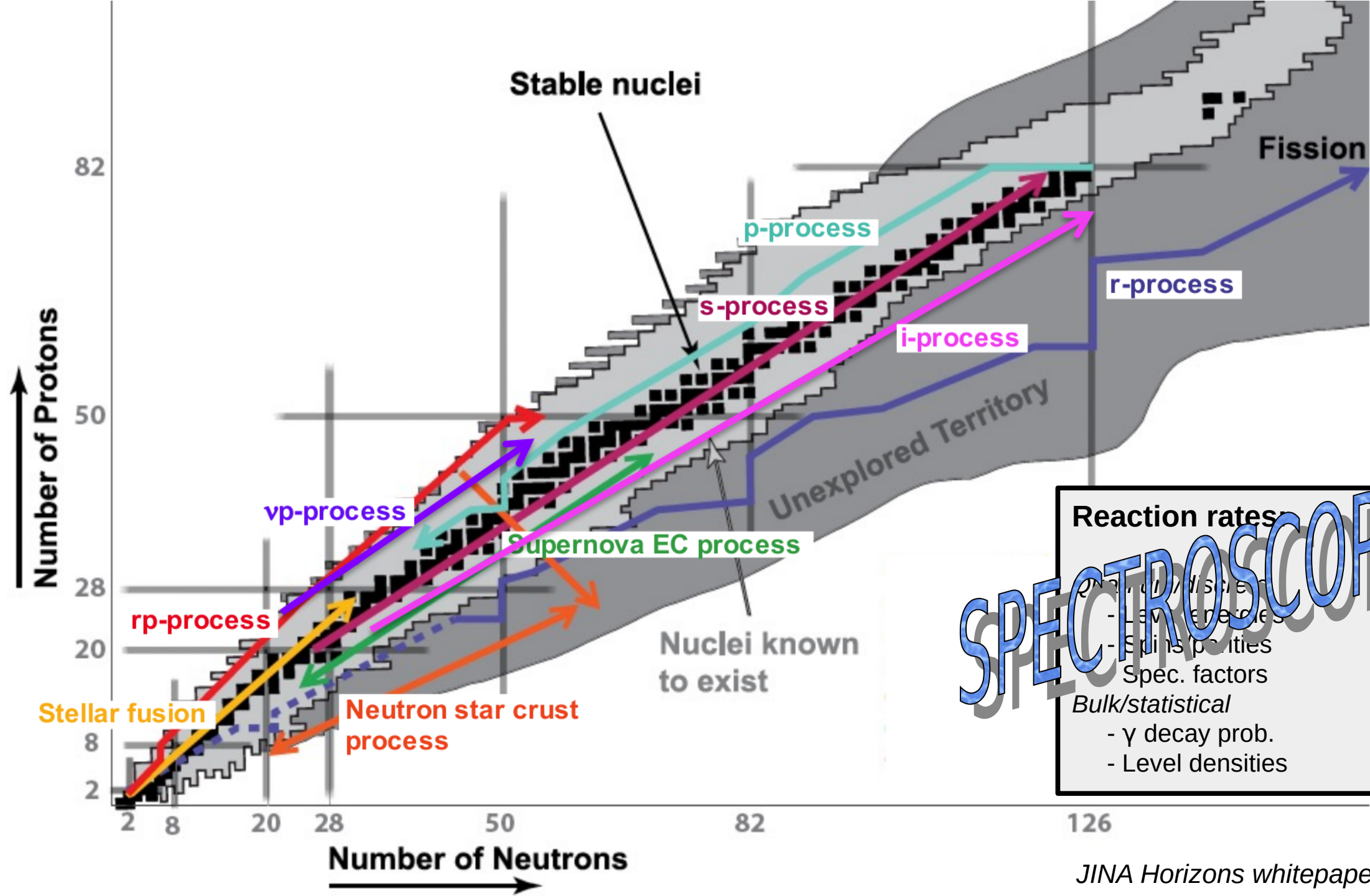
A star that normally slumbers around 12th magnitude suddenly "woke up" seven magnitudes brighter this past weekend. Now you can see it with the naked eye!



all are driven by nuclear reactions and decays involving proton-rich, radioactive nuclei







Novae endpoint nucleosynthesis: $^{38}\text{K}(p,\gamma)$

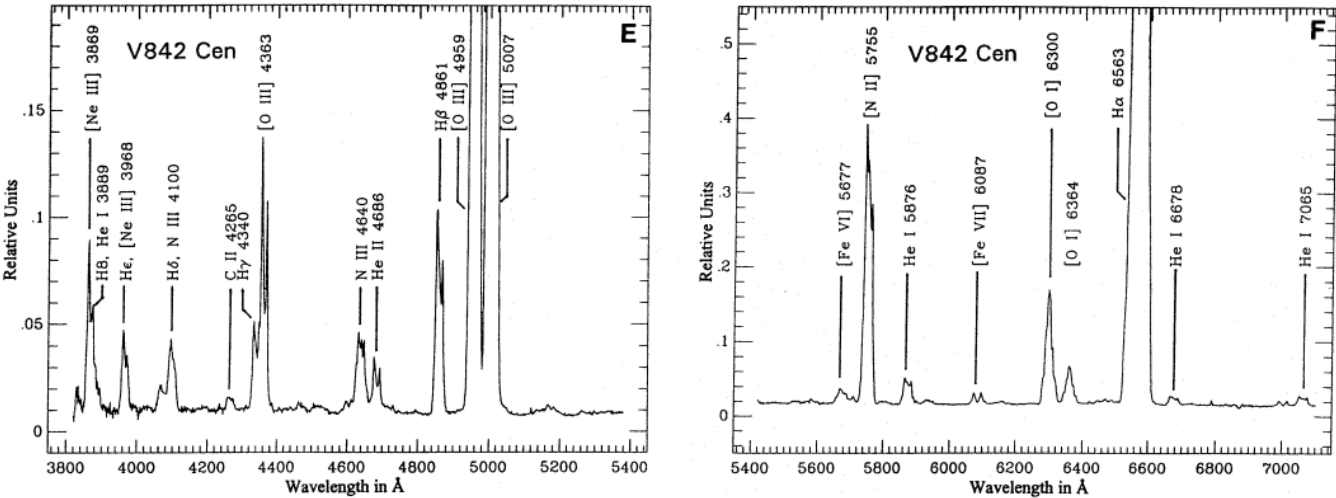


Fig. 1a–n. Examples of optical spectra of novae in nebular stage

Element	Sun	QV Vul (1987)	V2214 Oph (1988)	V977 Sco (1989)	V443 Sct (1989)
H	1.00	1.00	1.00	1.00	1.00
He	1.0 e-1	1.1 e-1	1.9 e-1	1.9 e-1	2.3 e-1
N	9.5 e-5	1.1 e-3	6.4 e-2	5.9 e-3	7.8 e-3
O	8.1 e-4	3.8 e-3	1.1 e-3	3.7 e-3	9.0 e-4
Ne	1.1 e-4	7.3 e-5	2.5 e-3	2.5 e-3	1.4 e-5
S	1.7 e-5	4.1 e-6	9.7 e-5	-	2.4 e-5
Ar	3.7 e-6	-	5.5 e-5	5.3 e-5	1.8 e-5
Ca	2.2 e-6	-	9.4 e-5	1.6 e-5	1.0 e-5
Fe	4.2 e-5	2.3 e-5	6.5 e-4	4.8 e-5	2.8 e-5
Z	0.019	0.05	0.37	0.08	0.06

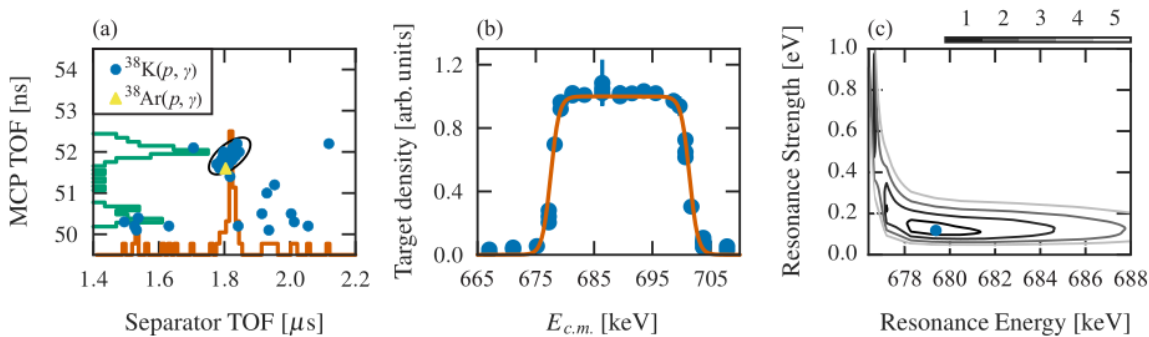
Andrea et al, A&A 291, 869

		Sc			36Sc	37Sc	38Sc	39Sc	40Sc	41Sc	42Sc	43Sc
								$J_{\pi}=(7/2^-)$	$J_{\pi}=4^-$ $T_{1/2}=1.823\text{E}$	$J_{\pi}=7/2^-$ $T_{1/2}=5.963\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=6.813\text{E}$	$J_{\pi}=7/2^-$ $T_{1/2}=1.401\text{E}$
Ca		34Ca	35Ca	36Ca	37Ca	38Ca	39Ca	40Ca	41Ca	42Ca		
	$J_{\pi}=0^+$		$T_{1/2}=5.000\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=1.020\text{E}$	$J_{\pi}=3/2^+$ $T_{1/2}=1.811\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=4.400\text{E}$	$J_{\pi}=3/2^+$ $T_{1/2}=8.596\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=1.000\text{E}$	$J_{\pi}=7/2^-$ $T_{1/2}=3.250\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=1.000\text{E}$		
32K	33K	34K	35K	36K	37K	38K	39K	40K	41K			
			$J_{\pi}=3/2^+$ $T_{1/2}=1.900\text{E}$	$J_{\pi}=2^+$ $T_{1/2}=3.420\text{E}$	$J_{\pi}=3/2^-$ $T_{1/2}=1.226\text{E}$	$J_{\pi}=3^+$ $T_{1/2}=4.582\text{E}$	$J_{\pi}=3/2^+$ $T_{1/2}=1.000\text{E}$	$J_{\pi}=4^-$ $T_{1/2}=4.030\text{E}$	$J_{\pi}=3/2^+$ $T_{1/2}=1.000\text{E}$			
31Ar	32Ar	33Ar	34Ar	35Ar	36Ar	37Ar	38Ar	39Ar	40Ar			
$T_{1/2}=1.510\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=9.800\text{E}$	$J_{\pi}=1/2^+$ $T_{1/2}=1.730\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=8.445\text{E}$	$J_{\pi}=3/2^+$ $T_{1/2}=1.775\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=1.000\text{E}$	$J_{\pi}=3/2^+$ $T_{1/2}=3.027\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=1.000\text{E}$	$J_{\pi}=7/2^-$ $T_{1/2}=8.489\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=1.000\text{E}$			
30Cl	31Cl	32Cl	33Cl	34Cl	35Cl	36Cl	37Cl	38Cl	39Cl			
	$T_{1/2}=1.500\text{E}$	$J_{\pi}=1^-$ $T_{1/2}=2.980\text{E}$	$J_{\pi}=3/2^-$ $T_{1/2}=2.511\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=1.526\text{E}$	$J_{\pi}=3/2^-$ $T_{1/2}=1.000\text{E}$	$J_{\pi}=2^+$ $T_{1/2}=9.499\text{E}$	$J_{\pi}=3/2^+$ $T_{1/2}=1.000\text{E}$	$J_{\pi}=2^-$ $T_{1/2}=2.234\text{E}$	$J_{\pi}=3/2^+$ $T_{1/2}=3.336\text{E}$			
29S	30S	31S	32S	33S	34S	35S	36S	37S	38S			
$J_{\pi}=5/2^+$ $T_{1/2}=1.870\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=1.178\text{E}$	$J_{\pi}=1/2^+$ $T_{1/2}=2.572\text{E}$	$J_{\pi}=1/2^+$ $T_{1/2}=1.000\text{E}$	$J_{\pi}=3/2^+$ $T_{1/2}=1.000\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=1.000\text{E}$	$J_{\pi}=3/2^+$ $T_{1/2}=7.561\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=1.000\text{E}$	$J_{\pi}=7/2^-$ $T_{1/2}=3.030\text{E}$	$J_{\pi}=1^+$ $T_{1/2}=1.022\text{E}$			
28P	29P	30P	31P	32P	33P	34P	35P	36P	37P			
$J_{\pi}=3^+$ $T_{1/2}=2.703\text{E}$	$J_{\pi}=1/2^+$ $T_{1/2}=4.140\text{E}$	$J_{\pi}=1^+$ $T_{1/2}=1.499\text{E}$	$J_{\pi}=1/2^+$ $T_{1/2}=1.000\text{E}$	$J_{\pi}=1^-$ $T_{1/2}=1.232\text{E}$	$J_{\pi}=1/2^-$ $T_{1/2}=2.189\text{E}$	$J_{\pi}=1^+$ $T_{1/2}=1.243\text{E}$	$J_{\pi}=1/2^+$ $T_{1/2}=4.730\text{E}$	$T_{1/2}=5.600\text{E}$	$T_{1/2}=2.310\text{E}$			
27Si	28Si	29Si	30Si	31Si	32Si	33Si	34Si	35Si	36Si			
$J_{\pi}=5/2^+$ $T_{1/2}=4.160\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=1.000\text{E}$	$J_{\pi}=1/2^+$ $T_{1/2}=1.000\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=1.000\text{E}$	$J_{\pi}=3/2^+$ $T_{1/2}=9.438\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=5.428\text{E}$	$T_{1/2}=6.180\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=2.770\text{E}$	$T_{1/2}=7.800\text{E}$	$J_{\pi}=0^+$ $T_{1/2}=4.500\text{E}$			
26Al	27Al	28Al	29Al	30Al	31Al	32Al	33Al	34Al	35Al			
$J_{\pi}=5^-$ $T_{1/2}=2.335\text{E}$	$J_{\pi}=5/2^+$ $T_{1/2}=1.000\text{E}$	$J_{\pi}=3^+$ $T_{1/2}=1.345\text{E}$	$J_{\pi}=5/2^+$ $T_{1/2}=3.936\text{E}$	$J_{\pi}=3^+$ $T_{1/2}=3.600\text{E}$	$J_{\pi}=(3/2,5/2)^+$ $T_{1/2}=6.440\text{E}$	$J_{\pi}=1^-$ $T_{1/2}=3.300\text{E}$		$T_{1/2}=6.000\text{E}$	$T_{1/2}=1.500\text{E}$			

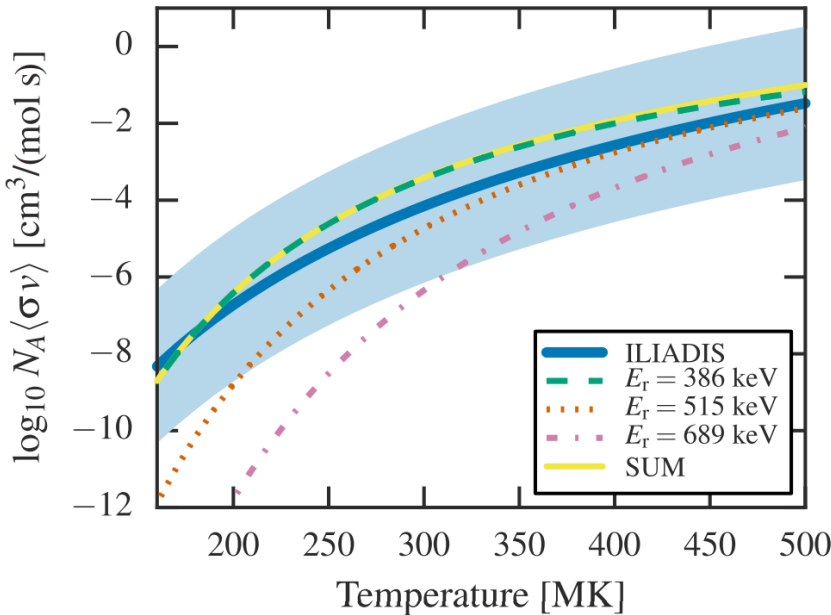
Iliadis et al, ApJSS 142, 105

$^{38}\text{K}(p,\gamma)^{39}\text{Ca}$	^{38}Ar	0.11
	^{39}K	9.5
	^{40}Ca	5.1

Spectroscopy of $^{38}\text{K}(p,\gamma)^{39}\text{Ca}$: putting the cart before the horse



Ref.	E_x (keV)	E_r (keV)	$\omega\gamma$ (meV)
	6157(10)	386(10)	≤ 2.54
Christian <i>et al.</i> [7]	6286(10)	515(10)	≤ 18.4
	6450(2)	679(2)	120(25)

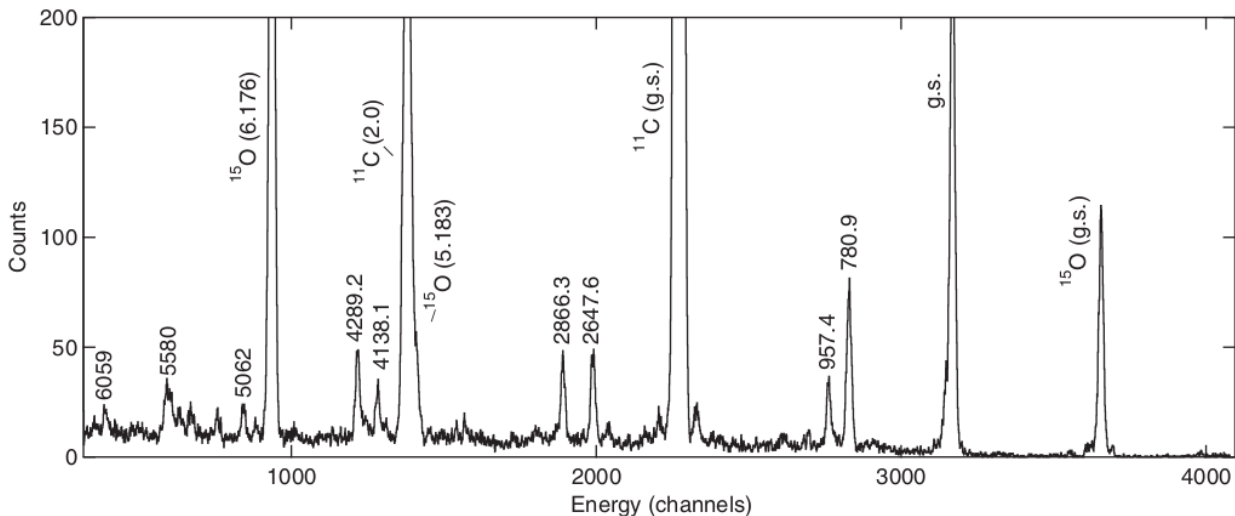


The chosen beam energies cover respective center-of-mass energies in the DRAGON gas target of 386 ± 13 , 515 ± 13 , and 689 ± 13 keV. The resonances in question were previously identified as $5/2^+$ ^{39}Ca states through $^{40}\text{Ca}(^3\text{He},\alpha)^{39}\text{Ca}$ [18], $^{40}\text{Ca}(d,t)^{39}\text{Ca}$ [19], and $^{40}\text{Ca}(p,d)^{39}\text{Ca}$ [20] transfer reaction studies. Their recommended excitation energies are 6157 ± 10 , 6286 ± 10 , and 6460 ± 10 keV, corresponding to $^{38}\text{K} + p$ resonances at 386 ± 10 , 515 ± 10 , and 689 ± 10 keV, respectively [21]. The respective (p,γ) cone angles for mea-

...what's 10 keV among friends?

Spectroscopy of $^{38}\text{K}(\text{p},\gamma)^{39}\text{Ca}$: pointing out the horse/cart situation

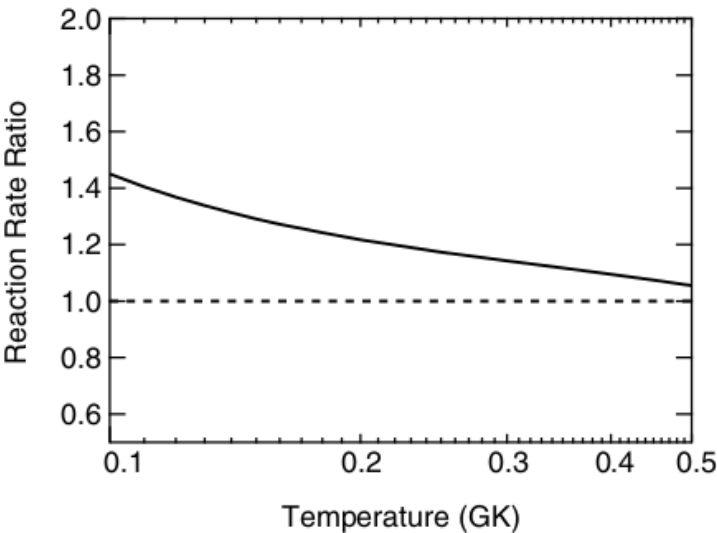
Setoodehnia et al, PRC98, 055804



$^{40}\text{Ca}(\text{}^3\text{He},\alpha)^{39}\text{Ca}$ using Enge spectrograph to constrain energies and spins

701 keV would have been on the edge of the DRAGON target!

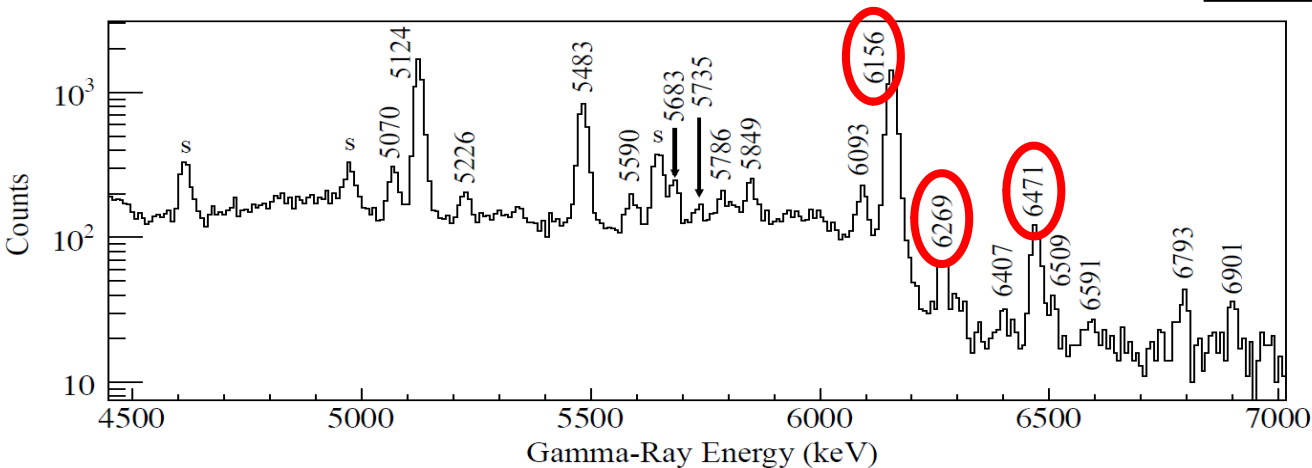
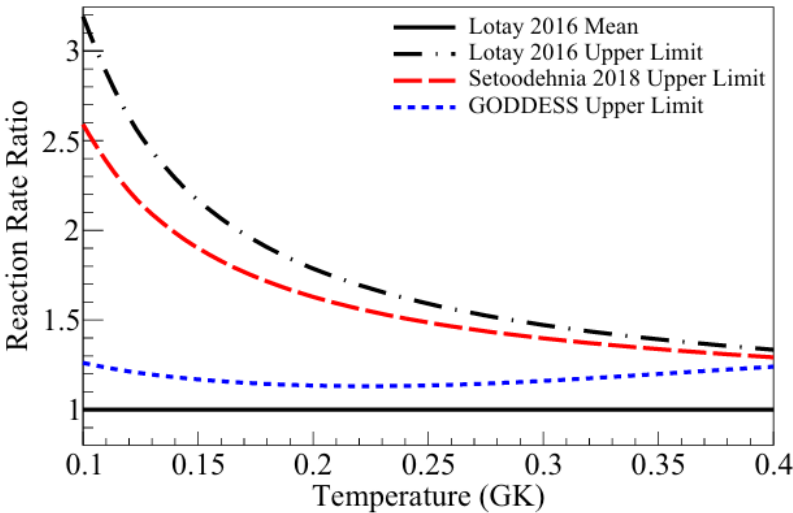
Ref.	E_x (keV)	E_r (keV)	$\omega\gamma$ (meV)
Christian <i>et al.</i> [7]	6157(10)	386(10)	≤ 2.54
	6286(10)	515(10)	≤ 18.4
	6450(2)	679(2)	120(25)
Setoodehnia <i>et al.</i> [11]	6154(5)	383(5)	≤ 2.6
	6286(10)	515(10)	≤ 18.4
	6472.2(24)	701.3(25)	126(39)



(b) Ratio of the new over old reaction rate.

Spectroscopy of $^{38}\text{K}(p,\gamma)^{39}\text{Ca}$: careful spectroscopy with solves the problem

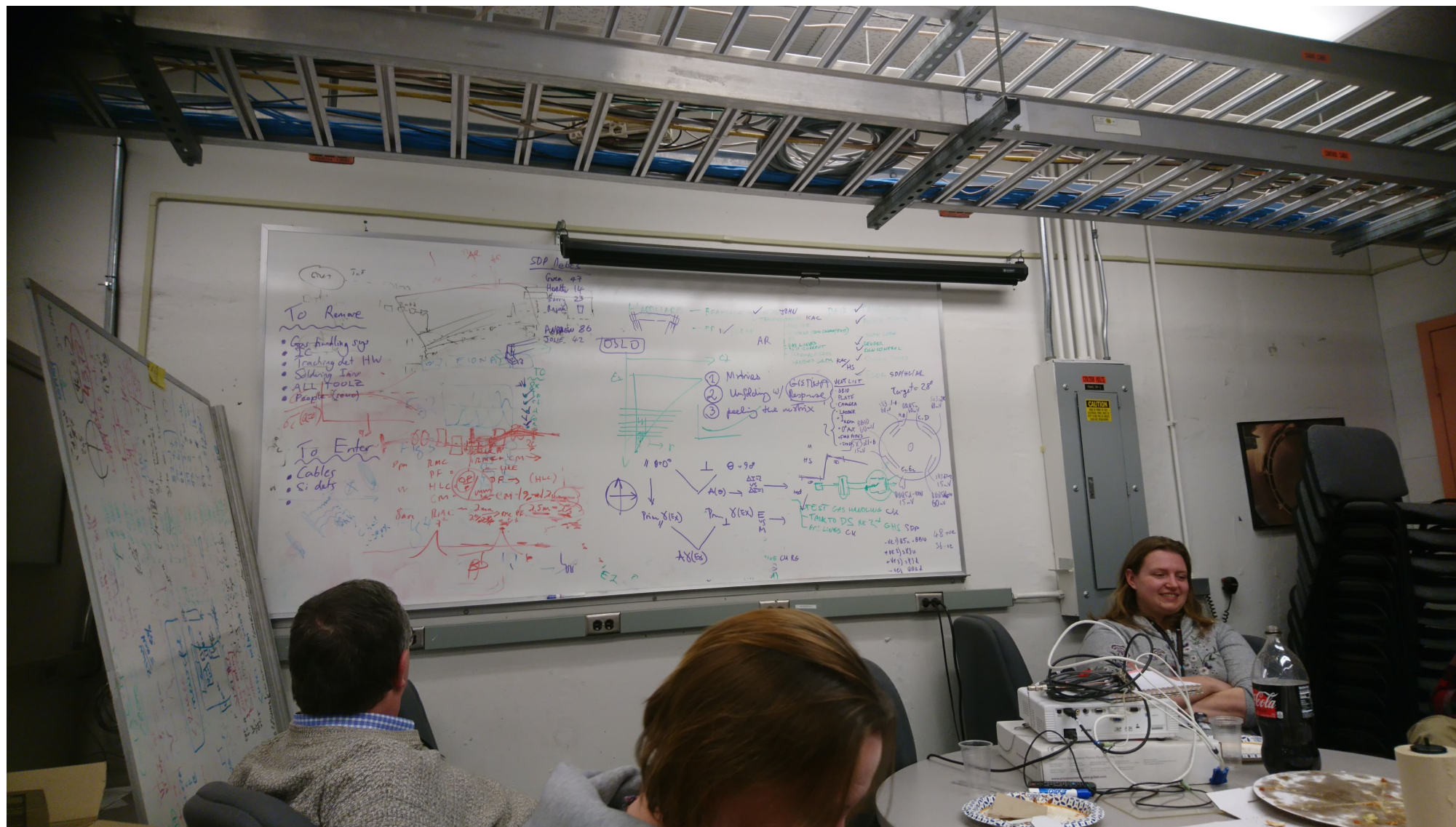
Hall et al, PRC101, 015804



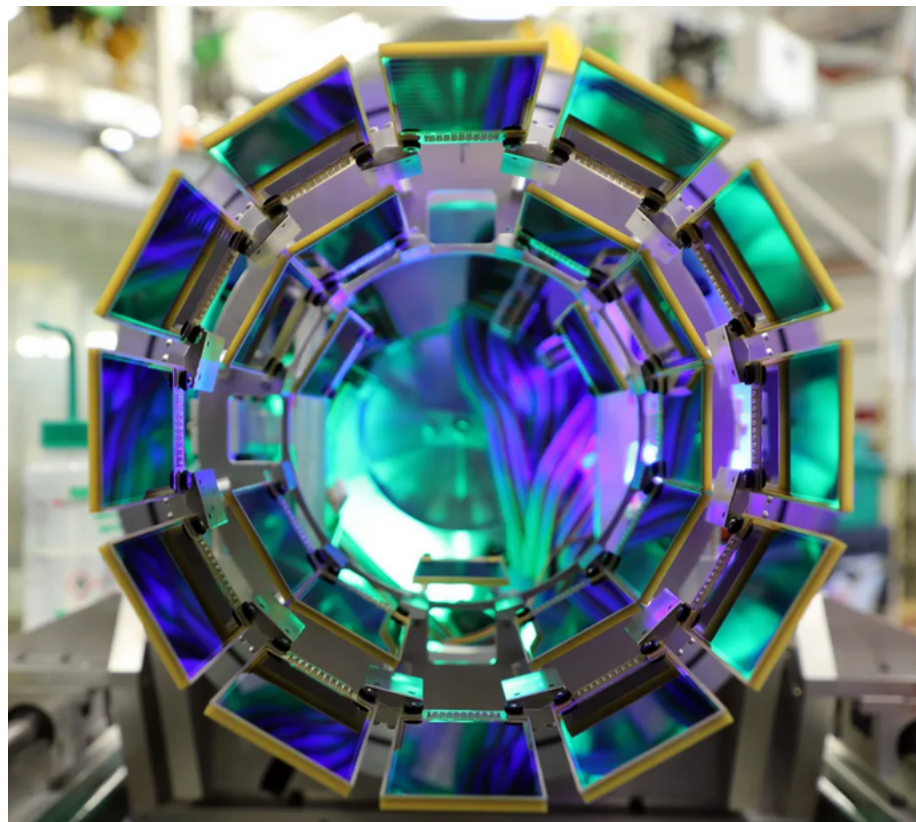
Ref.	E_x (keV)	E_r (keV)	$\omega\gamma$ (meV)
Christian <i>et al.</i> [7]	6157(10)	386(10)	≤ 2.54
	6286(10)	515(10)	≤ 18.4
	6450(2)	679(2)	120(25)
Setoodehnia <i>et al.</i> [11]	6154(5)	383(5)	≤ 2.6
	6286(10)	515(10)	≤ 18.4
	6472.2(24)	701.3(25)	126(39)
Present Work	6156.7(16)	386(2)	≤ 2.54
	6269.3(22)	498(2)	2.47 - 24.7
	6471.4(19)	701(2)	126(39)

- Constrain level energies to 2 keV
 - Good agreement for 6157-keV level
- Reduced reaction rate uncertainties
- Confirms 701-keV energy from SPS expt
 - places this resonance at edge of DRAGON target
- Suggests middle resonance is lower by 1-2 σ
 - outside DRAGON target?

clearly hard at work during the 2019 GODDESS campaign...



Spectroscopy of $^{38}\text{K}(p,\gamma)^{39}\text{Ca}$: constraining resonance strengths



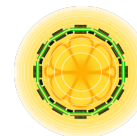
Proton single particle spectroscopic factors can be tricky:

- getting good resolution with (d,n)
- getting good res and sufficient target density for (^3He ,d)

For these N=Z nuclei, let's measure *neutron* single particle spectroscopic factors:

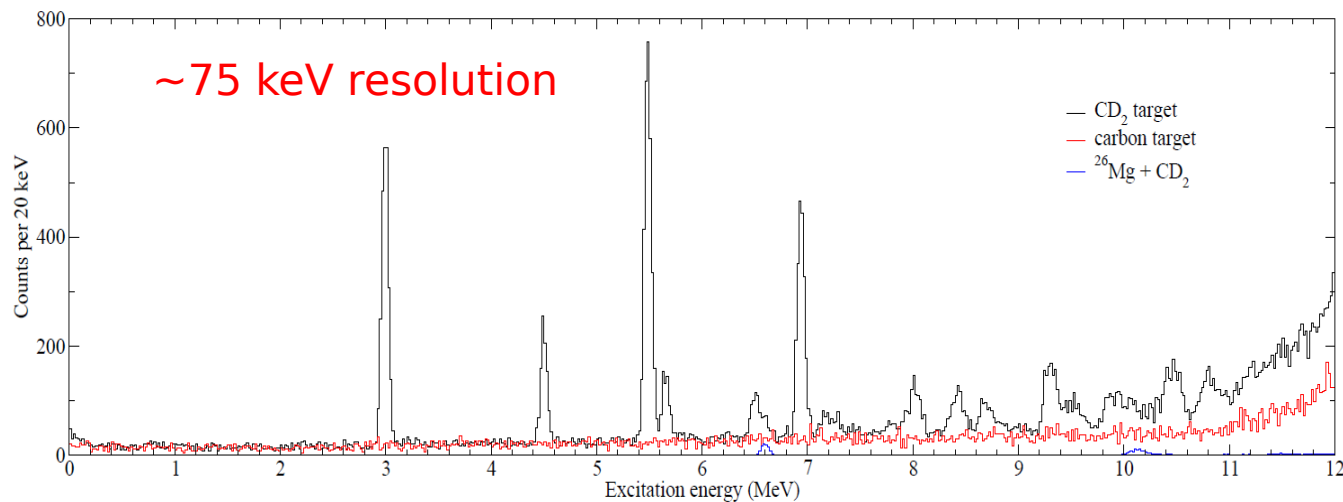
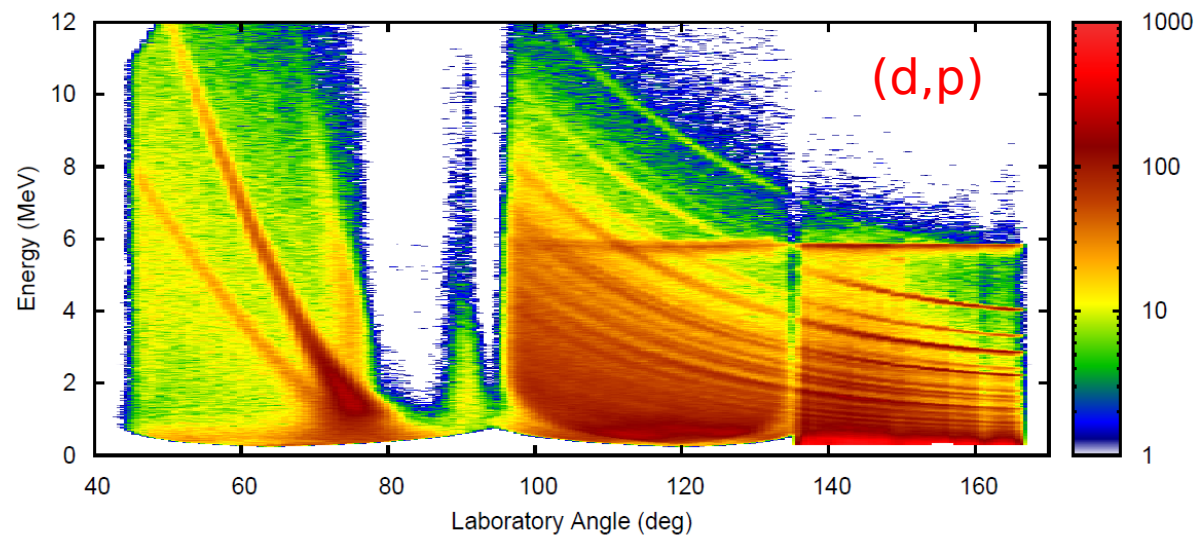
- mirror assignments and MED shifts from fusion evaporation studies
(with Gammasphere and GRETTINA!)
- (d,p) angular distributions straightforward to measure/interpret
($J\pi$ and spectroscopic factors)
- shell model embedded in the continuum corrections
(neutron SF \rightarrow proton SF)

$^{38}\text{K}(d,p)$ spectroscopic transfer reaction study undertaken with



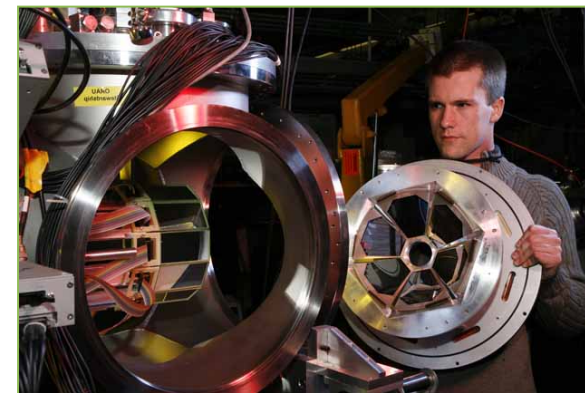
ORRUBA

For example: $^{26}\text{Al}(d,p)^{27}\text{Al}$ experiment

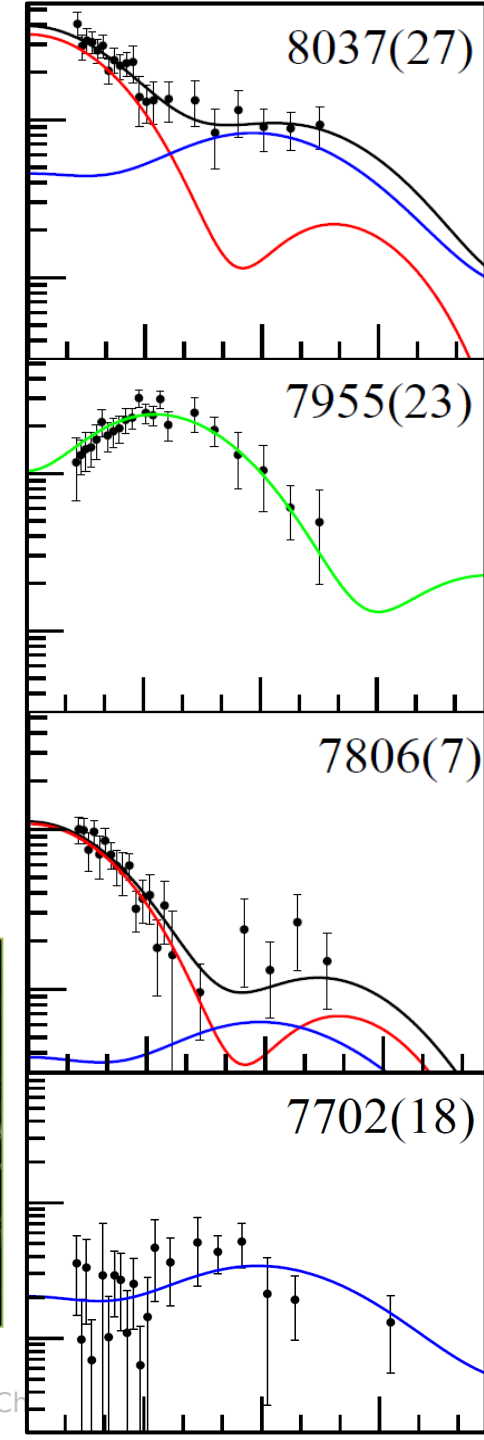


- 4.5 MeV/u ^{26}Al (HRIBF tandem)
- 5×10^6 pps
- $150 \mu\text{g}/\text{cm}^2$ CD_2
- MCP normalization

Pain et al, PRL114, 212501



K.A. CH



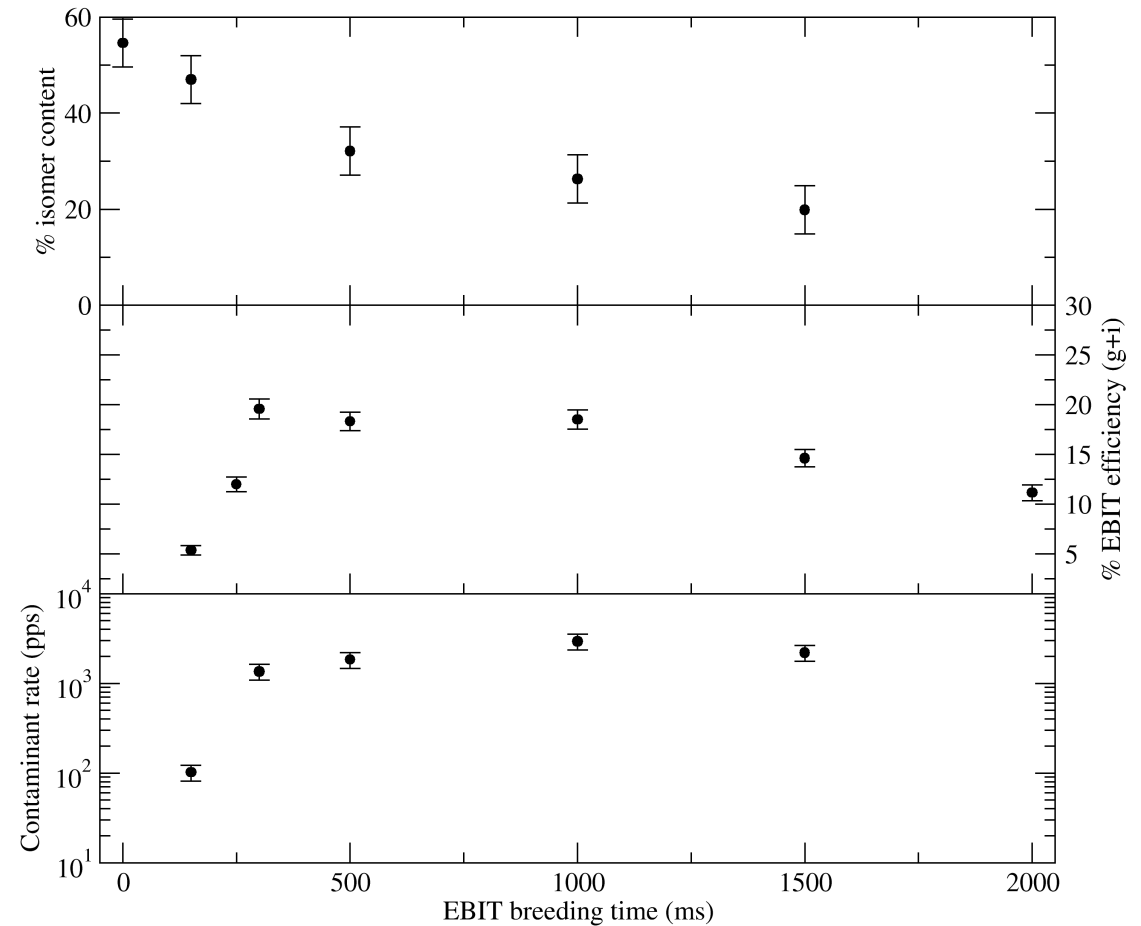
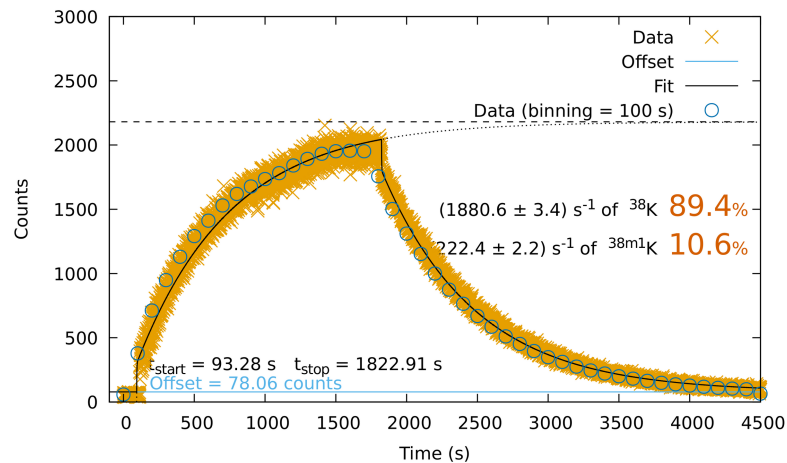
Spectroscopy of $^{38}\text{K}(p,\gamma)^{39}\text{Ca}$: don't forget the isomer!

^{38}K has a low-lying, large ΔJ , long-lived isomer
→ just like ^{26}Al !

Need to run $^{38}\text{K}(d,p)$ with two different beam settings:
mostly gs and *mostly isomer*
so that we can differentiate the strength built on each...

These isomers can be populated thermally in an
astrophysical environment, or as the endpoint of beta
decay

(in the case of $^{38}\text{K}^m$, it's almost 80%!)

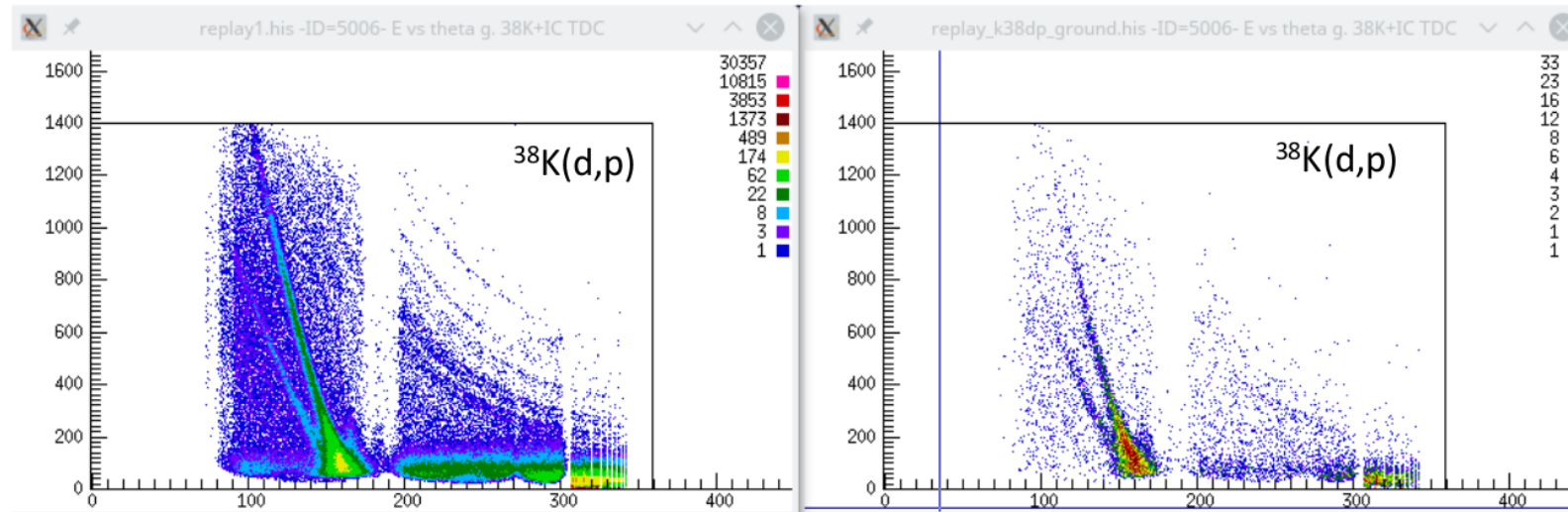


Chipps et al, PRAB 21, 121301

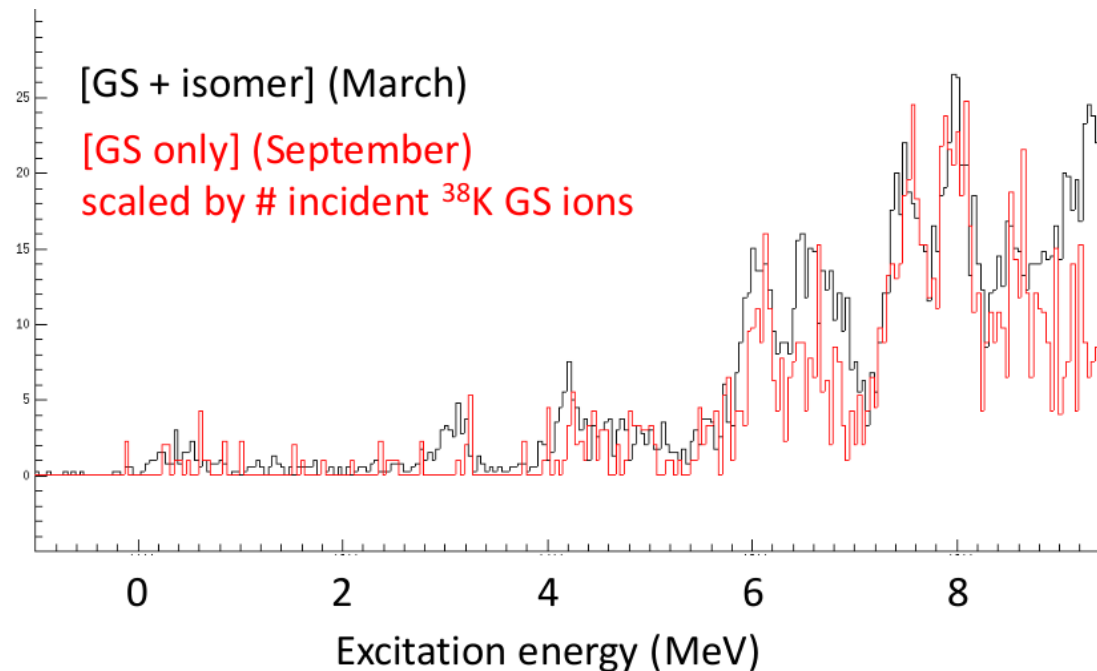
Spectroscopy of $^{38}\text{K}(p,\gamma)^{39}\text{Ca}$: don't forget the isomer!

Short breeding time (March)

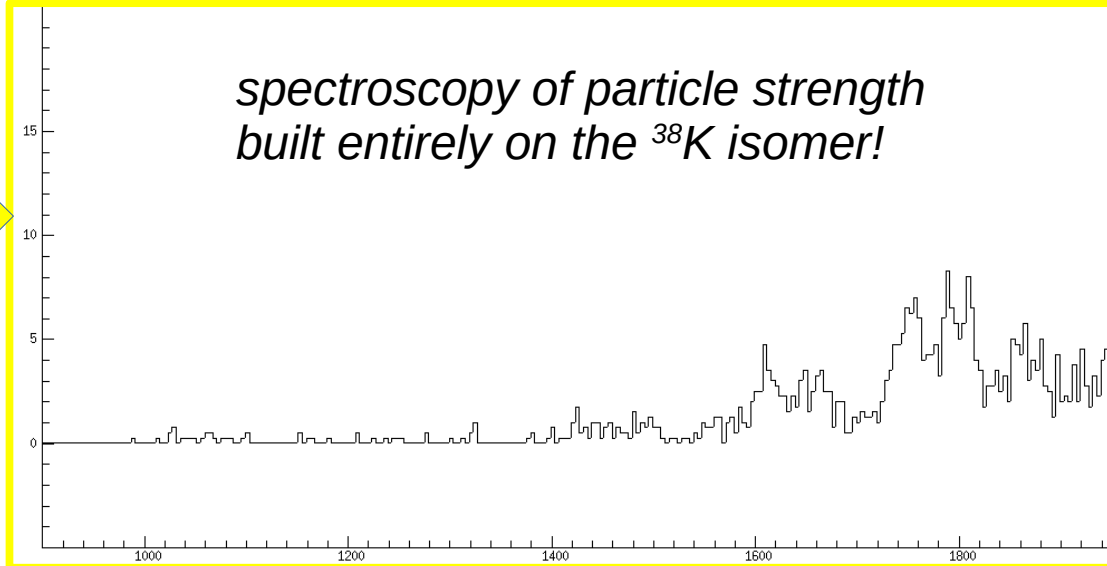
Long breeding time (September)



multiple ways to vary the isomer content of a beam – can be done at ATLAS and FRIB



spectroscopy of particle strength built entirely on the ^{38}K isomer!



Novae endpoint nucleosynthesis: $^{38}\text{K}(p,\gamma)$ and the necessity for spectroscopy in astro

$^{38}\text{K}(p,\gamma)^{39}\text{Ca}$	^{38}Ar	0.11
	^{39}K	9.5
	^{40}Ca	5.1



$^{38}\text{K}^m(p,\gamma)^{39}\text{Ca}$	^{38}Ar	
	^{39}K	
	^{40}Ca	

		Sc	36Sc	37Sc	38Sc	39Sc	40Sc	41Sc	42Sc	43Sc
						$J^{\pi}=(7/2^-)$	$J^{\pi}=4^-$ T1/2s=1.823E	$J^{\pi}=7/2^-$ T1/2s=5.963E	$J^{\pi}=0^+$ T1/2s=6.813E	$J^{\pi}=7/2^-$ T1/2s=1.401E
Ca	34Ca	$J^{\pi}=0^+$	35Ca T1/2s=5.000E	36Ca $J^{\pi}=0^+$ T1/2s=1.020E	37Ca $J^{\pi}=3/2^+$ T1/2s=1.811E	38Ca $J^{\pi}=0^+$ T1/2s=4.400E	39Ca $J^{\pi}=3/2^+$ T1/2s=8.596E	40Ca $J^{\pi}=0^+$ T1/2s=1.000E	41Ca $J^{\pi}=7/2^-$ T1/2s=3.250E	42Ca $J^{\pi}=0^+$ T1/2s=1.000E
	32K	33K	34K	35K $J^{\pi}=3/2^+$ T1/2s=1.900E	36K $J^{\pi}=2^+$ T1/2s=3.420E	37K $J^{\pi}=3/2^+$ T1/2s=1.226E	38K $J^{\pi}=3^+$ T1/2s=4.582E	39K $J^{\pi}=3/2^+$ T1/2s=1.000E	40K $J^{\pi}=4^-$ T1/2s=4.030E	41K $J^{\pi}=3/2^+$ T1/2s=1.000E
	31Ar	32Ar	33Ar	34Ar	35Ar	36Ar	37Ar	38Ar	39Ar	40Ar
	T1/2s=1.510E	$J^{\pi}=0^+$ T1/2s=9.800E	$J^{\pi}=1/2^+$ T1/2s=1.730E	$J^{\pi}=0^+$ T1/2s=8.445E	$J^{\pi}=3/2^+$ T1/2s=1.775E	$J^{\pi}=0^+$ T1/2s=1.000E	$J^{\pi}=3/2^+$ T1/2s=3.027E	$J^{\pi}=0^+$ T1/2s=1.000E	$J^{\pi}=7/2^-$ T1/2s=8.489E	$J^{\pi}=0^+$ T1/2s=1.000E
	30Cl	31Cl	32Cl	33Cl	34Cl	35Cl	36Cl	37Cl	38Cl	39Cl
		T1/2s=1.500E	$J^{\pi}=1^+$ T1/2s=2.980E	$J^{\pi}=3/2^+$ T1/2s=2.511E	$J^{\pi}=0^+$ T1/2s=1.526E	$J^{\pi}=3/2^+$ T1/2s=1.000E	$J^{\pi}=2^+$ T1/2s=9.499E	$J^{\pi}=3/2^+$ T1/2s=1.000E	$J^{\pi}=2^-$ T1/2s=2.234E	$J^{\pi}=3/2^+$ T1/2s=3.336E
	29S	30S	31S	32S	33S	34S	35S	36S	37S	38S
	$J^{\pi}=5/2^+$ T1/2s=1.870E	$J^{\pi}=0^+$ T1/2s=1.178E	$J^{\pi}=1/2^+$ T1/2s=2.572E	$J^{\pi}=0^+$ T1/2s=1.000E	$J^{\pi}=3/2^+$ T1/2s=1.000E	$J^{\pi}=0^+$ T1/2s=1.000E	$J^{\pi}=3/2^+$ T1/2s=7.561E	$J^{\pi}=0^+$ T1/2s=1.000E	$J^{\pi}=7/2^-$ T1/2s=3.030E	$J^{\pi}=0^+$ T1/2s=1.022E
	28P	29P	30P	31P	32P	33P	34P	35P	36P	37P
	$J^{\pi}=3^+$ T1/2s=2.703E	$J^{\pi}=1/2^+$ T1/2s=4.140E	$J^{\pi}=1^+$ T1/2s=1.499E	$J^{\pi}=1/2^+$ T1/2s=1.000E	$J^{\pi}=1^+$ T1/2s=1.232E	$J^{\pi}=1/2^+$ T1/2s=2.189E	$J^{\pi}=1^+$ T1/2s=1.243E	$J^{\pi}=1/2^+$ T1/2s=4.730E	T1/2s=5.600E	T1/2s=2.310E
	27Si	28Si	29Si	30Si	31Si	32Si	33Si	34Si	35Si	36Si
	$J^{\pi}=5/2^+$ T1/2s=4.160E	$J^{\pi}=0^+$ T1/2s=1.000E	$J^{\pi}=1/2^+$ T1/2s=1.000E	$J^{\pi}=0^+$ T1/2s=1.000E	$J^{\pi}=3/2^+$ T1/2s=9.438E	$J^{\pi}=0^+$ T1/2s=5.428E	T1/2s=6.180E	$J^{\pi}=0^+$ T1/2s=2.770E	T1/2s=7.800E	$J^{\pi}=0^+$ T1/2s=4.500E
	26Al	27Al	28Al	29Al	30Al	31Al	32Al	33Al	34Al	35Al
	$J^{\pi}=5^+$ T1/2s=2.335E	$J^{\pi}=5/2^+$ T1/2s=1.000E	$J^{\pi}=3^+$ T1/2s=1.345E	$J^{\pi}=5/2^+$ T1/2s=3.936E	$J^{\pi}=3^+$ T1/2s=3.600E	$J^{\pi}=(3/2,5/2)^+$ T1/2s=6.440E	$J^{\pi}=1^+$ T1/2s=3.300E		T1/2s=6.000E	T1/2s=1.500E



Sc		36Sc	37Sc	38Sc	39Sc	40Sc	41Sc	42Sc	43Sc
					$J^{\pi}=(7/2^-)$	$J^{\pi}=4^-$ T1/2s=1.823E	$J^{\pi}=7/2^-$ T1/2s=5.963E	$J^{\pi}=0^+$ T1/2s=6.813E	$J^{\pi}=7/2^-$ T1/2s=1.401E
Ca	34Ca	35Ca	36Ca	37Ca	38Ca	39Ca	40Ca	41Ca	42Ca
	$J^{\pi}=0^+$	T1/2s=5.000E	$J^{\pi}=0^+$ T1/2s=1.020E	$J^{\pi}=3/2^+$ T1/2s=1.811E	$J^{\pi}=0^+$ T1/2s=4.400E	$J^{\pi}=3/2^+$ T1/2s=8.596E	$J^{\pi}=0^+$ T1/2s=1.000E	$J^{\pi}=7/2^-$ T1/2s=3.250E	$J^{\pi}=0^+$ T1/2s=1.000E
32K	33K	34K	35K	36K	37K	38K	39K	40K	41K
			$J^{\pi}=3/2^+$ T1/2s=1.900E	$J^{\pi}=2^+$ T1/2s=3.420E	$J^{\pi}=3/2^+$ T1/2s=1.226E	$J^{\pi}=3^+$ T1/2s=4.582E	$J^{\pi}=3/2^+$ T1/2s=1.000E	$J^{\pi}=4^-$ T1/2s=4.030E	$J^{\pi}=3/2^+$ T1/2s=1.000E
31Ar	32Ar	33Ar	34Ar	35Ar	36Ar	37Ar	38Ar	39Ar	40Ar
T1/2s=1.510E	$J^{\pi}=0^+$ T1/2s=9.800E	$J^{\pi}=1/2^+$ T1/2s=1.730E	$J^{\pi}=0^+$ T1/2s=8.445E	$J^{\pi}=3/2^+$ T1/2s=1.775E	$J^{\pi}=0^+$ T1/2s=1.000E	$J^{\pi}=3/2^+$ T1/2s=3.027E	$J^{\pi}=0^+$ T1/2s=1.000E	$J^{\pi}=7/2^-$ T1/2s=8.489E	$J^{\pi}=0^+$ T1/2s=1.000E
30Cl	31Cl	32Cl	33Cl	34Cl	35Cl	36Cl	37Cl	38Cl	39Cl
	T1/2s=1.500E	$J^{\pi}=1^+$ T1/2s=2.980E	$J^{\pi}=3/2^+$ T1/2s=2.511E	$J^{\pi}=0^+$ T1/2s=1.526E	$J^{\pi}=3/2^+$ T1/2s=1.000E	$J^{\pi}=2^+$ T1/2s=9.499E	$J^{\pi}=3/2^+$ T1/2s=1.000E	$J^{\pi}=2^-$ T1/2s=2.234E	$J^{\pi}=3/2^+$ T1/2s=3.336E
29S	30S	31S	32S	33S	34S	35S	36S	37S	38S
$J^{\pi}=5/2^+$ T1/2s=1.870E	$J^{\pi}=0^+$ T1/2s=1.178E	$J^{\pi}=1/2^+$ T1/2s=2.572E	$J^{\pi}=0^+$ T1/2s=1.000E	$J^{\pi}=3/2^+$ T1/2s=1.000E	$J^{\pi}=0^+$ T1/2s=1.000E	$J^{\pi}=3/2^+$ T1/2s=7.561E	$J^{\pi}=0^+$ T1/2s=1.000E	$J^{\pi}=7/2^-$ T1/2s=3.030E	$J^{\pi}=0^+$ T1/2s=1.022E
28P	29P	30P	31P	32P	33P	34P	35P	36P	37P
$J^{\pi}=3^+$ T1/2s=2.703E	$J^{\pi}=1/2^+$ T1/2s=4.140E	$J^{\pi}=1^+$ T1/2s=1.499E	$J^{\pi}=1/2^+$ T1/2s=1.000E	$J^{\pi}=1^+$ T1/2s=1.232E	$J^{\pi}=1/2^+$ T1/2s=2.189E	$J^{\pi}=1^+$ T1/2s=1.243E	$J^{\pi}=1/2^+$ T1/2s=4.730E	T1/2s=5.600E	T1/2s=2.310E
27Si	28Si	29Si	30Si	31Si	32Si	33Si	34Si	35Si	36Si
$J^{\pi}=5/2^+$ T1/2s=4.160E	$J^{\pi}=0^+$ T1/2s=1.000E	$J^{\pi}=1/2^+$ T1/2s=1.000E	$J^{\pi}=0^+$ T1/2s=1.000E	$J^{\pi}=3/2^+$ T1/2s=9.438E	$J^{\pi}=0^+$ T1/2s=5.428E	T1/2s=6.180E	$J^{\pi}=0^+$ T1/2s=2.770E	T1/2s=7.800E	$J^{\pi}=0^+$ T1/2s=4.500E
26Al	27Al	28Al	29Al	30Al	31Al	32Al	33Al	34Al	35Al
$J^{\pi}=5^+$ T1/2s=2.335E	$J^{\pi}=5/2^+$ T1/2s=1.000E	$J^{\pi}=3^+$ T1/2s=1.345E	$J^{\pi}=5/2^+$ T1/2s=3.936E	$J^{\pi}=3^+$ T1/2s=3.600E	$J^{\pi}=(3/2,5/2)^+$ T1/2s=6.440E	$J^{\pi}=1^+$ T1/2s=3.300E		T1/2s=6.000E	T1/2s=1.500E



Teaching spectroscopy to the next generation of nuclear physicists...

2019



2002



Thank you
(and thanks to Robert for years of
mentorship!)

