

Nuclear Structure Research at Richmond

Report: 07/01/2005 – 04/30/2015

Grant Number: DE-FG02-05ER41379

P.I.: C.W. Beausang

This report focuses primarily on the period January 2014 through April 2015, roughly corresponding to the final year of the award. During this period, the Richmond group consisted of myself, postdoctoral fellows Anna Simon (through July) and Emma Wilson (from November 2014), and Ph.D. student Peter Humby (all supported via a separate award from the DOE NNSA). Two undergraduate students Kristen Gell ('15) and Nathan Watwood ('15) joined us for a summer research experience and continued their projects during the academic year.

The goals for the final year of the award were:

1. To continue my ongoing efforts to develop and enhance GRETINA and work towards GRETA.
2. To investigate the structure of non-yrast states in shape transitional Sm and Gd nuclei.
3. To investigate the structure of selected light Cd nuclei.
4. To exploit the surrogate reaction technique to extract (n,f) cross sections for actinide nuclei, particularly the first measurement of the ^{236}Pu and $^{237}\text{Pu}(n,f)$ cross sections.

Progress on each of these goals will now be briefly discussed. Details of other achievements can be found in earlier technical reports.

1. Development of GRETINA/GRETA

GRETINA is off to a great start and is perceived to be a great success by the community. The array has now completed (or shortly will) two successful science campaigns at the NSCL and ANL. It is currently transitioning back to the NSCL. Demand for beam time for the second NSCL campaign is strong.

I continued my service on the GRETINA advisory committee, which meets ~weekly, where we discuss the path forward to the full GRETA. My first GREINA paper, a study of triplet energy differences in $T = 1$ states in $A = 62$ isobars, a collaboration led by the University of York, UK has just been submitted for publication [1]. During the year, I presented a talk on the potential of using GRETA for surrogate reactions at the GRETINA/GRETA workshop at Argonne in June 2014 [2].

2. Non-yrast structures in transitional Sm and Gd nuclei.

During the year, significant progress was made on this front. Reports were presented at the DNP and APS April meetings as well as several other international meetings and seminars (see items 2-10 under contributed talks and item 6 under seminars below) and a

long paper following up on our 2013 Rapid communication [3] and detailing our results on the structure of non yrast states in $^{153,5}\text{Gd}$ following (p,d) reactions appeared [4].

In each of our (p,t) data sets on even-even Sm and Gd targets a prominent peak-like-feature is observed between 2 and 3 MeV excitation energy, near the pair-gap. The feature is very strongly populated, with a total cross section approaching that of the ground state. Very recently we have been able to identify multiple new discrete states that account for much of the intensity of this feature in $^{152,4}\text{Sm}$. Figure 1 shows a partial level scheme for ^{152}Sm where the new levels in the PLF are indicated in blue. The horizontal error bars indicate possible spin values based solely on the lower lying states fed. We find that roughly half of the new states in the PLF decay to lower lying 0 or 2+ states while the rest decay directly to much higher spin states including the yrast 7- level. This indicates that a wide range of angular momentum states are populated in the PLF, with individual cross sections approaching 10% of the ground state. A paper reporting these and other results for the Sm(p, t) reactions is being prepared for publication[5].

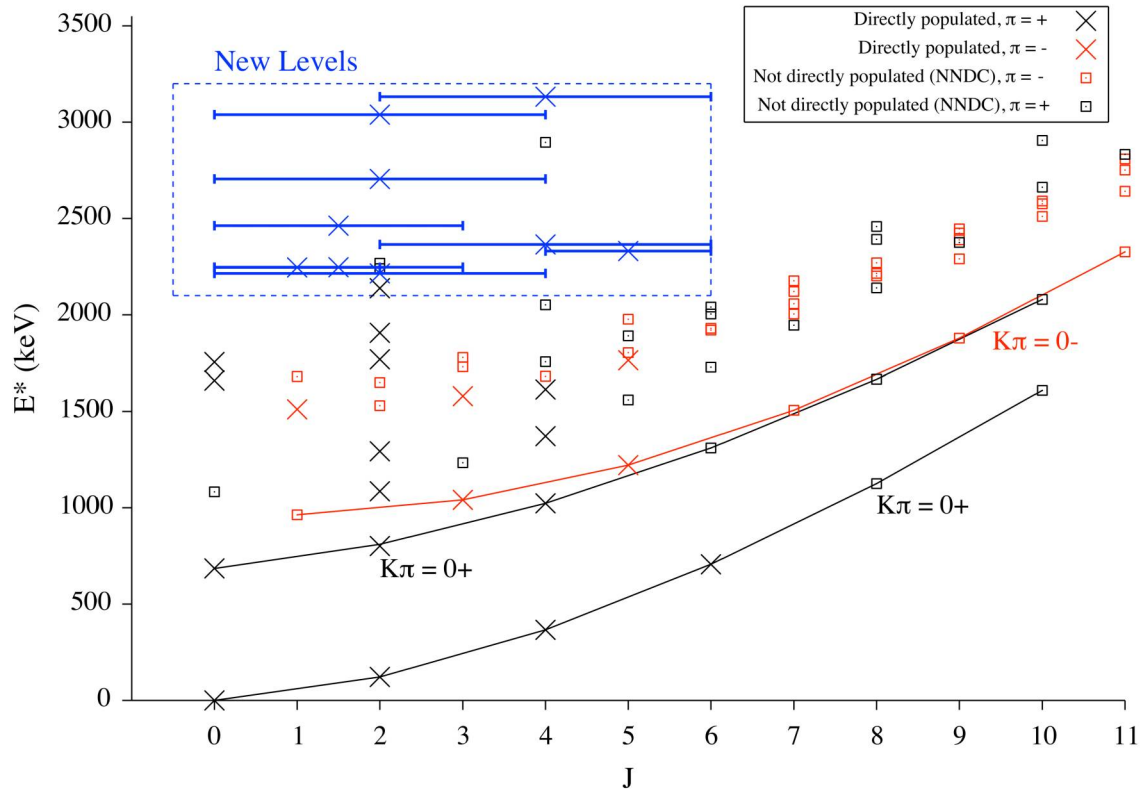


Figure 1: Partial level scheme of ^{152}Sm showing the new levels identified in the peak-like feature at around 3 MeV excitation energy. The figure also indicates (by X) which lower lying levels are directly populated by the (p,t) reaction. Open boxes indicate other known levels which are not directly populated via the (p, t) reaction.

Finally, during the year, a target of opportunity result presented itself. An out of beam analysis of our recent STARLITER data revealed that we could make an improved measurement of the lifetimes of two long lived isomers (96 minute and 9 hours) in ^{152}Eu , which were populated following the $^{154}\text{Sm}(p,3n)$ reaction. A paper was quickly written up

and published in Phys. Rev., the first first-author publication of graduate student Peter Humby [6].

3. Investigation of the structure of selected light Cd nuclei.

A preliminary report on this data was presented at the APS meeting in Savannah in April 2014 (item 1 under contributed talks). Further analysis revealed that there were significant issues with the data set, specifically to do with time correlations, or rather the lack of, between the particle and gamma data, most likely due to problems with the data acquisition following a major power outage mid-experiment. It is clear that further progress here must await additional data from a new experiment.

4. Exploitation of the surrogate reaction technique to extract (n,f) cross sections for actinide nuclei.

We continue to exploit the surrogate reaction technique to extract (n,f) cross sections for actinide nuclei.

Analysis of the $^{239}\text{Pu}((p,p'f), (p,df) \text{ and } (p,tf)$ data sets, surrogate for $^{238}\text{Pu}(n,f)$, $^{237}\text{Pu}(n,f)$ and $^{236}\text{Pu}(n,f)$, respectively, was completed and published [7]. Interestingly, for the lightest system, for $^{236}\text{Pu}(n,f)$, the results show significant deviations from the accepted ENDEF values (both the magnitude and the trends were different). Given the usually good agreement between surrogate and directly measured (n,f) reactions, including in this experiment for the $^{237}\text{Pu}(n,f)$ and $^{236}\text{Pu}(n,f)$ systems and the almost complete lack of directly measured (n, f) data to guide the models in this case, this discrepancy may well point to an issue with the data base values for $^{236}\text{Pu}(n,f)$.

This research has brought me high visibility in the community. For example, during the year, these and other surrogate results were reported by me via a variety of high profile invited talks including one at the Joint Division of Nuclear Physics and Japanese Physical Society meeting in Hawaii in October (see items 2 – 5, and 7 under seminars etc. below). In March I was invited to write a review article on surrogate reactions for ‘Reports on Progress in Physics’.

References

- [1] T.W. Henry, ... C.W. Beausang, et al., “*Triplet energy differences and the low lying structure of ^{62}Ga* ”, submitted for publication to Phys. Rev. C, May 2015.
- [2] C.W. Beausang, “*Structure(s) and Surrogates with GRET(in)A*”, talk presented at the GRETA / GRETINA Workshop, Argonne National Laboratory IL, June 2014.
- [3] T. J. Ross, R. O. Hughes, C. W. Beausang, et al., “*Spherical shell structures in deformed nuclei: The impact of an $N=64$ neutron subshell closure on the structure of $N\approx 90$ gadolinium nuclei*”, Phys. Rev. **C88**, 031301 (2013) (Rapid).
- [4] T.J. Ross, R.O. Hughes, J.M. Allmond, C.W. Beausang, et al., “*Spectroscopy of ^{153}Gd and ^{157}Gd following the $(p,d\gamma)$ reaction*”, Phys. Rev. **C90**, 044323 (2014).
- [5] P. Humby, C.W. Beausang, et al., to be published.

[6] P. Humby, A. Simon, C.W. Beausang, K. Gell, T. Tarlow, and G. Vyas, et al., “Improved Measurement of the Half Life of the $J\pi = 8^-$ Nuclear Isomer $^{152m2}\text{Eu}$ ”, Phys. Rev. **C91**, 024322, (2015).

[7] R. O. Hughes, C. W. Beausang, T. J. Ross, J. T. Burke, R. J. Casperson, N. Cooper, J.E. Escher, K. Gell, E. Good, P. Humby, M. McCleskey, A. Saastimoinen, T. D. Tarlow, and I. J. Thompson, “ $^{236}\text{Pu}(n,f)$, $^{237}\text{Pu}(n,f)$ and $^{238}\text{Pu}(n,f)$ cross sections deduced from (p,t) , (p,d) and (p,p') surrogate reactions”. Phys. Rev. **C90**, 014304, (2014).

Students and other group members (2014)

Anna Simon	Postdoctoral Fellow	DOE/NNSA
Emma Wilson	Postdoctoral Fellow	DOE/NNSA
Peter Humby	Ph.D. student	DOE/NNSA
Kristen Gell ('15)	Summer – 2014	DOE/OS
Nathan Watwood ('15)	Summer – 2014	DOE/OS

Synergistic Activities

Richmond Physics Olympics

An annual outreach event, the Richmond Physics Olympics, organized by me and based on my very successful Yale Physics Olympics, continues to be very successful attracting about 100 high school students and teachers annually. RPO 2014 occurred in March.

National / International Committees and Other Service

- 1) Member GRETINA Advisory Committee (GAC).
- 2) Chair, APS Committee on Scientific Publications.
- 3) Chair, Canadian Foundation for Innovation Expert Committee.
- 4) Member, Schubert Review at LLNL.

Honors

- 1) Chair, Physics Department, University of Richmond, 2007 → present.
- 2) Visiting Professor, University of Surrey, UK. June 2009 → present.
- 3) Invited guest, WNSL Summer 2014.
- 4) Adjunct Professor, Yale University from January 2005 → present.

Publications and Talks

University of Richmond co-authors are indicated by bold-face font. The symbol * refers to a Richmond postdoctoral fellow, ** a Richmond graduate student and *** a Richmond undergraduate student.

Seminars, Colloquia and Talks at Conferences

1. **A. Simon***, **C.W. Beausang**, **P. Humby****, **G. Vyas*****, and **T. Tarlow*****, “*Stewardship Science at the University of Richmond*”, talk presented at the 2014 Stewardship Science Academic Programs Symposium, Bethesda MD, Feb 2014.
2. **C.W. Beausang**, “*Structure and Surrogates from STARS*,” invited talk presented at ‘Nuclear Symmetries and Stewardship Science: the work of Jolie Cizewski’, Berkeley CA, April 2014.
3. **C.W. Beausang**, “*Structure(s) and Surrogates with GRET(in)A*”, talk presented at the GRETA / GRETINA Workshop, Argonne National Laboratory IL, June 2014.
4. **C.W. Beausang**, “*Structure(s) and Surrogates from STARLITER (and PAGAN)*”, talk presented at the ARUNA Workshop, Notre Dame University, South Bend IN, June 2014.
5. **C.W. Beausang**, “*Recent Experimental Progress on Surrogate Reactions*”, invited talk presented at the 4th Joint Division of Nuclear Physics and Japanese Physical Society meeting, Waikoloa HI, October 2014.
6. **C.W. Beausang**, “*Investigation of transitional rare earth nuclei using light ion reactions*”, seminar, Physics Department, Notre Dame University, January 2015.
7. **C.W. Beausang**, “*Stewardship Science at the University of Richmond*”, invited Talk, Stewardship Science Academic Programs Annual Symposium, Albuquerque, NM, March 2015

Contributed Talks and Posters

1. **Anna Simon***, **P. Humby****, **C.W. Beausang**, et al., “*Investigation of the structure of neutron-deficient Cd isotopes*”, talk presented at the spring meeting of the American Physical Society, Savannah, GA, April 2014.
2. **P. Humby****, **A. Simon***, **C.W. Beausang**, **K. Gell*****, **T. Tarlow*****, **G. Vyas*****, et al., “*Investigation of low/medium spin excited states in 150–154Sm via the (p,d) and (p,t) reactions*”, talk presented at the spring meeting of the American Physical Society, Savannah, GA, April 2014.
3. **E. Wilson***, **C.W. Beausang**, **P. Humby****, **A. Simon***, **K. Gell***** and **N. Watwood*****. “*Using the $^{154}\text{Sm}(p,d)$ reaction to extend the level scheme of ^{153}Sm to the continuum region*”, poster presented at the Stewardship Science Academic Programs (SSAP) Annual Review Symposium, Santa Fe, NM, March 2015.
4. **E. Wilson***, **C.W. Beausang**, **P. Humby****, **A. Simon***, T.J. Ross, R.O. Hughes, J.T. Burke, R.J. Casperson, J. Koglin, S. Ota, J.M. Allmond, M McCleskey, E. McCleskey, A. Saastamoinen, R. Chyzh, M. Dag, **K. Gell*****, **T. Tarlow***** and **G. Vyas*****. “*Using the $^{154}\text{Sm}(p,d)$ reaction to extend the level scheme of ^{153}Sm to the continuum region*”, contributed talk presented at the April meeting of the American Physical Society, Baltimore, MD, April 2015.

5. **P. Humby****, **A. Simon***, **C.W. Beausang**, **K. Gell*****, **T. Tarlow***** and **G. Vyas***** et al., “*Cross sections for populating excited states in $^{150-154}\text{Sm}$ via the (p,d) and (p,t) reactions*”, contributed talk presented at the Joint Meeting of the Physics Divisions of the American Physical Society and the Physical Society of Japan, Hawaii, October 2014.
6. **P. Humby****, **A. Simon***, **C.W. Beausang**, **K. Gell*****, **T. Tarlow***** and **G. Vyas***** et al., “*Investigation of the shape-transitional samarium nuclei around $N=90$ via the (p,d) and (p,t) reactions*”, poster presented at the Nuclear Structure 2014 conference, TRIUMF, Vancouver, July 2014.
7. **K. Gell*****, **C.W. Beausang**, **A. Simon***, **P. Humby****, T.J. Ross, R.O. Hughes, J.T. Burke, R.J. Casperson, J. Koglin, S. Ota, J.M. Allmond, M. McCleskey, E. McCleskey, A. Saastamoinen, R. Chyzh, M. Dag, **T. Tarlow*****, **G. Vyas***** and **N. Watwood***** “*Investigation of low-spin states in Sm nuclei following (p,t) reactions*”, poster presented at the Joint Meeting of the Nuclear Physics Division of the American Physical Society and the Physical Society of Japan, Hawaii, October 2014.
8. **N. Watwood*****, **C.W. Beausang**, **A. Simon***, **P. Humby****, T.J. Ross, R.O. Hughes, J.T. Burke, R.J. Casperson, J. Koglin, S. Ota, J.M. Allmond, M. McCleskey, E. McCleskey, A. Saastamoinen, R. Chyzh, M. Dag, **T. Tarlow*****, **G. Vyas***** and **K. Gell*****. “*Half-lives of ground states in Pm and Eu nuclei following the $^{154,152}\text{Sm}(p,x)$ reactions at 25 MeV*”, poster presented at the Joint Meeting of the Nuclear Physics Division of the American Physical Society and the Physical Society of Japan, Hawaii, October 2014.
9. **P. Humby****, **E. Wilson*** and **C.W. Beausang**. “*Enhanced two-neutron transfer populating states near the pair gap in the $N=90$ region*”, poster presented at the Stewardship Science Academic Programs (SSAP) Annual Review Symposium, Santa Fe, NM, March 2015.
10. **P. Humby****, **E. Wilson***, **C.W. Beausang**, **A. Simon***, **K. Gell*****, **T. Tarlow***** and **G. Vyas***** et al., “*Investigation of a peak-like feature observed in the triton energy spectra from the $^{152,154}\text{Sm}(p,t)$ reactions*”, contributed talk presented at the April meeting of the American Physical Society, Baltimore, MD, April 2015.

Publications

1. R. O. Hughes, **C. W. Beausang**, **T. J. Ross****, J. T. Burke, R. J. Casperson, N. Cooper, J.E. Escher, **K. Gell*****, **E. Good*****, **P. Humby****, M. McCleskey, A. Saastimoinen, **T. D. Tarlow*****, and I. J. Thompson, “ *$^{236}\text{Pu}(n,f)$, $^{237}\text{Pu}(n,f)$ and $^{238}\text{Pu}(n,f)$ cross sections deduced from (p,t) , (p,d) and (p,p') surrogate reactions*”. Phys. Rev. **C90**, 014304, (2014).
2. **T.J. Ross****, **R.O. Hughes***, J.M. Allmond, **C.W. Beausang**, C.T. Angell, M.S. Basunia, D.L. Bleuel, J.T. Burke, R.J. Casperson, J.E. Escher, P. Fallon, R. Hatarik, J.

- Munson, S. Paschalis, M. Petri, L.W. Phair, J.J. Ressler and N.D. Scielzo, “Spectroscopy of ^{153}Gd and ^{157}Gd following the (p,dy) reaction”, Phys. Rev. **C90**, 044323 (2014).
3. **P. Humby****, **A. Simon***, **C.W. Beusang**, T.J. Ross, R.O. Hughes, J.T. Burke, R.J. Casperson, J. Koglin, S. Ota, J.M. Allmond, M. McCleskey, E. McCleskey, A. Saastamoinen, R. Chyzh, M. Dag, **K. Gell*****, **T. Tarlow***** and **G. Vyas*****. “Improved Measurement of the Half Life of the $J\pi = 8^-$ Nuclear Isomer $152\text{m}2\text{Eu}$ ”, Phys. Rev. **C91**, 024322, (2015).
 4. S. N. T. Majola, D. J. Hartley, L.L. Riedinger, J.F. Sharpey-Schafer, J. M. Almond, **C.W. Beusang**, M.P. Carpenter, C.J. Chiara, N. Cooper, D. Curien, B. J. P. Gall, P.E. Garrett, F.G. Kondev, W.D. Kulp, T. Lauritsen, E.A. McCutchan, D. Miller, J. Piot, N. Redon, M.A. Riley, J. Simpson, I. Stefanescu, V. Werner, X. Wang, J.L. Wood, C.-H. Yu and S. Zhu, “Observation of γ -vibrations and alignments built on non-ground state configurations in ^{156}Dy ”, Phys. Rev. **C91**, 034330, (2015).
 5. T.W. Henry, M.A. Bentley, R.M. Clark, P.J. Davies, V.M. Bader, T. Baugher, D. Bazin, **C.W. Beusang**, J.S. Berryman, A.M. Bruce, C.M. Campbell, H.L. Crawford, M. Cromaz, P. Fallon, A. Gade, J. Henderson, H. Iwasaki, D. Jenkins, I.Y. Lee, A. Lemasson, S.M. Lenzi, A.O. Macchiavelli, D.R. Napoli, A.J. Nichols, S. Paschalis M. Petri, F. Recchia, J. Rissanen, E.C. Simpson, S.R. Stroberg, R. Wadsworth, D. Weisshaar, A. Wiens, and C. Walz, “Triplet energy differences and the low lying structure of ^{62}Ga ”, submitted for publication to Phys. Rev. C, May 2015.

Summary of Publications 2005 – 2015

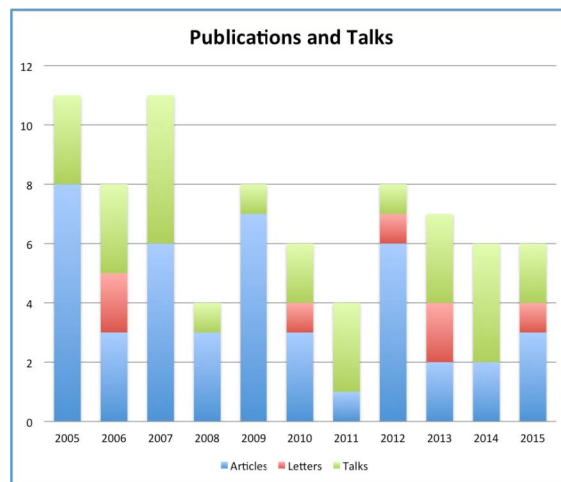


Figure 2: Summary of publications, broken down into article and letter types and talks presented by the P.I. from 2005 to 2015.