



Giant Resonances, Wavelets, Scales and Level Densities A Scientific and Personal Tribute to Björn Jonson

- Some personal recollections
- Giant resonances, damping mechanisms, time and energy scales
- Fine structure, wavelets and scales
- Application: GQR
- Many-body nuclear models and damping mechanisms
- Relevance of scales: GTR
- Level densities of $J^{\pi} = 1^+, 2^+, 2^-$ states

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NTERNATIONAL EVALUATION OF

PHYSICS

November 1987

Report to the Research Council by an international group of experts with the following members: doc Sven Björnholm, prof Vincent Gillet, prof Shoji Nagamiya, prof Achim Richter, dr John Sharpey-Schafer and prof Anders Flodström (rapporteur) Naturvetenskapliga forskningsrådet Swedish Natural Science Research Council Professor Björn Jonson and Docent Göran Nyman Department of Physics Chalmers University of Technology Göteborg

ISOL-Research, Development of High-Resolution Detectors, and Neutrino Mass Measurements

Evaluation

Recommendation

The research program of this group should be supported at the level they request. This group represents the major part of the Swedish effort in ISOLDE and therefore it should be very strongly encouraged.

Joint Publications with Björn Jonson 1988-2008 I

BETA-DELAYED PROTON AND ALPHA EMISSION IN THE DECAY OF ¹⁷Ne M.J.G. Borge, H. Cronberg, M. Cronqvist, H. Gabelmann, P.G. Hansen, L. Johanssen, B. Jonson, S. Mattson, G. Nyman, A. Richter, K. Riisager, O. Tengblad and M. Tomaselli

Nucl. Phys. A490, (1988) 287

THE AXIAL-VECTOR STRENGTH IN THE PROTON-RICH ARGON ISOTOPES

M.J.G. Borge, P.G. Hansen, B. Jonson, S. Mattsson, G. Nyman, A. Richter and K. Riisager Z.f. Physik <u>A332</u>, (1989) 413

THE BETA DECAY OF ⁹Li TO LEVELS IN ⁹Be: A NEW LOOK

G. Nyman, R.E. Azuma, P.G. Hansen, B. Jonson, P.O. Larsson, S. Mattsson, A. Richter, K. Riisager, O. Tengblad and K. Wilhelmsen Nucl. Phys. <u>A510</u>, (1990) 189

APPLICATIONS OF STATISTICAL NUCLEAR PHYSICS TO NUCLEAR SPECTROSCOPY

P.G. Hansen, B. Jonson and A. Richter Nucl. Phys. <u>A518</u>, (1990) 13

FIRST OBSERVATION OF BETA-DELAYED DEUTERON EMISSION

K. Riisager, M.J.G. Borge, H. Gabelmann, P.G. Hansen, L. Johannsen, B. Jonson, W. Kurcewicz, G. Nyman, A. Richter, O. Tengblad and K. Wilhelmsen

Phys. Letters <u>B235</u>, (1990) 30

OBSERVATION OF THE FORWARD NEUTRONS FROM THE BREAK-UP OF THE ¹¹Li NEUTRON HALO

R. Anne, S.E. Arnell, R. Bimbot, H. Emling, D. Guillemaud-Mueller, P.G. Hansen, L. Johannsen, B. Jonson, M. Lewitowicz, S. Mattson, A.C. Mueller, R. Neugart, G. Nyman, F. Pougheon, A. Richter, K. Riisager, M.G. Saint-Laurent, G. Schrieder, O. Sorlin and K. Wilhelmsen Phys. Letters <u>B250</u>, (1990) 19

SUPER-ALLOWED BETA DECAY OF NUCLEI AT THE DRIP-LINE

M.J.G. Borge, P.G. Hansen, L. Johannsen, B. Jonson, T. Nilsson, G. Nyman, A. Richter, K. Riisager, O. Tengblad and K. Wilhelmsen Z. f. Physik <u>A340</u>, (1991) 255

TWO NEUTRON REMOVAL REACTIONS FOR VERY NEUTRON RICH NUCLEI

K. Riisager, R. Anne, S.E. Arnell, R. Bimbot, H. Emling D. Guillemaud-Mueller, P.G. Hanssen, L. Johannsen, B. Jonson, A. Latimier, M. Lewitowicz, S. Mattson, A.C. Mueller, R. Neugart, G. Nyman, F. Pougheon, A. Richard, A. Richter, M.G. Saint-Laurent, G. Schrieder, O. Sorlin and K. Wilhelmsen

Nucl. Phys. <u>A540</u>, (1992) 365

Joint Publications with Björn Jonson 1988-2008 II

BETA-DACAY TO THE PROTON HALO STATE IN 17 F

M.J.G. Borge, J. Deding, P.G. Hansen, B. Jonson, G. Martinez-Pinedo, P. Moller, G. Nyman, A. Poves, A. Richter, K.Riisager and O. Tengblad Phys. Letters <u>B317</u>, (1993) 25

LONGITUDINAL AND TRANSVERSE MOMENTUM DISTRIBUTIONS OF ⁹Li FRAGMENTS FROM BREAK-UP OF ¹¹Li

F. Humbert, T. Nilsson, W. Schwab, M. Zinser, Th. Blaich, M.J.G. Borge, L.V. Chulkov, Th.W. Elze, H. Emling, B. Franzke, H. Freiesleben, H. Geissel, K. Grimm, D. Guillemaud-Mueller, P.G. Hansen, R. Holzmann, H. Irnich, L. Johannsen, B. Jonson, J.G. Keller, O. Klepper, H. Klingler, J.V. Kratz, R. Kulessa, D. Lambrecht, Y. Leifels, A. Magel, M. Mohar, A.C. Mueller, G. Münzenberg, P. Moeller, F. Nickel, G. Nyman, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, B.M. Sherrill, H. Simon, K. Stelzer, J. Stroth, O. Tengblad, W. Trautmann, E. Wajda and E. Zude

Phys. Letters <u>B347</u>, (1995) 198

NEUTRON MOMENTUM DISTRIBUTIONS FROM 'CORE BREAK-UP' REACTIONS OF HALO NUCLEI

T. Nilsson, Th. Blaich, M.J.G. Borge, L.V. Chulkov, Th.W. Elze, H. Emling, H. Geissel, K. Grimm, D. Guillemaud-Mueller, P.G. Hansen, R. Holzmann, P. Hornshoj, F. Humbert, H. Irnich, L. Johannsen, B. Jonson, M. Keim, J.G. Keller, H. Klingler, J.V. Kratz, R. Kulessa, D. Lambrecht, Y. Leifels, M. Lewitowicz, A. Magel, M.F. Mohar, A.C. Mueller, G. Münzenberg, R. Neugart, F. Nickel, G. Nyman, A. Richter, K. Riisager, M.G. Saint-Laurent, C. Scheidenberger, G. Schrieder, W. Schwab, B.M. Sherrill, H. Simon, O. Sorlin, K. Stelzer, J. Stroth, O. Tengblad, E. Wajda, K. Wilhelmsen Rolander, M. Zinser and E. Zude

Europhys. Letters <u>30</u>, (1995) 19

STUDY OF THE UNSTABLE NUCLEUS ¹⁰Li IN STRIPPING REACTIONS OF THE RADIOACTIVE PROJECTILES ¹¹Be AND ¹¹Li

M. Zinser, F. Humbert, T. Nilsson, W. Schwab, Th. Blaich, M.J.G. Borge, L.V. Chulkov, Th.W. Elze, H. Emling, B. Franzke, H. Freiesleben, H. Geissel, K. Grimm, D. Guillemaud-Mueller, P.G. Hansen, R. Holzmann, H. Irnich, L. Johannsen, B. Jonson, J.G. Keller, O. Klepper, H. Klingler, J.V. Kratz, R. Kulessa, D. Lambrecht, Y. Leifels, A. Magel, M. Mohar, A.C. Mueller, G. Münzenberg, F. Nickel, G. Nyman, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, B.M. Sherrill, H. Simon, K. Stelzer, J. Stroth, O. Tengblad, W. Trautmann, E. Wajda and E. Zude

Phys. Rev. Letters <u>75</u>, (1995) 1719

DISSOCIATION OF ⁸He INTO ⁶He + n + X AT 240 MeV/u

T. Nilsson, F. Humbert, W. Schwab, M. Zinser, Th. Blaich, M.J.G. Borge, L.V. Chulkov, H. Eickhoff, Th.W. Elze, H. Emling, B. Franzke, H. Freiesleben, H. Geissel, K. Grimm, D. Guillemaud-Mueller, P.G. Hansen, R. Holzmann, H. Irnich, L. Johannsen, B. Jonson, J.G. Keller, O. Klepper, H. Klingler, J.V. Kratz, R. Kulessa, D. Lambrecht, Y. Leifels, A. Magel, M. Mohar, E.F. Moore, A.C. Mueller, G. Münzenberg, P. Moller, F. Nickel, G. Nyman, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, B.M. Sherrill, H. Simon, K. Stelzer, J. Stroth, O. Tengblad, W. Trautmann, E. Wajda and E. Zude Nucl. Phys. A583,(1995) 795

Joint Publications with Björn Jonson 1988-2008 III

⁶He AND NEUTRON DISTRIBUTION FROM ⁸He IN NUCLEAR BREAK-UP REACTIONS AT 240 MeV/u

T. Nilsson, F. Humbert, W. Schwab, H. Simon, M.H. Smedberg, M. Zinser, Th. Blaich, M.J.G. Borge, L.V. Chulkov, Th.W. Elze, H. Emling, H. Geissel, K. Grimm, D. Guillemaud-Mueller, P.G. Hansen, R. Holzmann, H. Irnich, B. Jonson, J.G. Keller, H. Klingler, A.A. Korsheninnikov, J.V. Kratz, R. Kulessa, D. Lambrecht, Y. Leifels, A. Magel, M. Mohar, A.C. Mueller, G. Münzenberg, F. Nickel, G. Nyman, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, B.M. Sherrill, K. Stelzer, J. Stroth, O. Tengblad, W. Trautmann, E. Wajda, M.V. Zhukov and E. Zude

Nucl. Phys. <u>A598</u>, (1996) 418

INVARIANT MASS SPECTROSCOPY OF ¹⁰Li AND ¹¹Li

M. Zinser, F. Humbert, T. Nilsson, W. Schwab, H. Simon, T. Aumann, M.J.G. Borge, L.V. Chulkov, J. Cub, Th.W. Elze, H. Emling, H. Geissel, D. Guillemaud-Mueller, P.G. Hansen, R. Holzmann, H. Irnich, B. Jonson, J.V. Kratz, R. Kulessa, Y. Leifels, H. Lenske, A. Magel, A.C. Mueller, G. Münzenberg, F. Nickel, G. Nyman, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, K. Stelzer, J. Stroth, A. Surowiec, O. Tengblad, E. Wajda and E. Zude

Nucl. Phys. <u>A619</u>, (1997) 151

LARGE SPIN ALIGNMENT OF THE UNBOUND ⁵He FRAGMENT AFTER FRAGMENTATION OF 240 MeV/nucleon ⁶He

L.V. Chulkov, T. Aumann, D. Aleksandrov, L. Axelsson, T. Baumann, M.J.G. Borge, R. Collatz, J. Cub, W. Dostal, B. Eberlein, Th.W. Elze, H. Emling, H. Geissel, V.Z. Goldberg, M. Golovkov, A. Grünschloss, M. Hellström, J. Holoczek, R. Holzmann, B. Jonson, A.A. Korscheninnikov, J.V. Kratz, G. Kraus, R. Kulessa, Y. Leifels, A. Leistenschneider, T. Leth, I. Mukha, G. Münzenberg, F. Nickel, T. Nilsson, G. Nyman, B. Peterson, M. Pfützner, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, W. Schwab, H. Simon, M.H. Smedberg, M. Steiner, J. Stroth, A. Surowiec, T. Suzuki and O. Tengblad

Phys. Rev. Letters <u>79</u>, (1997) 201

INVARIANT MASS SPECTRUM AND α-n CORRELATION FUNCTION STUDIED IN THE FRAGMENTATION OF ⁶He ON A CARBON TARGET D. Aleksandrov, T. Aumann, L. Axelsson, T. Baumann, M.J.G. Borge, L.V. Chulkov, R. Collatz, J. Cub, W. Dostal, B. Eberlein, Th.W. Elze, H. Emling, H. Geissel, V.Z. Goldberg, M. Golovkov, A. Grünschloss, M. Hellström, J. Holoczek, R. Holzmann, B. Jonson, A.A. Korscheninnikov, J.V. Kratz, G. Kraus, R. Kulessa, Y. Leifels, A. Leistenschneider, T. Leth, I. Mukha, G. Münzenberg, F. Nickel, T. Nilsson, G. Nyman, B. Peterson, M. Pfützner, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, W. Schwab, H. Simon, M.H. Smedberg, M. Steiner, J. Stroth, A. Surowiec, T. Suzuki and O. Tengblad

Nucl. Phys. <u>A633</u>, (1998) 234

LONGITUDINAL MOMENTUM DISTRIBUTION OF ^{16,18}C FRAGMENTS AFTER ONE-NEUTRON REMOVAL FROM ^{17,19}C

T. Baumann, H. Geissel, H. Lenske, K. Markenroth, W. Schwab, M.H. Smedberg, T. Aumann, L. Axelsson, U. Bergmann, D. Cortina-Dil, L. Fraile, M. Hellström, M. Ivanov, N. Iwasa, R. Janik, B. Jonson, G. Münzenberg, F. Nickel, T. Nilsson, A. Ozawa, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, H. Simon, B. Sitar, P. Strmen, K. Sümmerer, T. Suzuki, M. Winkler, H. Wollnik and M.V. Zhukov

Phys. Letters <u>B439</u>, (1998) 256

Joint Publications with Björn Jonson 1988-2008 IV

HALOKERNE

B. Jonson and A. Richter Phys. Blätter 54, (1998) 1121

CONTINUUM EXCITATIONS IN ⁶He

T. Aumann, D. Aleksandrov, L. Axelsson, T. Baumann, M.J.G. Borge, L.V. Chulkov, J. Cub, W. Dostal, B. Eberlein, Th.W. Elze, H. Emling, H. Geissel, V.Z. Goldberg, M. Golovkov, A. Grünschloss, M. Hellström, K. Hencken, J. Holoczek, R. Holzmann, B. Jonson, A.A. Korscheninnikov, J.V. Kratz, G. Kraus, R. Kulessa, Y. Leifels, A. Leistenschneider, T. Leth, I. Mukha, G. Münzenberg, F. Nickel, T. Nilsson, G. Nyman, B. Peterson, M. Pfützner, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, W. Schwab, H. Simon, M.H. Smedberg, M. Steiner, J. Stroth, A. Surowiec, T. Suzuki, O. Tengblad and M.V. Zhukov

Phys. Rev. <u>C59</u>, (1999) 1252

NEW RESULTS ON THE HALO STRUCTURE OF ⁸B

M.H. Smedberg, T. Baumann, T. Aumann, L. Axelsson, U. Bergmann, M.J.G. Borge, D. Cortina-Dil, L. Fraile, H. Geissel, L. Grigorenko, M. Hellström, M. Ivanov, N. Iwasa, R. Janik, B. Jonson, H. Lenske, K. Markenroth, G. Münzenberg, T. Nilsson, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, W. Schwab, H. Simon, B. Sitar, P. Strmen, K. Sümmerer, M. Winkler and M.V. Zhukov Phys. Letters <u>B452</u>, (1999) 1

DIRECT EXPERIMENTAL EVIDENCE FOR STRONG ADMIXTURE OF DIFFERENT PARITY STATES IN ¹¹Li

H. Simon, D. Aleksandrov, T. Aumann, L. Axelsson, T. Baumann, M.J.G. Borge, L.V. Chulkov, R. Collatz, J. Cub, W. Dostal, B. Eberlein, Th.W. Elze, H. Emling, H. Geissel, A. Grünschloss, M. Hellström, J. Holeczek, R. Holzmann, B. Jonson, J.V. Kratz, G. Kraus, R. Kulessa, Y. Leifels, A. Leistenschneider, T. Leth, I. Mukha, G. Münzenberg, F. Nickel, T. Nilsson, G. Nyman, B. Peterson, M. Pfützner, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, W. Schwab, M.H. Smedberg, J. Stroth, A. Surowiec, O. Tengblad and M.V. Zhukov Phys. Rev. Letters <u>83</u>, (1999) 496

HALO EXCITATIONS IN FRAGMENTATION OF 6He AT 240 MeV/U ON CARBON AND LEAD TARGETS

D. Aleksandrov, T. Aumann, L. Axelsson, T. Baumann, M.J.G. Borge, L.V. Chulkov, J.Cub, W. Dostal, B. Eberlein, Th.W. Elze, H. Emling, H. Geissel, V.Z. Goldberg, A. Grünschloss, M. Hellstrom, J. Holeczek, R. Holzmann, B. Jonson, J.V. Kratz, G. Kraus, R. Kulessa, Y. Leifels, A. Leistenschneider, T. Leth, K. Markenroth, M. Meister, I. Mukha, G. Münzenberg, F. Nickel, T. Nilsson, G. Nyman, B. Petersen, M. Pfützner, V. Pribora, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, W. Schwab, H. Simon, M.H. Smedberg, J. Stroth, A. Surowiec, O. Tengblad and M.V. Zhukov

Nucl. Phys. <u>A669</u>, (2000) 51

MORE THAN 30 YEARS OF ISOLDE PHYSICS B. Jonson and A. Richter Hyperfine Int. <u>129</u>, (2000) 1

Joint Publications with Björn Jonson 1988-2008 V

THE REX-ISOLDE PROJECT

D. Habs, O. Kester, T. Sieber, H. Bongers, S. Emhofer, P. Reiter, P.G. Thirolf, G. Bollen, J. Aystö, O. Forstner, H. Ravn, T. Nilsson, M. Oimonen, H. Simon, J. Cederkall, F. Ames, P. Schmidt, G. Huber, J. Liljeby, O. Skoppstedt, K.G. Rensfeldt, F. Wenander, B. Jonson, G. Nyman, R. von Hahn, H. Podlech, R. Repnow, C. Gund, D. Schwalm, A. Schempp, K.-U. Kühnel, C. Welsch, U. Ratzinger, G. Walter, A. Huck, K. Kruglow, M. Huyse, P. Van den Bergh, P. Van Duppen, L. Weissman, A.C. Shotter, A.N. Ostrowski, T. Davinson, P.J. Woods, J. Cub, A. Richter, G. Schrieder and the REX-ISOLDE Collaboration

Hyperfine Int. <u>129</u>, (2000) 43

⁸He⁻⁶He: A COMPARATIVE STUDY OF NUCLEAR FRAGMENTATION REACTIONS

K. Markenroth, M. Meister, B. Eberlein, D. Aleksandrov, T. Aumann, L. Axelsson, T. Baumann, M.J.G. Borge, L.V. Chulkov, W. Dostal, Th.W. Elze, H. Emling, H. Geissel, V.Z. Goldberg, A. Grünschloß, M. Hellstrom, J. Holeczek, B. Jonson, J.V. Kratz, R. Kulessa, A. Leistenschneider, I. Mukha, G. Münzenberg, F. Nickel, T. Nilsson, G. Nyman, M. Pfützner, V. Pribora, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, H. Simon, J. Stroth, O. Tengblad and M.V. Zhukov

Nucl. Phys. <u>A679</u>, (2001) 462

⁸He–⁶He: A COMPARATIVE STUDY OF ELECTROMAGNETIC FRAGMENTATION REACTIONS

M. Meister, K. Markenroth, D. Aleksandrov, T. Aumann, T. Baumann, M.J.G. Borge, L.V. Chulkov, W. Dostal, D. Cortina-Gil, B. Eberlein, Th.W. Elze, H. Emling, H. Geissel, M. Hellström, B. Jonson, J.V. Kratz, R. Kulessa, A. Leistenschneider, I. Mukha, G. Münzenberg, F. Nickel, T. Nilsson, G. Nyman, M. Pfützner, V. Pribora, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, H. Simon, O. Tengblad and M.V. Zhukov Nucl. Phys. <u>A700</u>, (2002) 3

LOW-LYING RESONANCE STATES IN ⁷He

M. Meister, K. Markenroth, D. Aleksandrov, T. Aumann, L. Axelsson, T. Baumann, M.J.G. Borge, L.V. Chulkov, W. Dostal, B. Eberlein, Th.W. Elze, H. Emling, C. Forssen, H. Geissel, M. Hellström, R. Holzmann, B. Jonson, J.V. Kratz, R. Kulessa, A. Leistenschneider, I. Mukha, G. Münzenberg, F. Nickel, T. Nilsson, G. Nyman, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, H. Simon, O. Tengblad and M.V. Zhukov

Phys. Rev. Letters <u>88</u>, (2002) 102501

NUCLEAR AND COULOMB BREAKUP OF ⁸B

D. Cortina-Dil, J. Fernandez-Vazquez, F. Attallah, T. Baumann, J. Benlliure, M.J.G. Borge, L.V. Chulkov, C. Forssén, L.M. Fraile, H. Geissel, J. Gerl, K. Itahashi, R. Janik, B. Jonson, S. Karlsson, H. Lenske, S. Mandal, K. Markenroth, M. Meister, M. Mocko, G. Münzenberg, T. Ohtsubo, A. Ozawa, Yu. Parfenova, V. Pribora, A. Richter, K. Riisager, R. Schnieder, H. Scheit, G. Schrieder, N. Shulgina, H. Simon, B. Sitar, A. Stolz, P. Strmen, K. Sümmerer, I. Szarka, S. Wan, H. Weick and M.V. Zhukov Nucl. Phys. A720, (2003) 3

Joint Publications with Björn Jonson 1988-2008 VI

SEARCHING FOR THE ⁵He RESONANCE IN THE t + t + n SYSTEM

M. Meister, L.V. Chulkov, H. Simon, T. Aumann, M.J.G. Borge, Th.W. Elze, H. Emling, H. Geissel, M. Hellström, B. Jonson, J.V. Kratz, R. Kulessa, Y. Leifels, A. Leistenschneider, K. Markenroth, G. Münzenberg, F. Nickel, T. Nilsson, G. Nyman, V. Pribora, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder and O. Tengblad

Nucl. Phys. <u>A723</u>, (2003) 15

THE t + n + n SYSTEM AND ⁵H

M. Meister, L.V. Chulkov, H. Simon, T. Aumann, M.J.G. Borge, Th.W. Elze, H. Emling, H. Geissel, M. Hellström, B. Jonson, J.V. Kratz, R. Kulessa, Y. Leifels, K. Markenroth, G. Münzenberg, F. Nickel, T. Nilsson, G. Nyman, V. Pribora, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, O. Tengblad and M.V. Zhukov Phys. Rev. Letters 91, (2003) 162504

TWO- AND THREE-BODY CORRELATIONS: BREAKUP OF HALO NUCLEI

H. Simon, T. Aumann, M.J.G. Borge, L.V. Chulkov, Th.W. Elze, H. Emling, C. Forssen, H. Geissel, M. Hellström, B. Jonson, J.V. Kratz, R. Kulessa, Y. Leifels, K. Markenroth, M. Meister, G. Münzenberg, F. Nickel, T. Nilsson, G. Nyman, V. Pribora, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, O. Tengblad and M.V. Zhukov Nucl. Phys. A734, (2004) 323

EXPERIMENTAL INVESTIGATION OF THE ⁹Li + D REACTION AT REX-ISOLDE

H.B. Jeppesen, F. Ames, U.C. Bergmann, M.J.G. Borge, J. Cederkall, S. Emhofer, L.M. Fraile, H.O.U. Fynbo, S. Henry, H.T. Johansson, B. Jonson, M. Meister, T. Nilsson, G. Nyman, M. Pantea, K. Riisager, A. Richter, K. Rudolph, G. Schrieder, T. Siebert, O. Tengblad, E. Tengborn, M. Turrion, R. von Hahn, F. Wenander, B. Wolf and the ISOLDE and REX-ISOLDE Collaborations Nucl. Phys. A738, (2004) 511

"SAFE" COULOMB EXCITATION OF ³⁰Mg

O. Niedermaier, H. Scheit, V. Bildstein, H. Boie, J. Fitting, R. von Hahn, F. Köck, M. Lauer, U.K. Pal, H. Podlech, R. Repnow, D. Schwalm, C. Alvarez, F. Ames, G. Bollen, S. Emhofer, D. Habs, O. Kester, R. Lutter, K. Rudolph, M. Pasini, P.G. Thirolf, B.H. Wolf, J. Eberth, G. Gersch, H. Hess, P. Reiter, O. Thelen, N. Warr, D. Weisshaar, F. Aksouh, P. Van den Bergh, P. Van Duppen, M. Huyse, O. Ivanov, P. Mayet, J. Van de Walle, J. Äystö, P.A. Butler, J. Cederkäll, P. Delahaye, H.O.U. Fynbo, L.M. Fraile, O. Forstner, S. Franchoo, U. Köster, T. Nilsson, M. Oinonen, T. Sieber, F. Wenander, M. Pantea, A. Richter, G. Schrieder, H. Simon, T. Behrens, R. Gernhäuser, T. Kröll, R. Krücken, M. Münch, T. Davinson, J. Gerl, G. Huber, A. Hurst, J. Iwanicki, B. Jonson, P. Lieb, L. Liljeby, A. Schempp, A. Scherillo, P. Schmidt and G. Walter

Phys. Rev. Letters <u>94</u>, (2005) 172501

Joint Publications with Björn Jonson 1988-2008 VII

INVESTIGATION OF THE $^9\text{Li} + ^2\text{H} \rightarrow \ensuremath{\,^8\text{Li}}\xspace + t$ REACTION AT REX-ISOLDE

H. Jeppesen, A.M. Moro, F. Ames, P. van den Bergh, U.C. Bergmann, G. Bollen, M.J.G. Borge, J. Cederkall, P. Van Duppen, S. Emhofer, O. Fortsner, L.M. Fraile, H.O.U. Fynbo, J. Gomez-Camacho, D. Habs, R. von Hahn, G. Huber, M. Huyse, H.T. Johansson, B. Jonson, O. Kester, H. Lenske, M. Meister, G. Nyman, M. Oinonen, M. Pantea, H. Podlech, U. Ratzinger, K. Reisinger, K.G. Rensfelt, R. Repnow, K. Riisager, A. Richter, K. Rudolph, H. Scheit, A. Schempp, P. Schmidt, G. Schrieder, D. Schwalm, T. Sieber, H. Simon, O. Tengblad, E. Tengborn, M. Turrión, L. Weissmann, F. Wenander and B. Wolf

Phys. Letters <u>B635</u>, (2006) 30

STUDY OF ¹⁰Li VIA THE ⁹Li(²H,p) REACTION AT REX-ISOLDE

H.B. Jeppesen, A.M. Moro, U.C. Bergmann, M.J.G. Borge, J. Cederkall, L.M. Fraile, H.O.U. Fynbo, J. Gomez-Camacho, H.T. Johansson, B. Jonson, M. Meister, T. Nilsson, G. Nyman, M. Pantea, K. Riisager, A. Richter, G. Schrieder, T. Sieber, O. Tengblad, E. Tengborn, M. Turrión and F. Wenander

Phys. Letters <u>B642</u>, (2006) 449

SYSTEMATIC INVESTIGATION OF THE DRIP-LINE NUCLEI ¹¹Li AND ¹⁴Be AND THEIR UNBOUND SUBSYSTEMS ¹⁰Li AND ¹³Be H. Simon, M. Meister, T. Aumann, M.J.G. Borge, L.V. Chulkov, U. Datta Pramanik, Th.W. Elze, H. Emling, C. Forssén, H. Geissel, M. Hellström, B. Jonson, J.V. Kratz, R. Kulessa, Y. Leifels, K. Markenroth, G. Münzenberg, F. Nickel, T. Nilsson, G. Nyman, A. Richter, K. Riisager, C. Scheidenberger, G. Schrieder, O. Tengblad and M.V. Zhukov

Nucl. Phys. A791, (2007) 267

LITHIUM ISOTOPES BEYOND THE DRIPLINE

Yu. Aksyutina, H.T. Johannson, P. Adrich, F. Aksouh, T. Aumann, K. Boretzky, M.J.G. Borge, A. Chatillon, L.V. Chulkov, D. Cortina-Gil, U. Datta Pramanik, H. Emling, C. Forssén, H.O.U. Fynbo, H. Geissel, M. Hellström, G. Ickert, K.L. Jones, B. Jonson, A. Klimkiewicz, J.V. Kratz, R. Kulessa, M. Lantz, A.O. Lindahl, K. Mahata, M. Matos, M. Meister, G. Münzenberg, T. Nilsson, G. Nyman, R. Palit, M. Pantea, S. Paschalais, W. Prokopowicz, R. Reifarth, A. Richter, K. Riisager, G. Schrieder, H. Simon, K. Sümmerer, O. Tengblad, W. Walus, H. Weick and M.V. Zhukov

Phys. Letters <u>B666</u>, (2008) 430

Chalmers 1995



Alexander von Humboldt Award Bamberg 1998



Bamberg 1998



Wachtenburg / Rhein 1998



TU Darmstadt 1999



Radioactive Beam Research Copenhagen 2001



Nuclear Physics A518 (1990) 13–34 North-Holland

APPLICATIONS OF STATISTICAL NUCLEAR PHYSICS TO NUCLEAR SPECTROSCOPY*

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by high-resolution methods. We discuss (i) the determination of level densities, (ii) the role of Abstract: A number of new results pertaining to properties of complex nuclear spectra are given and illustrated with data from many experiments. We are concerned with the situation in which a group of closely spaced - though, in principle, still resolvable - nuclear levels is observed, and use the statistical model to interpret the properties of the corresponding particle and photon spectra. According to this model, physics information contained locally in such a spectrum may be widths. The local fine structure, on the other hand, remains unpredictable ("chaotic") but is governed by universal statistical laws. Experimental examples are taken from charged-particle and gamma-ray spectra following the beta decay of far-unstable nuclei and from (e, e') reactions studied fluctuation corrections in the interpretation of branching ratios and resonance lifetimes, and finally expressed in terms of a small number of average quantities: level spacings and reduced partial (iii) how Monte Carlo simulations of complex spectra may serve to test sensitivity and experimental bias.

Giant Resonances



Isoscalar Quadrupole Mode



Microscopic Picture of Giant Resonances: ⁹⁰Zr



Excitation and Decay of Giant Resonances



Doorway State Model



Fine Structure of Giant Resonances



- High resolution is crucial
- Possible probes: electrons and hadrons

Fine Structure of Giant Resonances



- Different probes but similar structures
- \rightarrow physical information content is the same

Fine Structure of Giant Resonances

- Global phenomenon?
 - Other nuclei
 - Other resonances

• Methods for characterization of fine structure

• Goal: dominant damping mechanisms

Fine Structure of the ISGQR



ΔE ≈ 1 MeV **TRIUMF** (1981)

 $\Delta E \approx 40 \text{ keV}$ iThemba (2004)

Fluctuations of different strengths and scales 0

Fine structure seen in all nuclei: a global phenomenon 0











²⁰⁸Pb(p,p[']) at iThemba LABS



²⁰⁸Pb(e,e[´]) at DALINAC



Summary of Scales



Three classes

- I: ~ 100 keV all nuclei
- II : ~ 200 900 keV changes with mass number
- III : $\sim 1.2 4.7$ MeV gross width

Interpretation of the Scales – Models for ²⁰⁸Pb

۰	RPA	Wambach et al.	(2000)	•
•	SRPA	Wambach et al.	(2000)	•
•	QPM	Ponomarev	(2003)	+
•	ETDHF	Lacroix et al.	(1997)	
0	1p – 1h ⊗ phonon ETFFS	Kamerdziev et al.	(1997)	

 Sizable differences between model predictions → use wavelet analysis for a quantitative measure in comparison with the experimental observations

²⁰⁸Pb RPA



No scales from 1p-1h states

²⁰⁸Pb SRPA



• Coupling to 2p-2h generates fine structure and scales

Experiment vs. Model Predictions

		Scales (keV)	
	- I	I	III
Exp / keV	110	550	1500 2600
Models / keV			
SRPA	80	250 800	2100
QPM	110	770	1400
ETDHF	120	230	1000
FTFFS	130	310 570	2500

- Three classes of scales as in the experiment on a qualitative level
- But strong variations of class II and class III scales
- Take QPM for semi-quantitative analysis of damping mechanisms

Semi-Quantitative Attempt of Interpretation: ²⁰⁸Pb as Example

Two types of dissipation mechanisms:



How Can the Two Mechanisms Be Separated: Distribution of the Coupling Matrix Elements



• QPM: distribution for $\langle 1p1h | V_{1p1h}^{2p2h} | 2p2h \rangle$

RMT: deviations at large and at small m.e.

Large m.e. define the collective damping mechanism

Small m.e. are responsible for the non-collective damping

Collective vs. Non-Collective Damping in ²⁰⁸Pb



• Collective part:

• Non-collective part:

all scales

no prominent scales

Stochastic coupling

Spreading of a GR due to the Coupling to Doorway States and Decay into Compound Nucleus States



• First step of coupling hierarchy 1p-1h \rightarrow 2p-2h has been tested

Further steps require improvement in resolution

Recent Improvement in Resolution



Are All Scales Equally Relevant for the Fine Structure?

Example: Gamow-Teller Giant Resonance



 $\Delta L = 0, \ \Delta T = 1, \ \Delta S = 1$

Fine Structure of the Spin-Flip GTR







Discrete Wavelet Analysis *



- Orthogonal basis of wavelet functions (e.g. biorthogonal form)
- Exact reconstruction of the spectrum is possible and it is fast

• Relevance of scales
•
$$\int_{-\infty}^{+\infty} E^n \Psi^* \left(\frac{E_x - E}{\delta E}\right) dE = 0, \quad n = 0, 1 \dots m - 1$$
 vanishing moments
this defines the shape and magnitude of the background
* http://www.mathworks.com/products/wavelet/

Decomposition



Decomposition of 90Zr(3He,t)90Nb Spectrum



 \leftarrow

 \leftarrow

 \leftarrow

- Reconstruct the spectrum using important scales
- Model-independent background determination + fluctuations \rightarrow level densities

Discrete Wavelet Transform: Reconstructed Spectra



Level Densities

Astrophysical network calculations

 Back-shifted Fermi gas model semiempirical approach shell and pairing effects

 Number of mic-mac models (not discussed here)

 $\rho(E_x, J) \sim e^{2\sqrt{a(E_x-\delta)}} \cdot e^{-\frac{J(J+1)}{2\sigma^2}}$

→ ● HF-BCS

microscopic statistical model (partition function, MSk7 force, local renormalization) shell effects, pairing correlations, deformation effects, collective excitations

→ ● Monte-Carlo shell model calculations parity dependence?

Monte-Carlo Shell Model Predictions: pf + g_{9/2} Shell



- Total level density (not spin projected) shows strong parity dependence*
- Questioned by recent experiments (⁴⁵Sc)**
- * Y. Alhassid, G.F. Bertsch, S. Liu, and H. Nakada, PRL 84 (2000) 4313
- ** S.J. Lokitz, G.E. Mitchell, and J.F. Shriner, Jr., PRC 71 (2005) 064315

Experimental Techniques

Selectivity

hadron scattering at extremely forward angles and intermediate energies $\rightarrow \rho_+$ electron scattering at 180° and low momentum transfers $\qquad \rightarrow \rho_-$

High resolution

lateral and angular dispersion matching faint beam method*

 Level density fluctuation analysis**

- Background discrete wavelet transform***
- * H. Fujita et al., NIM A484 (2002) 17
- ** P.G. Hansen, B. Jonson, and A. Richter, NPA 518 (1990) 13
- *** Y. Kalmykov et al., PRL 96 (2006) 012502

Fine Structure of the ISGQR: A = 90



• Selective excitation of $J^{\pi} = 2^+$ states

A. Shevchenko et al., PRL 93 (2004) 122501

Fine Structure of the M2 Resonance: A = 90



• Selective excitation of $J^{\pi} = 2^{-}$ states

P. von Neumann-Cosel et al., PRL 82 (1999) 1105

Fluctuations and Level Densities



Fluctuation Analysis



Autocorrelation Function and Mean Level Spacing

•
$$C(\varepsilon) = \frac{\langle d(E_x) d(E_x + \varepsilon) \rangle}{\langle d(E_x) \rangle \langle d(E_x + \varepsilon) \rangle}$$

autocorrelation function

•
$$C(\varepsilon = 0) - 1 = \frac{\langle d^2(E_x) \rangle - \langle d(E_x) \rangle^2}{\langle d(E_x) \rangle^2}$$

variance

•
$$C(\varepsilon) - 1 = \frac{\alpha \langle D \rangle}{2\sigma \sqrt{\pi}} \times f(\sigma, \varepsilon)$$

level spacing $\langle \mathsf{D} \rangle \to \rho$

•
$$\alpha = \alpha_{PT} + \alpha_W$$

selectivity

🥥 σ

resolution

P.G. Hansen, B. Jonson, and A. Richter, NPA 518 (1990) 13

Results and Model Predictions: A = 90, J^{π} = 1⁺



Y. Kalmykov, C. Özen, K. Langanke, G. Martínez-Pinedo, P. von Neumann-Cosel, and A. Richter, PRL 99 (2007) 202502

Fine Structure of Level Density: A = 90, J^{π} = 1⁺



Level Density of 2⁺ and 2⁻ States: ⁹⁰Zr



Y. Kalmykov, C. Özen, K. Langanke, G. Martínez-Pinedo, P. von Neumann-Cosel, and A. Richter, PRL 99 (2007) 202502

Equilibration of Parity-Projected Level Densities

● ⁵⁸Ni

 $\rho_{-} \approx \rho_{+}$ at $E_x \approx 20 \text{ MeV}$

90Zr

 $\rho_{-} \approx \rho_{+}$ at $E_x \approx 5 - 10$ MeV

Two energy scales which determine ρ_/ρ_ pair-breaking

 5 - 6 MeV for intermediate mass nuclei
 shell gap between opposite-parity states near the Fermi level
 depends strongly on the shell structure, e.g. ⁶⁸Zn Δ_{pf-g9/2} is small

 Core breaking

 e.g. near shell closure ⁵⁸Ni Δ_{sd-pf} transitions are important
 ρ_ would be enlarged



Summary

- Fine structure is a general phenomenon of many-body systems (particles, nuclei, atoms, molecules, clusters, condensates,...)
- Quantitative analysis of nuclear giant resonances with wavelets

- Origin of scales in GR's:
 - collective damping:
 - non-collective damping:

low-lying surface vibrations stochastic coupling

TU DARMSTADT

New method for level densities





Dear Björn,

since October 1st, i.e. for 16 days, I am Professor Emeritus myself and I am already convinced that it is a wonderful profession. It has the only disadvantage that it takes so long to reach it.

My best personal wishes for the years to come!