TRIUMF — RESEARCH PROPOSAL	Experiment no. 927	Sheet 1 of 16

Title of proposed experiment:

Spectroscopy of ^{20}Na and of proton-unbound ^{19}Na using (^{3}He,p)

Name of group: TUDA

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Start of preparations: February 2002

Date ready: Summer 2003

Completion date: Summer 2004

Beam time requested:

12-hr shifts	Beam line/channel	Polarized primary beam?
24+24	TUDA @ ISAC	No

We propose to use the ^{18}Ne(^{3}He,p)^{20}Na reaction in inverse kinematics to investigate the spectroscopy of ^{20}Na and especially, in an attempt to resolve a long standing issue, to determine the spin/parity of the astrophysically relevant 2643-keV state in ^{20}Na.

In a following experiment, we would like to use the reaction ^{17}Ne(^{3}He,p)^{19}Na to study proton-unbound ^{19}Na and to determine if its structure allows to consider the two-proton capture reaction ^{18}Ne(2p,γ)^{20}Mg as a viable alternative for bridging the waiting point ^{18}Ne at high temperature and density conditions.

Experimental area

ISAC-HE, TUDA

Primary beam and target (energy, energy spread, intensity, pulse characteristics, emittance)

p-MgO or SiC, 500 MeV, cw
ECR Source

Secondary channel ISAC-HE

Secondary beam (particle type, momentum range, momentum bite, solid angle, spot size, emmittance, intensity, beam purity, target, special characteristics)

^{17}Ne (unstable) up to 10^6 pps, Max. 1.64 MeV/u
^{18}Ne (unstable) up to 10^8 pps, Max. 1.64 MeV/u.

TRIUMF SUPPORT:

No unusual support required

NON-TRIUMF SUPPORT

The TUDA facility, including considerable manpower for setup and operation, will be provided by U. of Edinburgh and U. of York. The TUDA collaboration is supported by a NSERC grant for manpower, replacement parts and computing support. The He gas cell will be provided by Argonne National Laboratory.

Standard TUDA operation with short lived radioactive isotopes, (^{18}Ne, $T_{1/2}$=1.67s, ^{17}Ne, $T_{1/2}$=109.2ms). Low voltage detectors and electronics. Gas target.

1 Scientific Justification

The Carbon-Nitrogen-Oxygen (CNO) cycles are thought to be the main source of energy generation in novae and X-ray bursts in their ignition phase [1]. Under certain extreme conditions of temperature and density, these cycles may be broken by so-called breakout reactions such as ^{15}O(α,γ)^{19}Ne(p,γ)^{20}Na or ^{18}Ne(α,p)^{21}Na, which link the CNO cycles to the rp-process, a long sequence of proton captures and beta-decays towards higher masses. Precise knowledge of the structure of a few states above the relevant particle threshold in the compound nuclei is required to calculate the rate of the reactions involved in the breakout of the CNO cycles and in the subsequent rp-process.

The two following subsections give a description of the scientific justification for the two proposed experiments.

1.1 Nature of the 2643-keV state in ^{20}Na

The reaction sequence ^{15}O(α,γ)^{19}Ne(p,γ)^{20}Na is expected to form the dominant break-out path that connects the CNO cycle with the rp-process. The leak rate of the break-out is determined by the slower reaction which is believed to be the ^{15}O(α,γ)^{19}Ne reaction, however, both reaction rates remain undetermined. The reaction rate for ^{19}Ne(p,γ)^{20}Na is thought to be dominated by resonant capture on a single state at 2643 keV in ^{20}Na lying 448 keV above the ^{19}Ne+p threshold. The exact nature of this state has been a matter of intense debate for more than a decade.

DWBA analysis of the angular distribution of the reaction ^{20}Ne(^{3}He,t)^{20}Na provided the first tentative assignment J^π=1$^+$ of the 2643-keV state in ^{20}Na [2,3]. It was proposed to be the analog of the 1$^+$ state at 3172 keV in ^{20}F, the mirror nucleus of ^{20}Na. However, this mirror state appears to be weakly populated in the ^{20}Ne(t,^{3}He)^{20}F reaction [4], suggesting an incorrect assignment. This was pointed out by Brown et al. [5], who also argue that the Coulomb shift expected for this 1$^+$ state cannot account for the 529 keV energy displacement. By a process of elimination based on Coulomb shift analysis of the ^{20}Na-^{20}F mirror pair, Brown et al. found that only the 3$^+$ state at 2966 keV in ^{20}F could be the mirror of the 2643-keV state in ^{20}Na. This assignment seems to be supported by more recent studies. A measurement of the β-decay of ^{20}Mg, which should preferably populate 1$^+$ states in GT transition, shows no feeding of the 2643-keV state (log $ft \geq 6.2$) [6]. In a study of the ^{20}Ne(p,n)^{20}Na reaction at 135 MeV, the neutron angular distribution of the 2643-keV state shows essentially no strength at 0°, whereas neutrons are indeed observed at higher angles, indicating a Δl=2 transition consistent with a 3$^+$ assignment [7]. However, most recently, the ^{19}Ne(p,γ)^{20}Na reaction has been studied directly at Louvain-la-Neuve and an experimental upper limit for the resonance strength $\omega\gamma$ of 21 meV at the 90 % confidence level has been extracted [8]. This value disagrees by a factor of 4 with the 80 meV proposed value from Brown et al. assuming a 3$^+$ assignment [5], but is consistent with the value of 6 meV suggested by Lamm et al. for a 1$^+$ state [3]. [8] points out that the β-decay [6] and the charge-exchange [7] results could still, in some respect, be consistent with a 1$^+$ assignment. A recent report from Fortune, Sherr and Brown [9] proposed a re-analysis of the original paper from Brown et al. [5]. Based on updated information on the ^{20}F mirror γ-decay width and isospin non-conserving effects, they extract a new lower limit of 16 meV for the resonance strength of the ^{19}Ne(p,γ)^{20}Na reaction assuming a 3^+ assignment, tantalizingly close to the experimental upper limit of 21 meV proposed by Vancraeynest et al. [8]. At this point, a consensus was still to be met for the assignment of the 2643-keV state.

Last year, a novel idea of deducing the nature of the 2643-keV state from its γ-cascade and by comparing its deduced decay scheme to the known ones of the few states in ^{20}F, which are candidates to be its mirror state, have been investigated at Argonne National Laboratory [10]. A 66 MeV ^{12}C beam on a ^{10}B target was used to produce ^{20}Na via the 2n fusion-evaporation channel. The recoiling ^{20}Na was detected at the focal plane of the FMA, while γ-rays were recorded in prompt coincidence in the Argonne BGO array and two Germanium clover detectors provided by the University of Notre-Dame. At this point in the analysis, the γ-decay of a few subthreshold states in ^{20}Na (including the 2 first excited states) have been observed but there is so far no evidence that the spin/parity of the 2643-keV state could be identified in this experiment. The main difficulty of this experiment was that the entry point of the γ-cascade had to be reconstructed by summing the energy of all the detected γ-rays. In this case, it is proposed to use the ^{18}Ne(^{3}He,p)^{20}Na reaction in inverse kinematics to deduce the spin of the 2643 keV state in ^{20}Na. This time, based on the same principle of the Argonne experiment, the entry point would be deduced from the emitted proton and would therefore require p-γ rather than γ-γ(-γ) coincidences.

1.2 Spectroscopy of unbound ^{19}Na

Similarly to the triple-alpha reaction, where unbound ^{8}Be is created as an intermediate state toward the creation of ^{12}C, it is possible to consider a 2-proton capture process, which would connect ^{15}O with ^{17}Ne and ^{18}Ne with ^{20}Mg via respectively the unbound ^{16}F and ^{19}Na nuclei as intermediate states. To address this question, a precise knowledge of the structure of a few states in these unbound nuclei is required. J. Görres et al. estimates that the reaction rates deduced for this process cannot compete realistically with the reaction rate of their respective alpha-induced reaction for typical stellar conditions [11]. However, in the case of ^{19}Na, only the ground state and first excited state have been measured once with a precision of about 10 keV [12]. The other parameters in the calculation were based on theoretical considerations. An accurate determination of the energy and width of the ground state and the first excited states of ^{19}Na as well as an experimental spin assignment of these states are needed to fully calculate the reaction rate of the 2-step reaction ^{18}Ne(2p,γ)^{20}Mg.

It is also worth noting that, since ^{19}Na is unbound by only 320keV, an almost unique case among the light nuclei, it may be an excellent candidate to study the Thomas-Ehrmann effect beyond the proton drip-line [13,14]. Interestingly, while the other proton unbound nuclei display a Thomas-Ehrmann shift tending to lower the unbound states compared to their bound mirror states, ^{19}Na shows an inverse effect for the only known excited state [15]. In addition, ^{19}Na has a closed N=8 neutron shell and its states can be made subject to thorough shell or other model calculations.

Very recently, the structure of ^{19}Na has been investigated by resonant elastic scattering at GANIL and Louvain-la-Neuve, leading to the observation of discrete structures between 1 and 6 MeV. Analysis is under way [16]. However, resonant elastic scattering is limited to low spin states and/or resonances of relatively large width. The ground state and the first excited state have therefore not been observed. It is also not clear how much information would be deduced from the single large excitation function recorded at SPIRAL/GANIL. The proposed experiment, based on transfer reaction, is likely to provide the suitable complementary study of ^{19}Na.

2 Description of the Experiment

2.1 The (^{3}He,p) transfer reaction

We propose to use the (^{3}He,p) reaction in inverse kinematics at the TUDA scattering chamber [17] at ISAC-I as an alternative to elastic scattering. For proton-rich nuclei this reaction has a high Q-value, which allows the population of a wide range of states with a single beam energy.

At ISAC-I energies (maximum 1.64 MeV per nucleon), the deuteron transfer is expected to proceed mainly (but not exclusively) via a compound nucleus mechanism as it has been reported for the nearby reaction ^{20}Ne(^{3}He,p)^{22}Na at 2.8 and 3 MeV [18]. They also reports the observation of states with spins as high as 5^{+}, which shows that large L-transfers are possible although with a small cost in cross-section. It is therefore a suitable reaction to populate excited states rather indiscriminately, which is a clear advantage compared to resonant elastic scattering.

Estimates of the cross section will be discussed in the appropriate section of the proposal.

2.2 The ^{3}He gas target

The gas target will consist of a thin ^{3}He LN_2-cooled gas cell at a pressure of about 500 mbar and the entry foil of a 1mg/cm^2 Ni foil. It has been designed, built and already used for experiments [19] or secondary beam production [20] at Argonne National Laboratory. The clear advantage of such a cold target is that for a same pressure, it contains more ^{3}He atoms/cm^2 than at room temperature. Therefore, it allows the target to be thinner, enabling better energy resolution. When the time comes, it would be shipped to TRIUMF and fitted to the TUDA chamber for the experiment. A new flange supporting the target and including ^{3}He and LN_2 feed-throughs will need to be designed and built. A gas handling system is already in place underneath the TUDA experimental chamber.

The design of the target allows one to change the thickness of the gas cell, which will be determined such that it will allow an efficient excitation energy reconstruction both in the forward and the backward angles.

2.3 Nature of the 2643-keV state in ^{20}Na

The idea of this experiment is to populate the 2643 keV level in ^{20}Na by the ^{18}Ne(^{3}He,p)^{20}Na reaction in inverse kinematics and to study its γ decay path to the ground-state in coincidence with the proton emanating from the (^{3}He,p) reaction. Figure 1 shows the known level schemes of the mirror nuclei ^{20}F and ^{20}Na.

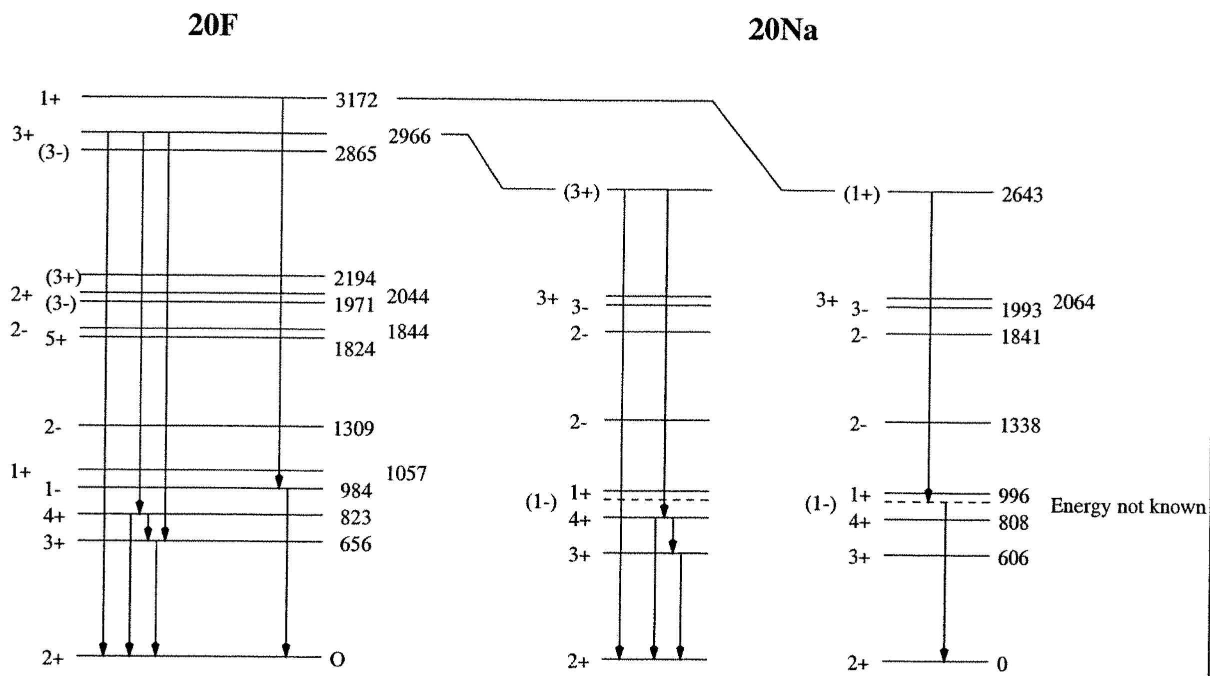

Fig. 1 Known γ-decay schemes of ^{20}F. Expected γ-decays from the 2643-keV state of ^{20}Na in both possible assignments.

As discussed in the scientific motivations, the 2643-keV state in ^{20}Na is believed to be paired with the 3^+ at 2966 keV or with the 1^+ at 3172 keV in ^{20}F. The only branch known for the γ-decay to the ground-state for this latter state is through a 1^- state located at 984 keV, which unfortunatly has not yet been paired with a state in ^{20}Na. In fact, this 1^- state is the only state below 1500 keV, which hasn't been yet observed in ^{20}Na. The 2966-keV state in ^{20}F has a few known decay-branches: a direct decay to the 2^+ ground-state (27 %), a decay to the first excited state (3^+) located at 656 keV (12 %) and a decay to the second excited state (4^+) at 822 keV (58 %) [21]. As expected, the 2966-keV 3^+ state decays preferentially to relatively high spin state, whereas the 3172-keV 1^+ state decays to a 1^- state. Assuming that the γ-decay of the 2643-keV in ^{20}Na follows the one of its mirror state, it is in principle possible to determine the spin and parity of this state [10]. In theory, the observation of the 1835 keV transition to the 4^+ would provide a unique signature of a 3^+ for the 2643-keV state. However, since the 1^- state, mirror of the 984-keV state in ^{20}F, hasn't yet been observed, it is possible, although unlikely, that it would be located too close to the 808-keV 4^+ state to be clearly separated by our γ experimental setup. From information on its mirror state, the 808-keV state would decay to the nearby 3^+ at 606 keV ($\sim$67 %) or to the 2^+ ground-state ($\sim$33 %). The observation of the 4^+ to 3^+ 202-keV transition would then be then a decisive argument, assuming that a 1^- to 3^+ transition would have a very weak branch (not observed in ^{20}F). It is worth noting that a full analysis of the experiment may also lead to a less direct determination of the spin/parity of the 2643-keV state. For example, if the missing 1^- state was to be observed or if a useful set of γ-γ coincidence data were obtained.

The entry point of the γ cascade (e.g. the state in ^{20}Na) is determined by the reconstruction of the excitation energy obtained from the detection of the proton. A fairly good separation from the contribution of the other states is needed to allow an unambiguous identification of the 2643-keV state. In fact, only a lower limit in the excitation energy is required since the states above 2643 keV all decay predominantly by particle emission, therefore no p-γ coincidences will be recorded. Interestingly, there is no known particle bound state above 2064 keV, which allows for a relatively poor energy resolution.

At maximum beam energy (1.64 MeV per nucleon), the ^{18}Ne beam loses about 6.2 MeV in the gas cell entry foil, which gives an actual beam energy of 23.3 MeV in the ^{3}He.

The high Q-value (6.1 MeV) and the kinematics of the reaction result in having a large range of proton energies in both forward and backward hemispheres. At the forward angles, the maximum proton energy is 15.8 MeV for the ground-state (12.4 MeV for the 2643-keV state), whereas in the backward hemisphere, the proton energy would be about 4.5 MeV for the ground-state and 2.7 MeV for the 2643-keV state.

At the forward angles, a ΔE-E system is required to reconstruct the trajectory and to deduce the initial excitation energy. Monte-Carlo simulations show that the energy reconstruction may require that the silicon detectors have a higher degree of segmentation. It is proposed to use as E, a stack of two LEDA detectors (300 μm and 1 mm), mounted such that each LEDA sector of the back detector is offset from its corresponding sector in the front detector by half a strip size in the radial direction. This results in having twice the resolution of a LEDA detector over most of its surface. The ΔE will consist of a 300μm thick CD-type silicon strip detector with a higher segmentation degree than its nominal design. At the backward angles, where the energy resolution is optimal, a single 300 μm LEDA is needed, since no trajectory reconstruction is required. Monte-Carlo simulations have been developed to optimize the experimental setup.

Finally, two HPGe clover detectors, providing high efficiency γ detection, will be placed around the target position. The Ge clover are likely to be the prototypes of the future TIGRESS array (Triumf Isac Gamma-Ray Escape Suppressed Spectrometer). Due to the geometry of the TUDA chamber, the Ge clover are likely to be placed at 90° with respect to the beam axis. The flange supporting the target will be designed such as the target will make an angle with respect to the beam to allow a better "γ-escape" at 90°. At 90°, the observed γ peaks will be doppler broadened. TIGRESS module have an effective segmentation of about 3 cm. Assuming that the Ge clovers would be placed at 5 cm from the target and an average energy of the recoiling ^{20}Na of 20 MeV, a conservative estimate of 6 keV maximum doppler broadening is obtained for a 200 keV γ-ray. No particular issue should then arise from doppler effects in this experiment.

Beside the identification of the spin/parity of the 2643-keV state, which is the main goal of this experiment, an additional detailed spectroscopy of ^{20}Na should be obtained.

2.4 Spectroscopy of unbound ^{19}Na

The experimental setup is similar to the one described above. The higher Q-value of the ^{17}Ne(^{3}He,p)^{19}Na reaction (Q=11.2 MeV) requires a similar particle detection setup to the experiment previously described, but with thicker silicon detectors to accommodate the higher energy protons emitted (E_p=22 MeV at 0° for the ground state of ^{19}Na). At ISAC-I, due to the complex reaction mechanism at these energies, it is not expected that spin assignments will be possible. Therefore, provided that we have enough beam intensity to carry out a first experiment, we would concentrate on a backward-only detection system which would only require a 600 μm thick LEDA array.

New states in ^{19}Na could be observed for the first time and their widths investigated.

3 Experimental Equipment and Readiness

As reported before, the TUDA facility has been fitted with a gas handling system, which will allow the gas cell to be kept at a constant pressure. A new flange will need to be designed to support the gas cell and feedthroughs. One 1mm thick LEDA detector has already been ordered by the University of York for the ^{18}Ne(α,p) experiment (proposal #E870). A new CD detector has been included into the TRIUMF-TUDA grant application submitted last October. One TIGRESS clover Ge prototype is to be received by the end of this year for tests, while the other is to be ordered. The side flanges of the TUDA chamber need to be replaced by two re-entry flanges in order to shorten the distance between the target and the clover germanium.

Both experiments should be ready to run by summer 2003.

4 Beam Time required

The yield of ^{17}Ne and ^{18}Ne have not yet been determined at ISAC. However, from estimates [22], it seems that as much as 10^8 ^{18}Ne per second could be delivered to the TUDA chamber from a SiC or a MgO target. From systematics, it is reasonable to estimate that the expected cross section for the reaction will be of the order of 0.1mb per state. With a target of 10^{19} atoms per cm^2 thickness of ^{3}He and about 30% (cm) of solid angle covered by the particle detection system, we expect about 100 events/hour/state. TIGRESS prototypes are designed to have excellent absolute efficiency (more than 50% at 200 keV), we estimate at about 5% the overall efficiency of the γ detection setup for a given γ-ray in the cascade. A detailed spectroscopy of subthreshold states in ^{20}Na should therefore be possible in a relatively short period of time. However, for the 2643-keV state, one has to consider the proton-γ branching ratio, which is estimated to be about 10% [8]. For this particular transition, only 1 p-γ coincidences every two hour are expected. Therefore, we request 24 shifts of 12h to carry out the ^{18}Ne(^{3}He,p)^{20}Na experiment. Some of the numbers quoted are conservative estimates, which should allow for less optimistic beam intensity delivered to the TUDA chamber.

The beam time estimate for the study of proton unbound ^{19}Na by the reaction ^{17}Ne(^{3}He,p)^{19}Na is somehow similar. Since it only requires particle detection, there is a factor 200 increase in efficiency compared to the ^{18}Ne(^{3}He,p)^{20}Na experiment, which can account for the loss of beam intensity in the beam time request. Upon success of the ^{18}Ne(^{3}He,p)^{20}Na experiment and provided that the beam intensity could reach 10^6 ^{17}Ne per second, we would request an other 24 shifts to carry out the ^{17}Ne(^{3}He,p)^{19}Na experiment.

References

1. M. Wiescher et al., Phil. Trans. Royal Soc. (London) **A356** (1998) 2105
2. S. Kubono et al., Z. Phys. **A331** (1989) 359; Astrophys. J. **344** (1989) 460
3. L.O. Lamm et al., Nucl. Phys. **A510** (1990) 503
4. N.M. Clarke et al., J. Phys. **G16** (1990) 1547
5. B.A. Brown et al., Phys. Rev. **C48** (1993) 1456
6. A. Piechaczek et al., Nucl. Phys. **A584** (1995) 509
7. B.D. Anderson et al., Phys. Rev. **C52** (1995) 2210
8. G. Vancraeynest et al., Phys. Rev. **C57** (1998) 2711
9. H.T. Fortune et al., Phys. Rev. **C61** (2000) 057303
10. P.J. Woods, F. Sarazin, D. Seweryniak et al., Argonne Proposal (2000)
11. J. Görres, M. Wiesher and F-K. Thielemann, Phys. Rev. **C51** (1995) 392
12. W. Benenson et al., Phys. Lett. **B58** (1975) 46
13. R.G. Thomas, Phys. Rev. **80** (1950) 136 ; Phys. Rev. **88** (1952) 1109
14. J.B. Ehrman, Phys. Rev. **81** (1951) 412
15. E. Comay, I. Kelson and A. Zidon, Phys. Lett. **B210** (1988) 31
16. F. De Oliveira et al., to be submitted (2002)
17. T. Davinson et al., to be published
18. C. Meynadier et al., Nucl. Phys. **A161** (1970) 305 (in french !)
19. A.A. Sonzogni et al., Phys. Rev. Lett. **84** (2000) 1651
20. B. Harss et al., Rev. Sci. Instr. **71** (2000) 380
21. Adopted levels and γ-decays from: http://www.nndc.bnl.gov
22. M. Dombsky, private communication (2002)

Include publications in refereed journal over at least the previous 5 years.

1. G.F.Grinyer, J.C.Waddington, C.E.Svensson, R.A.E.Austin, G.C.Ball, G.S.Hackman, C.Osborne, F.Sarazin, H.C.Scraggs, H.D.H.Stover,

   Half-Life of ^{176}Lu

   Submitted to Phys. Rev. C (2002).

2. C.Ruiz, F.Sarazin, L.Buchmann, T.Davinson, A.A.Chen, D.Groombridge, L.Ling, A.Murphy, J.Pearson, I.Roberts, A.Robinson, A.S.Shotter, P.Walden, P.J.Woods,

   strong resonances in elastic scattering of radioactive ^{21}Na on protons

   Phys. Rev. C65 (2002) 042801R.

3. F.M.Marques, M.Labiche, N.A.Orr, J.C.Angelique, L.Axelsson, B.Benoit, U.Bergmann, M.J.G.Borge, W.N.Catford, S.P.G.Chapell, N.M.Clarke, G.Costa, N.Curtis, A.DArrigo, F.de Oliveira, E.de Goes Brennand, O.Dorvaux, M.Freer, B.R.Fulton, G.Giardina, C.Gregori, S.Grevy, D.Guillemaud-Mueller, F.Hannappe, B.Heusch, B.Jonson, C.Le Brun, S.Leenhardt, M.Lewitowicz, M.J.Lopez, K.Markenroth, M.Motta, A.C.Mueller, T.Nilsson, A.Ninane, G.Nyman, I.Piqueras, K.Riisager, M.G.Saint-Laurent, F.Sarazin, S.M.Singer, O.Sorlin, L.Stuttgé,

   Detection of neutron clusters

   Phys. Rev. C65 (2002) 044006.

4. A.de Vismes, P.Roussel-Chomaz, W.Mittig, A.Pakou, N.Alamanos, J.C.Angelique, F.Auger, J.Barrette, E.Bauge, A.V.Belozyorov, C.Borcea, W.N.Catford, M.D.Cortina-Gil, J.P.Delaroche, Z.Dlouhy, A.Gillibert, M.Girod, D.Hirata, V.Lapoux, A.Lepine-Szily, S.M.Lukyanov, F.Marie, A.Musumarra, F.de Oliveira, N.A.Orr, S.Ottini-Hustache, Y.E.Penionzhkevich, F.Sarazin, H.Savajols, N.Skobelev,

   Proton reaction cross-section measurements on stable and neutron-rich nuclei as a probe of the Nucleus-Nucleus interaction

   Nucl. Phys. A706 (2002) 295.

5. F.M.Marques, M.Labiche, N.A.Orr, J.C.Angelique, L.Axelsson, B.Benoit, U.Bergmann, M.J.G.Borge, W.N.Catford, S.P.G.Chapell, N.M.Clarke, G.Costa, N.Curtis, A.D'Arrigo, F.de Oliveira, E.de Goes Brennand, O.Dorvaux, M.Freer, B.R.Fulton, G.Giardina, C.Gregori, S.Grevy, D.Guillemaud-Mueller, F.Hannappe, B.Heusch, B.Jonson, C.Le Brun, S.Leenhardt, M.Lewitowicz, M.J.Lopez, K.Markenroth, M.Motta, A.C.Mueller, T.Nilsson, A.Ninane, G.Nyman, I.Piqueras, K.Riisager, M.G.Saint-Laurent, F.Sarazin, S.M.Singer, O.Sorlin, L.Stuttgé,

   Three-body correlations in Borromean halo nuclei

   Phys. Rev. C64 (2001) 061301.

6. M.Labiche, N.A.Orr, F.M.Marques, J.C.Angelique, L.Axelsson, B.Benoit, U.Bergmann, M.J.G.Borge, W.N.Catford, S.P.G.Chapell, N.M.Clarke, G.Costa, N.Curtis, A.D'Arrigo, F.de Oliveira, E.de Goes Brennand, O.Dorvaux, G.Fazio, M.Freer, B.R.Fulton, G.Giardina, S.Grevy, D.Guillemaud-Mueller, F.Hannappe, B.Heusch, K.L.Jones, B.Jonson, C.Le Brun, S.Leenhardt, M.Lewitowicz, M.J.Lopez, K.Markenroth, A.Mueller, T.Nilsson, A.Ninane, G.Nyman, I.Piqueras, K.Riisager, M.G.Saint-Laurent, F.Sarazin, S.M.Singer, O.Sorlin, L.Stuttgé,

   The halo structure of ^{14}Be

   Phys. Rev. Lett. 86 (2001) 600.

7. F.Sarazin, H.Savajols, W.Mittig, F.Nowacki, N.A.Orr, Z.Ren, P.Roussel-Chomaz, G.Auger, D.Baiborodin, A.V.Belozyorov, C.Borcea, E.Caurier, Z.Dlouhy, A.Gillibert, A.S.Lalleman, M.Lewitowicz, S.M.Lukyanov, F.de Oliveira, Y.E.Penionzhkevich, D.Ridikas, H.Sakurai, O.Tarasov, A.de Vismes,

   Shape coexistence and the N=28 shell closure far from stability

   Phys. Rev. Lett. 84 (2000) 5062.

8. A.de Vismes, P.Roussel-Chomaz, W.Mittig, A.Pakou, N.Alamanos, J.C.Angelique, F.Auger, J.Barrette, A.V.Belozyorov, C.Borcea, W.N.Catford, M.D.Cortina-Gil, Z.Dlouhy, A.Gillibert, V.Lapoux, A.Lepine-Szily, S.M.Lukyanov, F.Marie, A.Musumarra, F.de Oliveira, N.A.Orr, S.Ottini-Hustache, Y.E.Penionzhkevich, F.Sarazin, H.Savajols,

   A determination of the $^{6}He{+}p$ *interaction potential*

   Phys. Lett. B476 (2000) 219

9. F.M.Marques, M.Labiche, N.A.Orr, J.C.Angelique, L.Axelsson, B.Benoit, U.Bergmann, M.J.G.Borge, W.N.Catford, S.P.G.Chapell, N.M.Clarke, G.Costa, N.Curtis, A.DArrigo, F.de Oliveira, E.de Goes Brennand, O.Dorvaux, M.Freer, B.R.Fulton, G.Giardina, C.Gregori, S.Grevy, D.Guillemaud-Mueller, F.Hannappe, B.Heusch, B.Jonson, C.Le Brun, S.Leenhardt, M.Lewitowicz, M.J.Lopez, K.Markenroth, M.Motta, A.C.Mueller, T.Nilsson, A.Ninane, G.Nyman, I.Piqueras, K.Riisager, M.G.Saint-Laurent, F.Sarazin, S.M.Singer, O.Sorlin, L.Stuttgé,

   Two-Neutron Interferometry as a probe of the Nuclear Halo

   Phys. Lett. B476 (2000) 219

10. F.M.Marques, M.Labiche, N.A.Orr, F.Sarazin and J.C.Angelique,

    Neutron cross-talk rejection in a modular array and the detection of neutron haloes

    NIM A450 (2000) 109.

11. Z.Ren, W.Mittig and F.Sarazin,

    Relativistic mean-field study on proton skins and proton halos in exotic nuclei

    Nucl. Phys. A652 (1999) 250-270

12. A.C. Morton, J.C. Chow, J.D. King, R.N. Boyd, N.P.T. Bateman, L. Buchmann, J.M. D'Auria, T. Davinson, M. Dombsky, W. Galster, E. Gete, U. Giesen, C. Iliadis, K.P. Jackson, J. Powell, G. Roy, and A. Shotter,

    Beta-delayed particle decay of ^{17}Ne

    Nucl. Phys. A, 706 (2002) 15

13. D. Anthony, L. Buchmann, P. Bergbusch, J.M. D'Auria, M. Dombsky, U. Giesen, K.P. Jackson, J.D. King, J. Powell, and F.C. Barker,

    Beta Delayed Deuteron emission from ^{6}He

    Phys. Rev. C, 65 (2002) 034310

14. P. Tischhauser, R.E. Azuma, L. Buchmann, R. Detwiler, U. Giesen, J. Görres, M. Heil, J. Hinnefeld, F. Käppeler, J.J. Kolata, H. Schatz, A. Shotter, E. Stech, S. Vouzoukas, and M. Wiescher,

    Elastic α-^{12} *scattering and the* $^{12}C(\alpha,\gamma)^{16}O$ *E2 S-factor*

    Phys. Rev. Let., 88 (2002) 072501

15. A. Zyuzin, S.H. Park, L. Buchmann, K.R. Buckley, A.R. Junghans, E.C. Mohrmann, K.A. Snover, T.D. Steiger, and J. Vincent,

    The fabrication of metallic ^{7}Be *targets with a small diameter for* $^{7}Be(p,\gamma)^{8}B$ *measurements*

    Nucl. Instr. Meth. B, 187 (2002) 264

16. A.R. Junghans, E.C. Mohrmann, K.A. Snover, T.D. Steiger, E.G. Adelberger, J.M. Casandjian, H.E. Swanson, L. Buchmann, S.H. Park, A. Zyuzin,

    $^{7}Be(p,\gamma)^{8}B$" *astrophysical S-factor from precision cross section measurements*

    Phys. Rev. Let., 88 (2002) 041101

17. L. Buchmann,

    "Radiative cascade transitions and the $^{12}C(\alpha,\gamma)^{16}O$ *E2 cross section to the ground state of* ^{16}O

    Phys. Rev. C., 64 022801(R) (2001)

18. N. Bateman, K. Abe, G. Ball, L. Buchmann, J. Chow, J.M.D'Auria, Y. Fuchi, C. Iliadis, H. Ishiyama, K.P. Jackson, S. Karataglidis, S. Kato, S. Kubono, K. Kumagai, M. Kurokawa, X. Liu, S. Michimasa, P. Strasser, and M.H. Tanaka,

    Measurement of the $^{24}Mg(p,t)^{22}Mg$ *reaction and implications for the* $^{21}Na(p,\gamma)^{22}Mg$ *stellar reaction rate*

    Phys. Rev. C, 63 (2001) 035803

19. L.Buchmann, E.Gete, J.C.Chow, J.D.King, and D.F. Measday,
The β-delayed particle decay of ^9C and the A-9, T=1/2 nuclear system; R-matrix fits, the A=9 nuclear system, and the stellar reaction rate of $^4He(\alpha n,\gamma)^9Be$
Phys. Rev. C., 63 (2001) 034303

20. E.Gete, L.Buchmann, R.E.Azuma, D.Anthony, N.Bateman, J.C.Chow, J.M.D'Auria, M.Dombsky, U.Giesen, C.Illiadis, K.P.Jackson, J.D.King, D.F. Measday, and A.C.Morton,
The β-delayed particle decay of ^9C and the A-9, T=1/2 nuclear system; Experiment, data and phenomenological analysis
Phys. Rev. C., 61 (2000) 064310

21. A.Y.Zyuzin, L.R.Buchmann, J.S.Vincent, K.R.Buckley, N.O.Bateman, K.A.Snover, J.M.Casandjan, T.D.Steiger, E.G.Adelberger, and H.E.Swanson,
Metallic beryllium-7 target of small diameter
Nucl. Inst. Meth., A438 (1999) 109

22. E.G.Adelberger, S.A.Austin, J.N.Bahcall, A.B.Balantkin, G.Bertsch, G.Bognert, L.S.Brown, L.Buchmann, F.E.Cecil, A.E.Champagne, L. de Braeckeleer, C.A.Duba, S.E.Elliott, S.J. Freedman, M.Gai, C.Goldring, C.R.Gould, A.Cruzinov, W.C.Haxton, K.M. Hoeger, E.Henley, C.W.Johnson, M. Kamionskowski, R.W. Kavanaugh, S.E.Koonin, K.Kubodera, K.Langanke, T. Motobayashi, V, Pandharipande, P.Parker, R.G.H. Robertson, C.Rolfs, R.F. Sawyer, N.Shaviv, T.D.Shoppa, K.Snover, E.Swanson, R.E.Tribble, S. Turck-Chiene, and J.F. Wikerson,
Solar Fusion Rates
Rev. Mod. Phys., 70 (1998) 1265

23. J.Görres, J. Meißner, H.Schatz, E.Stech, P.Tischhauser, M.Wiescher, R.Harkewics, B.Sherrill, M.Steiner, D. Bazin, M.Hellström, D.J.Morrissey, R.N.Boys, L.Buchmann, D.H.Hartmann, J.D.Hinnefeld,
Lifetime of ^{44}Ti as probe of supernova models
Phys. Rev Lett. 80 (1998) 2554

24. J.C.Chow, A.C.Morton, R.E.Azuma, N.Bateman, R.N.Boyd, L.Buchmann, J.M.D'Auria, T.Davinson, M.Dombsky, W.Galster, E.Gete, U.Giesen, C.Iliadis, K.P.Jackson, J.D.King, G.Roy, T.Shoppa, and A.Shotter,
Three-particle break-up of the isobaric analogue state in ^{17}F
Phys. Rev. C 57, (1998) R475