The **impact** of
15 years of RILIS at ISOLDE
and
25 years of r-process research at ISOLDE
“ recognition of the efforts of K.-L. Kratz”

William B. Walters

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This work has been supported by the US Department of Energy under grant DE-FG02-94-ER40834.


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Denton
Milford
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Easton
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Outline:

Chemists, abundances, and the r-process

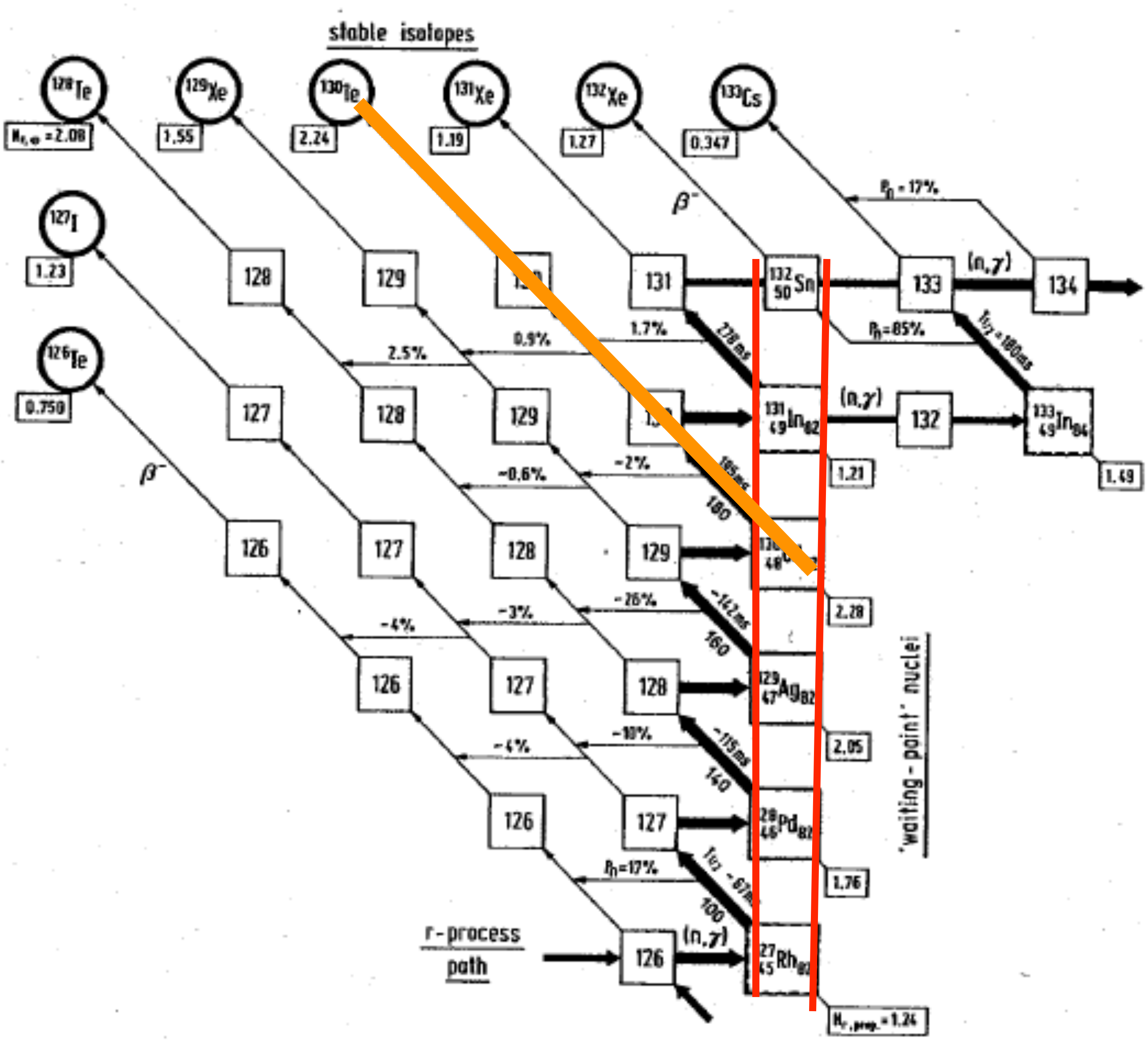
^{130}Cd…… the first data

Selectivity

^{129}Ag and the laser ion source….. Fine structure and isomer separation

Astrophysics Impact

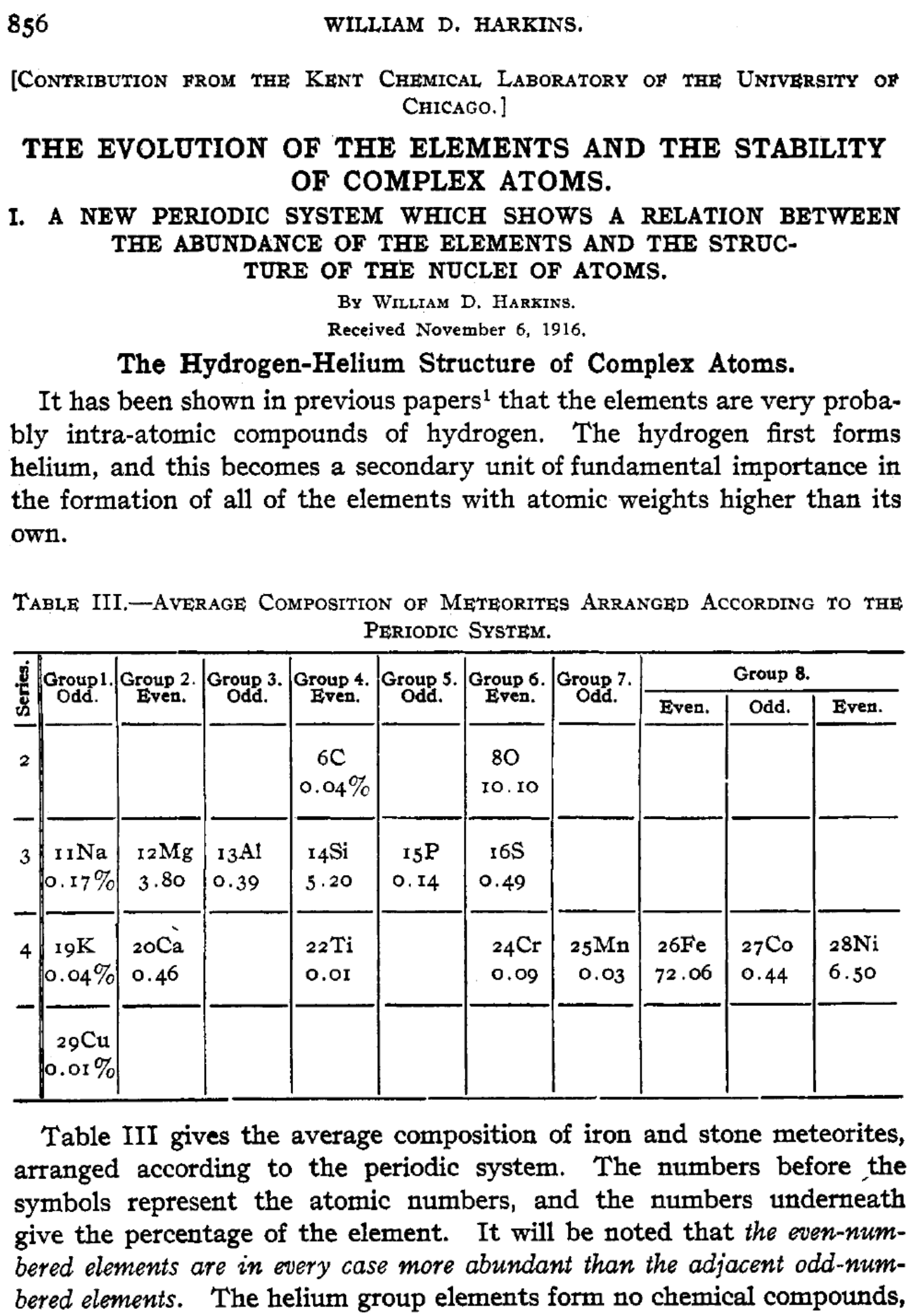
Nuclear Structure Impact the Fe, Cu, In and Cd isotopes



2010 marks the 25th anniversary of the first measurement of the half-life of the key waiting-point nucleus, ^{130}Cd and the ~15th anniversary of the successful operation of the RILIS at ISOLDE aimed at ^{129}Ag by Kratz et al.

This special 25-year/15-year celebration also extends to the ISOLDE technical staff for their 25 years of innovative work and technical genius.

It is one thing to have a vision for the solution of important scientific problems, but….another to actually find the technical means to accomplish the measurements.



856 WILLIAM D. HARKINS.

[CONTRIBUTION FROM THE KENT CHEMICAL LABORATORY OF THE UNIVERSITY OF CHICAGO.]

THE EVOLUTION OF THE ELEMENTS AND THE STABILITY OF COMPLEX ATOMS.

I. A NEW PERIODIC SYSTEM WHICH SHOWS A RELATION BETWEEN THE ABUNDANCE OF THE ELEMENTS AND THE STRUCTURE OF THE NUCLEI OF ATOMS.

By WILLIAM D. HARKINS.

Received November 6, 1916.

The Hydrogen-Helium Structure of Complex Atoms.

It has been shown in previous papers[1] that the elements are very probably intra-atomic compounds of hydrogen. The hydrogen first forms helium, and this becomes a secondary unit of fundamental importance in the formation of all of the elements with atomic weights higher than its own.

TABLE III.—AVERAGE COMPOSITION OF METEORITES ARRANGED ACCORDING TO THE PERIODIC SYSTEM.

Series.	Group 1. Odd.	Group 2. Even.	Group 3. Odd.	Group 4. Even.	Group 5. Odd.	Group 6. Even.	Group 7. Odd.	Group 8.		
								Even.	Odd.	Even.
2				6C 0.04%		8O 10.10				
3	11Na 0.17%	12Mg 3.80	13Al 0.39	14Si 5.20	15P 0.14	16S 0.49				
4	19K 0.04%	20Ca 0.46		22Ti 0.01		24Cr 0.09	25Mn 0.03	26Fe 72.06	27Co 0.44	28Ni 6.50
	29Cu 0.01%									

Table III gives the average composition of iron and stone meteorites, arranged according to the periodic system. The numbers before the symbols represent the atomic numbers, and the numbers underneath give the percentage of the element. It will be noted that *the even-numbered elements are in every case more abundant than the adjacent odd-numbered elements.* The helium group elements form no chemical compounds,

Journal of the American Chemical Society **39**, 856 (1917).

Chemists have long recognized the relationship between elemental abundances……measured by analytical chemists and by geochemists, and the structure of the nucleus, even before the neutron was discovered.

Chicago:

William Harkins

Harold Urey

Edward Anders

Andrew Davis

CCC

Phys. Rev. 78, 632 (1950)

Fast Neutron Cross Sections and Nuclear Shells

D. J. Hughes* and D. Sherman†
Argonne National Laboratory, Chicago, Illinois
April 10, 1950

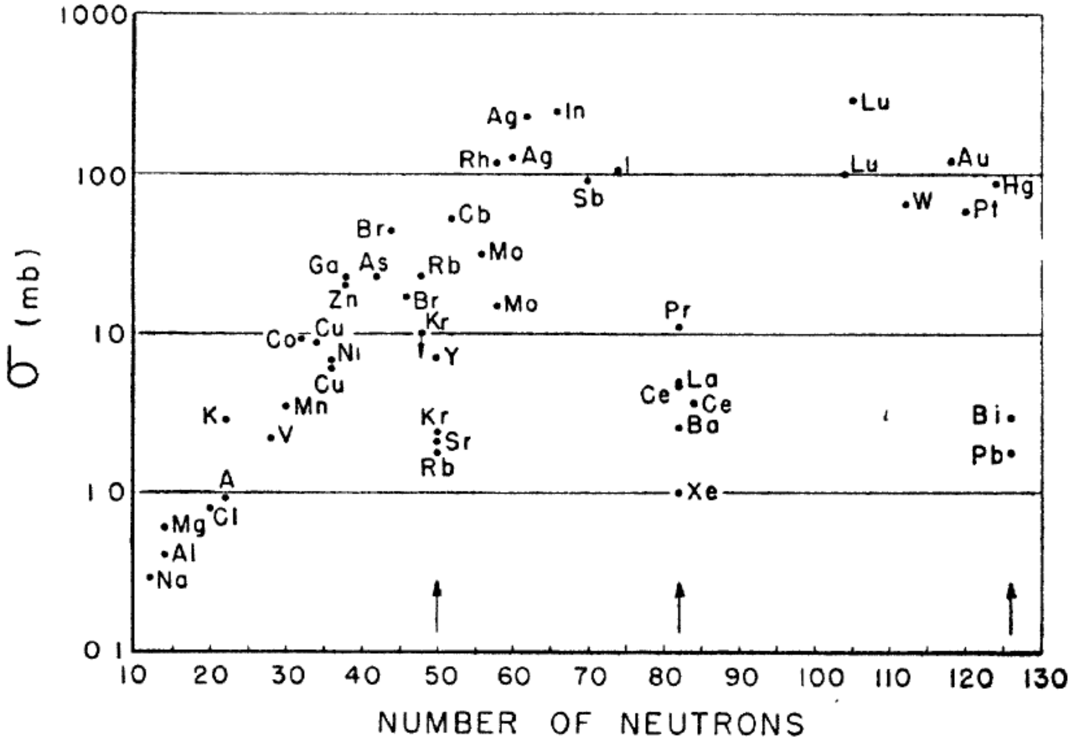


FIG. 1. Neutron cross sections *vs.* number of neutrons.

This paper laid the groundwork for the description of the s-process peaks as arising from closed shell nuclei "waiting" to capture neutrons. ….. And when two peaks were observed….. Perhaps a second "waiting spot".

This idea is <u>"natural" for chemists</u> who are familiar with the weak binding of the first electron beyond closed atomic shells, namely, the small ionization energy for the alkali metals.

Cameron (1925–2005)

Al Cameron's name is always listed along with Fowler and Hoyle in the development of the ideas about stellar nucleosynthesis.

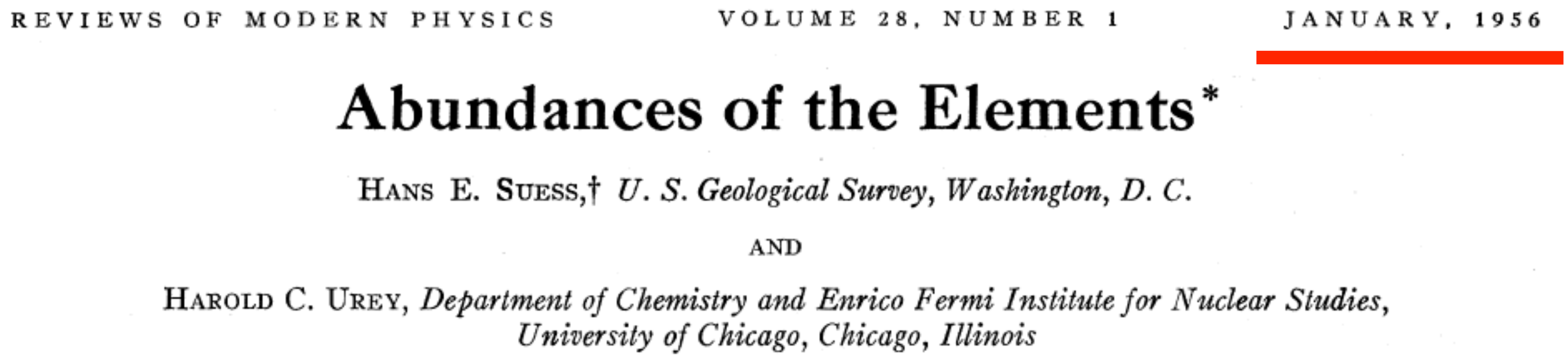
Cameron studied physics and mathematics at the University of Manitoba and earned his Ph.D. in nuclear physics at the University of Saskatchewan studying photonuclear reactions under Leon Katz. Upon graduation in 1952, he took a position at Iowa State College (now University), in Ames, Iowa, working at the Ames Laboratory of the U.S. Atomic Energy Commission. While browsing through an issue of *Science News Letter* (now *Science News*), he first saw a report that Mount Wilson Observatory astronomer Paul Merrill had observed the lines of the unstable element technetium in red giant stars. Cameron related: "That moment marked an instant turning point in my career. . . . I bought all the graduate-level astrophysics texts I could find, subscribed to *The Astrophysical Journal*, and started some intense reading."

By 1954, he was devoting all of his energies to exploring the astrophysical settings of nuclear physics, and he moved back to Canada to work for the Canadian Atomic Energy Project at Chalk River, Ontario. Here he first developed his numerical models for equilibrium burning and the s-process inside stars. He also formed a lifelong attachment to ever-faster computers, a passion that he kept to the end of his life.

The ~1952 discovery of Tc in red giants instantly revealed ongoing nucleosynthesis, as the longest Tc half-life is only a few million years.

1956 was an important year in the development of the understanding of the synthesis of elements, starting with the paper by Suess and Urey in January.

This paper provided a reliable, robust "target" at which to shoot!!!!!!



REVIEWS OF MODERN PHYSICS VOLUME 28, NUMBER 1 JANUARY, 1956

Abundances of the Elements*

HANS E. SUESS,† *U. S. Geological Survey, Washington, D. C.*

AND

HAROLD C. UREY, *Department of Chemistry and Enrico Fermi Institute for Nuclear Studies,*
University of Chicago, Chicago, Illinois

REVIEWS OF MODERN PHYSICS VOLUME 28, NUMBER 1 JANUARY, 1956

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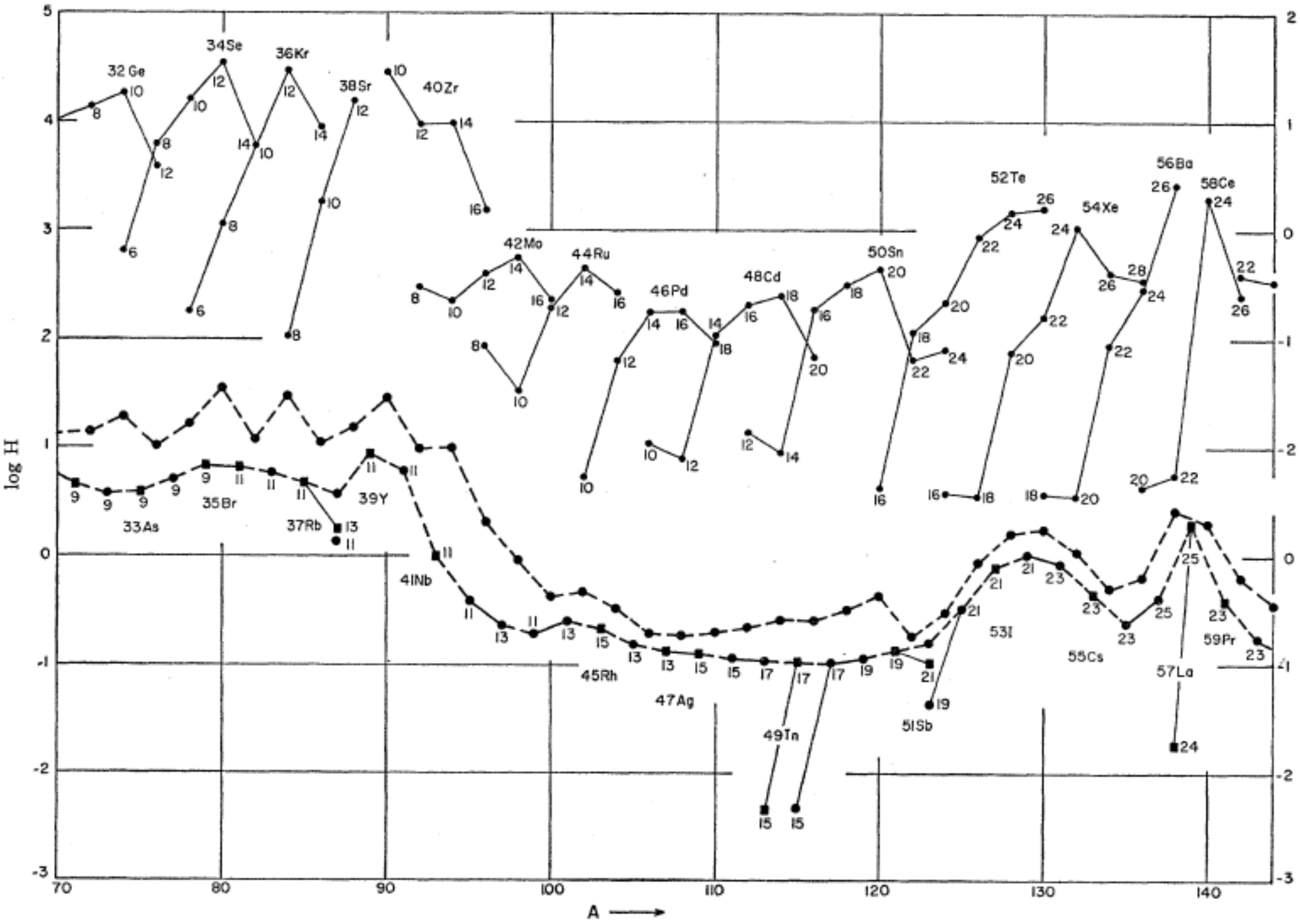


FIG. 1(b)

FIGS. 1(a)–1(c). Logarithm of abundance (silicon = 6) plotted against mass number (A). The even and odd mass numbers are on separate curves. The neutron excess numbers (I) are shown at each point. The curve without I indicated, shows the sum of the isobaric abundances for the even A series. Note that the right-hand scale is for the curve representing the even A series (light lines) beginning with $A = 64$ (Zn). [Part (c) on opposite page.]

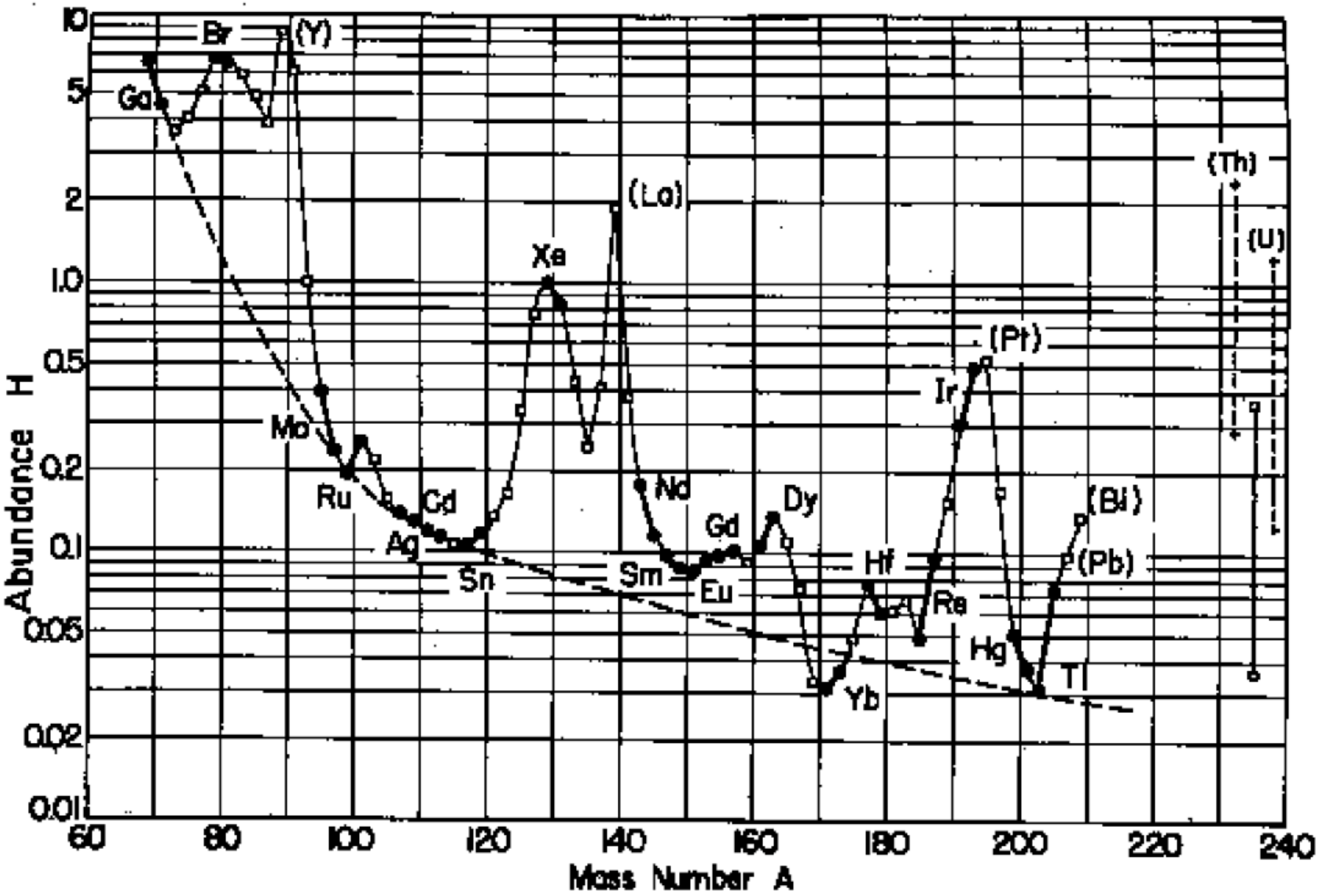


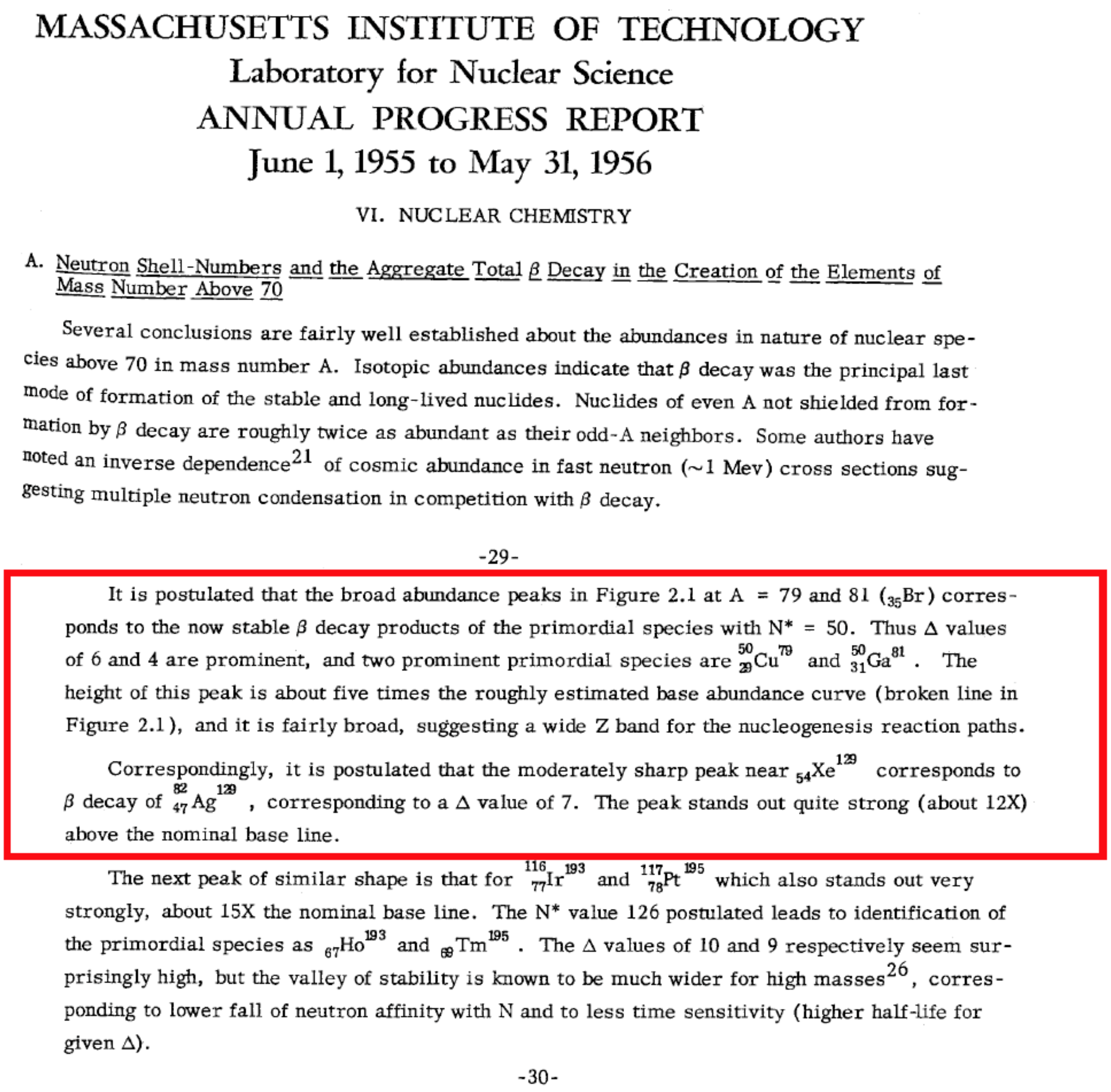
Figure 2.1
Cosmic abundances of the element, A.

Charles Coryell, MIT-LNS 1956 Progress Report AECU-3379

This is a photograph of Charles Coryell taken in about 1954. Charles' group discovered element 61 during the war, and he named it Promethium, Pm, for the god of fire.

At Cal Tech, he remains famous for a paper… "Pauling and Coryell" that opened Pauling's life-long study of hemoglobin and blood chemistry.

Surely, seeing those twin peaks near N = 82, coupled with his experience with beta decay and chemistry, it was a direct step to connect yields and neutron binding.



MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Laboratory for Nuclear Science
ANNUAL PROGRESS REPORT
June 1, 1955 to May 31, 1956

VI. NUCLEAR CHEMISTRY

A. Neutron Shell-Numbers and the Aggregate Total β Decay in the Creation of the Elements of Mass Number Above 70

Several conclusions are fairly well established about the abundances in nature of nuclear species above 70 in mass number A. Isotopic abundances indicate that β decay was the principal last mode of formation of the stable and long-lived nuclides. Nuclides of even A not shielded from formation by β decay are roughly twice as abundant as their odd-A neighbors. Some authors have noted an inverse dependence[21] of cosmic abundance in fast neutron (~1 Mev) cross sections suggesting multiple neutron condensation in competition with β decay.

-29-

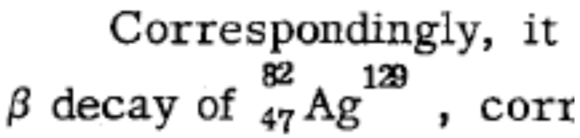
It is postulated that the broad abundance peaks in Figure 2.1 at A = 79 and 81 ($_{35}$Br) corresponds to the now stable β decay products of the primordial species with N* = 50. Thus Δ values of 6 and 4 are prominent, and two prominent primordial species are $^{50}_{29}\mathrm{Cu}^{79}$ and $^{50}_{31}\mathrm{Ga}^{81}$. The height of this peak is about five times the roughly estimated base abundance curve (broken line in Figure 2.1), and it is fairly broad, suggesting a wide Z band for the nucleogenesis reaction paths.

Correspondingly, it is postulated that the moderately sharp peak near $_{54}\mathrm{Xe}^{129}$ corresponds to β decay of $^{82}_{47}\mathrm{Ag}^{129}$, corresponding to a Δ value of 7. The peak stands out quite strong (about 12X) above the nominal base line.

The next peak of similar shape is that for $^{116}_{77}\mathrm{Ir}^{193}$ and $^{117}_{78}\mathrm{Pt}^{195}$ which also stands out very strongly, about 15X the nominal base line. The N* value 126 postulated leads to identification of the primordial species as $_{67}\mathrm{Ho}^{193}$ and $_{69}\mathrm{Tm}^{195}$. The Δ values of 10 and 9 respectively seem surprisingly high, but the valley of stability is known to be much wider for high masses[26], corresponding to lower fall of neutron affinity with N and to less time sensitivity (higher half-life for given Δ).

-30-

This report came almost immediately after the Seuss and Urey paper.



Correspondingly, it
β decay of $^{82}_{47}\mathrm{Ag}^{129}$, corr

^{129}Ag was deemed important on DAY ONE.

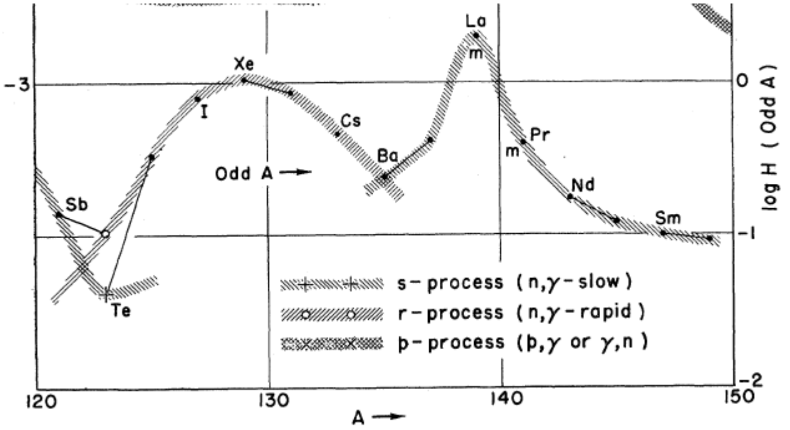
Coryell spent the war years studying fission and the properties of neutron-rich nuclei.

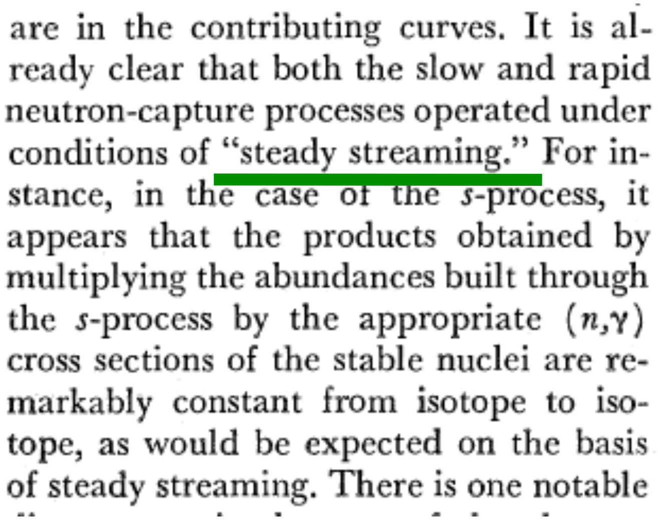
In other words, there were two waiting points, one for capture of neutrons on a slow time scale on elements near stability, and one for nuclei much farther from stability that must be on a faster time scale

The major BBFH paper appeared in 1957, but was preceded in 1956 by an article in Science.

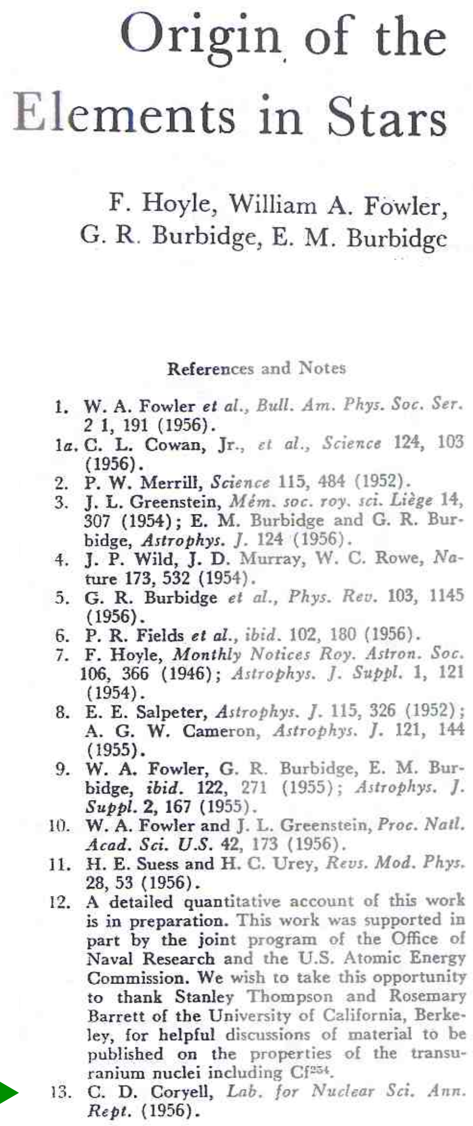
5 October 1956, Volume 124, Number 3223

SCIENCE





are in the contributing curves. It is already clear that both the slow and rapid neutron-capture processes operated under conditions of "steady streaming." For instance, in the case of the *s*-process, it appears that the products obtained by multiplying the abundances built through the *s*-process by the appropriate (n,γ) cross sections of the stable nuclei are remarkably constant from isotope to isotope, as would be expected on the basis of steady streaming. There is one notable



Origin of the Elements in Stars

F. Hoyle, William A. Fowler,
G. R. Burbidge, E. M. Burbidge

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11. H. E. Suess and H. C. Urey, *Revs. Mod. Phys.* 28, 53 (1956).
12. A detailed quantitative account of this work is in preparation. This work was supported in part by the joint program of the Office of Naval Research and the U.S. Atomic Energy Commission. We wish to take this opportunity to thank Stanley Thompson and Rosemary Barrett of the University of California, Berkeley, for helpful discussions of material to be published on the properties of the transuranium nuclei including Cf^{254}.
13. C. D. Coryell, *Lab. for Nuclear Sci. Ann. Rept.* (1956).

Stated another way, BBFH were aware of the Coryell work prior to this article and their seminal article in 1957.

Z. Phys. A – Atomic Nuclei 325, 489–490 (1986)

The Beta-Decay Half-Life of ${}^{130}_{48}\mathrm{Cd}_{82}$ and its Importance for Astrophysical *r*-Process Scenarios

K.-L. Kratz[1], H. Gabelmann[2], W. Hillebrandt[3], B. Pfeiffer[1], K. Schlösser[2],
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[2] CERN-ISOLDE, CH-1211 Geneva, Switzerland
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[4] Department of Astronomy, Harvard University, Cambridge, MA 02138, USA

Received October 10, 1986

It was THIRTY years after Coryell, and BBFH before the first successful measurement for the ^{130}Cd half life emerged here at ISOLDE.

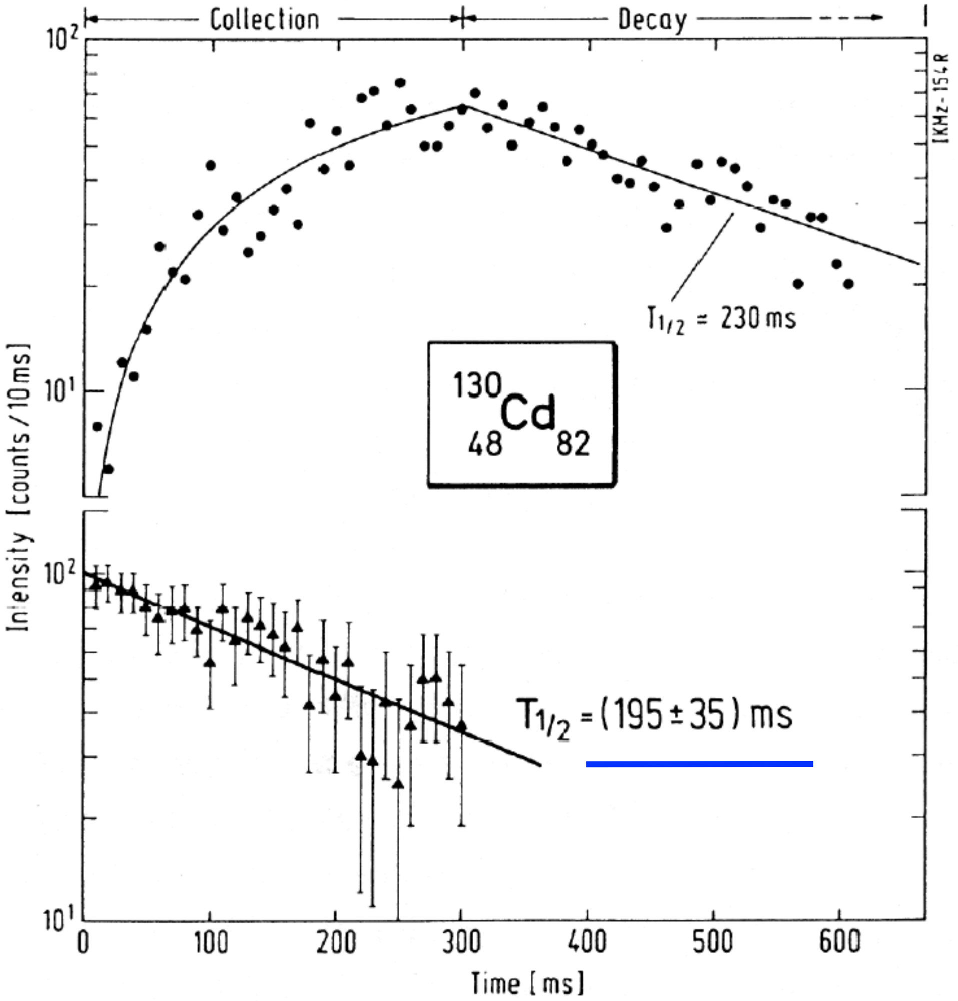
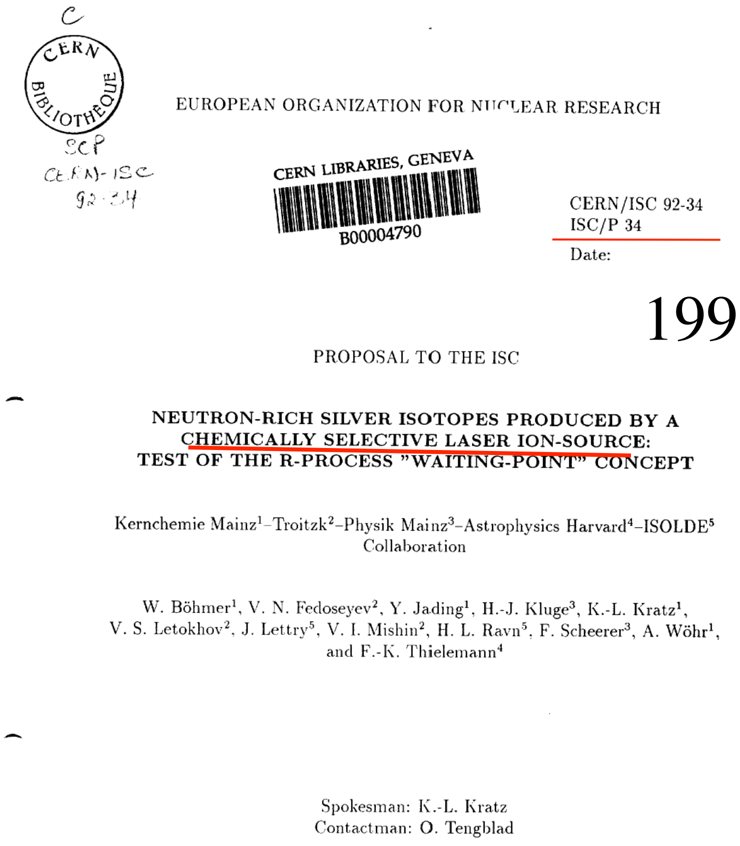


Fig. 8: Growth and decay curve of β-delayed neutron activity of ^{130}Cd. Data from about 36,000 multiscaling cycles were accumulated at 10 ms intervals.

order to enhance ^{130}Cd and minimize the 1.9 s βdn-background from ${}^{40}\mathrm{Ca}^{90}\mathrm{Br}^+$ at A = 130. Data

^{130}Ag	0.0		≈50 ms	$\%\beta^-=?$
^{130}Cd	0.0	0+	0.20 s *4*	$\%\beta^-=100$; $\%\beta^-n\approx4$
^{130}In	0.0	1(–)	0.29 s *2*	$\%\beta^-=100$; $\%\beta^-n=0.93$ *13*
	50	(10–)	0.54 s *1*	$\%\beta^-=100$; $\%\beta^-n=1.65$ *15*
	400	(5+)	0.54 s *1*	$\%\beta^-=100$; $\%\beta^-n=1.65$ *15*
^{130}Sn	0.0	0+	3.72 min *7*	$\%\beta^-=100$
	1946.88	(7–)	1.7 min *1*	$\%\beta^-=100$



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/ISC 92-34
ISC/P 34
Date:

1992

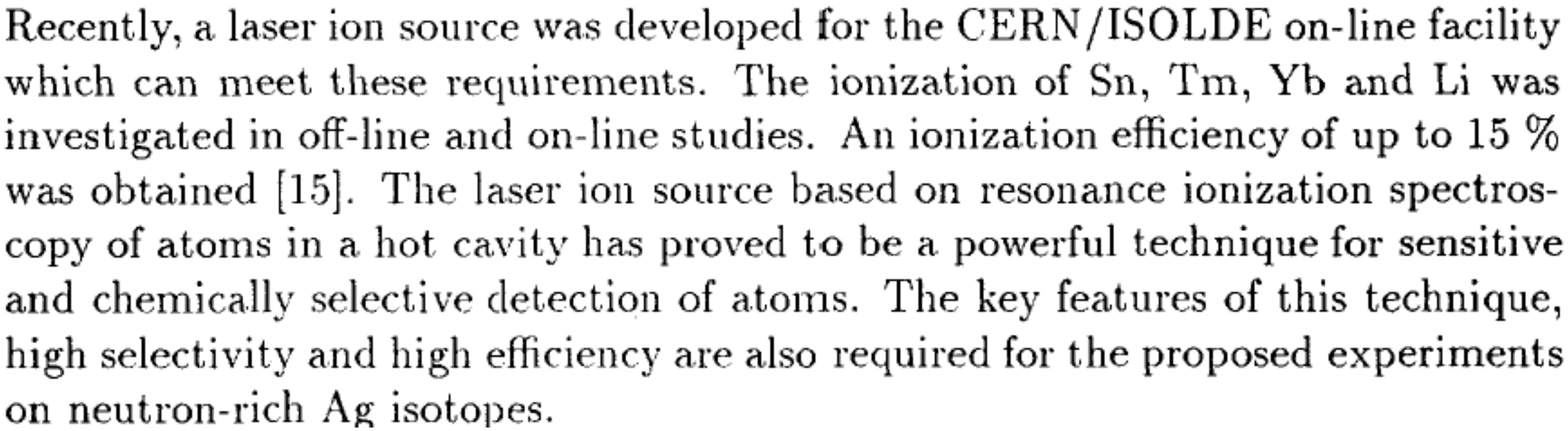
PROPOSAL TO THE ISC

NEUTRON-RICH SILVER ISOTOPES PRODUCED BY A CHEMICALLY SELECTIVE LASER ION-SOURCE: TEST OF THE R-PROCESS "WAITING-POINT" CONCEPT

Kernchemie Mainz[1]–Troitzk[2]–Physik Mainz[3]–Astrophysics Harvard[4]–ISOLDE[5]
Collaboration

W. Böhmer[1], V. N. Fedoseyev[2], Y. Jading[1], H.-J. Kluge[3], K.-L. Kratz[1],
V. S. Letokhov[2], J. Lettry[5], V. I. Mishin[2], H. L. Ravn[5], F. Scheerer[3], A. Wöhr[1],
and F.-K. Thielemann[4]

Spokesman: K.-L. Kratz
Contactman: O. Tengblad



Recently, a laser ion source was developed for the CERN/ISOLDE on-line facility which can meet these requirements. The ionization of Sn, Tm, Yb and Li was investigated in off-line and on-line studies. An ionization efficiency of up to 15 % was obtained [15]. The laser ion source based on resonance ionization spectroscopy of atoms in a hot cavity has proved to be a powerful technique for sensitive and chemically selective detection of atoms. The key features of this technique, high selectivity and high efficiency are also required for the proposed experiments on neutron-rich Ag isotopes.

5. Mishin, V. I. *et al.*, Nucl. Instr. Meth. **B73**, 550 (1993).

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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Physica Scripta. Vol. T56, 262–265, 1995

Beta Decay of the New Isotope ^{101}Sn

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Received October 15, 1994; accepted October 31, 1994

Abstract

The very neutron-deficient isotope ^{101}Sn was produced in a ^{50}Cr(^{58}Ni, 2p5n) reaction and its decay properties were determined for the first time. By using chemically selective ion sources of an on-line mass separator, the energy spectrum and the half-life (3 ± 1 s) of beta-delayed protons of ^{101}Sn were measured. These results are compared to theoretical predictions.

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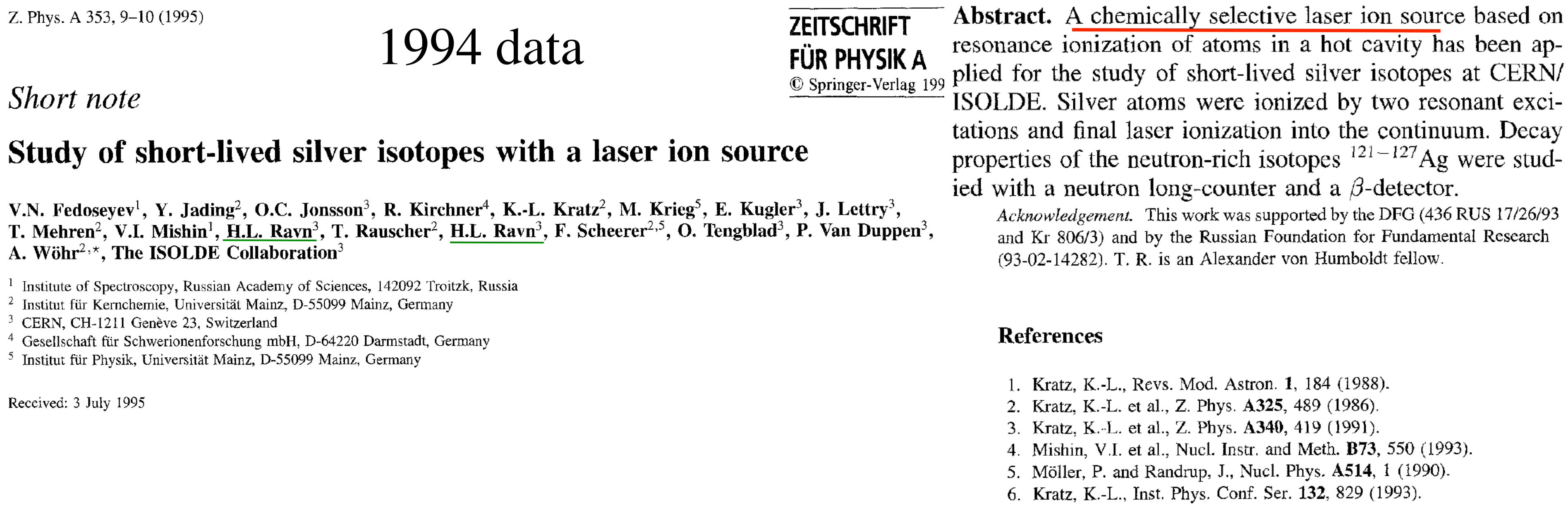
5. Mishin, V. I. *et al.*, Nucl. Instr. Meth. **B73**, 550 (1993).

1994 data



Z. Phys. A 353, 9–10 (1995)

ZEITSCHRIFT FÜR PHYSIK A

Short note

Study of short-lived silver isotopes with a laser ion source

V.N. Fedoseyev[1], Y. Jading[2], O.C. Jonsson[3], R. Kirchner[4], K.-L. Kratz[2], M. Krieg[5], E. Kugler[3], J. Lettry[3], T. Mehren[2], V.I. Mishin[1], H.L. Ravn[3], T. Rauscher[2], H.L. Ravn[3], F. Scheerer[2,5], O. Tengblad[3], P. Van Duppen[3], A. Wöhr[2,]*, The ISOLDE Collaboration[3]

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Received: 3 July 1995

Abstract. A chemically selective laser ion source based on resonance ionization of atoms in a hot cavity has been applied for the study of short-lived silver isotopes at CERN/ISOLDE. Silver atoms were ionized by two resonant excitations and final laser ionization into the continuum. Decay properties of the neutron-rich isotopes $^{121-127}$Ag were studied with a neutron long-counter and a β-detector.

Acknowledgement. This work was supported by the DFG (436 RUS 17/26/93 and Kr 806/3) and by the Russian Foundation for Fundamental Research (93-02-14282). T. R. is an Alexander von Humboldt fellow.

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3. Kratz, K.-L. et al., Z. Phys. **A340**, 419 (1991).
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5. Möller, P. and Randrup, J., Nucl. Phys. **A514**, 1 (1990).
6. Kratz, K.-L., Inst. Phys. Conf. Ser. **132**, 829 (1993).

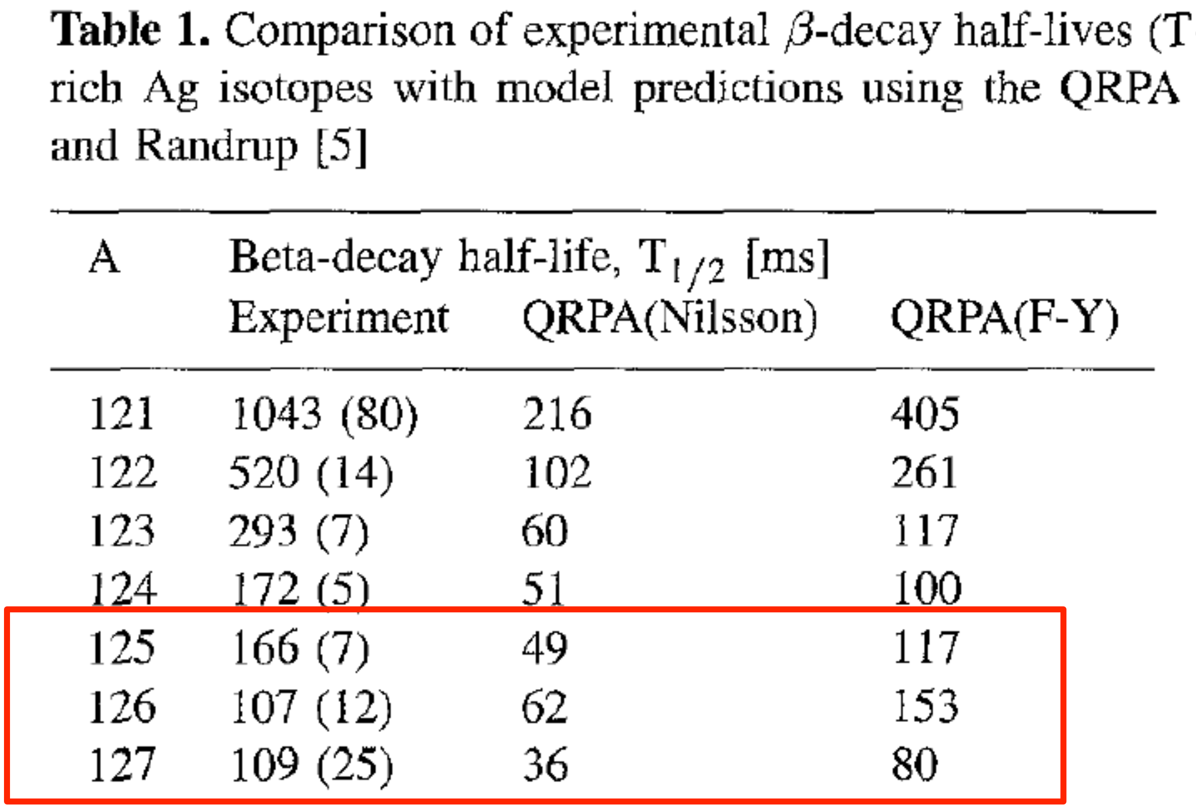


Table 1. Comparison of experimental β-decay half-lives ($T_{1/2}$) of neutron-rich Ag isotopes with model predictions using the QRPA code of Möller and Randrup [5]

A	Beta-decay half-life, $T_{1/2}$ [ms]		
	Experiment	QRPA(Nilsson)	QRPA(F-Y)
121	1043 (80)	216	405
122	520 (14)	102	261
123	293 (7)	60	117
124	172 (5)	51	100
125	166 (7)	49	117
126	107 (12)	62	153
127	109 (25)	36	80

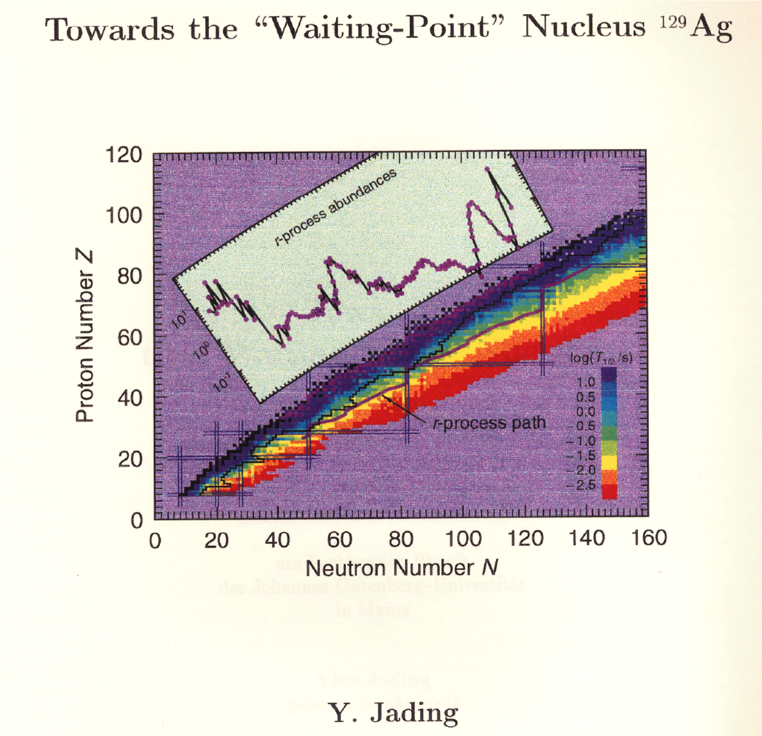
^{127}Ag was difficult, I have another report showing a half-life of 133 ms. Below A = 127, there are no β delayed neutron emitters in the indium isotopes.

CERN/ISC 96-4
ISC/P34 Add.1
Date: January 19, 1996

Status Report on Experiment IS333 part II and Request for Beam Time

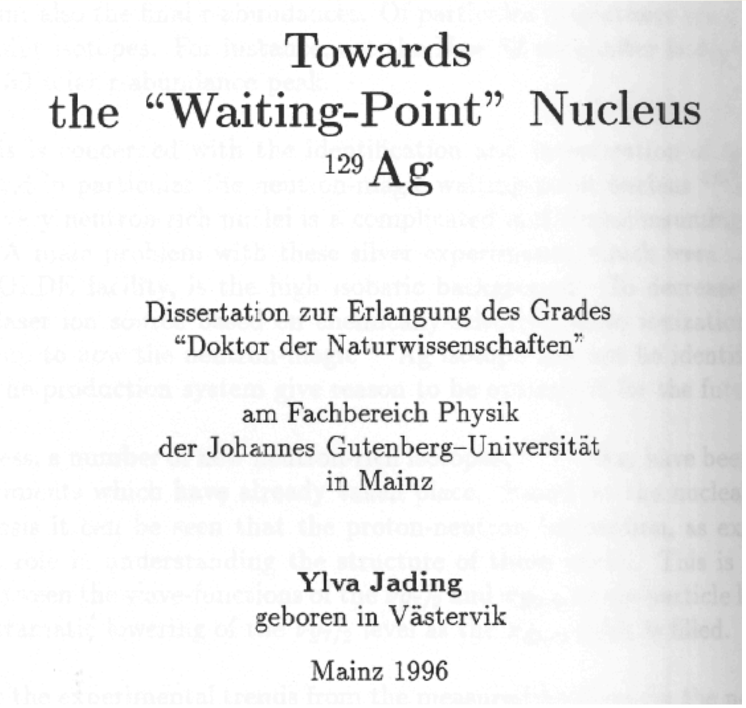
NEUTRON-RICH SILVER ISOTOPES PRODUCED BY A CHEMICALLY SELECTIVE LASER ION-SOURCE:

Kernchemie Mainz – Russian Academy of Sciences Troitzk – Nuclear Chemistry
Maryland – KU Leuven – ISOLDE Collaboration



Towards the “Waiting-Point” Nucleus ^{129}Ag

Y. Jading



Towards
the “Waiting-Point” Nucleus
^{129}Ag

Dissertation zur Erlangung des Grades
“Doktor der Naturwissenschaften”

am Fachbereich Physik
der Johannes Gutenberg–Universität
in Mainz

Ylva Jading
geboren in Västervik

Mainz 1996

1996

A = 127

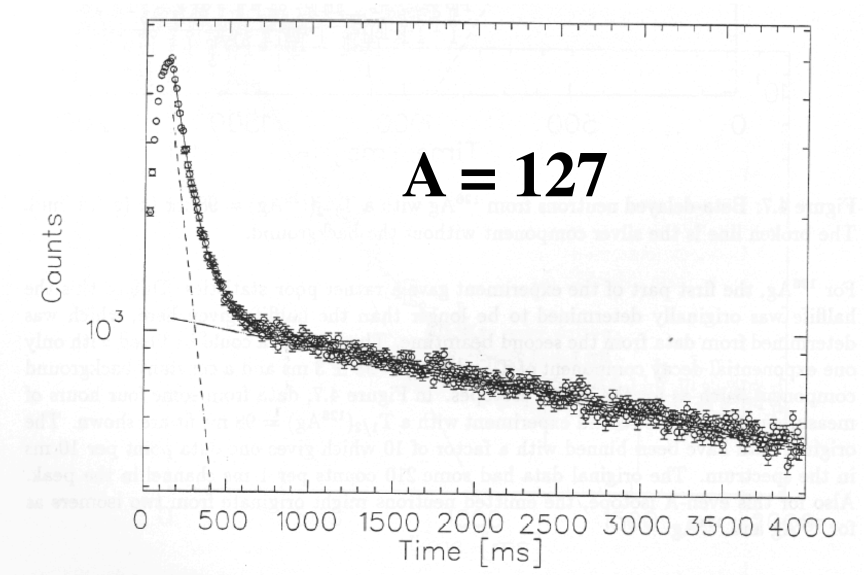


Figure 4.8: Beta-delayed neutrons from ^{127}Ag and ^{127}In (solid line). The short broken line represent the Ag component and the long broken line the In component.

A = 128

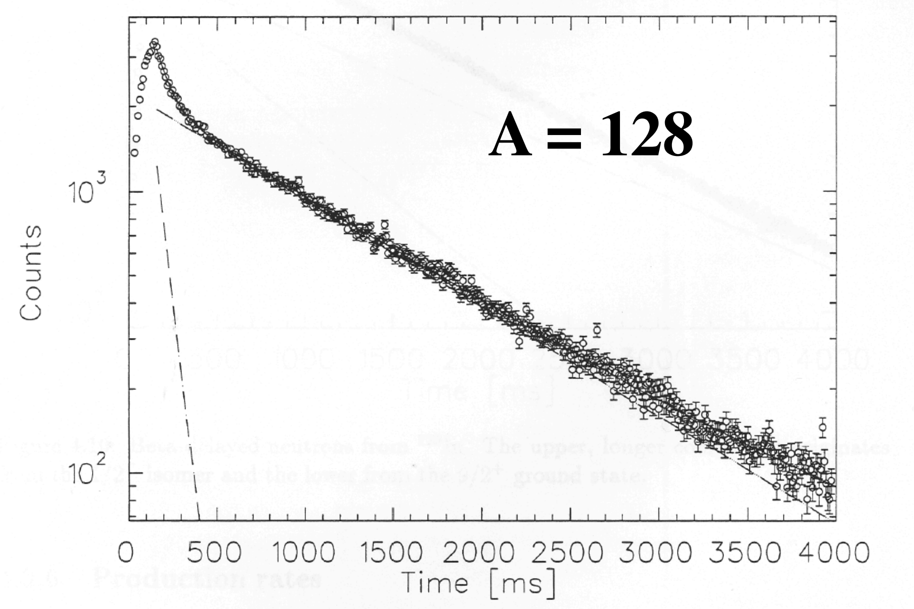
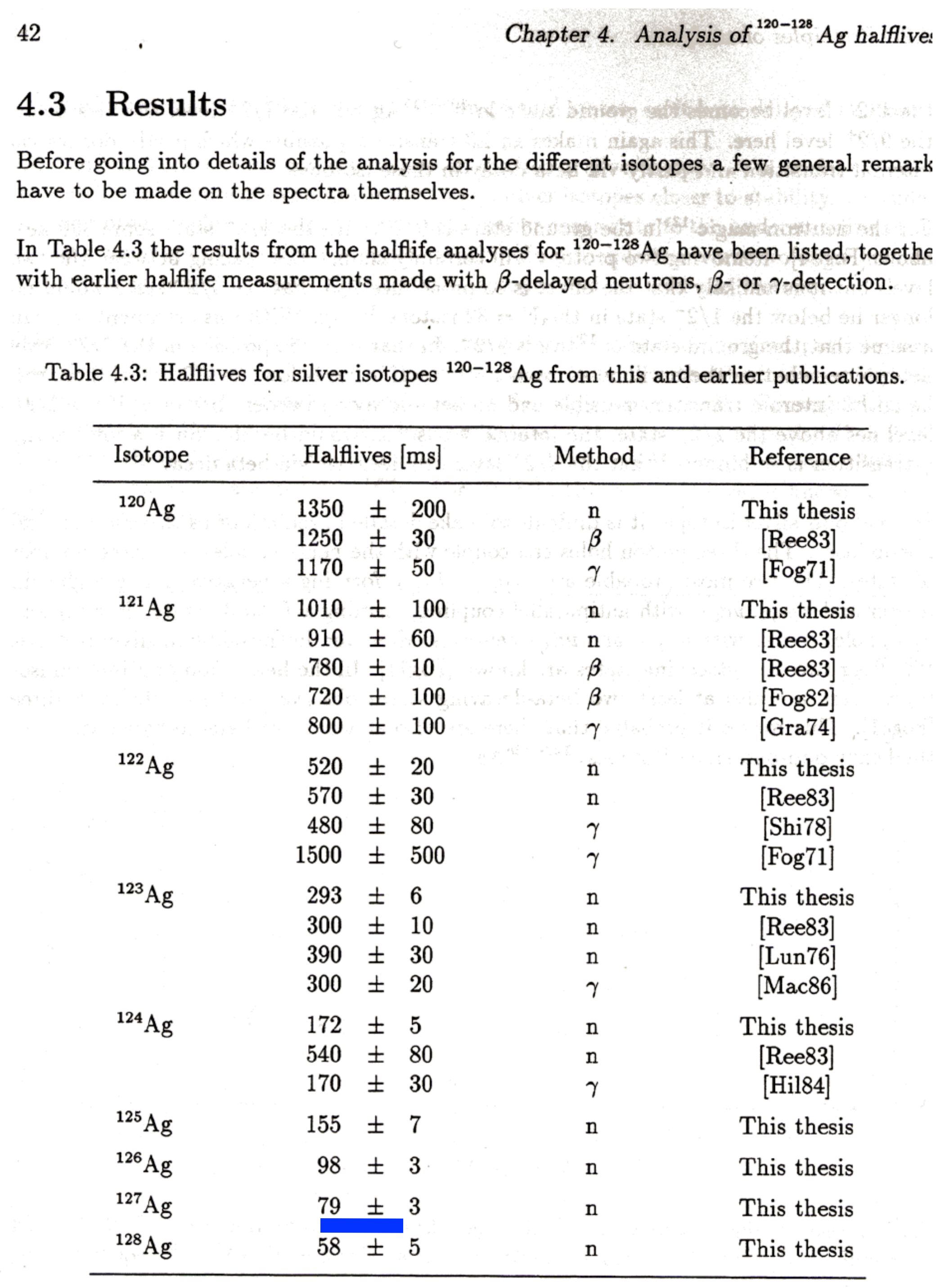


Figure 4.9: Beta-delayed neutrons from ^{128}Ag and ^{128}In. The short broken line is the silver component and the long broken line is the average indium component.



4.3 Results

Before going into details of the analysis for the different isotopes a few general remark have to be made on the spectra themselves.

In Table 4.3 the results from the halflife analyses for $^{120-128}$Ag have been listed, togethe with earlier halflife measurements made with β-delayed neutrons, β- or γ-detection.

Table 4.3: Halflives for silver isotopes $^{120-128}$Ag from this and earlier publications.

Isotope	Halflives [ms]	Method	Reference
^{120}Ag	1350 ± 200	n	This thesis
	1250 ± 30	β	[Ree83]
	1170 ± 50	γ	[Fog71]
^{121}Ag	1010 ± 100	n	This thesis
	910 ± 60	n	[Ree83]
	780 ± 10	β	[Ree83]
	720 ± 100	β	[Fog82]
	800 ± 100	γ	[Gra74]
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	300 ± 20	γ	[Mac86]
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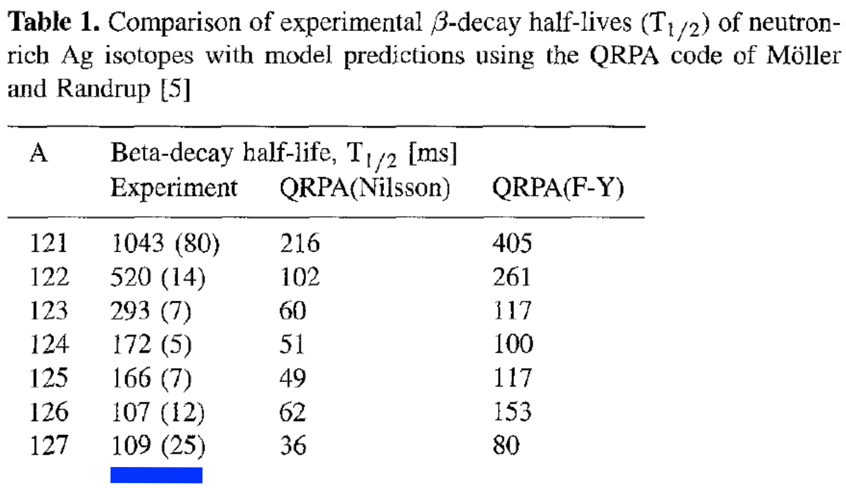
	170 ± 30	γ	[Hil84]
^{125}Ag	155 ± 7	n	This thesis
^{126}Ag	98 ± 3	n	This thesis
^{127}Ag	79 ± 3	n	This thesis
^{128}Ag	58 ± 5	n	This thesis



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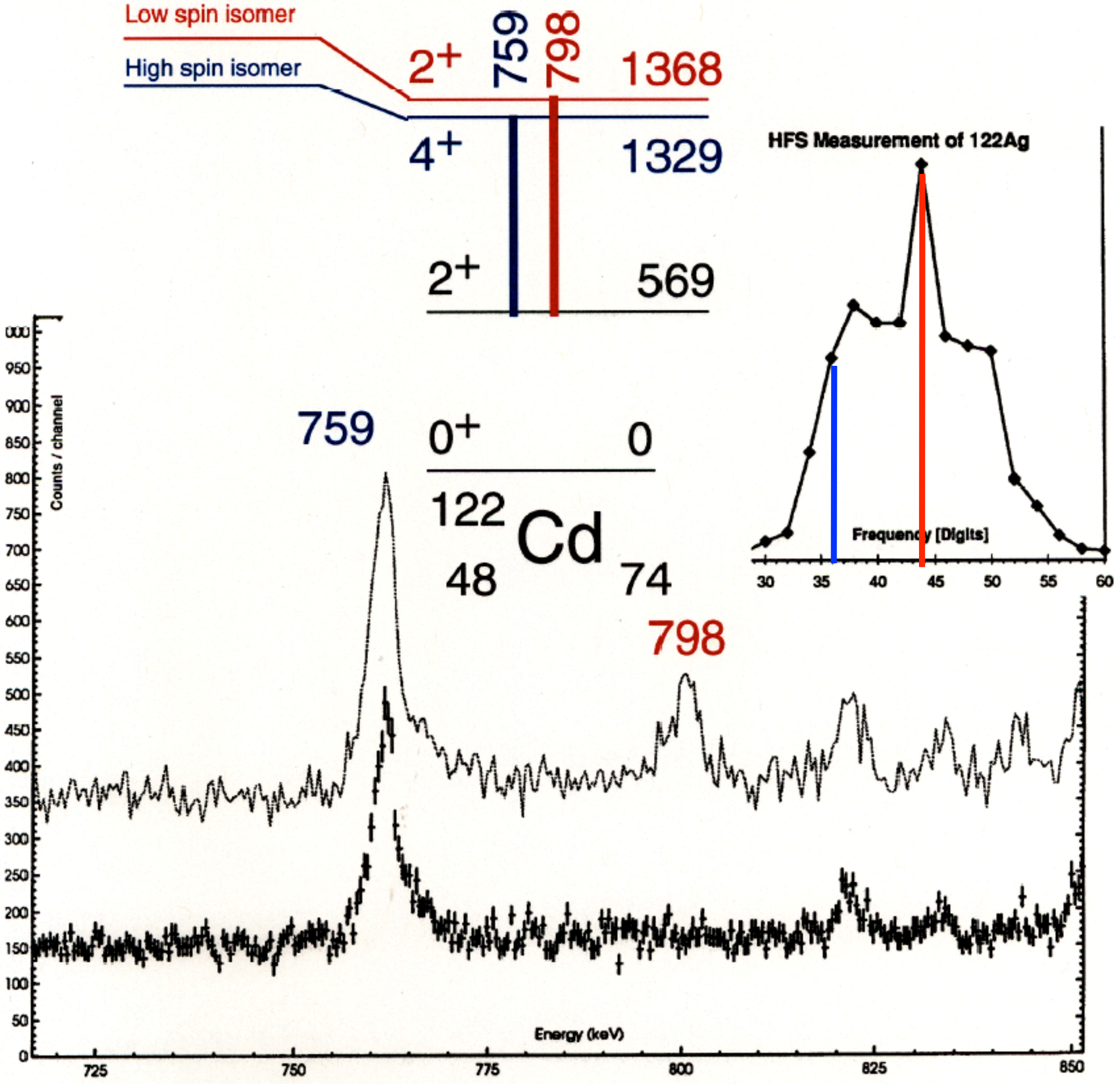
125	166 (7)	49	117
126	107 (12)	62	153
127	109 (25)	36	80

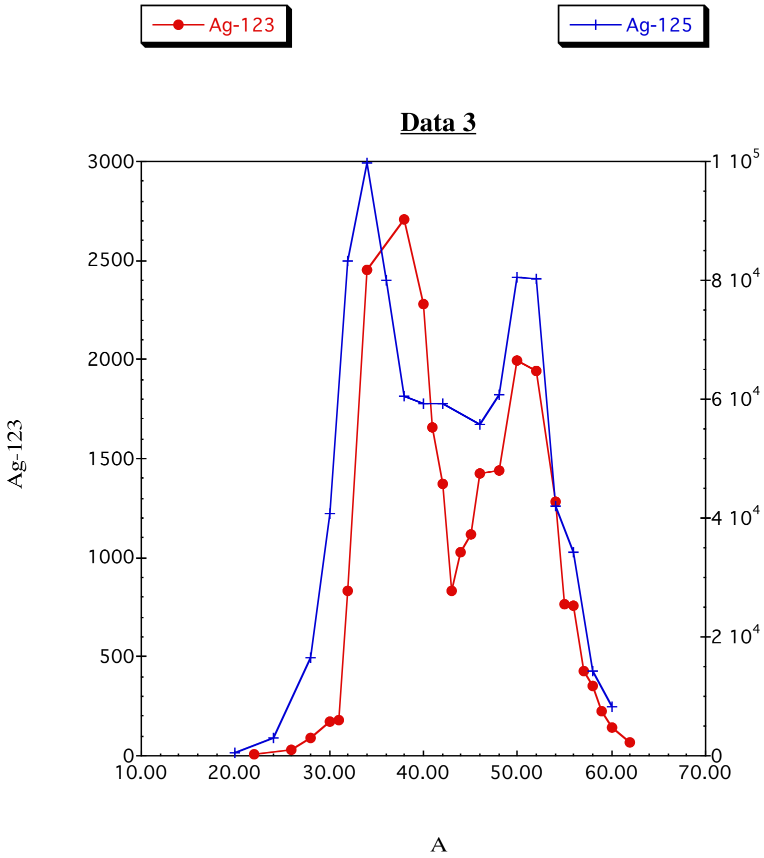
Part of the γ-ray spectrum of the decay of Ag-122 isomers.

The upper spectrum was taken with the laser frequency set at 44 and may be compared with the lower spectrum which was taken with the laser set at 36. The gamma ray at 798.4 keV is attributed to the decay of the 2_2^+ level to 2_1^+ level whereas the line at 759 keV is attributed to the decay of the 4_1^+ level to 2_1^+ level.



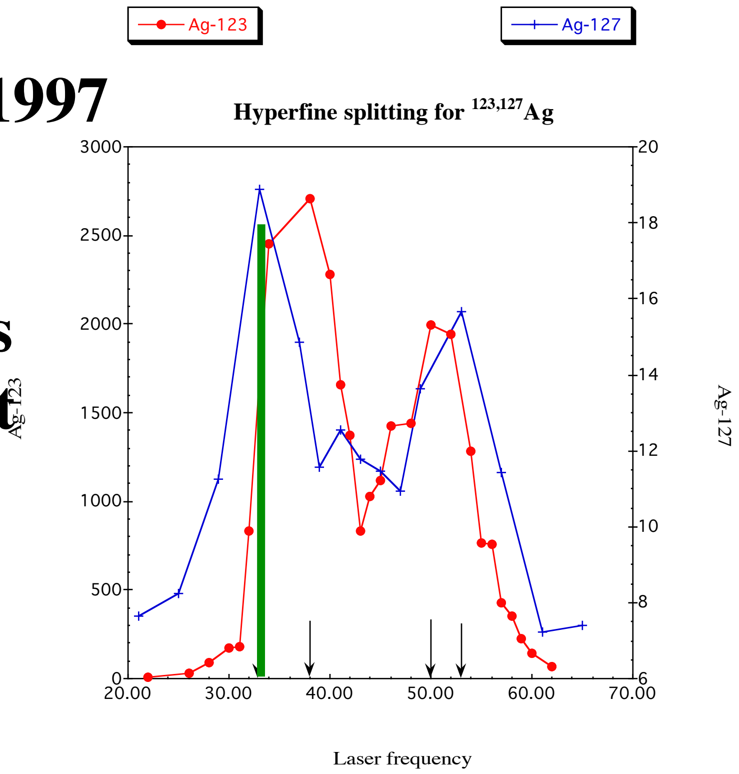
25 August 1997

These data are interpreted to mean that the low-spin isomer has a configuration involving a $p_{1/2}$ proton with a small magnetic moment, whereas, the high-spin isomer has a configuration involving a $g_{9/2}$ proton with a much larger magnetic moment.



4 November 1997

The search for ^{129}Ag was performed at the “green” setting.

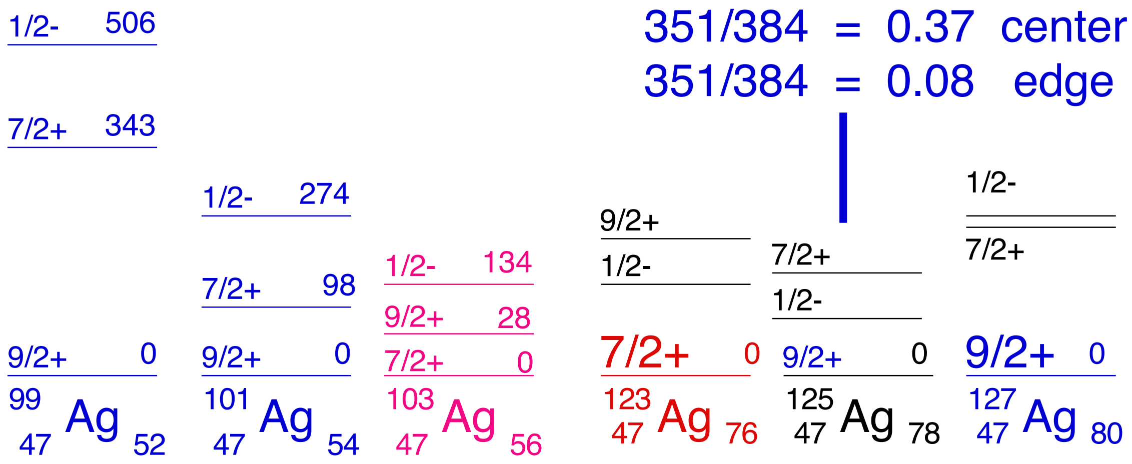


These β-delayed neutron data support the presence of β-decaying ½- isomers in ^{125,127}Ag, but not necessarily ^{123}Ag, but P_n could be a factor.

Well established data

Speculative

351/384 = 0.37 center
351/384 = 0.08 edge



1/2- 506
7/2+ 343
9/2+ 0
$^{99}_{47}\text{Ag}_{52}$

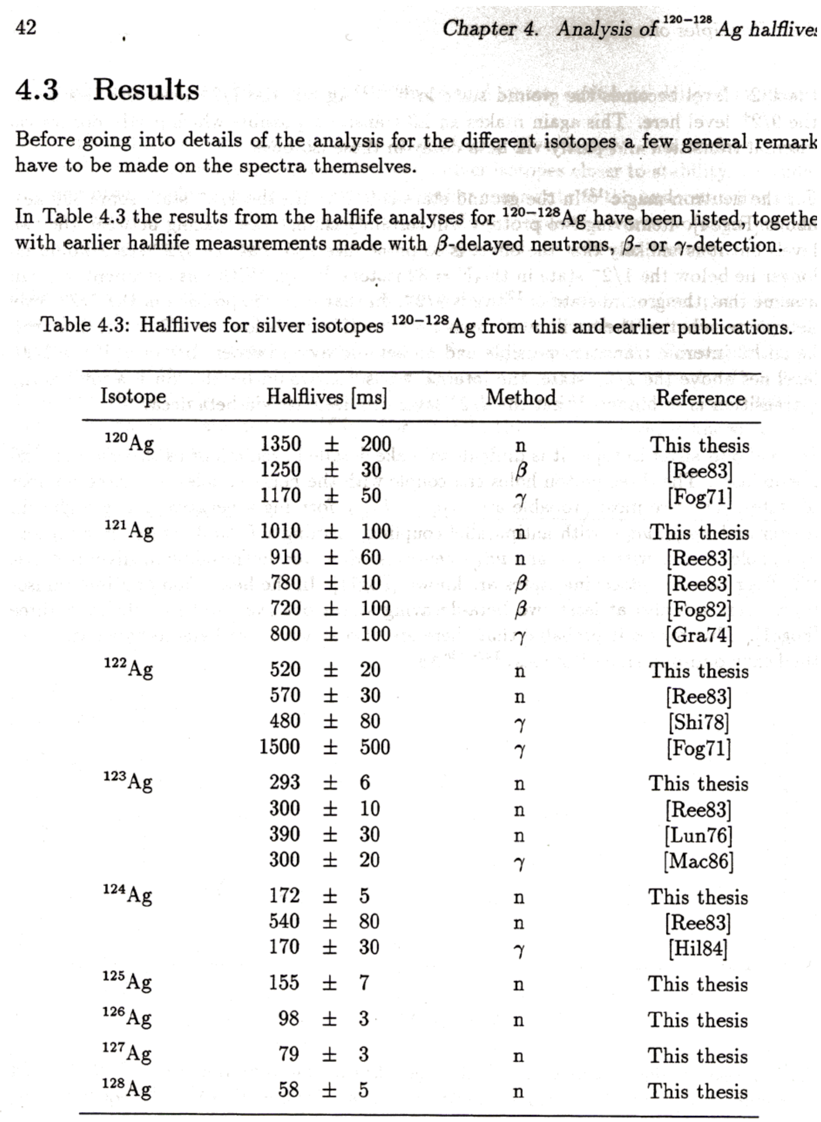
1/2- 274
7/2+ 98
9/2+ 0
$^{101}_{47}\text{Ag}_{54}$

1/2- 134
9/2+ 28
7/2+ 0
$^{103}_{47}\text{Ag}_{56}$

9/2+
1/2-
7/2+ 0
$^{123}_{47}\text{Ag}_{76}$

7/2+
1/2-
9/2+ 0
$^{125}_{47}\text{Ag}_{78}$

1/2-
7/2+
9/2+ 0
$^{127}_{47}\text{Ag}_{80}$



42 Chapter 4. Analysis of $^{120-128}$Ag halflive

4.3 Results

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^{125}Ag	155 ± 7	n	This thesis
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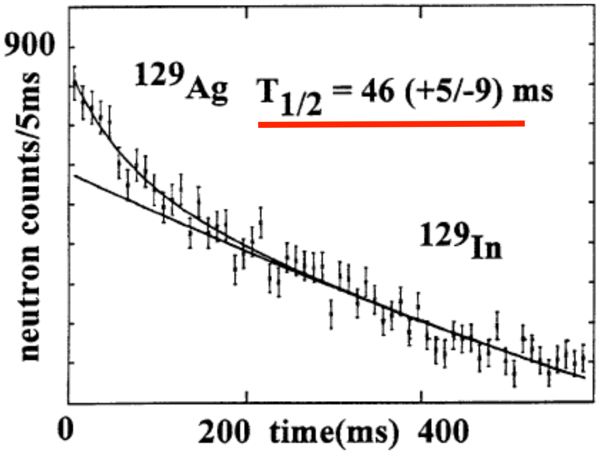
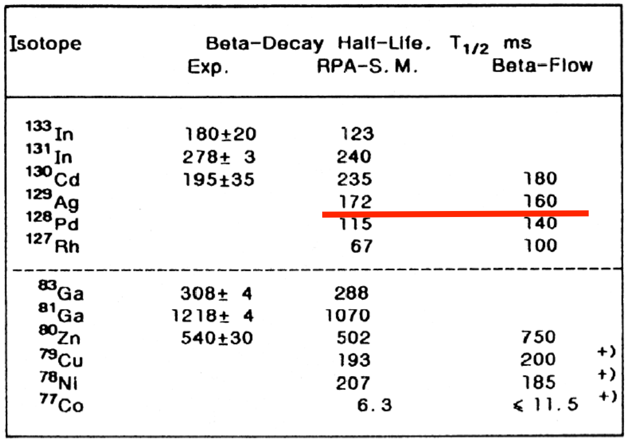
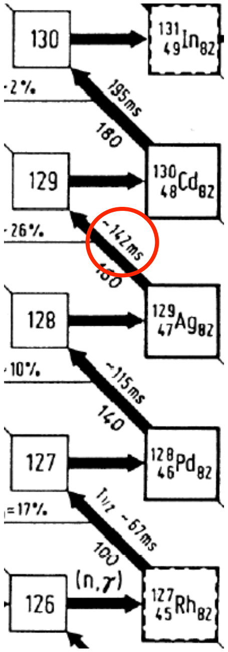
^{127}Ag	79 ± 3	n	This thesis
^{128}Ag	58 ± 5	n	This thesis



Reviews in Modern Astronomy, Vol.1 Cosmic Chemistry
Editor: G. Klare © Springer-Verlag Berlin Heidelberg 1988



Isotope	Beta-Decay Half-Life, $T_{1/2}$ ms Exp.	RPA-S.M.	Beta-Flow	
^{133}In	180±20	123		
^{131}In	278± 3	240		
^{130}Cd	195±35	235	180	
^{129}Ag		172	160	
^{128}Pd		115	140	
^{127}Rh		67	100	
^{83}Ga	308± 4	288		
^{81}Ga	1218± 4	1070		
^{80}Zn	540±30	502	750	
^{79}Cu		193	200	+)
^{78}Ni		207	185	+)
^{77}Co		6.3	≤ 11.5	+)



The astrophysical impact was large as the short half life "removed" ^{129}Ag as a major waiting-point nucleus, and also strongly suggested that the lower N = 82 isotones would also have shorter half-lives and also not be major waiting points. Although it was a "theoretical surprise", any look at the half-lives for the lighter Ag nuclei could see…… 100 80 60….40.

VOLUME 91, NUMBER 16 PHYSICAL REVIEW LETTERS week ending 17 OCTOBER 2003

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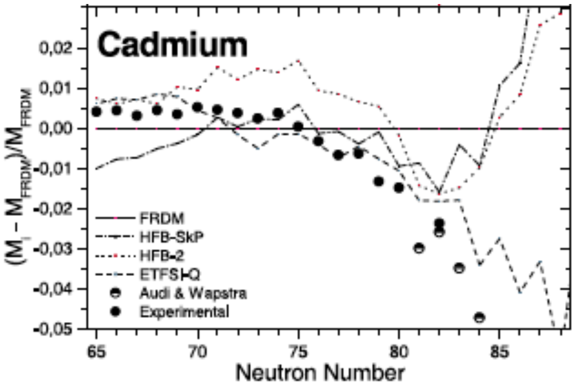
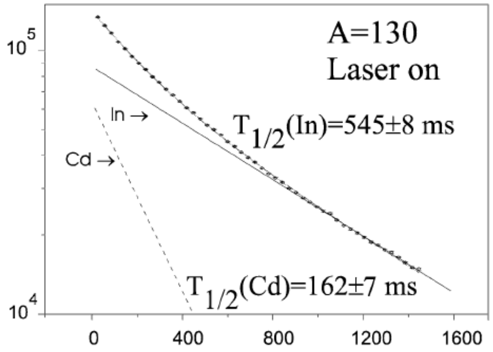
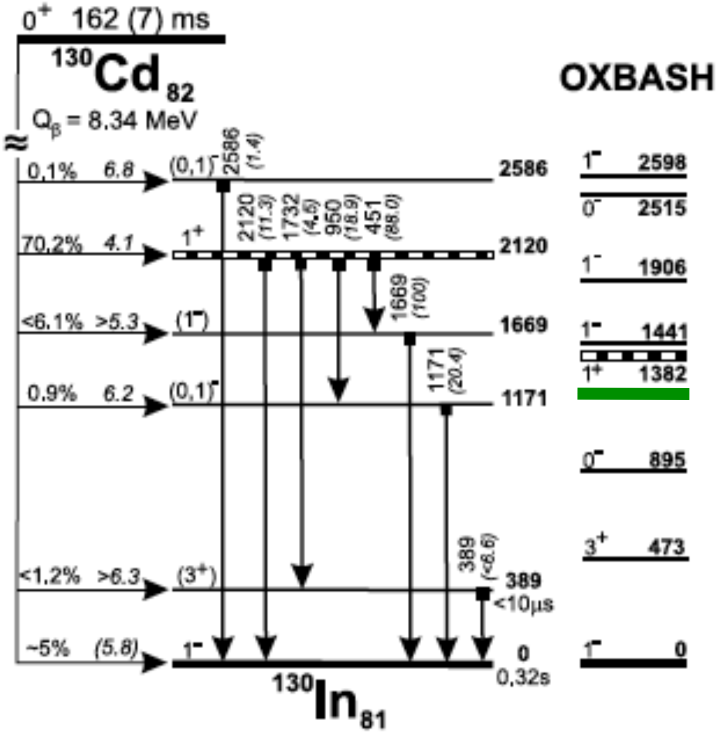


FIG. 3 (color online). Comparison of normalized mass deviations of $_{50}$Sn and $_{48}$Cd isotopes from model predictions with "shell quenching" [25,26,28], experimental values, and very recent short-range extrapolations for $^{135-137}$Sn and $^{129-132}$Cd [15,21] relative to the "unquenched" FRDM [22]. The deviation to our experimental value of ^{130}Cd corresponds to a mass difference of 1.57 MeV.

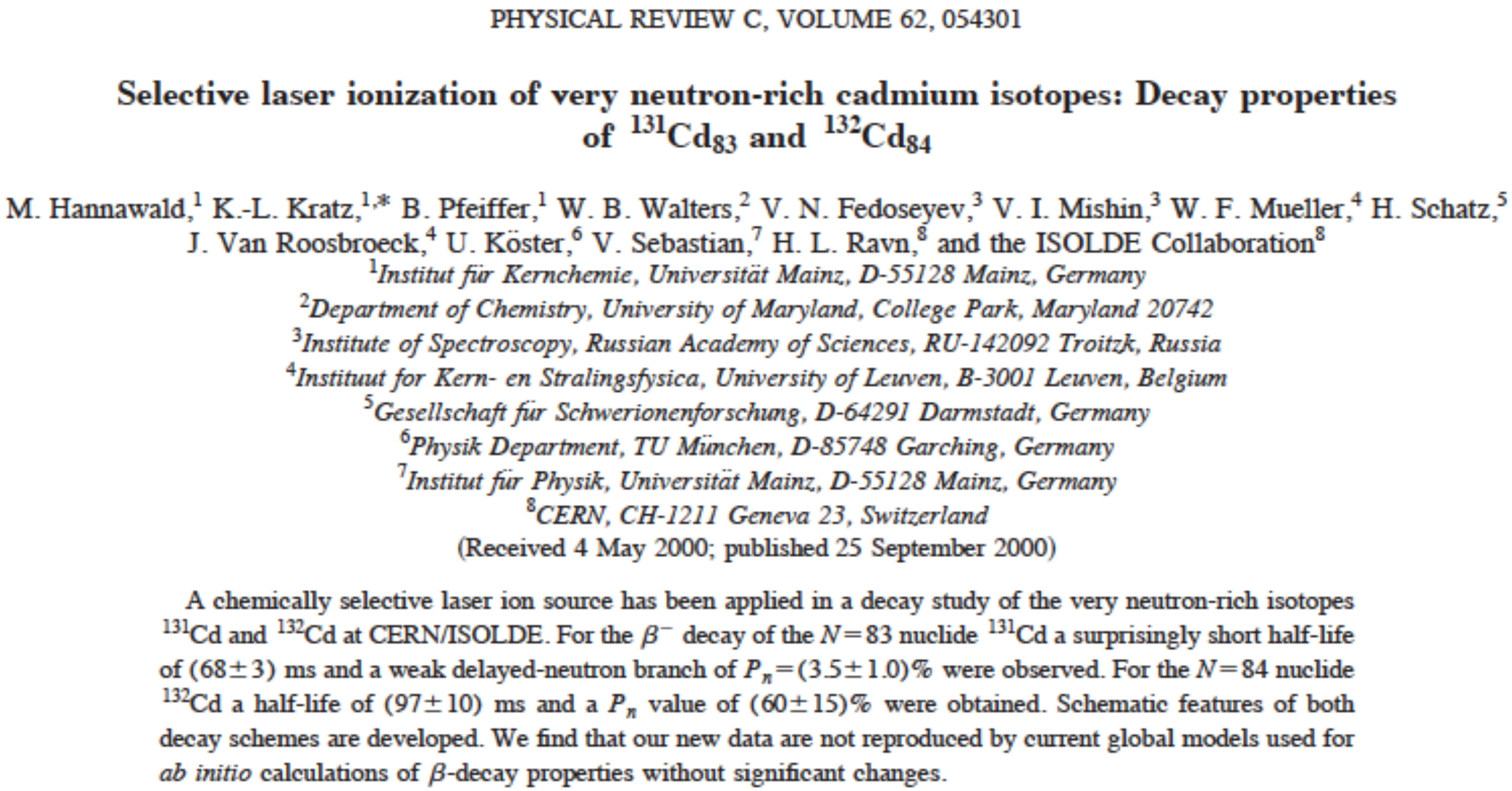




This drawing exhibits the difference between the measured mass of ^{130}Cd and the value calculated by the FRDM, showing that ^{130}Cd is 1.6 MeV less bound than expected.

Also shown is the measured position of the 1^+ level in ^{130}In that is 740 keV higher in energy than the value calculated prior to the measurement. The measured value can be fitted by a 30% reduction in the proton-neutron interaction strength.

Hence, there is now evidence that some reduction in both "neutron-neutron" and "proton-neutron" interactions may be needed.



PHYSICAL REVIEW C, VOLUME 62, 054301

Selective laser ionization of very neutron-rich cadmium isotopes: Decay properties of $^{131}Cd_{83}$ and $^{132}Cd_{84}$

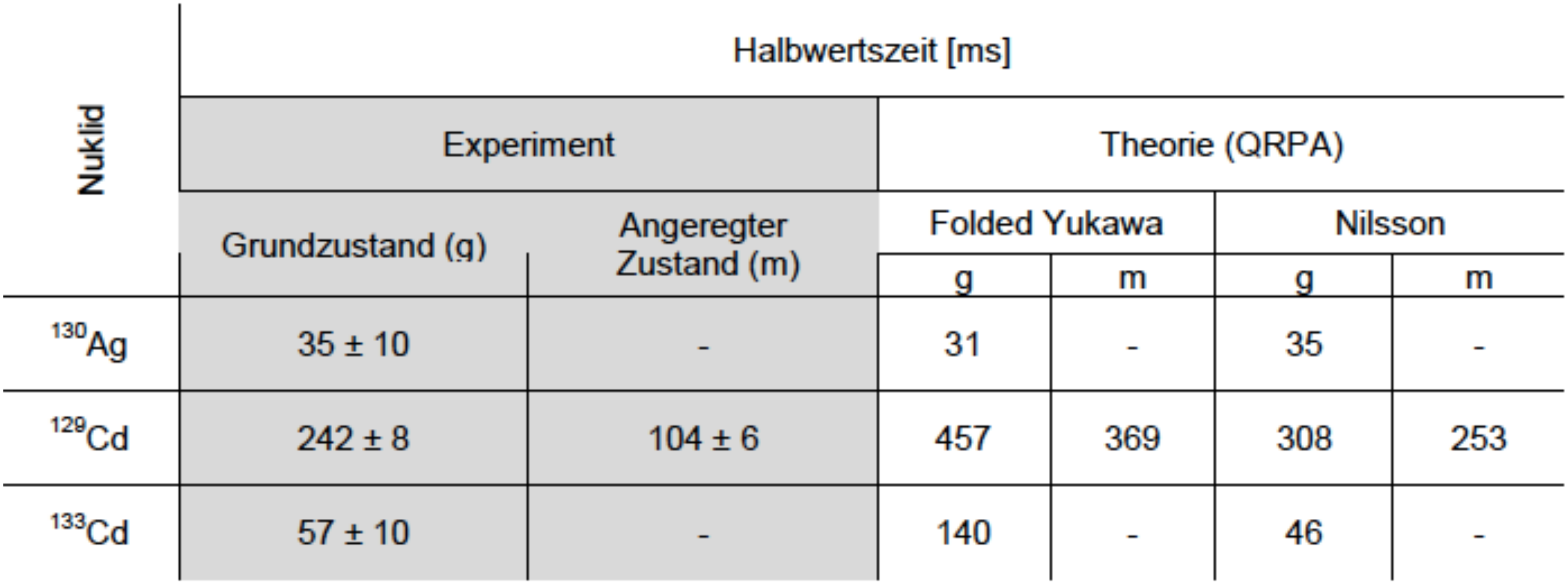
M. Hannawald,[1] K.-L. Kratz,[1,*] B. Pfeiffer,[1] W. B. Walters,[2] V. N. Fedoseyev,[3] V. I. Mishin,[3] W. F. Mueller,[4] H. Schatz,[5] J. Van Roosbroeck,[4] U. Köster,[6] V. Sebastian,[7] H. L. Ravn,[8] and the ISOLDE Collaboration[8]
[1]*Institut für Kernchemie, Universität Mainz, D-55128 Mainz, Germany*
[2]*Department of Chemistry, University of Maryland, College Park, Maryland 20742*
[3]*Institute of Spectroscopy, Russian Academy of Sciences, RU-142092 Troitzk, Russia*
[4]*Instituut for Kern- en Stralingsfysica, University of Leuven, B-3001 Leuven, Belgium*
[5]*Gesellschaft für Schwerionenforschung, D-64291 Darmstadt, Germany*
[6]*Physik Department, TU München, D-85748 Garching, Germany*
[7]*Institut für Physik, Universität Mainz, D-55128 Mainz, Germany*
[8]*CERN, CH-1211 Geneva 23, Switzerland*

(Received 4 May 2000; published 25 September 2000)

A chemically selective laser ion source has been applied in a decay study of the very neutron-rich isotopes ^{131}Cd and ^{132}Cd at CERN/ISOLDE. For the β^- decay of the $N=83$ nuclide ^{131}Cd a surprisingly short half-life of (68 ± 3) ms and a weak delayed-neutron branch of $P_n=(3.5\pm1.0)\%$ were observed. For the $N=84$ nuclide ^{132}Cd a half-life of (97 ± 10) ms and a P_n value of $(60\pm15)\%$ were obtained. Schematic features of both decay schemes are developed. We find that our new data are not reproduced by current global models used for *ab initio* calculations of β-decay properties without significant changes.

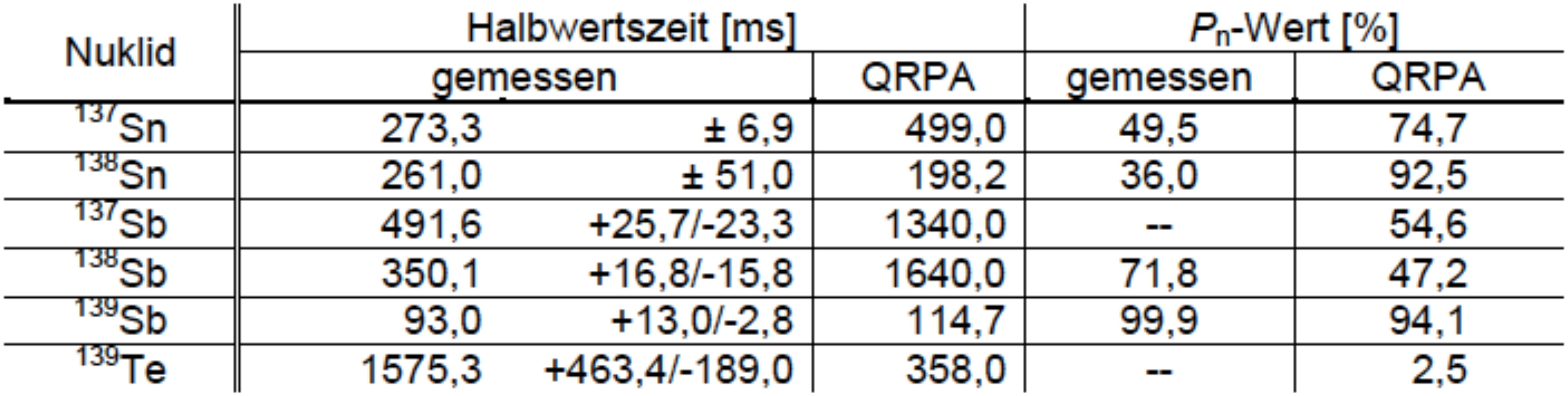
^{131}Cd: 68(3) ms **^{132}Cd 97 (10) ms** **^{133}Cd 57(10)**

The 68 (3) ms half-life and 3.5% P_n values for ^{131}Cd remain somewhat anomalous and deserve more attention.

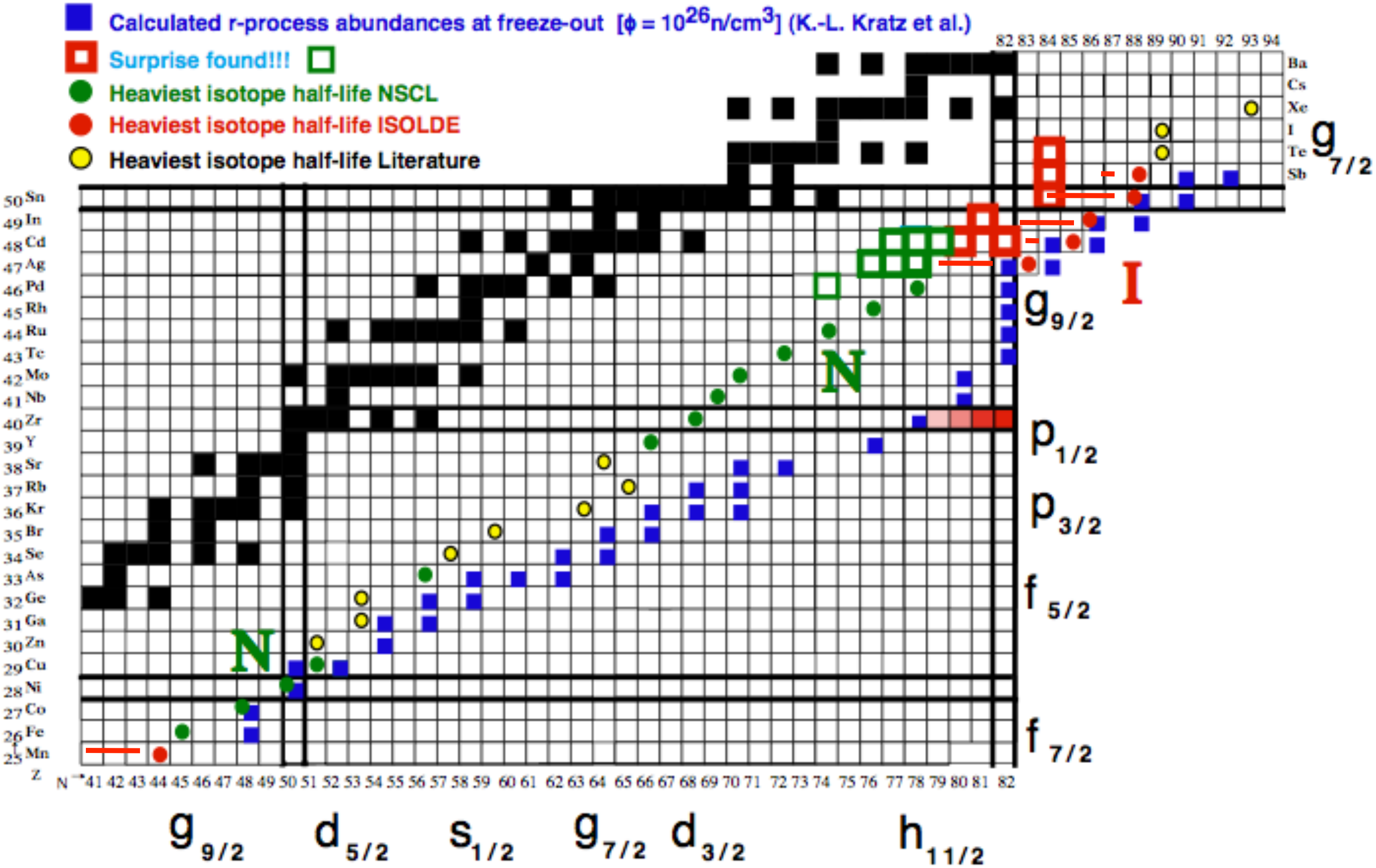


Nuklid	Halbwertszeit [ms]					
	Experiment		Theorie (QRPA)			
	Grundzustand (g)	Angeregter Zustand (m)	Folded Yukawa		Nilsson	
			g	m	g	m
^{130}Ag	35 ± 10	-	31	-	35	-
^{129}Cd	242 ± 8	104 ± 6	457	369	308	253
^{133}Cd	57 ± 10	-	140	-	46	-

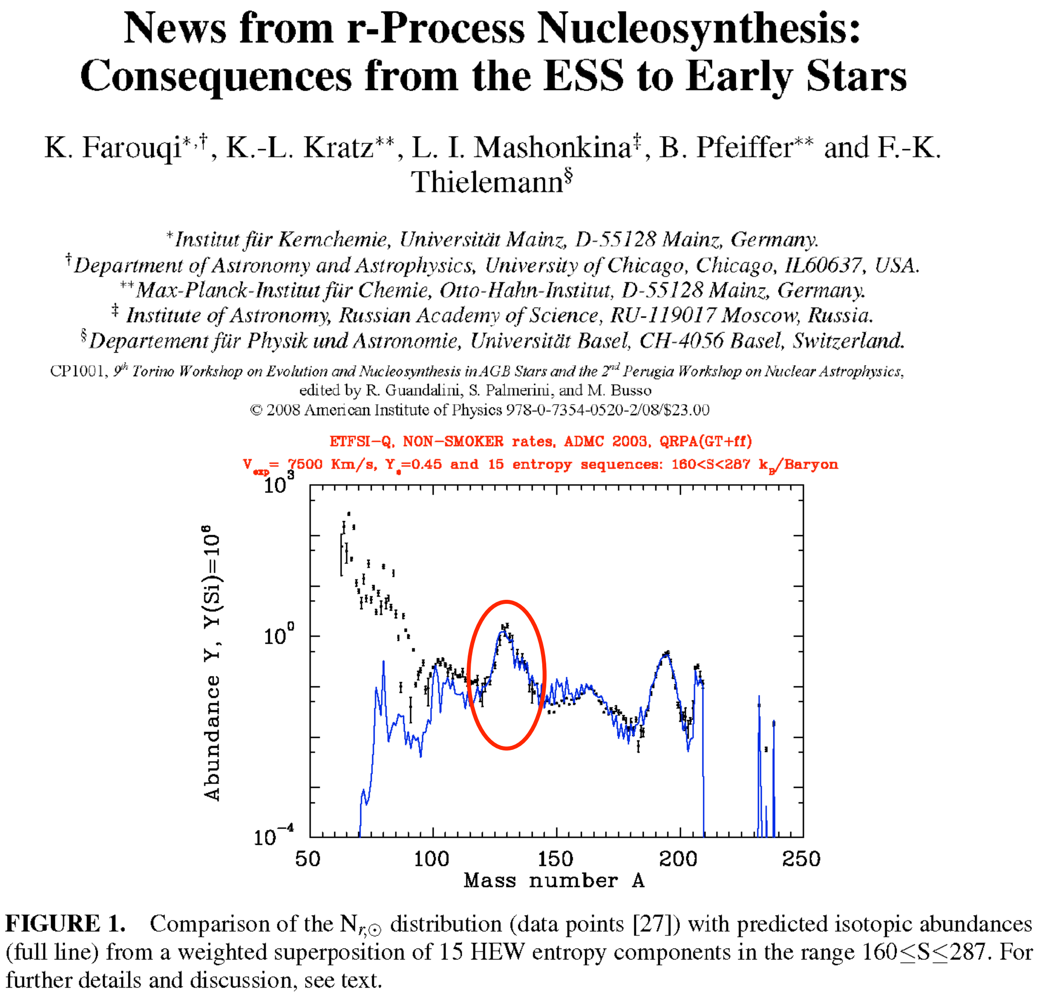
Oliver Arndt: diploma thesis and Ph. D. thesis



Nuklid	Halbwertszeit [ms]			P_n-Wert [%]	
	gemessen		QRPA	gemessen	QRPA
^{137}Sn	273,3	± 6,9	499,0	49,5	74,7
^{138}Sn	261,0	± 51,0	198,2	36,0	92,5
^{137}Sb	491,6	+25,7/-23,3	1340,0	--	54,6
^{138}Sb	350,1	+16,8/-15,8	1640,0	71,8	47,2
^{139}Sb	93,0	+13,0/-2,8	114,7	99,9	94,1
^{139}Te	1575,3	+463,4/-189,0	358,0	--	2,5



The blue squares are Kratz's calculations for the waiting points for neutron densities of 10^{26}n/cm^3, needed to produce U and Th. These ISOLDE measurements are "in the waiting-point path" whereas, elsewhere, data are further from the path.



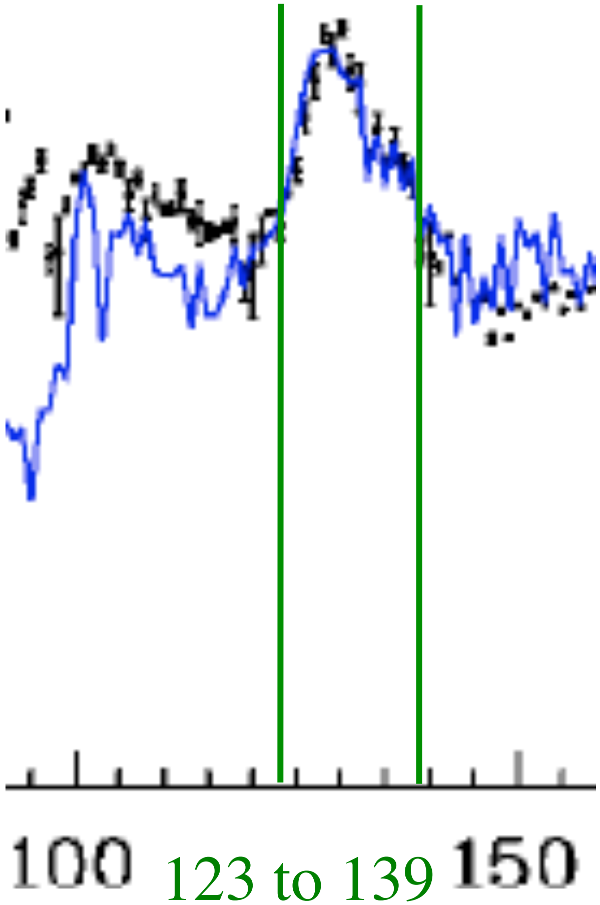
News from r-Process Nucleosynthesis: Consequences from the ESS to Early Stars

K. Farouqi[*,†], K.-L. Kratz[**], L. I. Mashonkina[‡], B. Pfeiffer[**] and F.-K. Thielemann[§]

[*]Institut für Kernchemie, Universität Mainz, D-55128 Mainz, Germany.
[†]Department of Astronomy and Astrophysics, University of Chicago, Chicago, IL60637, USA.
[**]Max-Planck-Institut für Chemie, Otto-Hahn-Institut, D-55128 Mainz, Germany.
[‡] Institute of Astronomy, Russian Academy of Science, RU-119017 Moscow, Russia.
[§]Departement für Physik und Astronomie, Universität Basel, CH-4056 Basel, Switzerland.

CP1001, *9th Torino Workshop on Evolution and Nucleosynthesis in AGB Stars and the 2nd Perugia Workshop on Nuclear Astrophysics,*
edited by R. Guandalini, S. Palmerini, and M. Busso
© 2008 American Institute of Physics 978-0-7354-0520-2/08/$23.00

FIGURE 1. Comparison of the $N_{r,\odot}$ distribution (data points [27]) with predicted isotopic abundances (full line) from a weighted superposition of 15 HEW entropy components in the range 160≤S≤287. For further details and discussion, see text.



During the past 15 years, the half-lives have been measured from ^{129}Ag to ^{139}Sb. The work at N = 82 has improved the ability to extrapolate "down the N = 82 chain" to make better estimates for the other N = 82 "likely waiting-point isotopes". The IMPACT is that it is now possible to provide a "reasonable" model fit for the r-process yields!!!! These data make it possible to account for the "steep" left slope of the peak owing to the shorter-than-expected half-lives up the N = 82 chain, and, perhaps, somewhat longer-than-expected half-lives for the Sn and Sb nuclei.

Z. Phys. A 355, 117-127 (1996)

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Ground state properties and β-decay half-lives near ^{132}Sn in a self-consistent theory

I.N. Borzov[1,⋆], S.A. Fayans[2,3,⋆⋆], E. Krömer[3], D. Zawischa[3]

[1] Institut d'Astronomie et d'Astrophysique, Université Libre de Bruxelles, Campus Plaine, CP226 Boulevard du Triomphe, B-1050 Bruxelles, Belgium
[2] Institut des Sciences Nucléaires, 53 avenue des Martyrs, F-38026 Grenoble Cedex, France
[3] Institut für Theoretische Physik, Universität Hannover, Appelstrasse 2, D-30167 Hannover, Germany

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Communicated by A. Schäfer

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Table 3. Half-lives of nuclides near ^{132}Sn

Nuclide	$T_{1/2}$, s					
	other works			this work		exp.
	[8]	[9, 10]	[27, 28]	DF2	DF3	
^{123}Ag	1.31	0.117	–	0.79	0.75	0.297(6)^a
^{125}Ag	0.494	0.115	0.164-0.249	0.30	0.28	0.156(7)^a
^{127}Ag	0.202	0.083	0.092-0.151	0.25	0.24	0.109(15)^a
^{129}Ag	0.274	0.047	0.054-0.088	0.16	0.16	–^{b}
^{124}Cd	–	6.357	–	1.71	1.60	0.9(2)^c
^{125}Cd	–	2.431	–	1.20	1.15	0.68(4)^d
^{126}Cd	2.18	1.710	–	0.94	0.84	0.506(15)^e
^{127}Cd	0.104	2.507	–	0.82	0.65	0.43(3)^f
^{128}Cd	0.772	1.002	–	0.76	0.48	0.34(3)^f
^{129}Cd	0.482	3.148	–	0.49	0.36	0.27(4)^f
^{130}Cd	0.274	1.123	–	0.46	0.37	0.195(35)^g
^{131}Cd	0.052	0.074	0.233	0.16	0.14	–^{b}
^{132}Cd	0.034	0.043	0.118	0.11	0.08	–^{b}
^{133}Cd	0.038	0.034	0.232	0.13	0.10	–^{b}
^{131}In	0.394	0.147	0.332	0.39	0.35	0.287(4)^h
^{133}In	0.060	0.140	–	0.19	0.20	0.180(20)^i
^{135}In	0.034	0.090	0.100-0.652	0.13	0.16	0.195(3)^j
^{133}Sn	0.823	10.29	1.26	(83.9)9.32	(62.1)8.20	1.20(5)^h
^{134}Sn	0.335	3.54	0.816	(37.4)9.06	(30.1)8.84	1.050(11)^h
^{135}Sb	0.624	56.36	1.300	(134.1)7.05	(118.7)5.15	1.662(10)^h
^{138}Te	1.494	30.13	1.760	(43.5)28.7	(39.4)31.1	1.4(4)^k

79(3) ms
46 (5) ms

162(7) ms
68 (3)
97(10)
57 (10)

ELSEVIER Nuclear Physics A621 (1997) 307c–310c

Microscopic calculations of β–decay characteristics near the A=130 r-process peak

I.N.BORZOV[a] * †, S. GORIELY[a] ‡, J.M. PEARSON[a] § a

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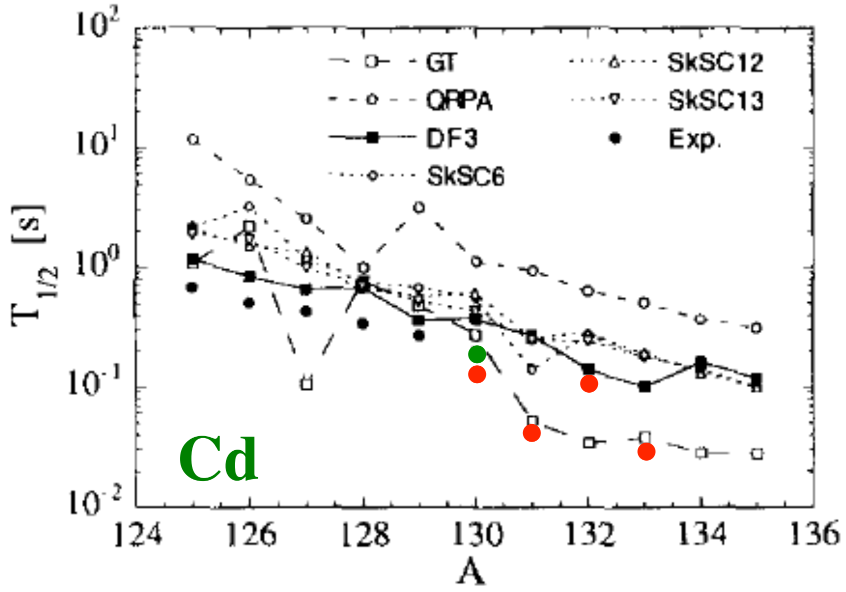
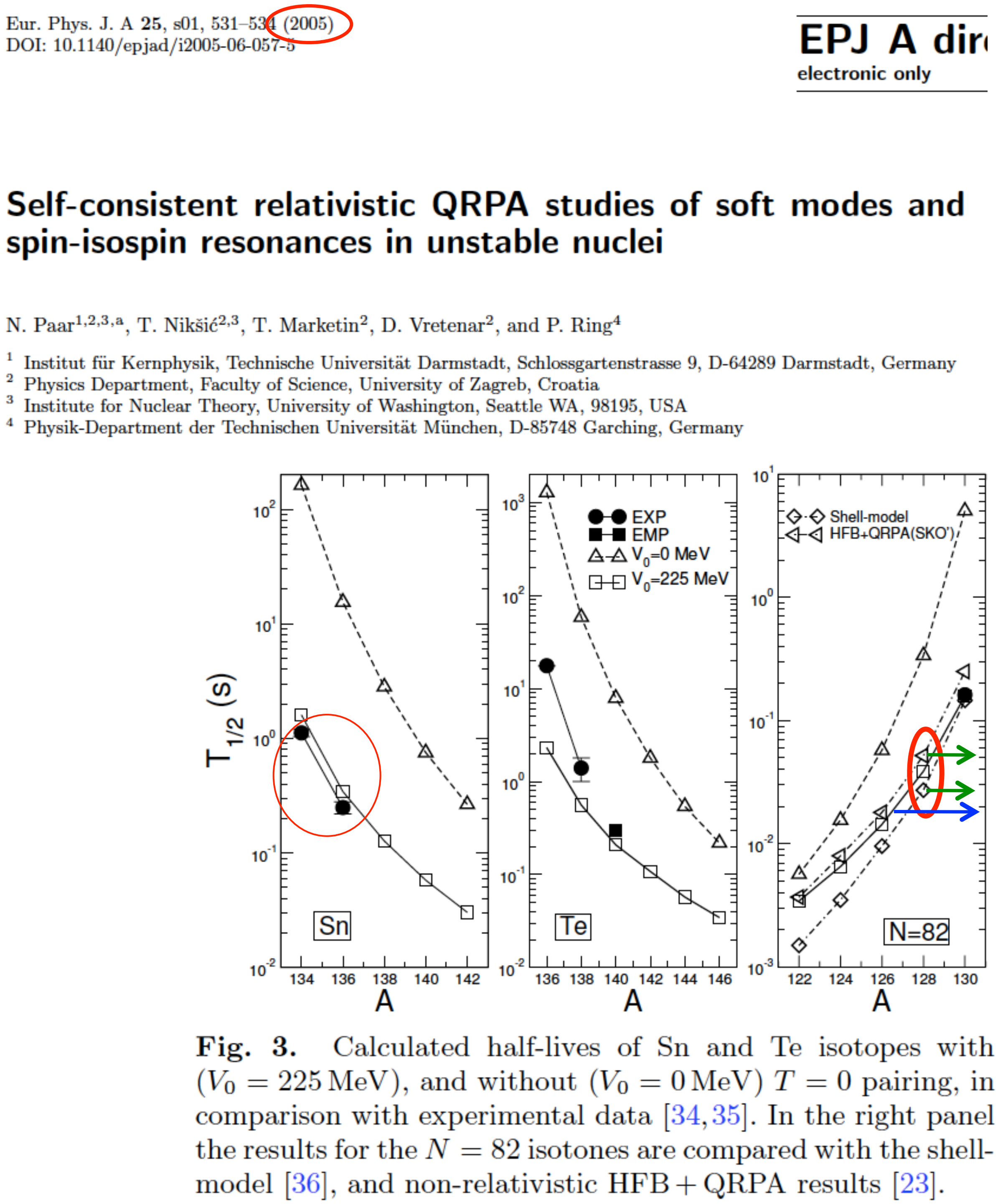


Figure 1. Comparison of experimental half-lives with the ones calculated with the ETFSI potentials (SKSC6-13) and with GT, QRPA and DF3 models.

The green dot is the 1986 point whereas the red dots are from the 1999 measurements performed with RILIS. One observation is that, at that time, nearly all calculated half-lives were HIGHER the values eventually observed.



Eur. Phys. J. A **25**, s01, 531–534 (2005)
DOI: 10.1140/epjad/i2005-06-057-5

EPJ A dir
electronic only

Self-consistent relativistic QRPA studies of soft modes and spin-isospin resonances in unstable nuclei

N. Paar[1,2,3,a], T. Nikšić[2,3], T. Marketin[2], D. Vretenar[2], and P. Ring[4]

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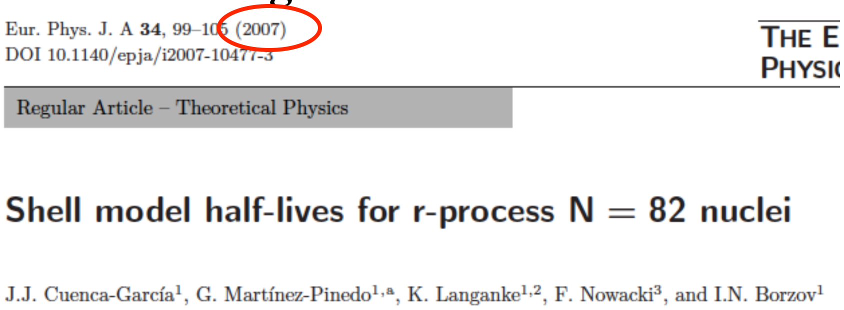
Fig. 3. Calculated half-lives of Sn and Te isotopes with ($V_0 = 225$ MeV), and without ($V_0 = 0$ MeV) $T = 0$ pairing, in comparison with experimental data [34,35]. In the right panel the results for the $N = 82$ isotones are compared with the shell-model [36], and non-relativistic HFB + QRPA results [23].

One major impact of these measurements has been the ability to identify model calculations that do not provide good fits to the data. For ^{128}Pd, the range is from 30 to 50 ms. For ^{126}Ru, the maximum is only about 20 ms…..not much waiting with that half-life.

Again, the impact is to rid the literature of "bad" calculations. You can see below how nice it would be to have smaller error bars for ^{130}Cd and real data for ^{129}Ag.


Eur. Phys. J. A **34**, 99–105 (2007)
DOI 10.1140/epja/i2007-10477-3

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PHYSI

Regular Article – Theoretical Physics

Shell model half-lives for r-process N = 82 nuclei

J.J. Cuenca-García[1], G. Martínez-Pinedo[1,a], K. Langanke[1,2], F. Nowacki[3], and I.N. Borzov[1]

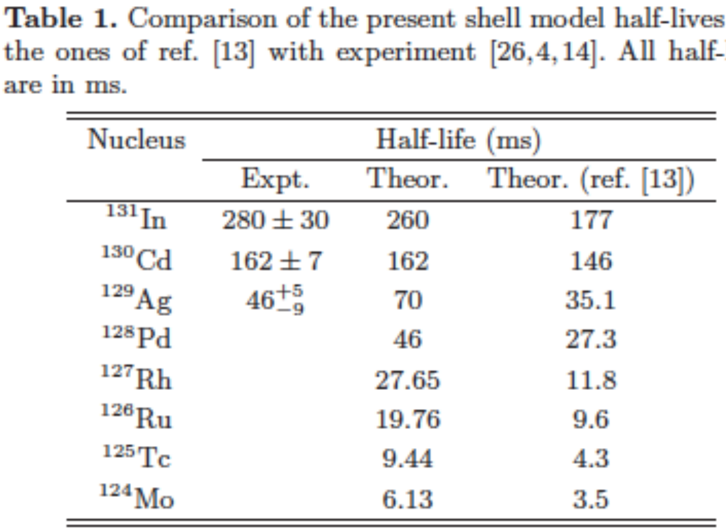


Table 1. Comparison of the present shell model half-lives and the ones of ref. [13] with experiment [26,4,14]. All half-lives are in ms.

Nucleus	Half-life (ms)		
	Expt.	Theor.	Theor. (ref. [13])
^{131}In	280 ± 30	260	177
^{130}Cd	162 ± 7	162	146
^{129}Ag	46^{+5}_{-9}	70	35.1
^{128}Pd		46	27.3
^{127}Rh		27.65	11.8
^{126}Ru		19.76	9.6
^{125}Tc		9.44	4.3
^{124}Mo		6.13	3.5

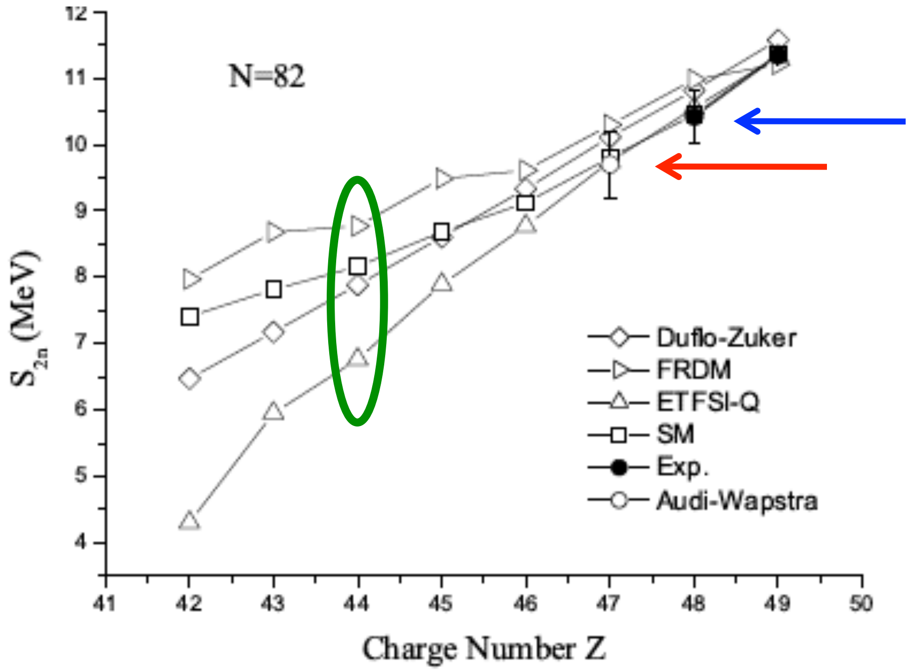


Fig. 13. Comparison of the shell model two-neutron separation energies for the $N = 82$ nuclei to the data [22] and predictions of other models: FRDM [6], Duflo-Zuker [15] and ETFSI-Q [23].

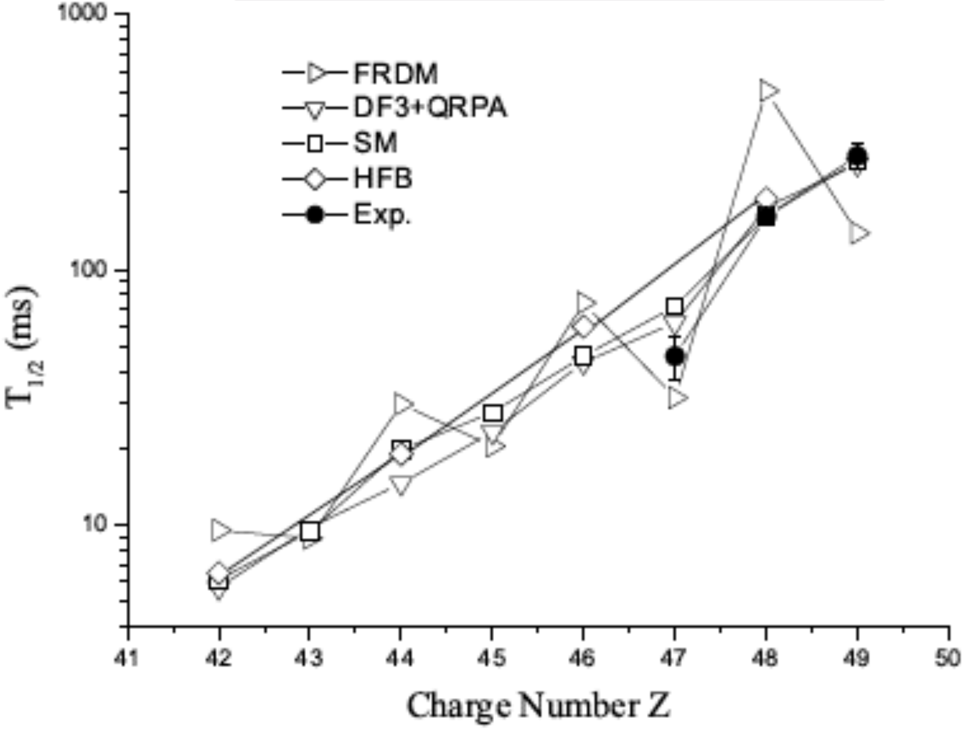
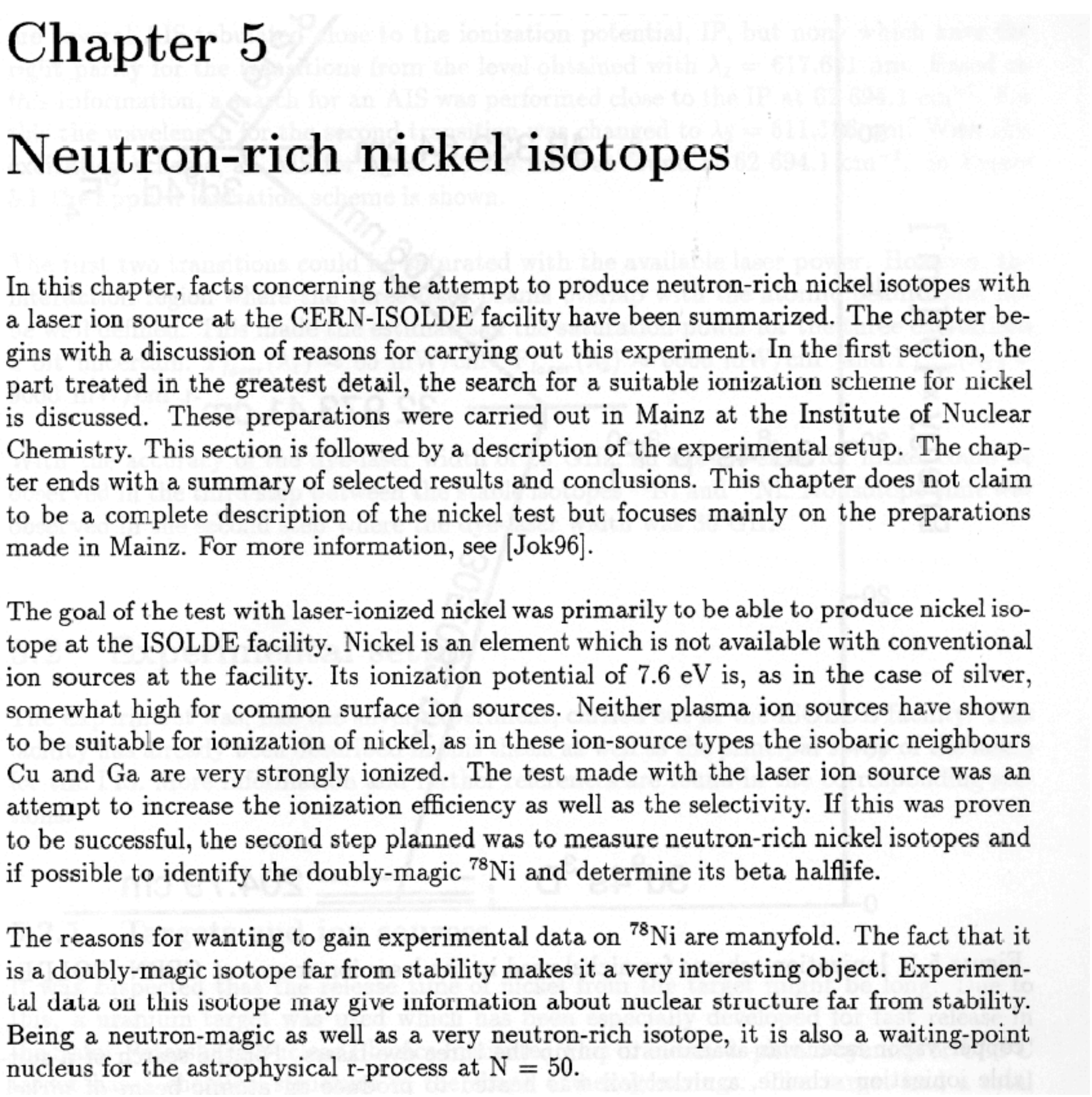


Fig. 3. Comparison of half-lives of the $N = 82$ isotones as calculated in the FRDM [6], HFB [9], and the present shell model approaches with data [4,14].

Ylva’s thesis



Chapter 5

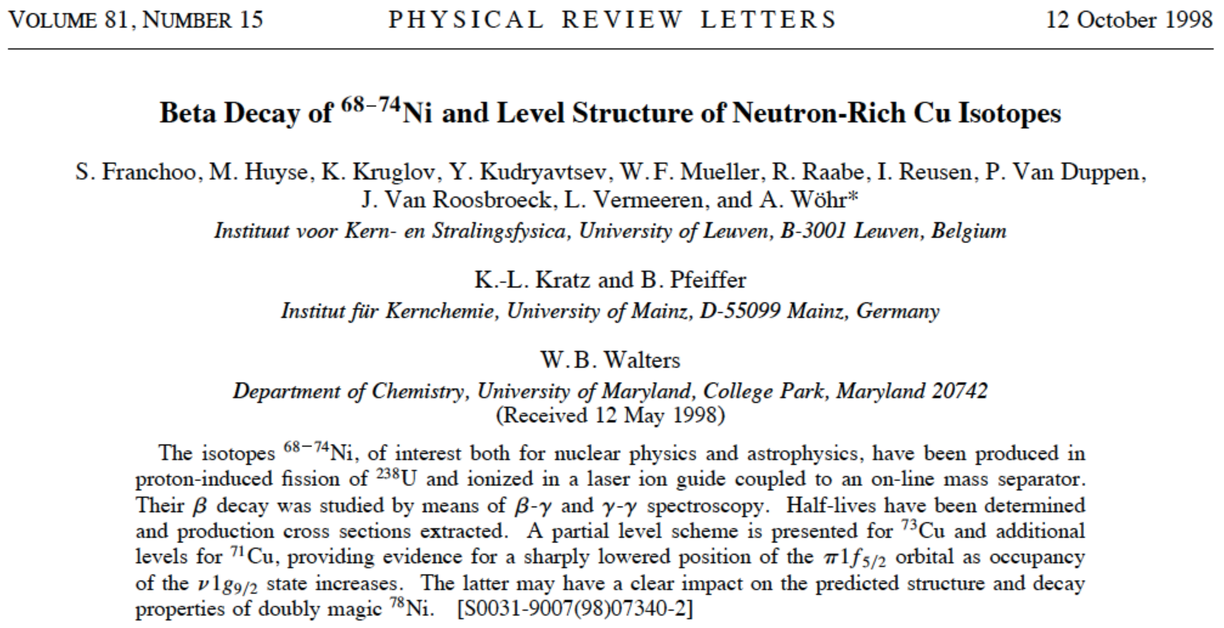
Neutron-rich nickel isotopes

In this chapter, facts concerning the attempt to produce neutron-rich nickel isotopes with a laser ion source at the CERN-ISOLDE facility have been summarized. The chapter begins with a discussion of reasons for carrying out this experiment. In the first section, the part treated in the greatest detail, the search for a suitable ionization scheme for nickel is discussed. These preparations were carried out in Mainz at the Institute of Nuclear Chemistry. This section is followed by a description of the experimental setup. The chapter ends with a summary of selected results and conclusions. This chapter does not claim to be a complete description of the nickel test but focuses mainly on the preparations made in Mainz. For more information, see [Jok96].

The goal of the test with laser-ionized nickel was primarily to be able to produce nickel isotope at the ISOLDE facility. Nickel is an element which is not available with conventional ion sources at the facility. Its ionization potential of 7.6 eV is, as in the case of silver, somewhat high for common surface ion sources. Neither plasma ion sources have shown to be suitable for ionization of nickel, as in these ion-source types the isobaric neighbours Cu and Ga are very strongly ionized. The test made with the laser ion source was an attempt to increase the ionization efficiency as well as the selectivity. If this was proven to be successful, the second step planned was to measure neutron-rich nickel isotopes and if possible to identify the doubly-magic ^{78}Ni and determine its beta halflife.

The reasons for wanting to gain experimental data on ^{78}Ni are manyfold. The fact that it is a doubly-magic isotope far from stability makes it a very interesting object. Experimental data on this isotope may give information about nuclear structure far from stability. Being a neutron-magic as well as a very neutron-rich isotope, it is also a waiting-point nucleus for the astrophysical r-process at N = 50.

This is the KUL-LISOL Ion Guide Laser paper motivated by astrophysics to describe ^{78}Ni decay. Before this paper, there had been interest in movement of single-particle levels, but no “smoking gun” where the ONSET of the monopole shift **could be observed** and an apparent **“cause and effect”** could be identified. Namely, adding high-j $g_{9/2}$ neutrons to the nucleus.



VOLUME 81, NUMBER 15 PHYSICAL REVIEW LETTERS 12 October 1998

Beta Decay of $^{68-74}$Ni and Level Structure of Neutron-Rich Cu Isotopes

S. Franchoo, M. Huyse, K. Kruglov, Y. Kudryavtsev, W.F. Mueller, R. Raabe, I. Reusen, P. Van Duppen,
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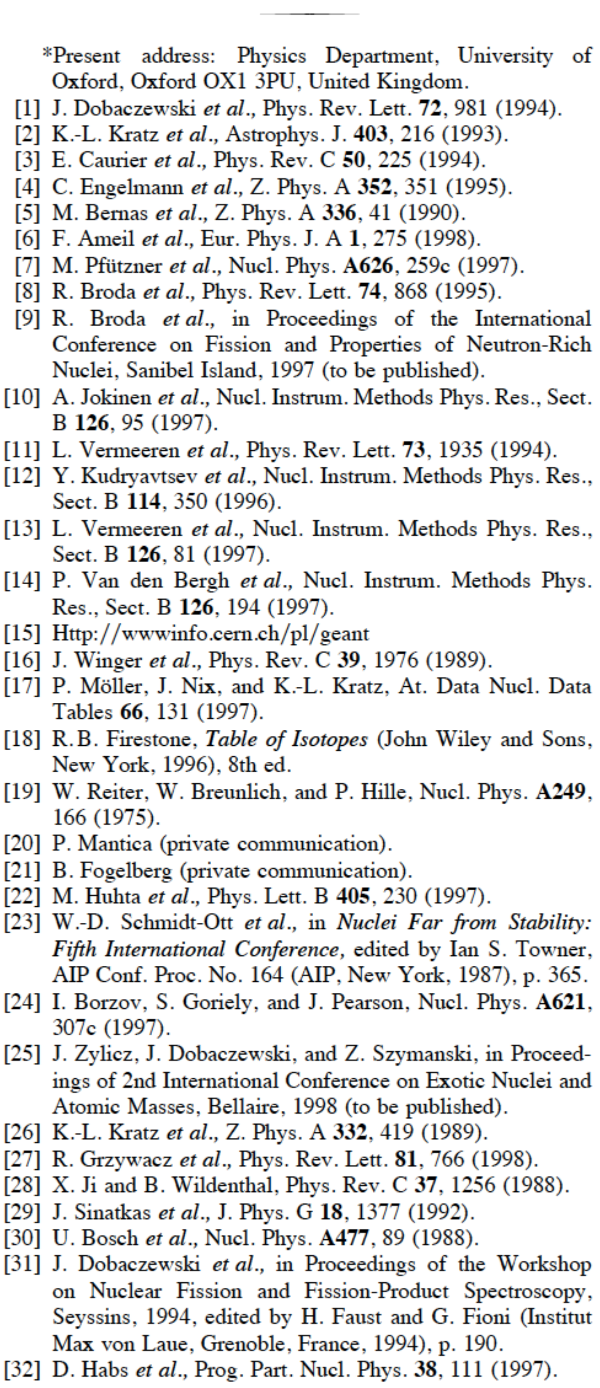
(Received 12 May 1998)

The isotopes $^{68-74}$Ni, of interest both for nuclear physics and astrophysics, have been produced in proton-induced fission of ^{238}U and ionized in a laser ion guide coupled to an on-line mass separator. Their β decay was studied by means of β-γ and γ-γ spectroscopy. Half-lives have been determined and production cross sections extracted. A partial level scheme is presented for ^{73}Cu and additional levels for ^{71}Cu, providing evidence for a sharply lowered position of the $\pi 1f_{5/2}$ orbital as occupancy of the $\nu 1g_{9/2}$ state increases. The latter may have a clear impact on the predicted structure and decay properties of doubly magic ^{78}Ni. [S0031-9007(98)07340-2]



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PHYSICAL REVIEW C, VOLUME 64, 054308

Monopole migration in ^{69,71,73}Cu observed from β decay of laser-ionized $^{68-74}$Ni

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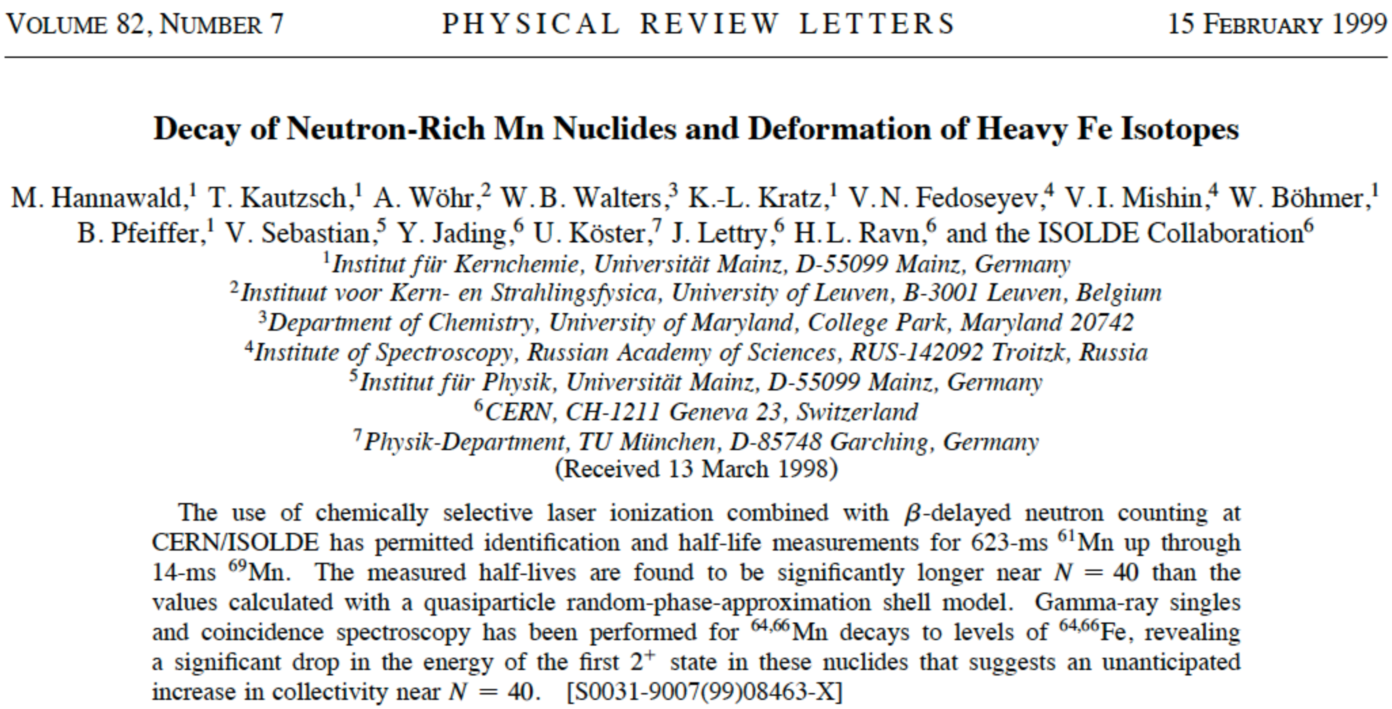

VOLUME 82, NUMBER 7 PHYSICAL REVIEW LETTERS 15 FEBRUARY 1999

Decay of Neutron-Rich Mn Nuclides and Deformation of Heavy Fe Isotopes

M. Hannawald,[1] T. Kautzsch,[1] A. Wöhr,[2] W.B. Walters,[3] K.-L. Kratz,[1] V.N. Fedoseyev,[4] V.I. Mishin,[4] W. Böhmer,[1]
B. Pfeiffer,[1] V. Sebastian,[5] Y. Jading,[6] U. Köster,[7] J. Lettry,[6] H.L. Ravn,[6] and the ISOLDE Collaboration[6]
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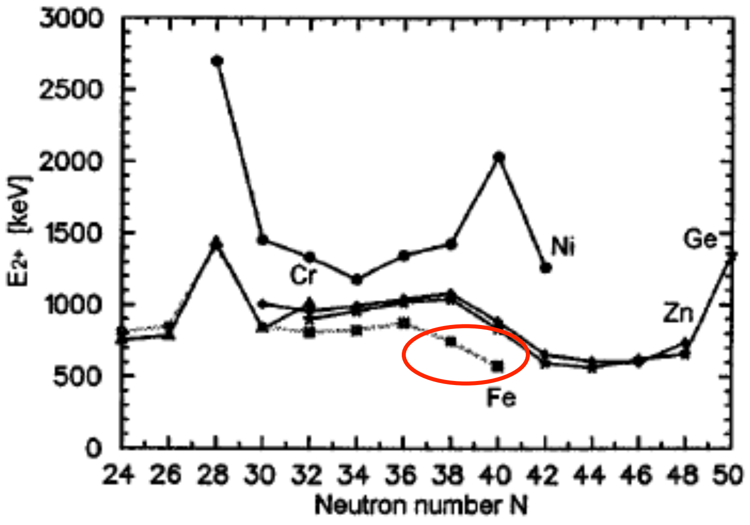
(Received 13 March 1998)

The use of chemically selective laser ionization combined with β-delayed neutron counting at CERN/ISOLDE has permitted identification and half-life measurements for 623-ms ^{61}Mn up through 14-ms ^{69}Mn. The measured half-lives are found to be significantly longer near $N = 40$ than the values calculated with a quasiparticle random-phase-approximation shell model. Gamma-ray singles and coincidence spectroscopy has been performed for ^{64,66}Mn decays to levels of ^{64,66}Fe, revealing a significant drop in the energy of the first 2^+ state in these nuclides that suggests an unanticipated increase in collectivity near $N = 40$. [S0031-9007(99)08463-X]

Keeping with the topic of impact, here is the 1999 PRL…submitted in 1998 from the August 1997 test run. Lots of crabbing by the referees “stating that these measurements and ideas… must be impossible”. Ah, the ability to turn off the laser!!!!



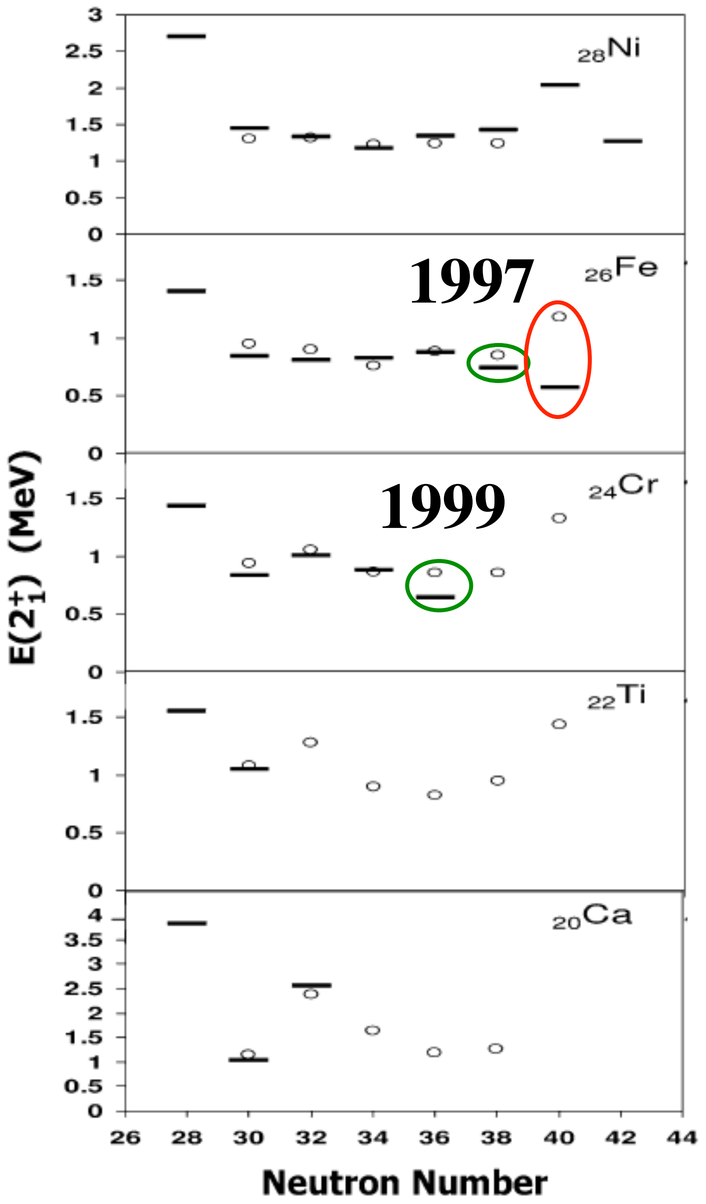


Fig. 4. $E(2_1^+)$ versus neutron number for neutron-rich nuclides between $20 \leqslant Z \leqslant 28$. The experimental $E(2_1^+)$ values are denoted by dashes, where the data was obtained from Refs. [4,14,17,19]. The open circles represent $E(2_1^+)$ values obtained from truncated shell-model calculations. See text for detai

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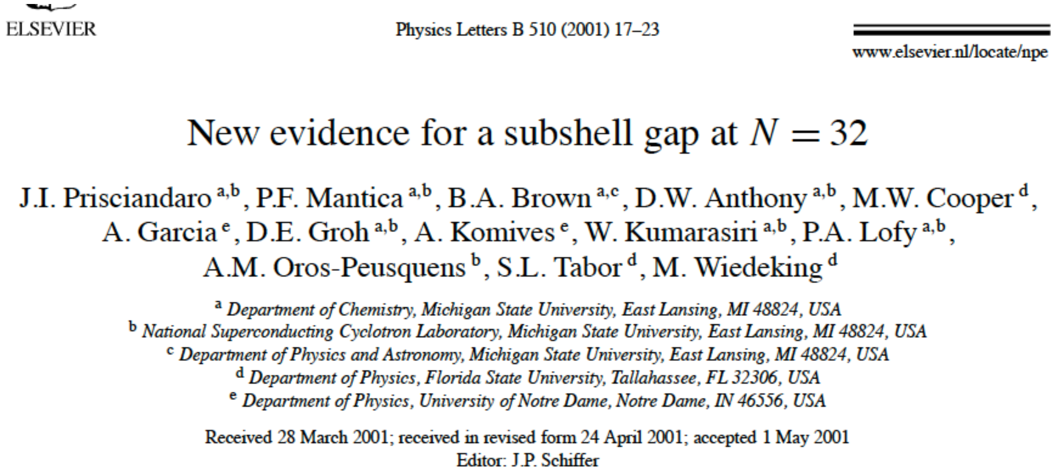
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Physics Letters B 510 (2001) 17–23

www.elsevier.nl/locate/npe

New evidence for a subshell gap at $N = 32$

J.I. Prisciandaro [a,b], P.F. Mantica [a,b], B.A. Brown [a,c], D.W. Anthony [a,b], M.W. Cooper [d],
A. Garcia [e], D.E. Groh [a,b], A. Komives [e], W. Kumarasiri [a,b], P.A. Lofy [a,b],
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Editor: J.P. Schiffer

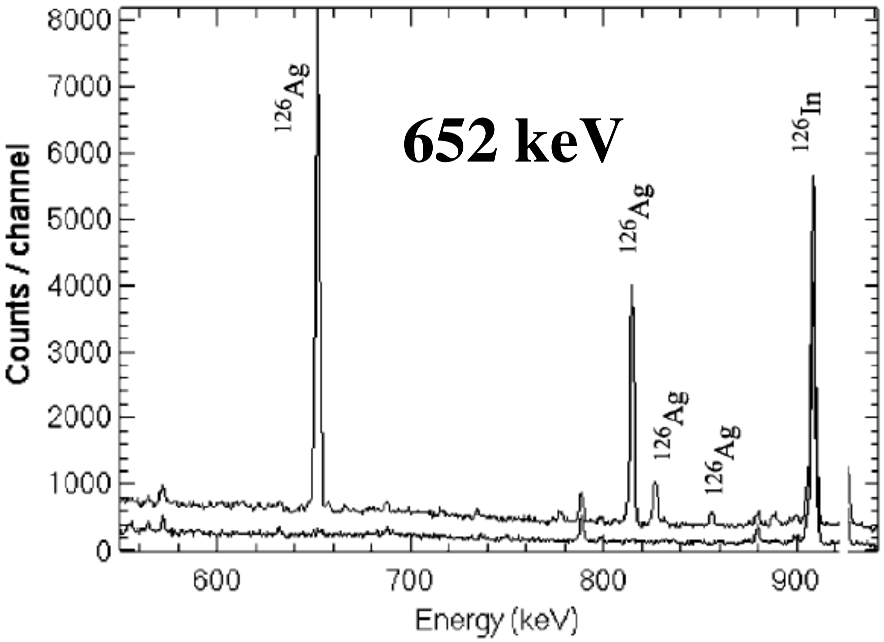
In 1997, Alex Brown's calculations fit all of these data closely!!! The 746-keV 2+ energy for ^{64}Fe could have been "ignored", but not the 546-keV value for ^{66}Fe.

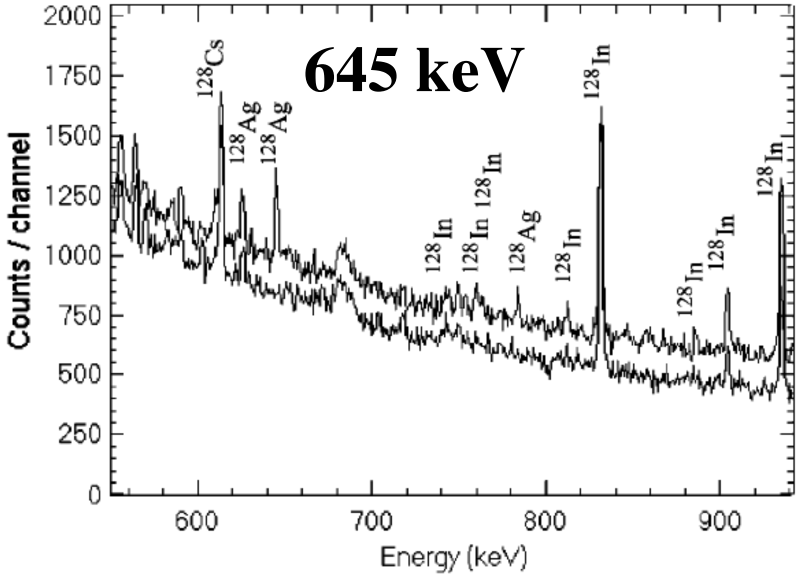
When the GANIL group published the lower value for ^{60}Cr in 1999, it was consistent with the newer ideas about deformation and intruders.

New states in heavy Cd isotopes and the N = 82 shell structure

Eur. Phys. J. A 9, 201–206 (2000)

T. Kautzsch[1], W.B. Walters[2], M. Hannawald[1], K.-L. Kratz[1,a], V.I. Mishin[3], V.N. Fedoseyev[3], W. Böhmer[1], Y. Jading[4], P. Van Duppen[4,5], B. Pfeiffer[1], A. Wöhr[4,5], P. Möller[6], I. Klöckl[1], V. Sebastian[4,7], U. Köster[4,8], M. Koizumi[4,9], J. Lettry[4], H.L. Ravn[4], and the ISOLDE Collaboration[4]

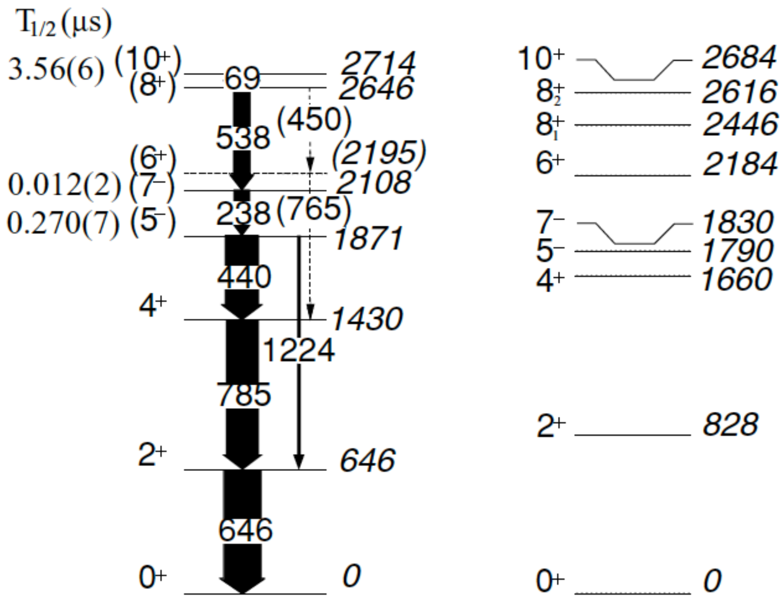




The word for the study of the neutron-rich Cd isotopes has been **“frustration”**. It started with the first measurement that showed the small decline in the 2+ energy for ^{128}Cd relative to ^{126}Cd.

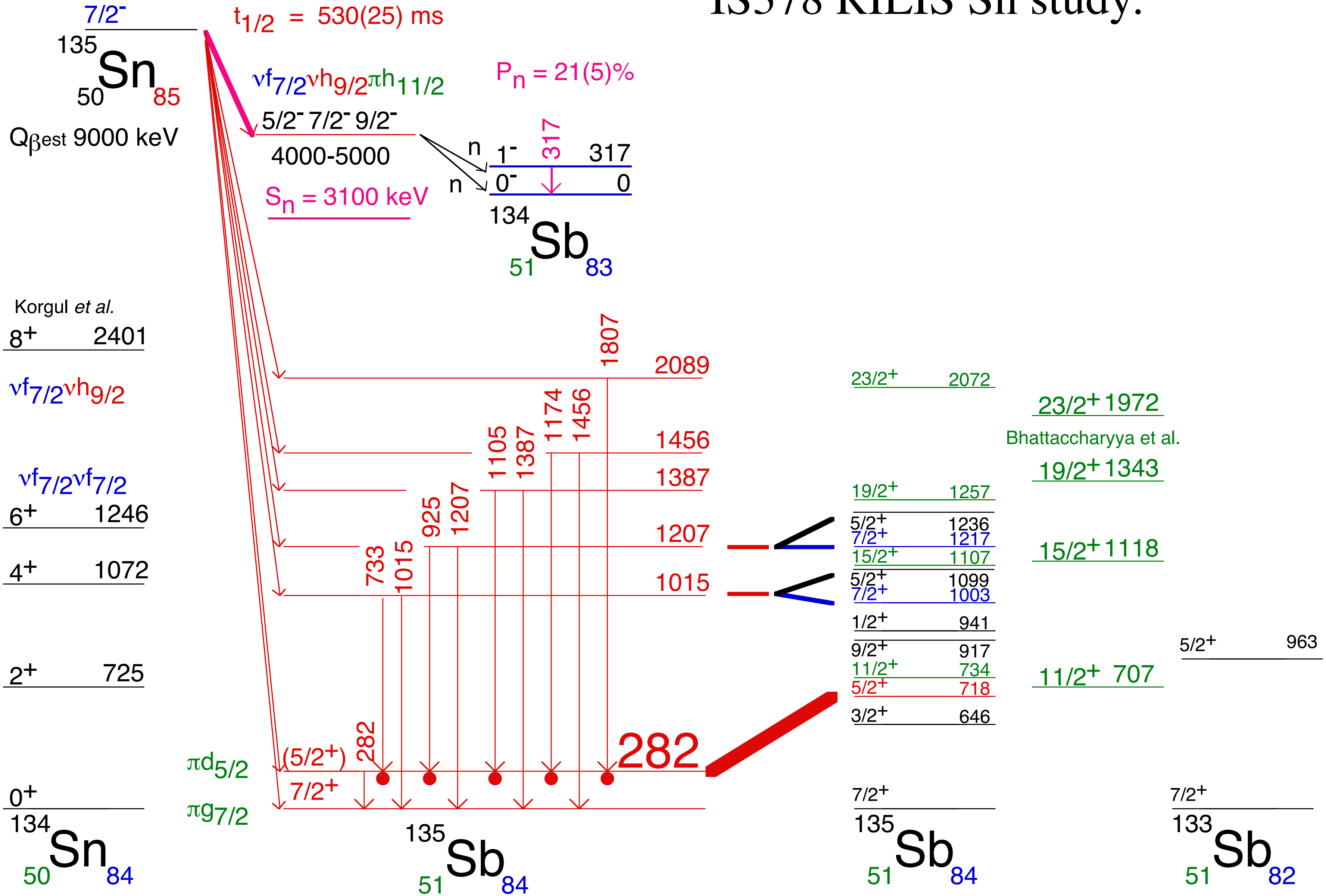
Attempts to find a consistent way to describe these results in the shell model have proved frustrating. The frustration is shown at the right for the GSI calculation for ^{128}Cd. **If the 10+, 6+ and 5- levels are fit, then the 2+, 4+, and 7- are not.**

There are unresolved issues for all of the Cd isotopes with A ≥ 125. The ISOLDE 2+ energy for ^{128}Cd was "just the start".



^{128}Cd…GSI

IS378 RILIS Sn study.



OXBASH CALCULATION: B. A. BROWN, 2000

The 718-keV level is ~ 70 % single-particle $d_{5/2}$.

Summary… (but not the conclusion):

Karl-Ludwig's vision of a mechanism "for the selective ionization of an element via resonant laser excitation" that would permit the study of ^{129}Ag decay has had major impacts on both nuclear astrophysics and nuclear structure physics, and was derived from knowledge of work by Mainz and GSI collaborators for the study of ^{101}Sn. Studies followed for Cd, In, Sn, and Sb.

r-process nucleosynthesis: cleaned up the needed parameters for the A=130 abundance peak

nuclear structure: ^{128}Cd, identified low 2+ energy…still not understood

^{66}Fe, identified low 2+ energy…leading to intruders and deformation

^{73}Cu, via Leuven, identified low 5/2- level, monopole shifts, tensor idea

^{135}Sb, identified low 5/2+ level….reasons still debated…..there is a story

^{130}In identified high 1+ level……reasons still debated

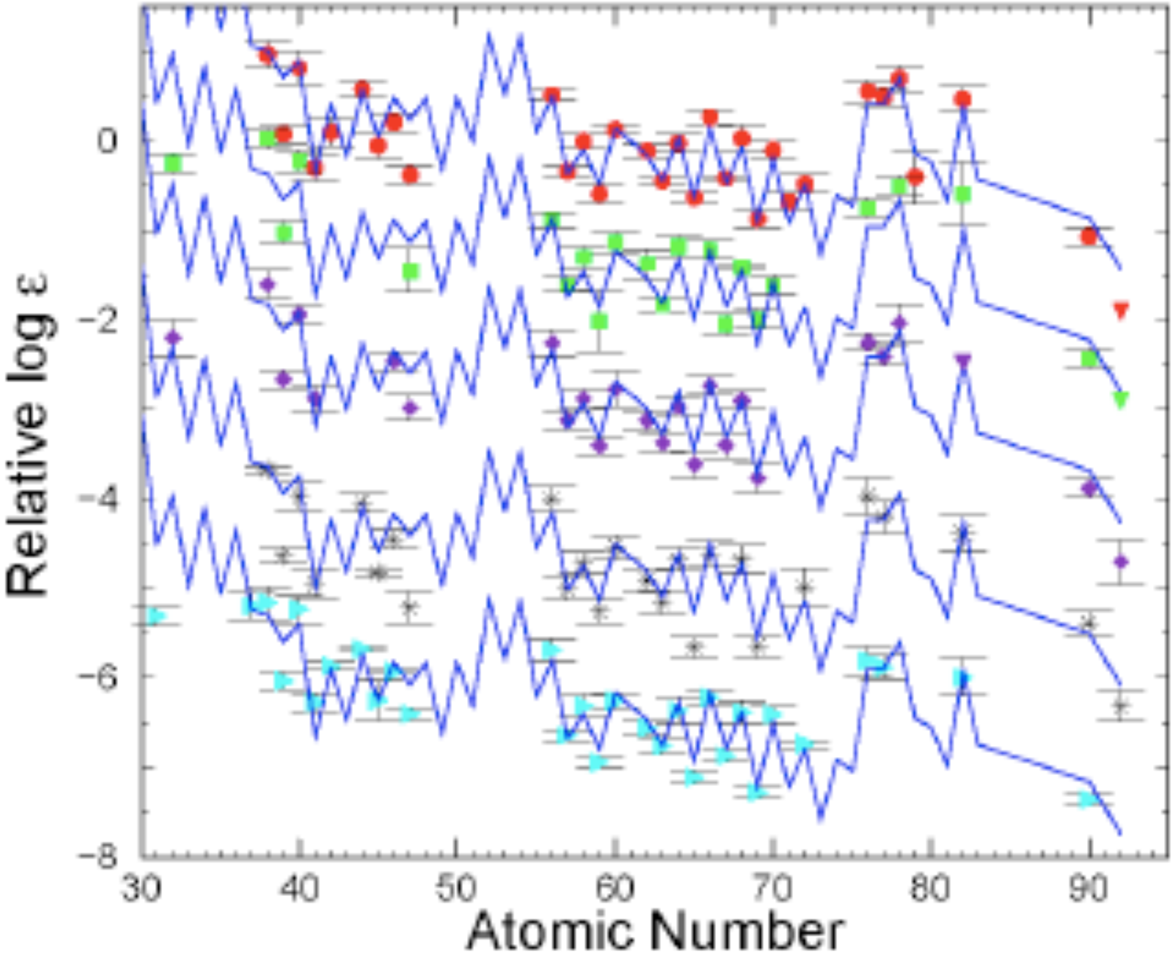


FIGURE 3. Comparisons of neutron-capture abundances in five *r*-process-rich Galactic halo stars: starting from the top - CS 22892-052 (circles), HD 115444 (squares), BD +17°3248 (diamonds), CS 31082-001 (stars), and HD 221170 (right-facing triangles). The solid lines are the scaled *r*-process only solar system elemental abundance curves (after [15]).

The observation that these old halo stars had abundance patters similar to the solar abundances has led to the idea that the r-process which produces elements above Z = 55 is a robust process.

Abundance Signatures in Halo Stars: Clues to Nucleosynthesis in the First Stars

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***Department of Physics, University of Wisconsin, Madison, WI 53706*

CP990, *First Stars III*, edited by B. W. O'Shea, A. Heger, and T. Abel,

148

Nucleosynthesis Modes in the High-Entropy-Wind Scenario of Type II Supernovae

K. Farouqi*,†, K.-L. Kratz*,**, J. J. Cowan‡, L. I. Mashonkina§, B. Pfeiffer*, C. Sneden¶, F.-K. Thielemann‖ and J. W. Truran†,††

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CP990, *First Stars III, edited by B. W. O'Shea, A. Heger, and T. Abel,*

Sr, Y, Zr seed for the r-process, NOT Fe and Ni isotopes!!!!! To include Y means ^{89}Y, and also ^{88}Sr and ^{90}Zr. These elements are thought to be produced by a Light-Element Primary Process, LEPP, whose details are elusive. If these elements are the r-process seeds, then the waiting–points around ^{78}Ni are "out of the loop".

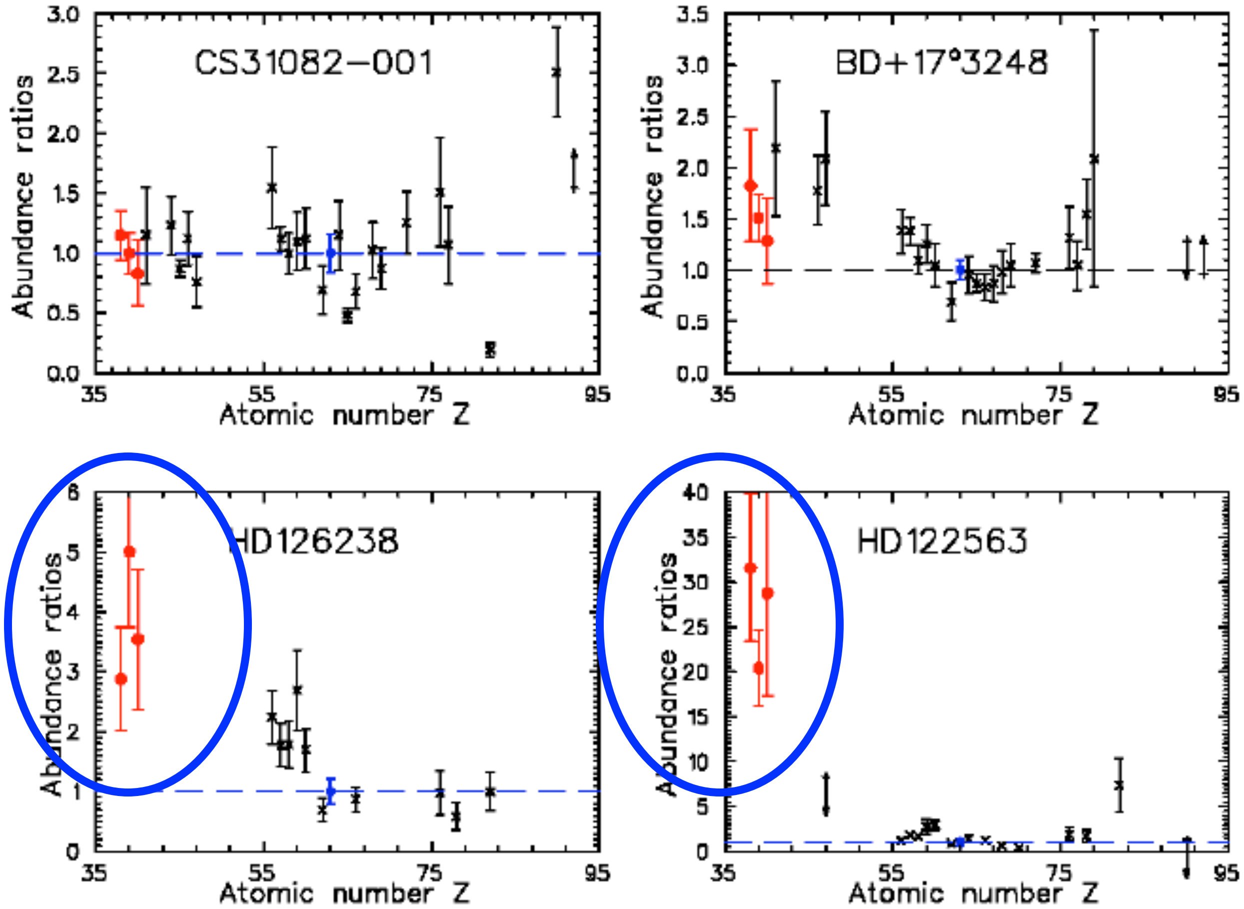
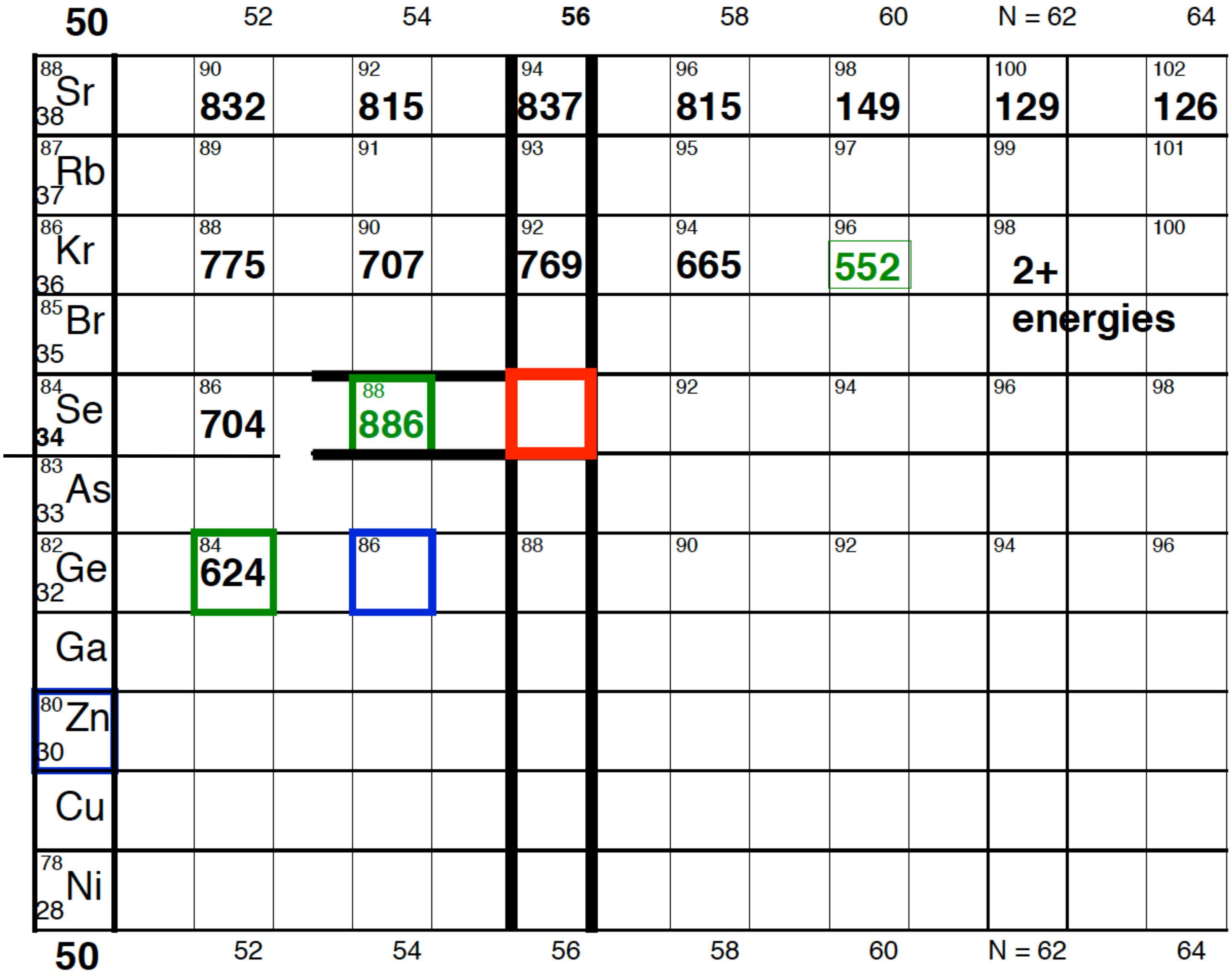


FIGURE 3. Elemental abundances of CS 31082-001[21], BD +17°3248 [22], HD 126238 [23], HD122563 [19] relative to CS 22892-052 [20] For discussion, see text.

Future challenge…..Ga, As, and Ge, decay around a possible double-magic ^{90}Se nucleus $\pi(f_{5/2})^6 \bullet \nu(d_{5/2})^6$



50	52	54	56	58	60	N = 62	64
$^{88}_{38}$Sr	90 **832**	92 **815**	94 **837**	96 **815**	98 **149**	100 **129**	102 **126**
$^{87}_{37}$Rb	89	91	93	95	97	99	101
$^{86}_{36}$Kr	88 **775**	90 **707**	92 **769**	94 **665**	96 **552**	98 **2+**	100
$^{85}_{35}$Br						**energies**	
$^{84}_{34}$Se	86 **704**	88 **886**		92	94	96	98
$^{83}_{33}$As							
$^{82}_{32}$Ge	84 **624**	86	88	90	92	94	96
Ga							
$^{80}_{30}$Zn							
Cu							
$^{78}_{28}$Ni							

Thank you for your attention.