Research in an emerging "big science" discipline: the case of neutron scattering in Spain

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Abstract

Neutron scattering (NS) is a "big science" discipline whose research spans over a wide spectrum of fields, from fundamental or basic science to technological applications. The objective of this paper is to track the evolution of Spanish research in NS from a bibliometric perspective and to place it in the international context. Scientific publications of Spanish authors included in the Web of Science (WoS 1970-2006) are analysed with respect to five relevant dimensions: volume of research output, impact, disciplinary diversity, structural field features and internationalisation. NS emerges as a highly internationalised fast-growing field whose research is firmly rooted in Physics, Chemistry and Engineering, but with applications in a wide range of fields. International collaboration links -present in around 70% of the documents- and national links have largely contributed to mould the existing structure of research in the area, which evolves around major neutron scattering facilities abroad. The construction of a new European neutron source (ESS) would contribute to the consolidation of the field within the EU, since it will strengthen research and improve current activity.

Keywords

Neutron scattering; Spain; Bibliometrics; Research evaluation; Big science

Introduction

Neutron scattering techniques (NS) are based in the interaction between a beam of neutrons with matter, which gives accurate information about the structure and dynamics at the microscopic length-scale. Although neutron techniques have been under development for decades now, the most dramatic breakthroughs are quite recent, as a result of the introduction of ever more intense neutron sources and advanced instruments (spectrometers and diffractometers), together with a

substantial enhancement of the efficiency of detectors. As a token of this field's import we can mention that Clifford Shull and Bertran Brockhouse were awarded the Nobel Prize for Physics in 1994 for their pioneering work in developing neutron techniques to determine the structure and dynamics of materials at the molecular level. The scope of these techniques is multidisciplinary, due to their applications in a wide spectrum of fields, such as chemistry, physics and materials science, but also in biology or medicine, since these techniques can be used for the study of biological processes at cellular or molecular level. Research in neutron scattering presents some features typical of "big science", because specific large facilities (either nuclear reactors or spallation neutron sources), which exist only in a limited number of countries due to their technologically complex and costly nature, are required.

The objective of this study is to analyse the development of NS research in Spain through the scientific publications of Spanish scientists in the Web of Science (WoS) international database over the 1970-2006 period. Assuming that scientific publications are an essential output of the research process, bibliometric indicators are widely used for supporting science policy makers and research managers as well as for the study of science. The obtention of in-depth knowledge on the current status of neutron-related research in Spain is especially relevant and timely at present; since Spain is one of the countries that has applied to host the European Spallation Source (ESS) in Bilbao (Basque Country).

In the last decades, Europe has been on the forefront of NS research thanks to its powerful neutron sources (including, inter alia, ILL and LLB in France, ISIS in the United Kingdom, HMI and FRM II in Germany, and SINQ in Switzerland). Nevertheless, there is an increasing demand from the European scientific community for using NS facilities, even though the number of neutron sources in Europe will decrease in the future due to the aging of existing reactors. Moreover, a third generation of spallation neutron sources is on the pipeline and will be operational soon: SNS (Oak Ridge) in the United States, and JSNS (J-PARK centre) in Japan. Hence, Europe has to improve its structure to maintain its global leading status. To meet this challenge, the European Spallation Source (ESS) project was launched with the aim of building a new neutron facility in Europe. The ESS will largely boost the development of research in the area, and will act as a "*driving force*" for progress in numerous technological applications across a variety of industries including the pharmaceutical, automotive, aeronautic or electronic sectors. It is expected to have both direct and indirect impacts on the development of new technologies as well as in the design and fabrication of new materials with enhanced properties. Spain, together with Sweden and Hungary, has applied to host this new facility.

A series of questions emerge when we turn to analyse the development of research in a given country: how large is the scientific community working on the subject? Who are the main actors

involved? Is the discipline in its initial stage of development or does it present signs of consolidation? Is the discipline self-centred or is it open to other thematic areas? Do scientists show signs of integration in the international scientific community? Which is the contribution of the country to the world research output in the subject? This article provides a bibliometric perspective of NS research in Spain, as part of a study recently commissioned by the *Spanish Society for Neutron Scattering Techniques* (SETN) (*Sociedad Española de Técnicas Neutrónicas*)¹ to increase available knowledge about the state of development of the discipline and to support research management decisions. It will complement other studies which analyse the field from different perspectives (i.e. socioeconomic or historical points of view^{2,3}).

Methodology

This study uses the Web of Science database (WoS) as source of information. This multidisciplinary database includes more than 9,300 scientific journals selected following criteria of scientific and formal quality. The scientific production of Spain in neutron scattering during 1970-2006 was identified by searching the lexeme “neutron*” in the title, keywords or abstract fields and “Spain” in the address of the documents. The downloaded documents were reviewed by a group of experts of the SETN to check the relevance of said documents and remove non-relevant retrievals (for example, those related to “neutron stars” or “neutron irradiation”).

The analysis of these scientific publications of international scope provides an interesting picture of Spanish research in neutron scattering over the last 4 decades. In order to track the evolution and current development state of the discipline, we focus on a number of different aspects: quantitative evolution of research output, impact measures, disciplinary diversity, structural features and internationalisation. Finally, we analyse the contribution of Spanish research on neutron scattering to world output in this field. Main indicators used to study each of the mentioned aspects are defined in the following lines.

- a) Volume and evolution of research output. Which are the main actors in the field? Are they active in the international context? Is there any sign of expansion of the field?
 - Evolution of the total number of documents in the discipline.
 - Evolution of the number of active actors: centres and authors.
- b) Impact indicators. As a proxy for the quality of research, different indicators based on the impact factor of publication journals and citations received by documents are used.
 - Publication strategy. This is the average impact factor of publication journals weighted by the number of papers published in each journal, following Vinkler⁴. Annual JCRs were used⁵.

- Number and percentage of documents in first quartile journals (No.Q1 Doc ; %Q1 Doc.). This includes the absolute number and percentage of documents published in the 25% of the journals with the highest impact factor in each discipline. Annual JCRs were used when available ^a.
- Number of citations per document. It is an indicator of the impact or influence of papers on the scientific community. The number of citations is analysed with different citation windows: several fixed-citation windows (1, 2, 3 and 4 years), and a variable-citation window (from publication date to the last year included in our reference period).
- Relative Impact Factor (RIF). This indicator compares the mean Journal Impact Factor of a specific unit of analysis (in this case, the set of Spanish NS documents in each subject category) with the mean Journal Impact Factor of a reference unit (In this study, total Spanish documents in each subject category in the period of study)
- Relative Citation Rate⁶. This indicator compares the mean number of citations of a specific unit of analysis (in this case, the set of Spanish NS documents in each subject category) with the mean of its publication journal, in order to determine if the unit of analysis' scientific performance is more visible than its journals of publication.
- Relative Rate Cited Document. It compares the percentage of cited documents of a specific unit of analysis (in this case, the set of NS documents in each subject category) with the corresponding value of a reference unit (in this study, the set of Spanish documents in each subject category in the period of study).

c) Disciplinary diversity/Openness of the discipline.

Changes in the thematic profile of research on NS are studied by means of the distribution of papers by JCR subfields, which consist of more than 220 subfields arranged for the purposes of this study into eight large areas (see Gómez et al.¹). Our purpose is to assess the propensity to use NS in an increasing number of research areas over the years through two measures: diversity (number of different subfields) and concentration (as measured with the Pratt index, which ranges from 0 –lowest concentration- to 1 –highest concentration-)⁷.

d) Structural area features. The study of collaborative links between authors and centres is essential to gain insight of the structure of the area. Different aspects are studied:

- Total, national and international collaboration rates.
- Co-authorship index or number of authors per document.
- Collaboration networks through social network analysis (NetDraw software).

^a The 1997 JCR was used for documents published before 1997, since annual JCRs were not available before that year.

- e) Internationalisation of the Spanish scientific community. To analyse the integration of Spanish researchers in the international scientific community, the following aspects are studied:
- % of international collaboration, namely, percentage of documents with at least one foreign centre in the address.
 - Identity and diversity of main foreign partners.
 - % of papers from Spanish scientists in foreign centres. The list of Spanish researchers working abroad was provided by the “Spanish Society for Neutron Scattering Techniques”.
- f) Spanish science in the world. The contribution of Spanish research to world science in terms of number of publications and impact is analysed.

Results

During the 1970-2006 period, the scientific production of Spain on neutron scattering amounts to 1,687 documents with at least one Spanish institution in the address and 435 documents by Spanish scientists working abroad. The production of Spanish researchers working abroad amounts to nearly 20% of the total production during the entire period. More than 96% of the documents are original articles, while reviews represent 2% of the total. The citable items (articles, reviews and notes) constitute 99% of the documents in the entire period (1,668 citable items) and English is the prevailing language, used in 99% of the documents.

An important concentration of production in a few regions is observed, since Madrid, Catalonia and the Basque Country are responsible of 75% of the publications. On the other hand, the specialisation of three regions (the Basque Country, Aragón and Cantabria) on the topic is striking, since their relative contribution to the discipline is 2 to 4 times higher than that of the total Spanish output. As regards institutional sectors, the highest contribution corresponds to Universities (69%), followed by the Spanish National Research Council (CSIC) (36%), being CSIC and CSIC-University joint centres those showing a higher specialisation in the discipline (see appendix for a breakdown of papers by regions and institutional sectors). A high concentration of research and resources within a few specialised centres was also described in other studies on “big science” areas ⁸ and it has been related with the capital-intensive character of the research in the topic.

a) Quantitative evolution of research output and main actors

The first document dates from 1977. Until 1990, the production is very irregular and occasional (33 documents by scientists in Spain and 24 from Spanish scientists abroad), while from 1991 onwards

it follows an almost linear growth in the number of documents (see Figure 1a). The fact that more than 57% of the production of the whole period has been made in the most recent seven years (between 2000 and 2006) is a sign of the important growth of the discipline.

The growth-rate of Spanish publications in neutron scattering is higher than that of the total Spanish production included in the WoS (Figure 1b). Neutron scattering papers show a four-fold increase from the period 1990-1992 to that of 2004-2006, whilst the total number of Spanish papers multiply their number by 2.8. But the highest relative increase corresponds to the production of Spanish scientists from abroad, which is multiplied by 4.5 throughout the period. It is interesting to remark that scientific output from abroad remains quite stable in the most recent years (“plateau” in figure 1), while national publications show a continuous upward trend during the whole period with no signs of saturation.

Figure 1. Evolution of Spanish scientific production in neutron scattering (Web of Science)

a) Evolution of the number of documents

Note: Regression equation for documents by authors in Spain: $y=8.72x-7.35$ ($R^2=0.94$); for documents by authors abroad: $y=2.07x-0.52$ ($R^2=0.77$).

b) Increase in the number of Spanish documents on neutron scattering and in all disciplines (base= period 1990-1992).

Main actors: centres

The increase of production over the years is linked to an important growth in the number of Spanish centres active in the discipline. The number of centres which have published at least one document on the topic rises from 40 (in the period 1991-1994) to 109 centres (during 2003-2006). However, the production tends to concentrate in a few centres, so that 50% of the output comes from only 5 centres in the first period and from 11 centres in the second one. In any event, 33 out of the 40 centres identified in the first period are also active in the most recent years. In fact, more than 80% of the centres involved in neutron scattering research at the beginning of the period have consolidated their position in the area late in the period. Among the most productive centres in the period we can mention two CSIC institutes (the *Institute for Material Sciences* in Madrid and the *Institute for Material Sciences of Aragón*, in Zaragoza) and two University faculties (the *Chemistry Faculty of the Complutense University* in Madrid and the *Science and Technology Faculty of the Basque Country University* in Bilbao).

Main actors: authors

The number of active authors in the field increases from 417 in 1991-1994 to 1,552 in 2003-2006 (a four-fold increase). This growth is higher than that observed for the number of documents (a three-fold increase). However, nearly 65% of these researchers are occasional authors or, in other words, they participate as authors of only one document during the whole period, being this

percentage consistent with that described in other areas⁹. On the other end of the spectrum we identify a core of 10-14% highly productive scientists, who appear in more than one document per year.

Table 1 shows the distribution of authors in three classes by level of productivity: occasional authors, regular authors and highly productive ones. A consistent growth in the population of active authors has been observed over the years, the highest increase corresponding to occasional authors and the lowest to highly productive ones. It is necessary to take into account that both Spanish scientists and foreign collaborators are included in this analysis.

Table 1. Evolution of the number and percentage of authors by four-year periods (WoS)

	1991-1994	2003-2006	% increase
No. Documents	219	579	164%
Total number of authors	417	1,552	272%
Occasional Authors (1 doc)			
Number	265	1,081	308%
% Authors	64%	70%	
Highly productive authors (at least 4 docs)			
Number	59	163	176%
% Authors	14%	10%	
Regular authors (2-3 doc)			
Number	93	308	231%
% Authors	22%	20%	

b) Impact indicators

An upward trend is observed in the prestige of publication journals and in the number of citations received by the documents over the years. The annual evolution of the percentage of documents published in first-quartile journals (Q1) is shown in table 2. A tendency to publish in journals with higher impact is observed. Thus, nearly 80% of the articles published in the recent years appeared in Q1-journals.

Table 2 Evolution in the number of documents published in Q1 journals (WoS 1991-2006)

	1991-94	1995-98	1999-02	2003-06
No. Documents	157	354	495	470
No. Q1 Doc	72	194	359	368
% Q1 Doc	45.86	54.80	72.53	78.30

Which is the more convenient window for collecting citations in this discipline? A short citation window favours fast-aging disciplines with high cited half-lives, while documents in slow-aging disciplines need much more time to be cited. A fast citation pattern in the field of High Energy

Physics was observed in a study by Davidse and Van Raan¹⁰, in which the maximum citation peak for three important international research centres was located between the first and the third year following publication. As regards our study, Figure 2 shows the average number of citations received by documents according to different citation windows: 1, 2, 3 or 4 years following publication. Obviously, the average number of citations per document tends to grow in parallel to the width of the citation window. Interestingly, citation peaks are more clearly identified as the width of the citation window is broadened, although these peaks can be identified for narrow two-year windows. In this study, we use the three-year citation window since it is more sensitive than narrower windows allowing for the evaluation of quite recent results and we noted a good correlation between 3-year and 4-year citations ($R^2=0.94$). This citation window is widely used in existing literature (see for example Glänzel¹¹, Leeuwen, Moed, and Reedijk¹²).

An upward trend over the years in the number of citations per document is observed for Spanish output on neutron scattering and becomes ever more evident as the citation window is expanded. Therefore, not only are the articles published in journals with higher impact, but they also receive, on average, a higher number of citations (Figure 2).

Figure 2. Evolution of the number of citations per document received by publications according to the width of the citation window (WoS 1970-2006)

c) *Disciplinary diversity of research*

The distribution of documents by areas shows that the production is concentrated in Physics (58% of total), followed by Chemistry (40%) and Engineering and Technology (23%). The contribution of other areas is very small. Research in Chemistry shows a significant growth over the years (from 27% in 1991-1994 to 48% in 2003-2006), whilst the contribution of Physics shows a decline (from 70% of documents in 1991-1994 to 51% in 2003-2006) (Figure 3). In each area, publications on neutron scattering tend to be published in journals with a better impact factor than the average Spanish production (RIF>1). It is interesting to remark that the trend to receive more citations than the average Spanish output is observed in the four subject areas shown in table 3. Given the heterogeneous nature of these areas which cover various disciplines with differences in their citation patterns, the analysis at the level of specific categories can be especially timely.

Figure 3 Evolution over time of the thematic profile in Spanish neutron scattering research (WoS 1970-2006)

Table 3 Relative impact by areas (WoS 2000-2006)

Areas	Relative indicators		
	RIF	Relative Citation Rate	Rel.Rate Cited Doc.
Physics	0.96	1.10	1.05
Chemistry	1.25	1.15	1.04
Engineering, Technology	1.83	1.44	1.29
Biomedicine	0.95	2.06	1.17

An in-depth thematic analysis shows that production is distributed among 56 disciplines, being the most important ones by number of documents: Solid-State Physics (34%), Physical Chemistry (24%), Materials Science/Multidisciplinary (19%), and Inorganic and Nuclear Chemistry (13%). The percentage of Solid-State Physics shows a steady decline over the years, whilst the contribution of other disciplines increases (21 disciplines in 1991-1994 vs. 49 in 2003-2006). The high growth-rate of some disciplines such as Inorganic and Nuclear Chemistry (512% increase), Physical Chemistry (318% increase) and Atomic, Molecular and Chemistry Physics (264%) is outstanding and all of them present growth-rates above the average in the field. A slightly lower concentration of production by disciplines is observed in 1991-94 (Pratt index = 0.66) than in 2001-03 (Pratt index=0.78); since in the last period there is a higher number of different disciplines (diversity) but many of them including very low production.

Neutron scattering research tends to be published in journals with higher impact than average Spanish scientific papers in most of the ten most productive disciplines (RIF>1), whilst it receives more citations than the country's average in half of them (relative citation rate>1). Special attention deserves the high relative impact factor of Polymers and the high relative citations of Chemistry/Multidisciplinary.

d) Structural features: basic data on scientific collaboration

On average, the articles related with neutron scattering present around 5 authors and 3 research centres per document, with a slight upward trend over the years (table 4).

Table 4. Evolution over time of scientific collaboration in neutron scattering (WoS 1970-2006)

	< 1987	1987-90	1991-94	1995-98	1999-02	2003-06	Total
No. authors / document	3.33	5.10	4.77	4.78	5.18	5.41	5.10
No. centres / document	2.67	2.57	2.36	2.46	3.06	3.09	2.80
Collaboration rates							
International collaboration	100	80.00	67.42	67.79	77.77	73.28	72.85
National collaboration	0	26.66	22.17	20.34	38.79	41.26	33.31
Without collaboration	0	16.67	25.79	24.58	11.72	15.07	17.49

Note: collaboration rates total more than 100% as national and international collaboration can occur simultaneously in a given document.

Research in neutron scattering presents a high collaboration rate, especially in as far as international collaboration is concerned, which is clearly revealed when the collaboration profile in the area is compared with that of Spanish publications in Physics or in all scientific areas combined (figure 4a). Moreover, during the period 2000-2006, less than 14% of the documents in neutron scattering were carried out by a single institution, against 24% of the total Spanish production in

Physics. As a whole, the field presents a slightly higher national collaboration rate than that of the country's average in Physics (40% vs. 34%), but the international collaboration rate is much higher (75% vs. 59%).

An increase in the percentage of documents in collaboration is observed throughout the reference period under study. As described above, the total number of documents shows a four-fold increase from 1990-92 to 2004-06, which is the same multiplier observed for the number of internationally co-authored documents (x4). Moreover, papers with national collaboration (two or more Spanish centres) display the highest increase (x8) with a large positive slope in the last 10 years (see Figure 4b). This is a sign of the growth of the NS scientific community in the country which not only increases its size but also the relationship between its members and the development of networks that will favour the exchange of knowledge and the consolidation of the field. Growth in the number of documents without collaboration was lower (x3).

Figure 4. Scientific collaboration of Spanish research on neutron scattering: a) Collaboration profile in neutron scattering as compared with Physics and all areas in Spain (WoS 2000-2006); b) Increase in the number of Spanish documents by type of collaboration (base period= 1990-92).

a)

b)

Research in international collaboration presents some specific features, such as the higher number of authors and centres per document. Besides, all research fields are not equally internationalised. Research in Physics is more likely to be carried out with international collaboration, whilst this is less frequent in Chemistry-related areas.

e) Internationalisation

In the period under study collaboration within the European Union clearly prevails (61%), although its relative contribution shows a slight decline over time due to the strengthening of links with other world regions (for instance with the United States, the contribution of which grows from 7% to 10%) (table 5).

Table 5. Trends over time of international collaboration in geographical terms (WoS 1970-2006)

	>1987	1987-1990	1991-1994	1995-1998	1999-2002	2003-2006	Total	%
European Union	3	24	134	210	320	337	1,028	60.94
North America	0	1	16	28	65	61	171	10.14
Latin America	0	0	7	13	45	44	109	6.46
Other European countries	0	0	5	16	8	45	74	4.39
Other countries	0	0	1	23	38	60	122	7.23
Total	3	30	221	354	495	584	1,687	89.15

Spanish scientists maintain collaboration links with many different countries. Major partners who have collaborated in more than 10 documents in the most recent period (2000-2006) are listed in table 6. The position held by France is very striking because its frequency is four times higher than

that of the following country. Attention must be paid to the fact that these major partners differ from those described in other areas of research. Table 6 shows the position of each country in the ranking of partners for neutron scattering (A) and for all scientific areas (B). Most of the countries in the top positions are present in both lists, but there are significant changes in their relative contributions. In this sense, France is Spain's leading partner for neutron scattering research, and French institutions are involved in 55% of Spanish internationally-coauthored documents in the field, whereas collaboration with France represents only 17% of the overall Spanish scientific output (all areas combined). On the other hand, the United States is Spain's leading overall scientific partner (27% of Spanish internationally-coauthored documents), but this partnership accounts only for 14% of Spanish internationally-coauthored documents on neutron scattering. The most striking differences are those referred to France and India, because the percentage of documents with collaboration in neutron scattering is three times higher than the percentage shown when all areas are combined (see activity index –AI– in the last column of table 6). The weight of collaboration between Spain and Argentina is remarkable too.

Table 6. Major foreign partners of Spain in neutron scattering (A) and in all areas (B) (WoS 2000-2006)

Countries	Neutron Scattering (A)			All areas Spain (B)			AI
	Rank	No.Doc.	%	Rank	No.Doc.	%	
France	1	398	54.82	3	13,024	17.16	3.19
United Kingdom	2	109	15.01	2	15,070	19.85	0.76
United States	3	101	13.91	1	20,799	27.41	0.51
Germany	4	97	13.36	4	11,543	15.21	0.88
Argentina	5	51	7.02	12	2,746	3.62	1.94
Italy	6	30	4.13	5	10,478	13.81	0.30
India	7	25	3.44	30	789	1.04	3.31
Switzerland	8	25	3.44	7	3,756	4.95	0.69
Japan	9	24	3.31	16	2,144	2.83	1.17
Russia	10	21	2.89	13	2,606	3.43	0.84
Netherlands	11	20	2.75	6	5,210	6.87	0.40
Sweden	12	18	2.48	11	3,008	3.96	0.63
Brazil	13	16	2.2	17	2,045	2.69	0.82
Portugal	14	13	1.79	10	3,096	4.08	0.44
People Rep. China	15	12	1.65	25	1,231	1.62	1.02
Belgium	16	11	1.52	8	3,620	4.77	0.32
Canada	17	10	1.38	9	3,487	4.59	0.30

Note: The United Kingdom includes England, Scotland, Wales and Northern Ireland. Percentages calculated over the total number of documents in international collaboration.

The high affinity of Spain with specific countries is explained by the presence of special facilities for neutron scattering research in those nations. The main foreign centres which have collaborated with Spain in neutron scattering research are shown in Table 7. Strong collaboration figures with the Institute Laue–Langevin (ILL) in Grenoble (France), which contributes to 36% of the Spanish

production in neutron scattering are particularly noteworthy. Spain has been associated to the ILL for more than 20 years.

Table 7. Main foreign centres which collaborate with Spain in neutron scattering research (WoS 2000-2006)

Centres	Country	No. Doc.	% International Collaboration
Inst Max Von Laue Paul Langevin, ILL	France	264	36.36
CEA Saclay, Lab Leon Brillouin, LLB	France	36	4.96
ISIS-Rutherford Appleton Lab	United Kingdom	35	4.82
KFA Forschungszentrum Julich GmbH	Germany	29	3.99
European Synchrotron Radiat Facility, ESRF	France	25	3.44
Ctr Atom Bariloche	Argentina	22	3.03
Lab Louis Neel, CNRS	France	18	2.48
Inst Natl Sci Appl	France	18	2.48
Paul Scherrer Inst	Switzerland	17	2.34
Argonne Natl Lab	United States	16	2.20
Iowa State Univ	United States	15	2.07
Los Alamos Natl Lab	United States	14	1.93
Univ Cambridge	United Kingdom	14	1.93
Swiss Federal Institute of Technology Zurich	Switzerland	13	1.79
Uppsala Univ	Sweden	13	1.79
Interfac Reactor Inst, Delft Univ Technol	Netherlands	12	1.65
Hahn Meitner Inst Berlin GmbH	Germany	12	1.65
Russian Acad Sci	Russia	11	1.52
Univ Nacl Cordoba	Argentina	11	1.52
Univ Calif San Diego	United States	10	1.38
Inst Sci Mat & Rayonnement	France	10	1.38
Bhabha Atom Res Ctr	India	10	1.38
Univ Paris 11	France	10	1.38

Previous studies have shown positive effects of international collaboration on the impact of research, since documents with foreign partners tend to be published in more prestigious journals and are likely to receive more citations. These findings have been described in different areas and countries^{13, 14}. In the case of the Spanish publications on neutron scattering, the expected and observed impact figures (impact factor, number of citations) are slightly higher for internationally co-authored documents, but the differences are not statistically significant (table 8).

However, the benefits of international collaboration may differ depending on the partner. As we can see in table 8, the highest returns seem to emanate from collaboration with North America, since documents co-authored with this region obtain the highest impact: they are published in more prestigious journals (higher IF) and receive more citations than those conducted in collaboration with other countries or without international collaboration ($p < 0.05$).

Table 8. Influence of international collaboration on the impact of Spanish documents (WoS, 2000-2006)

	No.	Publication Strategy (Mean Impact Factor)	Citation rate (3-year citation window)
Without international collaboration	244	2.64±1.78	4.16±6.10
With international collaboration	720	2.67±1.68	4.64±6.56
European Union	580	2.60±1.66	4.26±5.56
North America	108	3.20±1.93	7.64±10.37
Latin America	79	2.48±1.38	3.25±3.78
Other European countries	49	3.31±1.71	5.37±4.21
Other countries	91	2.46±1.25	5.39±5.77

Notes:

Only regions with more than 50 documents co-authored with Spain are included.

Values expressed in terms of average±standard deviation.

No.Citations/doc: only for documents published in 2000-2004 to allow for a 3-year citation window.

f) Structural features: evolution of the collaboration networks between centres

Collaboration between centres is extremely important in the area, since only 17% of documents between 1970 and 2006 were published by a single institution. What are the main changes occurred in this field's network during the 37-year period under review? An exploratory study by means of social network analysis gives us an interesting insight into this matter. We have taken into account two different periods, namely, 1991-94 and 2003-2006, in order to analyse its evolution.

The number of nodes that conforms the network grew by a factor of three from one period to the other. In both periods two different components are identified and 58% of the nodes are connected. The main component, which is organised around the ILL, includes 71% of the connected nodes in the first period, and 95% in the second one. Although the size of the network grows, its monocentric array based around the ILL remains in the most recent period (table 9).

Table 9. Comparative description of the network among centres in two periods

	1991-1994	2003-2006
Total number of nodes	24	66
Number of isolated nodes (% total number of nodes)	10 (41%)	28 (42%)
Number of connected nodes (% total number of nodes)	14 (58%)	38 (58%)
Number of components	2	2
Number of nodes in the main component	10	36
% nodes of the main component/total number of nodes	41%	54%
% nodes of the main component/total number of connected nodes	71%	95%

Note: only centres with at least 5 documents in collaboration in each period are considered.

Links among Spanish centres tend to increase over the years. Most of the Spanish centres included in the main component of the network in the first period, are also active in the most recent

years with similar collaboration intensity. On the other hand, some actors that were isolated in the first period have seen their relevance enhanced in the most recent years and appear as connected nodes in a component (figure 5). The most important centres in both periods are: the *Chemistry Faculty of the Complutense University* in Madrid, the *Institute of Structure of Matter-CSIC*, Madrid, and the *Institute of Material Sciences-CSIC-U.Zaragoza*. In the latter period a network unit formed by three Basque institutions (the *Chemistry Faculty of the Basque Country University*, the *Donostian Institute of Physics* and the *Unit of Physics of Materials in San Sebastián*) and the *German Forschungszentrum Jülich*, has emerged.

Table 10. Comparative description of the main component of the network in two periods

	1991-1994	2003-2006
Degree Network Centralization	72.22%	59.50%
Closeness Network Centralization	75.96%	67.46%
Betweenness Network Centralization	70.68%	83.07%
Density	0.311	0.095
Average distance	1.800	2.456

Centrality measures (degree, closeness, betweenness) provide a good indicator for communication levels and knowledge flows among centres. Degree centrality refers to the number of nodes to which an actor is adjacent and reflects the potential communication activity of the nodes. Considering the main component, a trend towards less centrality is observed through different indicators. The degree falls considerably, because the number of nodes included in the component increases, but the new nodes are located in the periphery and the monocentric array of the network remains unchanged. Other findings include: an increase of the average distance, which indicates the effort required from an actor to liaise with another one; density loss, as a measurement of network cohesion in terms of the number of real links as against the total number of potential links between network nodes; and closeness reduction, which measures the distance between each actor and the rest of actors in the network (table 10).

With regard to the position of the nodes in the network, the centrality of the ILL is remarkable, since this node presents the highest centrality in the two periods when measured through any of the selected variables—degree, closeness and betweenness—. Among Spanish centres, the highest centrality corresponds in both periods to the *Institute of Material Sciences-CSIC* in Madrid. In recent years the centrality of some foreign centres declines (this does not apply to the ILL) due to the surge in relative values of some active Spanish centres.

The network maintains its monocentric layout in the second period, but new elements are included in the periphery which collaborates with some of the established actors. The degree and closeness centrality of the main centres of the network tend to decrease slightly, while their betweenness

grows due to the emergence of new active centres in the periphery of the network. Due attention should be paid to the influence of geographical proximity in the establishment of links among nodes, causing centres located in the same region to be more likely to collaborate.

Figure 5. Changes over time in the collaboration networks among centres (only centres with more than 4 documents in collaboration)

g) *World context*

What is the contribution of Spain to the world output in neutron scattering? An exploratory study was conducted to establish the global position of Spain in the international scene according to its contribution to research in neutron scattering. The most active countries in this research field were identified in the Web of Science database searching for those documents containing the term “neutron” in their title. Although the effectiveness of this search without expert validation is limited, we consider it provides a useful approach to the relative contribution of countries in this regards.

Two different time periods were selected: 1991-94 and 2003-2006 with the aim of identifying possible changes in the relative position of countries over the years (table 11). The US was the most productive country in the two periods (28% of world output in the subject), followed, in the first period, by France and Germany; and by Japan, France and Germany in the second one. The highest increase in number of publications corresponds to South Korea and China, the production of which has dramatically risen in all fields over the last years (see for example, National Science Board¹⁵). Spain also shows a high growth rate, its contribution mounting from 1.5% to 3% of world output (from the 17th to the 11th place in the ranking of most productive countries). Moreover, it must be pointed out that Spain is the 2nd most productive country among countries lacking a neutron source on national soil.

Table 11. Ranking of the most productive countries in neutron scattering techniques in two periods

	1991-94		2003-06		%change
	No.Doc.	%	No.Doc.	%	
US	1,949	27.91	2,303	27.58	18
JAPAN	815	11.67	1,314	15.74	61
FRANCE	1,114	15.96	1,283	15.37	15
GERMANY	964	13.81	1,253	15.01	30
UK	879	12.59	935	11.20	6
RUSSIA ^c	-	-	875	10.48	-
ITALY	300	4.30	616	7.38	105
CHINA	131	1.88	408	4.89	211
SWITZERLAND	203	2.91	369	4.42	82
POLAND	164	2.35	319	3.82	95
SPAIN	106	1.52	258	3.09	143
INDIA	178	2.55	251	3.01	41
SWEDEN	136	1.95	235	2.81	73
NETHERLANDS	182	2.61	233	2.79	28
CANADA	193	2.76	224	2.68	16
SOUTH KOREA ^b	26	0.37	206	2.47	692
BELGIUM	98	1.40	205	2.46	109
AUSTRALIA	93	1.33	191	2.29	105
CZECH.REP. ^c	-	-	153	1.83	-
AUSTRIA	115	1.65	134	1.60	17
HUNGARY	62	0.89	119	1.43	92
DENMARK ^a	131	28.04	-	-	-
WORLD	6,982	100	8,349	100	20

Source: Web of Science (search in January 09). Citations since publication date till search date.

^a not included among the most productive countries in the second period

^b not included among the most productive countries in the first period

^c follow-up not possible due to changes over time concerning the legal status of the country

As regards the impact of publications, the distribution of countries according to the average number of citations received in the two periods under analysis is shown in figure 6. Higher citation rates are observed in the first period due to the broader citation window. Countries in the upper right area show impact values above world average in both periods, whilst those in the bottom left area are below world average. Some of the countries with a high growth-rate in the number of publications, such as China, are still below world average in impact, while others show above average results for the most recent period (Poland, Sweden). It is interesting to highlight the position of Spain in the upper right area of Figure 6, reflecting that the average number of citations per document for Spain is above world average in both periods. If we restrict our scope to the 11 most productive countries for the 2003-2006 period, Spain was 4th by number of citations per document, after the US, the UK and Italy.

Figure 6. Chart of the most productive countries in 2003-06 according to their impact in two different periods

Note: AUS=Austria; AUST=Australia; BEL=Belgium; CAN=Canada; CHIN=China; FRA=France; GER=Germany; HUN=Hungary; IND=India; ITA=Italy; JAP=Japan; NETH=Netherlands; POL=Poland; SKOR=South Korea; SPA=Spain; SWE=Sweden; UK= United Kingdom; US= United States. Quadrants defined by world average number of citations per document.

Discussion and conclusions

The study of neutron scattering scientific output on the five dimensions proposed has proved useful to gain an in-sight into the state of development of the discipline in Spain. NS documents published by Spanish scientists during the past three decades show a positive growth both in quantity and international visibility. This is a dynamic internationally-oriented field, whose main findings are summarised below.

Fast-growing field

Neutron scattering research is a relatively young field in Spain, since very few publications from Spanish researchers were published before the 1990s. However, as described by Fernández-Barquín et al.³, pioneering researchers in the area were trained in foreign centres during the 1980s and their work was essential for the initial development of the field. .

Since the early 1990s until now, the growth rate of the field is higher than that of the overall Spanish scientific production during the same period. In fact, since the 1990s to the present date, Spain has improved its position in the world ranking by number of documents on neutron scattering research, from the 17th to the 11th place. Spain contribution to world output in neutron scattering is 3%, being this percentage similar to that described for the country's contribution to overall world output.

The takeoff of Spanish production took place after Spain became, in 1987, an associated scientific member of the Institute Max von Laue-Paul Langevin (ILL), which is an international reference centre in neutron scattering research. Other decisive factors have been the creation of the “*Users Commission*” in Spain, which is an advisory body providing advice in the discipline to the Spanish Administration, and the establishment in 1997 of the “*Spanish Society of Neutron Scattering*” (<http://www.icmab.es/setn/>), with a current membership of over 250 members. The Society has been a cornerstone for the consolidation and institutionalisation of the discipline in Spain, since it has contributed to foster communication among Spanish scientists in the field.

The growth in production is strongly related to the *increase in the number of active authors and centres, and in the links that bind them together*. Our study shows that the most active *centres* tend to consolidate their leading position increasing their production consistently over the years, while new centres make inroads and become new members of emerging networks. Most of Spanish active centres operate in the framework of Universities or belong to the CSIC, with low involvement of companies. Neutron scattering techniques are highly

specialised, thus leading to a high concentration of research in specific centres. However, the fact that the main increase is due to occasional authors may indicate a wider base of users who use neutron scattering techniques occasionally in their research projects. This would suggest that these techniques are being increasingly applied in diverse research fields, entailing positive growth for the discipline. Specific scientific policy measures are needed to promote research from different types of neutron scattering users: scientists whose research is focused on the issue, regular scientists who frequently use these techniques, and occasional users. Moreover, fostering participation by industry stakeholders is a current objective to be pursued.

Thematic diversity and openness

A moderate level of concentration of publications over a few disciplines is observed and tends to increase slightly over the years. However, documents are published in a wider range of different disciplines in the most recent years, so the *thematic diversity* of NS research has been growing. Accordingly, some disciplines include the “basic core” of research in NS, but these techniques are applied in the context of an increasing number of different disciplines and with different purposes. We have identified an increase in Chemistry-related research and a relative decline in Physics. Promoting the use of neutron scattering in disciplines other than Physics was a recommendation included in the last survey of the ENSA report commissioned by the ESF to evaluate different aspects of research in this field¹⁶. The broadening of the user base is deemed to be beneficial for scientific research but also for the development of industrial applications and for society at large.

Structure of the field

Scientific collaboration plays a very important role in the development of this field. The strengthening of national links has contributed to the generation and consolidation of networks within the country; whilst international links, that are present in nearly 70% of the documents, have made the integration of Spanish researchers in the international scientific community possible. Our survey reveals the existence of a *radial network* around neutron scattering facilities, and especially around the ILL, a top-tier source in Europe.

The major role played in the area by large facilities devoted to neutron scattering explains the strong international collaboration pattern observed, since Spain does not host any of these facilities. Many publications and, in particular, those with a strong connection with Physics-related issues, are conducted in collaboration with foreign scientists and, in some

cases, result from stays of Spanish researchers in one of these centres. Even for documents without apparent international collaboration (there is no foreign centre in the authors' work address) links with foreign centres have been detected, such as a mention on the development of experiments or the use of data obtained at a foreign neutron source^b. A sign of the importance of international collaboration is that it is already present in the small number of documents published before the 1990s, and that even in those years, there were papers written by Spanish scientists working abroad, maybe because Spain lacked consolidated research groups and the first generations of scientists were trained abroad. At present, there is still a high dependence on the large facilities existing in a few countries to develop research, but there are consolidated groups in Spanish centres which collaborate nationally and internationally to conduct research on this field. In the last decade, 8 out of every 10 documents written by Spanish researchers had at least one Spanish address, six of them with international collaboration, whereas the other two were written by Spanish researchers abroad.

France, which is Spain's leading partner in this field, is present in half of the Spanish documents with international collaboration. This is due to the fact that France hosts some of the major facilities for the discipline and, in particular, the ILL. The presence of Spanish researchers at the French centre has been promoted by the Spanish Public Administration and has led to the creation of a special group within the ILL named '*Spanish Initiatives on Neutron Scattering*' (SpINS-ILL). This study shows that Spanish scientists are highly dependent on the ILL for the development of their research. Although new centres have been added to the network over the years, thereby enlarging it and also the number of links among Spanish institutions, the radial structure around ILL still prevails, with this centre remaining as a basic structural element of the network.

As for the scope of collaboration, mention should be made of the fact that Spanish researchers tend to collaborate with EU countries in 61% of their publications and only in 14% of them with the US, being this last percentage a lower figure than in other fields (20%). The existence of an active European Neutron Scattering Association (ENSA) (<http://neutron.neutron-eu.net/>) that groups the main national associations in this field at European level and organises different regular activities and conferences has to be taken into account. This association promotes and supports research in this discipline, coordinates the development of new facilities, and encourages the development of links with industry and society. Accordingly, this is an element which promotes cohesion and

^b Several authors mention in a document sentences such as the following: "The experiment was performed using the D20 instrument of the Institute Max von Laue–Paul Langevin (ILL), in Grenoble, France"; other authors include in the acknowledgements section: "We thank ESRF [European Synchrotron Radiation Facility] and, in particular, BM29 staff for granting beam time and assistance during the experiment."

integration among European countries, thus favouring regional links against intercontinental ones.

Research impact

Our study reveals an *upward trend in the observed and expected impact* of scientific production, since researchers tend to publish their papers in more prestigious journals and receive more citations in recent years. Furthermore, papers from Spanish scientists obtain an impact above world average in this field.

Although a higher impact has been described in literature for research developed in international collaboration (see for instance Bordons et al.¹⁷; Vogel¹⁸; Van Raan¹³; Rovira, Senra, and Jou¹⁹; Glanzel and Schubert²⁰; Leta and Chaimovich²¹; Ma and Guan¹⁴), no significant differences in impact were found in our study stemming from the presence or absence of foreign centres in the publications. Internationally co-authored documents showed a higher number of authors and centres per document, which according to literature may well cause an increase of the citations received by documents in the long term (Katz and Martin²²), but this was not the case in our study.

A possible explanation is that research in this field is highly dependent on international collaboration, whilst in other disciplines the latter is frequently limited to the most prestigious scientists or groups. Similarly, no higher impact in international collaboration was found either in a former study in Physics (Royle et al.²³) where its authors pointed out that the decisive factor was not international collaboration itself, but the capacity of cooperating with well-connected agents (Tang and Shapira²⁴). In this sense, we must note the higher expected and observed impact identified for Spanish publications in collaboration with North American centres. This result strongly supports the case for encouraging these ties, which are weaker in this discipline than in other research fields.

Also small science?

Although neutron scattering research is highly dependent on special facilities, our data show that some research conducted in the area does not present the typical features of big science, such as international collaboration or an outstandingly high number of authors per document. It would seem that there is also some kind of “small science” being developed within this field in academic settings, which mainly corresponds to theoretical studies on neutron scattering. This is coherent with the findings of other authors concerning Mexican science in Elementary Particle Physics²⁵.

Are Spanish scientists well-integrated in the international scientific community?

Different factors support the internationalisation of Spanish science, such as the high international collaboration rate or the increasing presence of Spanish scientists working abroad. Moreover, other important facts include the involvement of Spanish scientists as participants in the main conferences of the discipline (*European Conference on Neutron Scattering*, *American Conference on Neutron Scattering*), as members of scientific committees or as members of panels for the evaluation of experiments in main European neutron sources (Fernández-Barquín et al.³). Curiously enough, Spanish scientists are seldom present in American committees (we checked the three last editions of American conferences), maybe due to the important role played by the main societies and facilities in the development of research within their own areas of influence.

In summary, neutron scattering research is currently in a phase of strong development in Spain, both in quantitative and qualitative terms, with an impact above world average and a high concentration of the activity in some specialised centres. The development of this field has been closely connected to growing access of Spanish researchers to existing neutron sources across the world, which play a structural role in this particular field. The installation of a new European spallation neutron source would become an unquestionable incentive for the development of competitive and high-quality research in this field (ESF¹⁶). It would change the structure and dynamics of the research networks in the field, as well as yield scientific and economic benefits not only for the host country, but also for all European states and for society at large.

Appendix 1. Scientific publications by Spanish autonomous communities (WoS 2000-2006)

Autonomous Communities	Neutron Scattering		All areas		AI
	No.Doc.	%	No.Doc.	%	
Madrid	358	36.91	62,954	28.34	1.30
Catalonia	193	19.9	54,888	24.71	0.81
Basque Country	167	17.22	8,914	4.01	4.29
Andalusia	112	11.55	32,326	14.55	0.79
Aragon	105	10.82	7,648	3.44	3.15
Valencian Community	51	5.26	24,995	11.25	0.47
Cantabria	38	3.92	3,633	1.64	2.39
Galicia	30	3.09	14,604	6.57	0.47
Castile and Leon	23	2.37	10,471	4.71	0.50
Asturias	21	2.16	6,480	2.92	0.74
Navarre	17	1.75	5,234	2.36	0.74
Canary Islands	13	1.34	6,994	3.15	0.43
Extremadura	8	0.82	3,034	1.37	0.60
Murcia	7	0.72	5,884	2.65	0.27
Castile-La Mancha	2	0.21	3,863	1.74	0.12
La Rioja	1	0.1	720	0.32	0.31
Balearic Islands	0	0	2,978	1.34	0
Total	970		222,123		

AI= Activity index: it analyses the specialization of a region/sector in neutron scattering research. It is calculated as the ratio between the contribution of a region/sector to the Spanish production in neutron scattering and the contribution of that region/sector to the whole Spanish production.

Appendix 2. Scientific publications by Spanish institutional sectors (WoS 2000-2006)

Institutional Sectors	Neutron scattering		All Areas in Spain		AI
	No.Doc.	%	No.Doc.	%	
University	674	69.48	135,252	60.89	1.14
CSIC	350	36.08	30,505	13.73	2.63
CSIC-University	187	19.28	10,509	4.73	4.08
Non-profit organizations	55	5.67	9,869	4.44	1.28
Other Public Research Centres	4	0.41	6,833	3.08	0.13
Industry	4	0.41	8,161	3.67	0.11

References

1. GÓMEZ, I., FERNÁNDEZ, T., BORDONS, M., MORILLO, F., GONZÁLEZ-ALBO, B., FILIPPO, D. DE, HERRERO, M., APARICIO, J. (2007). Producción científica de los investigadores españoles en técnicas neutrónicas: (Web of Science, 1970-2006). Report. Madrid: CINDOC-CSIC.
2. CAMPO, J. (2007). La investigación en España con Técnicas Neutrónicas: un informe preliminar. Sociedad Española de Técnicas Neutrónicas.
3. FERNÁNDEZ BARQUÍN, L.; ARBE, A.; BERMEJO, F.J.; CAMPO, J.; CUELLO, G.J.; GARCÍA MUÑOZ, J.L.; GARCÍA SAKAI, V.; GORRIA, P.; GUTIÉRREZ, G. (2008). Veinte años de investigación con técnicas de neutrones en España. Revista de la Sociedad Española de Física, 22(4), noviembre-diciembre. <http://rsef.uc3m.es/images/REF/vol22n4/4.pdf>.
4. VINKLER, P. (1997) Relations of relative scientometric impact indicators. The relative publication index. *Scientometrics* 40(1):163-169.
5. JOURNAL CITATION REPORTS (1997-2006). Philadelphia: Thomson Reuters.
6. SCHUBERT, A.; BRAUN, T. (1986). Relative indicators and relational charts for comparative assessment of publication output and citation impact. *Scientometrics* 9(5-6): 281-291.
7. PRATT, A.D. (1977). A measure of class concentration in Bibliometrics. *Journal of the American Society of Information Science* 28: 285-292.
8. IRVINE, J.; MARTIN, B.R. (1985). Evaluating Big Science: CERN's past performance and future prospects. *Scientometrics* 7(3-6): 281-308.
9. LOTKA, A.J. (1926). The frequency distribution of scientific productivity. *Journal of the Washington Academy of Science* 16: 317-123.
10. DAVIDSE, R. J. ; VAN RAAN, A. F. J. (1997). Out of particles: Impact of CERN, DESY and SLAC research to fields other than Physics. *Scientometrics* 40(2):171-193.
11. GLANZEL, W. (1997) On the Possibility and Reliability of Predictions Based on Stochastic Citation Processes. *Scientometrics*. 40(3):481-492.
12. LEEUWEVEN, T. N. Van; MOED, H. F.; REEDIJK, J. (1999) Critical Comments on Institute for Scientific Information Impact Factors: a Sample of Inorganic Molecular Chemistry Journals. *Journal of Information Science*. 25(6):489-498.
13. VAN RAAN, A. F. J. (1998). The influence of international collaboration on the impact of research results. Some simple mathematical considerations concerning the role of self-citations. *Scientometrics* 42(3):423-428.
14. MA, N.; GUAN, J. C. (2005). An exploratory study on collaboration profiles of Chinese publications in Molecular Biology. *Scientometrics* 65(3):343-355.
15. NATIONAL SCIENCE BOARD (2008). Science and Engineering Indicators. Arlington, VA: National Science Foundation.
16. EUROPEAN SCIENCE FOUNDATION (2007). The ESF/ENSA Survey 2005 of the Neutron Scattering Community in Europe. France: ESF.
17. BORDONS, M.; GOMEZ, I.; FERNANDEZ, M. T.; ZULUETA, M. A., MENDEZ, A. (1996). Local, domestic and international scientific collaboration in biomedical research. *Scientometrics* 37(2):279-295.
18. VOGEL, E. E. (1997). Impact factor and international collaboration in Chilean Physics: 1987-1994. *Scientometrics* 38(2):253-263.

19. ROVIRA, L.; SENRA, P.; JOU, D. (2000). Bibliometric Analysis of Physics in Catalonia: towards quality consolidation? *Scientometrics* 49(2):233-256.
20. GLANZEL, W.; SCHUBERT, A. (2001). Double Effort = Double Impact? A critical view at International co-authorship in Chemistry. *Scientometrics* 50(2):199-214.
21. LETA, J.; CHAIMOVICH, H. (2002). Recognition and international collaboration: the Brazilian case. *Scientometrics* 53(3):325-335.
22. KATZ, J. S.; MARTIN, B. R. (1997). What is research collaboration? *Research Policy* 26(1):1-18.
23. ROYLE, J.; COLES, L.; WILLIAMS, D.; EVANS, P. (2008). Publishing in international journals - an examination of trends in Chinese co-authorship. *Scientometrics* 71(1):59-86.
24. TANG, L.; SHAPIRA, P. (2008). Research collaboration in Nanotech research: a case study of China. PRIME Winter School on emerging nanotechnologies; PINSOT (Allenrand).
25. COLLAZO-REYES, F.; LUNA-MORALES, M.; RUSSELL, J. (2004). Publication and citation patterns of the Mexican contribution to a "Big Science" discipline: Elementary Particle Physics. *Scientometrics* 60(2): 131-143.