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How physics works: scientific capital in the space of physics institutions

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Abstract This paper investigates the social space of physics research institutions. Scientific capital is a well-known concept for measuring and assessing the accumulated recognition and the specific scientific power developed by Pierre Bourdieu. The scientific capital of a physics research institution manifests itself as a reputation, a high-profile name in the field of physics, symbols of academic recognition, and scientific status. Using citation statistics from the Web of Science Core Collection and sociological data of dedicated survey "The Monitoring of the Labor Market for Highly Qualified R&D Personnel" we construct the social space of Russian physics institutions. The analysis reveals generalized grounds of social space of Russian physics institutions: principles of visibility and scientific capital. The study highlights internal differentiation of physics institutions on three groups ("major", "high energy", and "secondary" institutions). The social space of physics research institutions provides a map of field of physics in Russia. This research may be a useful starting point for developing a more comprehensive study of the field of physics.

Keywords Scientific capital · Scientometrics · Sociology of science · Physics research institutions

Mathematics Subject Classification 91D30 · 91D99

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Introduction

Physics has a crucial part to play in the present state of science. To understand how modern physics functions, we need to explore the aggregate of physics research institutions (PI). From a Bourdieusian framework and using the idea of social topology, indicated aggregate can be conceptualized as "a space (with several dimensions) constructed on the basis of principles of differentiation or distribution [and] constituted by the set of properties active within the social universe in question, i.e. capable of conferring strength, power within that universe, on their holder" (Bourdieu 1985, pp. 723–724). Such space is comprised of a system of relations between scientific positions. This means that knowledge of the position of an institution in the space indicated above provides information on the properties inherent in the given institution and its relationship with other institutions. The relational way of thinking about the space of science led Bourdieu to the concept of "scientific field" (Bourdieu and Wacquant 1992, p. 96), which is both "a system of objective relations between positions already won (in previous struggles)" and a "battlefield" of "a competitive struggle, in which the *specific* issue at stake is the monopoly of *scientific authority*, defined inseparably as technical capacity and social power" (Bourdieu 1975, p. 19). [A nice general reference book for Bourdieu's concepts is Grenfell (2012).] Conceptually, Bourdieu makes three claims about the nature of the scientific field:

1. scientific authority, or a structured field of social forces [which imposes itself on scientific "agents, that to say the isolated scientists, teams or laboratories" (Bourdieu 2004, p. 33)],
2. a locus of a competitive struggle for resources, or capital, takes place between unequally positioned agents,
3. the capacity to exercise a degree of autonomy, "that is, the capacity it has gained, in the course of its development, to insulate itself from external influences and to uphold its own criteria of evaluation over and against those of neighbouring or intruding fields (scientific originality versus commercial profit or political rectitude, for example)" (Wacquant 2008, p. 269).

Furthermore, the scientific field is a structured space of scientific positions, which are determined "by their situation in the structure of the distribution" of specific capital the possession of which provides access to scientific benefits and influence (cf. Bourdieu and Wacquant 1992, p. 97). In other words, the scientific field is held together through the concept of scientific capital (SC; Bourdieu 1997, pp. 14–21). SC—defined as that which allows an agent to make substantial achievements—offers many attractive features for the sociology of science and scientometrics.

Theoretically, the scientific field is structured and gives rise to SC, and at the same time is transformed and reproduced through the distribution of SC (cf. Bourdieu 1985, pp. 724–725). SC takes its form and content from the scientific field within which it is used. SC is country-specific and its currency varies across different national social spaces.

Many studies have empirically tested Bourdieu's approach to SC (Bourdieu 1988; Brosnan 2011; Garforth and Kerr 2011; Hong 2008; Lebaron 2001; McGuire 2011; Panofsky 2011; Ruget 2002; Sidhu et al. 2014). For critical analyses of this approach, see Archer et al. (2015), Bellotti (2011), Brubaker (2005), Calhoun (1993), Camic (2011), Coradini (2010), Lebaron (2009), Lebaron (2003), Sismondo (2011). SC is also presented as the sum of knowledge and work-relevant skills, social links, and resources (Corolleur et al. 2004; Bozeman et al. 2001; Bozeman and Corley 2004; Dietz and Bozeman 2005;

Lin and Bozeman 2006). However, Bourdieu's version of SC—which has an integral character and strives to eliminate the contradictions between micro- and macro-sociological analysis, agents, and structures seems preferable. Continuing Bourdieu's line of reasoning, SC can offer a conceptual bridge between sociology and scientometrics.

Purpose

The aim of this paper is to construct the Russian social space of PI, or the field of physics (FP) in Russia. To achieve this goal, we explore citation statistics of PI and integrate them together with sociological data within a SC framework. Note that we use two interpretations for the abbreviation FP: as the Russian social space of PI and as the field of physics in Russia. In essence, such a dual interpretation is quite acceptable and does not lead to confusion.

Bibliometric data are traditionally used in sociological studies of science (Cole and Cole 1981; Zuckerman 1996; Bornmann and Daniel 2008). However, the problem of integrating bibliometrics and the sociology of science is rarely examined (Gläser and Laudel 2001, 2007). Many authors agree that scientometric studies are often based on uncertain or fuzzy models of science (Leydesdorff 1998; Small 1998). We proceed from the assumption that bibliometric data provide an important source of information on the relations between PI, and can therefore be used to construct the social space of these institutions, i.e. FP. The proper structure of the FP is related to a specific configuration of PI. The PI in the FP are put into objective relations, determined by the distribution of SC and by corresponding information processes.

SC appeared as a result of the development of scientometrics. It is undoubtedly true that citation analysis remains to this day the simplest and most successful area of scientometrics. Nevertheless, in recent decades, scholars studying bibliometric distributions noticed that a significantly richer scientometric structure is concealed behind citations. This is what many sociologists call the "social structure of science", for which we shall use the term SC.

Scientific capital

The conceptualization of SC is related to "the set of actually usable resources and powers" (Bourdieu 1984, p. 114). In general, SC may be defined as "accumulated labor...which, when appropriated on a private, i.e. exclusive, basis by agents or groups of agents, enables them to appropriate social energy in the form of reified or living labor" (Bourdieu 2002, p. 280). According to Bourdieu, SC is a configuration of active properties (active in the sense that the properties represent a field of forces) that provide the agent with authority, recognition, influence, and power in a given scientific field (Bourdieu 2004, pp. 55–58). SC tends to set ensembles of active properties (hereafter we use the notation AP) of agents within the social structure of the scientific field.

Bourdieu's concept of SC exhibits three principal characteristics:

1. SC expresses the emergent quality of the set of collective and individual agents' AP. The SC is examined as an attribute of unified scientific field.
2. Understanding SC as an integral configuration of AP is tantamount to rejecting single-variant analysis based on "*linear thinking*, which only recognizes the simple ordinal

structures of direct determination, and endeavors to reconstruct the networks of interrelated relationships which are present in each of the factors" (Bourdieu 1984, p. 107). SC is a system of AP in which each quality strengthens the others.

3. The AP are the efficient characteristics "that are selected as principles of construction" of the scientific field, and "are the different kinds" of SC (Bourdieu 1985, p. 724).

The AP are allowed to operationalize as socially significant resources in the production of scientific knowledge. Here, we refer to resources that regularly result in a specific gain, a stake in the scientific game bounded by the FP, and that endure for a long period. Bourdieu's usage of the concept of "social energy" is a metaphorical but fruitful extension of SC. In this type of interpretation, SC determines the chances of an agent's attaining recognition or an administrative post. From this perspective, maximizing SC can serve as the conceptual focus of the FP. This principle is naturally reflected in the variational principle, which can roughly be described as follows: under quasi-steady-state conditions, among all the possible configurations of AP, the observed configuration maximizes SC. In this case, it should be borne in mind that each agent may have his or her own variational principle, whose applicability is limited by his or her position in the FP and his or her social trajectory. Thus, the agent's AP attain a configuration corresponding to the maximum SC allowable for his or her scientific position and social trajectory. Typically, SC is maximized not as a result of rational planning but *post factum*. The variational principle does not require rational behavior from the agent. Maximizing SC is the result of the determinations of social structures and of the practical character of the agent's actions.

Our presentation of a mathematical model of SC follows (Katchanov and Shmatko 2014). The details of this model are quite cumbersome, but the big picture is simple. The big picture is that the there is a rule $\varphi : f(\cdot) \mapsto \mathrm{SC}$ for determining a number $\mathrm{SC}(f)$ from a function $f(\varrho)$. Here the function $f(\varrho)$ takes each agent to the empirical probability density function of social differences ϱ. The view of scientific agents as points in some space of AP equipped with the Kolmogorov metric is well-defined. In our approach the random variable ϱ corresponds to a set of realizations of the Kolmogorov distance between a given agent and all other agents within a given sample. Intuitively, FP can be regarded as a network which consists of social differences between scientific agents. This is natural treatment of FP since social differences can be interpreted as social relations. The exact form of φ, i.e. the actual rule for attaching a value to SC for the random variable ϱ, may be obtained by the following variational principle: among all admissible $f(\varrho)$, the function $\hat{f}(\varrho)$, which actually describes social differences of a given scientific agent, is assigned in such a way that the "energy functional" reaches its minimum. For more details, the reader is referred to Katchanov and Shmatko (2014). The proposed model embraces the interrelations between isolate sociological variables, providing a quantified sociological view of SC.

Data and methods

The present study focuses on the 39 PI that are part of the Russian Academy of Sciences, or have been at various times (see Table 1 of Appendix 4). In this study, we used two sources of information to establish a profile for each institution.

Bibliometric data

1. Bibliometric data were extracted from the Web of Science Core Collection of Thomson Reuters (Web of Science). A publication is associated with Russia if it is listed in the affiliated address of the author or one of the co-authors. Authors' affiliations provide information on the institutions where the paper was written. A major problem when dealing with such data is the inconsistency of the information. Web of Science data have no unique organization identifier therefore institutions' names must be disambiguated. The cleaning process had two steps. First, we cleaned and standardized the address data. The data were processed by OpenRefine, a tool for processing and cleaning messy data. The second stage involved a manual check. Authors affiliated with these institutions published 41,321 papers, which accounts for 20.5 % of total Russian publications in the Web of Science in 2008–2013.
2. Data on highly cited authors were extracted from the "Expert Corpus". This is a database of Russian highly cited scientists who work in the fields of physicsm astronomy, chemistry, and other natural sciences.

Sociological data

Our analysis of SC among Russian doctorate holders (DH) is based on the data from the survey "Monitoring of the Labor Market for Highly Qualified R&D Personnel" conducted by the Institute for Statistical Studies and Economics of Knowledge, National Research University Higher School of Economics, Moscow. Part of the international project "Careers of Doctorate Holders" (CDH; Auriol 2007, 2014; Auriol et al. 2013), the Russian panel survey aims to monitor the professional shifts and achievements of DH. Russia took part in two previous rounds of data collection for the CDH survey (2010 and 2013). The questionnaire and the sample were approximately the same in 2010 and 2013 (see details of Appendix 1). Of the 39 PI listed in Table 1 (Appendix 4), we surveyed 1524 DH. Using the indicators that Bourdieu employed in his investigation of the French scientific field (Bourdieu 1988), we developed 35 variables to operationalize the SC of the respondents (see Appendix 2). Values for respondents' SC were calculated as per (Katchanov and Shmatko 2014).

Methods

The empirical distribution of SC can be approximated as the 3-parameter lognormal ($\sigma = 0.0092$, $\mu = 2.206$, $\gamma = -8.375$). The assumption that SC is distributed according to the 3-parameter lognormal law was tested using the Kolmogorov–Smirnov goodness-of-fit test. The value of criterion z was 0.0183 with a goodness of fit p value of 0.692. Therefore, we can not reject the null hypothesis of the statistical 3-parameter lognormal distribution of SC.

Henceforth, we use SCI to denote the SC of a given research physics institution. To estimate the SCI, one should study the SC of all its scientific personnel. However, in practice it is difficult to implement. The sample realization of SCI is only the evaluation of SC of the physics institution at the level adopted. The possible values $SCI_1, \ldots, SCI_{39}$, can be regarded as points in the space X. Consider the matrix D of pairwise distances, in the space X, between Russian PI:

$$D = \left(d_{ij}\right)_{i,j=1}^{i,j=39}. \tag{1}$$

In this paper, the distances d_{ij} between Russian PI are computed as set-set distances

$$d_{ij} = \inf\left\{\xi_i \in I, \xi_j \in J : \left|\xi_i - \xi_j\right|\right\}, \tag{2}$$

where ξ_i and ξ_j denote the values of SC for the respondents that we have taken from the physics institution I and from the physics institution J, respectively. To determine the one-dimensional configuration of Russian PI in the space X, we used the ALSCAL procedure (Takane et al. 1977), found in IBM SPSS Statistics 20. We interpret this configuration (see Fig. 1) in a broader sense as the sociological variable that indicates the SCI. It is intuitive that SCI is related to the number of star researchers. Indeed, these two variables are significantly correlated (the Pearson's correlation coefficient r is equal to 0.595, while the significance level p is 0.000, see also Fig. 2).

On the other hand, we think that "above" each point of X is another space, called a scientometric. We must also associate a vector $\eta_i = \left\{\eta_i^{(1)}, \ldots, \eta_i^{(19)}\right\}$ of values of the 19 scientometric variables (see variable list in Appendix 3) with each physics institution. A space Y consists of the set of all vectors η_i. Moreover, to build the FP, it is simplest to look at the space consisting roughly of vectors η_i from the scientometric space Y yet equipped with weights that are based on the distances d_{ij} between PI in the space X. More concretely, let $\Omega = \left(\omega_k\right)_{k=1}^{k=39}$ be the empirical space of Russian PI endowed with the weighted Euclidean norm:

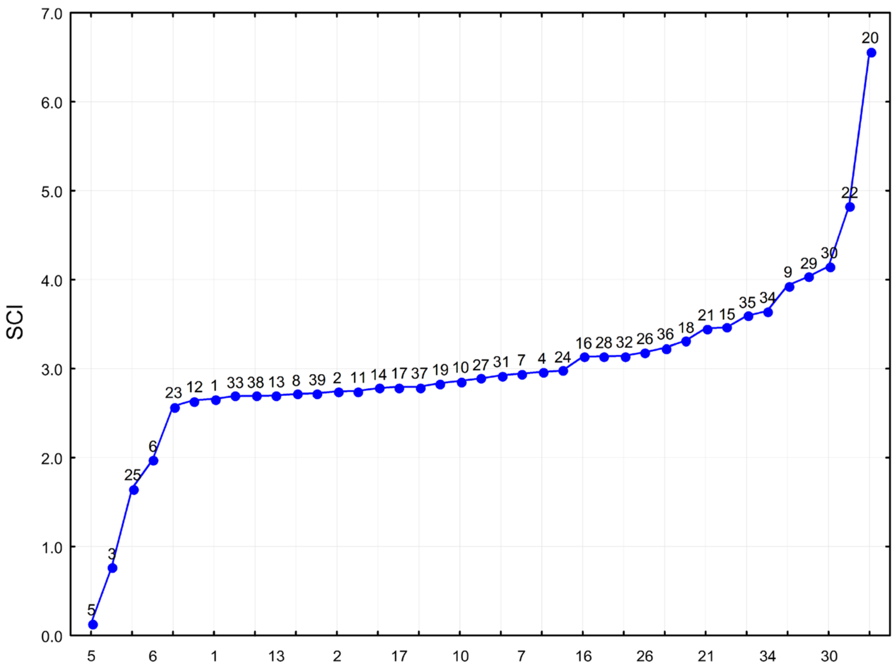

Fig. 1 Line plot of SCI (list of PI see in Table 1 of Appendix 4)

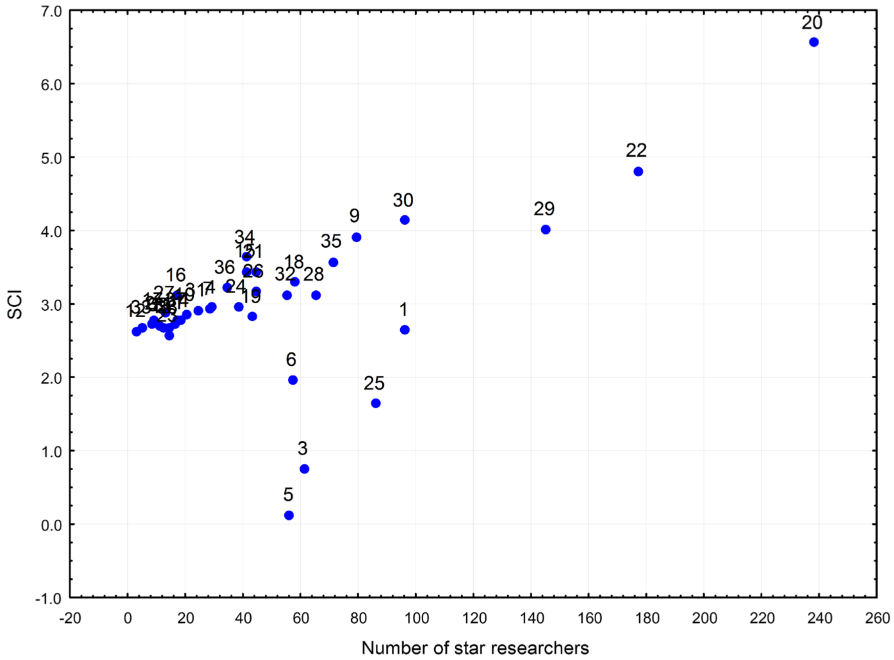

Fig. 2 Scatterplot of SCI against number of star researchers (list of PI see in Table 1 of Appendix 4)

$$\|\omega\| = \left(d_{ij}\langle\eta_i, \eta_j\rangle\right)^{\frac{1}{2}}, \qquad (3)$$

where $\langle\eta_i, \eta_j\rangle$ is the inner product of η_i and η_j. In order to furnish a treatment in terms of SC, we provide in Eq. (3) an additional variable d_{ij} (see Eq. (2)).

Thus, we characterized each of the 39 PI using 19 scientometric variables and SC. The resulting dataset was subjected to Multidimensionalscaling [or MDS, for technical details of this method, see, e.g., Borg and Groenen (2005)]. MDS makes it possible to "summarize" statistical relationships and identify the main factors that describe the distribution of PI' properties. This then allows us to create an integrative framework of the FP in Russia. The FP is one such geometric structure in which different points are related to each other in the same "scientometric" patterns as the different PI (cf. Lebaron and Grenfell 2014). In our case, MDS graphically represents social relationships between PI in the form of geometric relationships of points in a two-dimensional space.

General features of PI

The general analysis of the basic features of PI shows a significant correlation between three variables: "number of scientific personnel", "total number of publications", and "total number of citations". It is clear from Fig. 3 below that the number of scientific personnel has an important influence on publication output ($r^2 = 0.902$).

"Total number of publications", in turn, positively correlates with "total number of citations". The Pearson's correlation coefficient (r) is 0.843 (see Fig. 4). Thus, the strong

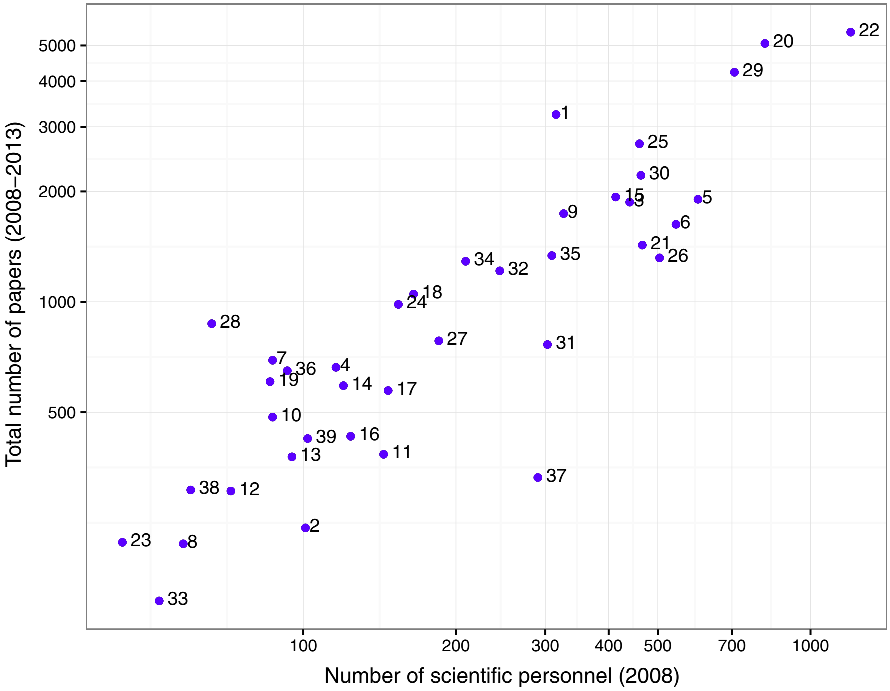

Fig. 3 Number of scientific personnel (2008) and the total number of papers in 2008–2013 (lg scale; list of PI see in Table 1 of Appendix 4)

connection between the three variables indicates that the size of the physics institution influences its publications output and scientific impact.

Social space of PI

To provide a bidimensional representation of the scientometric differences on the basis of the measured variables, the MDS method was applied to the distances matrix

$$M = \left(\|\omega_i - \omega_j\|\right)_{i,j=1}^{i,j=39} \tag{4}$$

(generated by the norm Eq. (3)) using the ALSCAL procedure in IBM SPSS Statistics 20. We then obtained the FP (see Fig. 5).

The abscissa axis of the distribution of physics institutions correlates with the variable # 16 and the variable # 17 (see Appendix 4). The Pearson's correlation coefficient r for the first variable is 0.979 ($p = 0.000$), for the second one is 0.962 ($p = 0.000$).

The following PI lie on the right pole of the abscissa axis: Joint Institute for Nuclear Research, Lebedev Physical Institute, Ioffe Institute, Institute for High Energy Physics, and the Alikhanov Institute for Theoretical and Experimental Physics. These all have the highest values for variables such as "number of scientific personnel", "number of publications", "number of citations", and "number of highly cited authors". These institutions

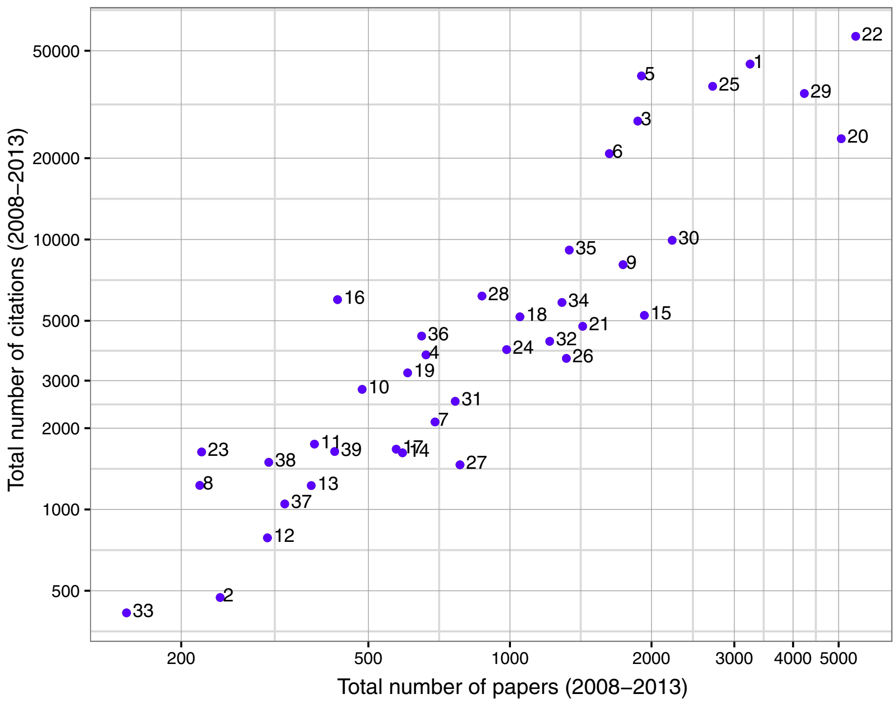

Fig. 4 Total number of papers and the total number of citations in 2008–2013 (lg scale; list of PI see in Table 1 of Appendix 4)

are located in the key Russian scientific "clusters" of Moscow and Moscow Region, St. Petersburg, and Leningrad Region.

Situated on the left pole of the first axis are the Amirkhanov Institute of Physics, Shafer Institute of Cosmophysical Research and Aeronomy, Zavoisky Kazan Physical Technical Institute, Institute of Continuous Media Mechanics, and the Institute of Electrophysics. These are small PI with roughly 100 researchers, and low levels of publication activity and citations. These PI are based outside the key Russian scientific "clusters" in the cities of Makhachkala, Yakutsk, Kazan, and Yekaterinburg.

The first axis of the distribution of PI contrasts the large institutions, which have high values for all the variables, with the small institutions, which have low values for the variables analyzed. This axis can be called "visibility".

The variable #13 ("share of Russian institutions") shows the impact of the Russian physics institutions in the production of the papers attributed to this institution. It serves an indicatorof the level of an institution's integration with the global scientific community in terms of international collaboration. The lower the share of Russian institutions the higher the level of international intergration and collaboration. The highest level of international collaboration is seen among institutions working in the field of high energy physics. These PI (Joint Institute for Nuclear Research, Alikhanov Institute for Theoretical and Experimental Physics, Konstantinov Petersburg Nuclear Physics Institute, and the Budker Institute of Nuclear Physics) are situated towards the right of the visibility axis. Russia's share in the publications of these institutions is only (5 %) of all co-authors of these publications. The low value of this variable is unsurprising. High energy physics is

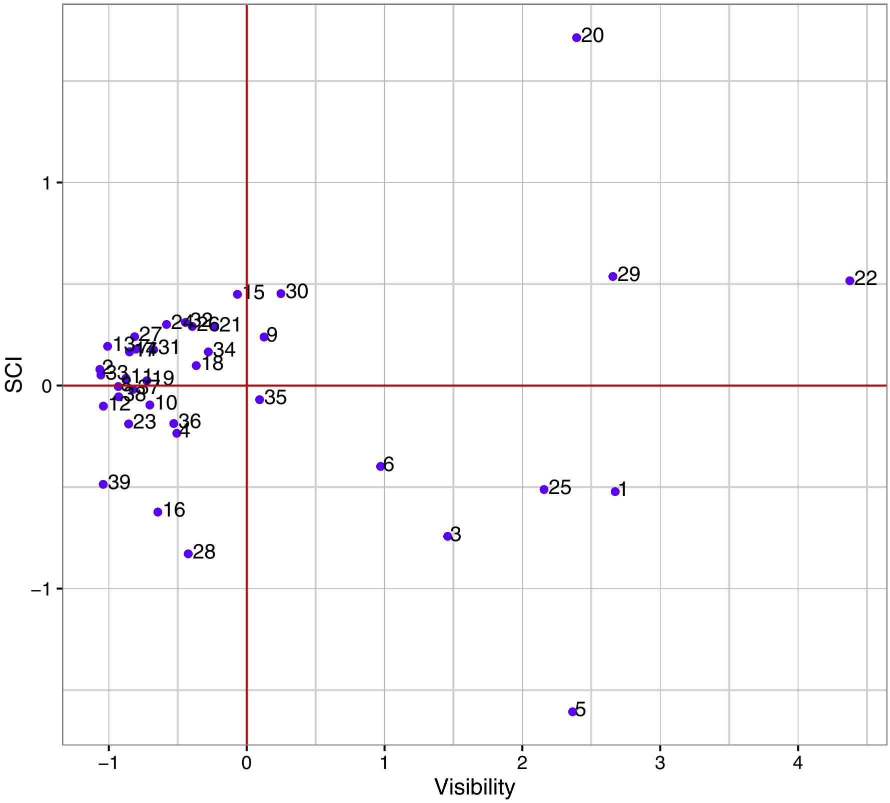

Fig. 5 Social space of Russian PI obtained by MDS (list of PI see in Table 1 of Appendix 4)

characterized by a well-developed division of scientific labor and a high level of international collaboration. It is in this field that the phenomenon of "hyper-authorship" is clearly manifested (see, e.g., Cronin 2001; Hu et al. 2010; Must 2014; Pritychenko 2015). There are instances when the number of co-authors of such publications reaches 5000 people (Castelvecchi 2015). It is therefore to be expected that the relative contribution of each country, calculated according to formal criteria, may be small. Institutions that are far less integrated into international research projects are located towards the left of the visibility axis. Here the share of Russian institutions averages at 67 %.

The ordinate axis of the distribution of PI correlates with the variable SCI ($r = 0.839$, $p = 0.000$). This axis can be called "SCI".

The most well-known Russian PI are situated in the upper part of the ordinate axis: the Ioffe Institute, Lebedev Physical Institute, and the Joint Institute for Nuclear Research. The less renowned PI and PI working in the field of high energy physics are situated in the lower part of the ordinate axis. The latter are familiar but in a much more niche field than the institutions in the upper part of this axis.

To classify the sample of Russian PI in such a way that similar PI fall into the same group, an unweighted pair-group centroid hierarchical clustering algorithm (UPGMC; Everitt et al. 2011; available in StatSoft Statistica 10) was applied to the distances matrix M (Eq. (4)). It reveals three groups of institutions (see Fig. 6).

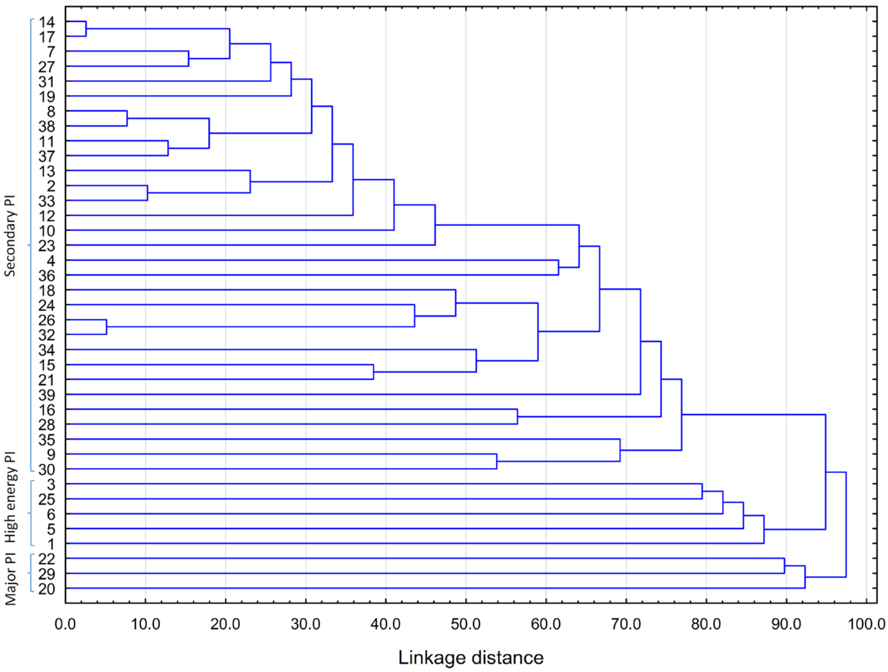

Fig. 6 Tree diagram for 39 PI (cluster analysis of the distances matrix *M* using UPGMC; list of PI see in Table 1 of Appendix 4)

1. *"Major" PI*. This group includes large institutions that carry out research in various fields of physics and have varying levels of integration in international scientific projects. These are the Ioffe Institute, Joint Institute for Nuclear Research and Lebedev Physical Institute. All the institutions in this group have the highest values for variables such as "number of scientific personnel", "number of publications", "number of citations", "number of star researchers", and "number of stars' citations".
2. *High energy PI*. This group comprises the following PI: the Alikhanov Institute for Theoretical and Experimental Physics, Konstantinov Petersburg Nuclear Physics Institute, Budker Institute of Nuclear Physics, Institute for Nuclear Research and the Institute for High Energy Physics. They all work in the field of high energy physics. They are PI with a high number of scientific personnel, high level of publication output and citation, and strong integration in international scientific projects. Unlike the "major" PI, there are far fewer star researchers affiliated with high energy PI. The PI of the first group counts in total 560 stars, while the second group has 356 stars. However, the average citation level for star researchers at "major" PI is lower (2712 citations per star researcher) than at high energy PI (4929 citations per star researcher). At the same time, there is a difference in the speed of citations' accumulation: stars working in the field of high energy physics accumulate citations faster than stars from "major" PI. This suggests that SCI in the various groups of PI has a different structure and dynamics.
3. *Secondary PI*. The third group includes small and medium PI. They count around 180 researchers while institutions of the first and the second group comprise about 900 and 470 scientists respectively. These PI have significantly less publications and citations,

than institutes of two other groups. They have fewer numbers of stars: the mean value is 32 researchers. In comparison, PI of the first and the second group have 187 and 71 stars per institute respectively. On the contrary, the value "share of Russian institutions" is significantly higher for the PI of the third group. They are less involved in international scientific collaboration than the others. Mean value for "share of Russian institutions" is 0.64 whereas PI of the first and the second group count 0.21 and 0.05.

Discussion

The social space of Russian PI is not arbitrarily-structured but rather in accordance with immanent trends. The first factor (visibility axis) which determines the differences among Russian PI is their informational significance in the international field of physics. This fact demonstrates the rules of the game in FP, which establish what is important and what is not at the present moment. To be more precise, we are saying that the highest stake in the indicated game is the citability of the papers and degree of PI integration in international cooperation. Besides, based on the distribution of PI on the visibility axis, we can conclude with a certain amount of credibility that the most successful, highly prioritized or "in vogue" research trend over 2008–2013 was high energy physics.

The second factor determining FP is SCI. This fact suggests that the socially acknowledged scientific competence of PI (i.e. SCI) presents a standalone basis for differentiation of PI, relatively independent of PI input in informational processes in FP proper (i.e. visibility). Consequently, SCI determines the objective probability of a physics research institution changing its position in FP: the higher SCI is, the more likely the physics research institution is to preserve or even strengthen its position. Therefore, the SCI axis juxtaposes PI, which have a vested interest in the amendment of laws regulating the distribution of scientific power and influence, and PI which receive dividends from the existing FP configuration. As Fig. 5 shows, in the course of 2008–2013 this was a matter of major PI and smaller ones being in opposition to each other.

Given that visibility does not depend on SCI, there may be discord between them. To cite one example, the family of PI related to high energy physics (Institute for High Energy Physics, Budker Institute of Nuclear Physics, Alikhanov Institute for Theoretical and Experimental Physics, and Konstantinov Petersburg Nuclear Physics Institute) occupies an ambivalent position in FP. On the one hand, these PI exhibit high visibility values, on the other hand, they have low SCI values. It is safe to assume that the indicated PI will soon be able to act as revolutionaries fighting for the revision of criteria which determine SCI.

It should also be noted that there is no radical gap between visibility and SCI. As is clear from Fig. 5, a sustainable combination of big SCI and low visibility and vice versa is not typical for FP. Ioffe Institute, Joint Institute for Nuclear Research, and Lebedev Physical Institute can serve as examples of PI which possess both high visibility and large SCI.

Conclusions

In constructing the FP, the problem of differentiating PI in a new light arises. In other words, we see a reduction of the basic concepts of sociology of science to SC. We consider FP (Fig. 5), in which the markers stand to each other in the same spatial relations, as the PI stand to each other in the social relations. The FP is inseparable from the concept of SC, and, in fact, the distribution of AP yields two principles of classifying and distinguishing Russian PI: *visibility* and *SCI*. The value of the FP is determined by the agreement of our model"s conclusions with empirical data and therefore depends on the choice of the theoretical constructs characterizing the FP. In this connection, the visibility looks obvious and natural. SCI is more fragile and less easy to perceive. For example, contrary to the opinion based on particular cases that small organizational units in science are more effective (see, e.g., Bak 1996), our study shows that large research institutions having large SCI are more productive and have more impact. Nevertheless, in the FP, visibility complements the bibliometric aspect with the sociological: one no longer needs to explain how and where the concept of SCI comes.

Our analysis has identified three groups of PI (Fig. 6), which differ considerably in their characteristics. This finding has important implications for the FP as a whole that can not be ignored by scientific policies. The specific characteristics identified suggest that the institutions in different groups each have their own features, which need to be taken into account by policy makers. When providing scientific policy, an in-depth approach is needed to develop performance indicators for research assessment and evaluation. Such an approach would mean that it is possible to distinguish between research institutions according to their properties that are essential for physics as an scientific field.

The defined FP can be considered as a map of Russian PI. The approach proposed jointly applying scientometric and sociological methods may be a useful starting point for developing a broader, more comprehensive, and theoretical study of the FP.

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Appendix 1: Description of the sample the scientists design

The target population included persons aged from 25 to 69 years who live and work in Russia and have doctoral degrees. In this survey, multistep stratified sampling was used with quotas under the following parameters: gender, age, field of science, employment sector and geographical area. The nationally representative sample was clustered within eight Russian Federal districts and stratified by the number of Ph.D. graduates in each district. The sample was about the same in 2010 (3450 persons) and in 2013 (3492 persons). In 2013, the selected population was comprised of 1914 men (54.8 %) and 1578 women (45.2 %) who were employed at research institutions, universities and R&D organizations and represented all fields of science and engineering. Individual on-the-job interviewing was used.

Appendix 2: Variables related to SC

1. *"Symbolic power"—the active properties that provide the respondent with the ability to apportion other signs of scientific recognition:*

   (1) biography published in the Russian encyclopedia/handbook
   (2) biography published in the international/foreign Encyclopedia/handbook
   (3) public conference/talk in Russia

(4) public conference/talk in foreign countries
(5) publications in the media
(6) speech on the radio or on television
(7) publications about him/her in the media (interviews, reviews, etc.)
(8) personal blog or site on the Internet
(9) citation index
(10) number of peer-reviewed articles in leading Russian journals
(11) number of peer-reviewed articles in leading International journals (Web of Science, Scopus, etc.)
(12) monographs in a national publisher house
(13) monographs in a foreign publisher house
(14) translations of his or her work into foreign languages
(15) patents
(16) scientific and academic awards from Russia and other countries
(17) personal grants received
(18) number of the foreign languages used by respondent in professional communication (reading literature, presentations or lectures, writing papers)

2. *"Bureaucratic power"—the active properties that allow the respondent access to institutional resources:*

(19) participation in scientific councils
(20) membership on editorial boards
(21) membership in governmental/national expert boarding/council
(22) membership in committee on graduate programs for graduate theses
(23) assignment to administrative posts connected with the distribution of employment and financial resources
(24) administrative posts connected with management of national and international scientific and educational projects
(25) leading position at university/research institution

3. *"Academic power"—the active properties that enable control of the social reproduction of the corps of scientists:*

(26) membership in professional organizations/associations
(27) membership in governmental/national expert boarding/council
(28) membership in thesis/dissertation examining committee
(29) supervision of dissertations
(30) number of doctorate awarded under his/her supervision

4. *Post-graduate training/retraining:*

(31) courses, trainings, seminars in own or related areas
(32) courses, trainings, seminars in other areas of specialization
(33) courses, trainings, workshops in management, planning, etc.
(34) computer courses in certain software products
(35) foreign languages courses

Appendix 3: The variables used when constructing the social space of Russian PI

- Variables #1–6. Number of publications in 2008–2013
- Variables #7–12. Number of citations to papers published in 2008–2013
- Variable #13. Share of Russian institutions, i.e. the average share of Russian organizations in the total number of organizations affiliated with the publications of an institution and published in 2008–2013
- Variable #14. Number of scientific personnel in 2008
- Variable #15. Number of highly cited authors (stars)
- Variable #16. Total number of citations to publications of highly cited authors (starting from 1986)
- Variable #17. Average number of citations to papers published by one highly cited author (starting from 1986)
- Variable #18. Total number of citations to publications of highly cited authors (over the last 7 years)
- Variable #19. Average number of citations to papers published by one highly cited author (over the last 7 years)
- Variable #20. Scientific capital of physics institution (SCI)

Notes:

1. Information on publications and citations (variables # 1–13) was extracted from the database Web of Science. Accessed: June 2014.
2. Data for variable # 14 were extracted from the website of the Russian Academy of Sciences. Source: http://www.ras.ru/presidium/documents/directions.aspx?ID=07f28cf4-5660-46a3-abab-e18dd3771026. Accessed: April 2015.
3. Data for variables # 15–19 were extracted from the "Expert Corpus". Source: http://expertcorps.ru/science/whoiswho/affs. Accessed: April 2015.

Appendix 4: Russian PI in the sample

See Table 1.

Table 1 Sample PI

Id	Organization	Total number of publications (2008–2013)	Total number of citations (2008–2013)	Number of researchers (in 2008)	Share of Russian affiliations (%)	Region
1	Alikhanov Institute for Theoretical and Experimental Physics	3241	44,633	315	5	Moscow
2	Amirkhanov Institute of Physics	242	472	101	87	Dagestan Republic
3	Budker Institute of Nuclear Physics	1870	27,446	440	5	Novosibirsk

Table 1 continued

Id	Organization	Total number of publications (2008–2013)	Total number of citations (2008–2013)	Number of researchers (in 2008)	Share of Russian affiliations (%)	Region
4	Central Pulkovo Astronomical Observatory	663	3737	116	23	Saint Petersburg
5	Institute for High Energy Physics	1904	40,353	600	5	Moscow Oblast
6	Institute for Nuclear Research	1627	20,797	543	5	Moscow Oblast
7	Institute for Physics of Microstructures	693	2109	87	76	Nizhny Novgorod
8	Institute for Theoretical and Applied Electromagnetics	219	1228	58	64	Moscow
9	Institute of Applied Physics	1740	8067	326	15	Nizhny Novgorod
10	Institute of Astronomy	485	2785	87	43	Moscow
11	Institute of Automation and Electrometry	384	1746	144	76	Novosibirsk
12	Institute of Continuous Media Mechanics	305	785	72	72	Perm
13	Institute of Electrophysics	378	1226	95	93	Ekaterinburg
14	Institute of High Current Electronics	591	1621	120	83	Tomsk
15	Institute of Metal Physics	1931	5235	413	81	Ekaterinburg
16	Institute of Microelectronics Technology and High Purity Materials	430	5988	124	68	Moscow Oblast
17	Institute of Solar-Terrestrial Physics	573	1672	147	71	Irkutsk Oblast
18	Institute of Solid State Physics	1050	5171	165	59	Moscow Oblast
19	Institute of Spectroscopy	606	3206	86	65	Moscow Oblast
20	Ioffe Institute	5064	23611	813	54	Saint Petersburg
21	Joint Institute for High Temperatures	1428	4768	466	68	Moscow
22	Joint Institute for Nuclear Research	5435	56,553	1200	5	Moscow Oblast
23	Kapitza Insitute for Physical Problems	221	1633	44	51	Moscow
24	Kirensky Institute of Physics	984	3910	154	85	Krasnoyarsk Krai
25	Konstantinov Petersburg Nuclear Physics Institute	2698	36,922	460	5	Leningrad Oblast

Table 1 continued

Id	Organization	Total number of publications (2008–2013)	Total number of citations (2008–2013)	Number of researchers (in 2008)	Share of Russian affiliations (%)	Region
26	Kotelnikov Institute of Radioengineering and Electronics	1318	3627	504	75	Moscow
27	Kutateladze Institute of Thermophysics	783	1464	185	86	Novosibirsk
28	Landau Institute for Theoretical Physics	872	6174	66	47	Moscow Oblast
29	Lebedev Physical Institute	4226	34,728	708	5	Moscow
30	Prokhorov General Physics Institute	2213	9930	463	69	Moscow
31	Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation	765	2515	303	69	Moscow Oblast
32	Rzhanov Institute of Semiconductor Physics	1215	4195	244	76	Novosibirsk
33	Shafer Institute of Cosmophysical Research and Aeronomy	153	414	52	79	Yakutsk
34	Shubnikov Institute of Crystallography	1290	5844	209	68	Moscow
35	Space Research Institute	1337	9136	309	24	Moscow
36	Special Astrophysical Observatory	649	4389	93	31	Karachay–Cher-kess Republic
37	Troitsk Institute of Innovative and Thermonuclear Research	332	1048	290	49	Moscow Oblast
38	Verechshagin Institute for High Pressure Physics	307	1495	60	64	Moscow Oblast
39	Zavoisky Kazan Physical Technical Institute	424	1639	102	68	Tatarstan Republic

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