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Science Diplomacy in Action: European Collaboration and US Participation in Research Infrastructures

Maria Moskovko and Albert H. Teich

Multinational collaboration in large- and mid-scale research infrastructure (RI) is increasingly essential, as cutting-edge research requires costly and sophisticated instrumentation and national governments face financial constraints. In the European context, the term RI encompasses large, single-sited facilities (e.g., particle accelerators), distributed resources (e.g., biobanks and data repositories, computing systems, or networks), and mobile equipment (e.g., oceanographic vessels and floats). In the American context, RI might also include "tools, services, and installations,"[1] "instrumentation, informational and human resources,"[2] or general-purpose infrastructure and its maintenance.[3] Apart from enabling scientific work and providing training to future generations of scientists and engineers, RIs are often expected to bring socio-economic benefits to the sponsoring nations.[4] This is particularly important in Europe, where RIs tie into the higher ambitions of the European Union (EU) – innovation, competitiveness and regional development – and therefore play an important role in its research and innovation policy.[5]

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Science is an institution,[6] with its own formal and informal "rules of the game."[7] This article views RIs as a type of scientific cooperation[8] that takes place in particular institutional settings. Several observers have examined the institutional composition of RIs from the perspective of science diplomacy[9] and elucidated the challenges for these types of scientific partnerships.[10] This paper takes a close look at five European RIs with strategic importance in which the US is a "participant"[11] (see Annex I), in order to understand what motivates European partners and American participants to start and maintain such collaborations and how institutional frameworks enable or constrain this type of international relations on science. Since multinational mega-projects often receive more attention than mid-scale RI,[12] we have chosen to focus predominantly on the latter. The diversity in purposes and disciplines was selected in order to show how different models of collaboration and institutional settings work in different technical fields.[13]

The first section of this paper introduces the peculiarities of RI in the EU and US contexts. The following sections reveal the origins, governance, and nature of the transatlantic partnerships in the five selected cases. This paper argues that science diplomacy is necessary but not sufficient to the formation and operation of RIs in the European context. Beyond science diplomacy, these organizations also require political and administrative support from the partner governments. US participation can play an important role with benefits to both sides.

RIs in the European and US Contexts

Collaboration on scientific infrastructure in Europe began in the post-World War II era[14] mainly due to the need to share costs when building large-scale research instruments and to keep up with the US after the wartime destruction. Today, European RIs have a special status in the context of political and economic integration of the EU. Although the member states have been the main funders of RI,[15] the EU[16] began to support RIs through the Second Framework Program (FP2, 1987-1991), allocating 30 million euros[17] to "major installations."[18] This fund gradually expanded[19] and the launch of the ambitious European Research Area (ERA) initiative in the early 2000s placed RIs in the center of EU-wide science and technology policy.

Several pan-European RIs have been prioritized by the European Strategy Forum on Research Infrastructures (ESFRI) roadmaps since 2006. Set up in 2002, ESFRI consists of representatives from member states, the European Commission, associate countries, and observers. The forum has an advisory function and is tasked with priority-setting and coordinating efforts in the RI domain. Once an

RI is included on the ESFRI roadmap, it is eligible for some grants from the EU, while individual countries commit to its long-term funding. The EU preparatory phase funding aims at lifting initial project initiatives off the ground and enabling joint work on scientific, technological, political, and administrative developments before the official commitments of the contributing nations. Individual countries, however, remain the stakeholders in these RIs, and not the EU. Additionally, the EU has instituted a new kind of legal-administrative entity, European Research Infrastructure Consortium (ERIC) to establish and operate collaborative RIs.[20] To date, 21 RIs operate within the ERIC framework.

Although the ESFRI roadmap signifies the strategic importance of the RIs for Europe, RIs are generally open to users from around the world. The facilities may be located outside of Europe or serve as the European nodes of larger global initiatives.[21] While the European approach to RI is based on coordination among countries and funding agencies, the US generally acts as sole funder of its facilities. Virtually all US federal budgeting is done on an annual basis and requires the agreement of the executive branch and both houses of Congress, making long-term commitments difficult. Formal international collaboration on RIs is thus the exception, not the rule and is employed when circumstances require it (e.g., for financial or political reasons, as in the case of the International Space Station).

Several additional unique aspects of US policies and procedures shape its approach to RIs. There is no overall federal RI policy in the US; instead, the major science funders, with guidance from advisory committees of scientists and under supervision of the Office of Management and Budget and the White House Office of Science and Technology Policy, plan and execute policies and funding schemes for their own infrastructure. Private foundations, such as the Keck Foundation, are playing a growing role in the construction and support of American RIs. Industrial firms have also long been engaged as both suppliers of equipment and, through contracts, as managers of facilities. The network of the US Department of Energy (DOE) national laboratories, most of which originated during the Second World War, operated by contractors, represent a successful model of long-term public-private collaboration on large RIs.

Hence, the major differences between European and US RI contexts derive from their respective political and administrative characteristics as well as their differing histories. Some of those differences will be visible below in the individual cases of transatlantic cooperation on RI. We have chosen to focus on the five RIs prioritized by the ESFRI that list the US as a participant (see Annex I). Three of them are in the area of physical sciences and engineering (as designated by ESFRI) – the Cherenkov Telescope Array (CTA), the Square Kilometre Array (SKA) and the Second-generation System for On-line Production of Accelerated Radioactive

Ions (SPIRAL 2). The International Centre for Advanced Studies on River-Sea Systems (DANUBIUS) is in the area of environment and the Common Language Resources and Technology Infrastructure (CLARIN) is in the area of social and cultural innovation. Four of them are in the construction or operational phases and one is still in the planning phase. The diversity in purposes and disciplines show how different models of collaboration work in different technical fields.

Origins and Characteristics of RIs

CTA (Cherenkov Telescope Array)

Once the CTA is operational in 2024, it will be the world's most sensitive ground-based gamma-ray telescope array, with telescopes in Spain and Chile exploring larger areas and wider ranges of the high-energy universe than existing instruments allow. The CTA builds upon earlier European and American telescope projects.[22] Among those are the German-Swiss First G-APD Cherenkov Telescope (FACT) and several international projects – High Energy Stereoscopic System (HESS) and Major Atmospheric Gamma Imaging Cherenkov Telescopes (MAGIC), as well as the US-based Very Energetic Radiation Imaging Telescope Array System (VERITAS) and its proposed upgrade, the Advanced Gamma-ray Imaging System (AGIS).

Funding from the EU in its preparatory phase allowed the CTA to develop its governance system and set up an interim German non-profit company (CTA Observatory (CTAO) in Heidelberg (Germany)).[23] Nine European countries, the European Organisation for Astronomical Research in the Southern Hemisphere (ESO), Australia, and Japan are the shareholders. CTAO is governed by a twelve-member council that in 2016 selected Bologna (Italy) as the CTA headquarters and chose the ERIC framework. The decision was motivated by the possibility of a tax exemption – an essential element for the construction phase.[24]

The scientific consortium – CTAC – involves more than 1,500 scientists and engineers from about 200 institutes across 31 countries, responsible for the development of the telescope.[25] CTAC is governed by a non-binding memorandum of understanding (MOU) and has a chair, spokespersons, and a board. Each participating research institution is currently bearing its own expenses for the work it performs.

The US became involved with CTA following a recommendation from the National Academy of Sciences' Astronomy and Astrophysics Decadal Survey that it do so, rather than pursuing upgrades to one of its existing telescope arrays, given the similarity of the projects, the complementarity of their designs, and cost savings.[26] Similarly, the US-based Particle Physics Project Prioritization Panel recommended that NSF Astronomy, NSF Physics, and DOE invest in CTA for its capability of dark matter signal detection.[27] Still, one interviewee believed it "unlikely" that the US would formally engage with the CTA, in view of the US's science priorities and funding limitations.[28] Moreover, as ERICs are entities of the EU, participating countries must submit to the jurisdiction of the European Court of Justice (ECJ) – which undermines US sovereignty.

The CTA-US group is comprised of 24 research institutions contributing to an innovative two-mirror telescope design.[29] The scientific justification of CTA, titled "Science with the CTA," was edited by an American scientist who is also a co-spokesperson for CTAC. Activities of the US participants are funded by shorter-term grants, mostly from the NSF. A representative from the US-CTA group noted that funding of mid-scale RI appears to work better in Europe, where governments are more willing to commit to longer-term projects of that scale.[30] The interviewee also noted that the scarcity of resources for upgrading existing scientific instruments has motivated the Group contribute to the next-generation instrument, allowing the field of gamma-ray astronomy to "survive" in the US.

SKA (Square Kilometre Array)

SKA will be the world's largest radio telescope, with its collecting area of one square kilometer enabling observations of unprecedented sensitivity. In March 2019, Australia, China, Italy, the Netherlands, Portugal, South Africa, and the UK established SKA as an intergovernmental organization (IGO).[31] Five more nations are eventually expected to join. SKA builds on the tradition of interferometric radio telescopes that were constructed in Europe, Australia, and the US in the 1960s and 70s, the most powerful of which is the Very Large Array (VLA) in the US.[32] In the 1980s, the potential for a facility with up to 100 times more collecting area than the VLA began to be discussed by the global research community. A scientific justification of a large array was presented at a conference in 1991 and an international working group formed in 1993.

Due to its size, effort and cost, the SKA "was born global"[33] with no dominant partner. The expected division of construction and operating costs was one third each for Europe, the US, and the rest of the world. The first MOU was signed by the collaborating institutions in 1997, starting a research and technology study program. Formal governance was established in August 2000 when a second MOU was signed, setting up an international steering committee and a management team. The project office was established in 2003, an "informal group" of funding agencies began to hold regular meetings on the project in 2005,[34] and by 2011, nine funding agencies and governments committed to the so-called "pre-legal entity founding board" and established the SKA Organization (SKAO) in the UK as a company limited by guarantee. SKAO has a board of directors and a director-general with overall management responsibility, and with four committees assisting them. Fourteen scientific working groups address the different research areas that SKA will enable.

The US SKA Consortium had been formed in 1999 by a group of American universities. The National Radio Astronomy Observatory (NRAO) – a federally funded organization – joined at a later stage. This consortium of 14 organizations contributed to the development of the scientific foundation and carried out design-related work between 2002-2012, based on the concept of "Large-N-Small-D" (LNSD), or a large number of small-diameter antennae in an array. The US was also considered as a potential site until 2005. By 2010, however, it had become clear that NSF would be unable to commit to the proposed construction schedule and the US ceased formal collaboration. The schedule did not match the NSF's funding cycles, according to the previously mentioned Decadal Survey.[35] The expensive Atacama Large Millimeter/submillimeter Array[36] was also being commissioned in the 2000s, making US participation in similar projects possible only with increased funding or the continued closing of existing radio astronomy facilities. Because of this, a mid-scale radio telescope called Hydrogen Epoch of Reionization Array was allocated funding and its technological and scientific development contributed to the conceptual development of SKA.[37]

Hypothetically, the US SKA Consortium could have remained involved in the global SKA effort had they communicated that their intention was to participate only in further design and development efforts, rather than contributing to construction as a formal member. But, as one interviewee called, "apparently, we [people involved in SKA] did not make it clear […] that we were looking into the next decade not for the construction funds [and] that we were asking not for a billion dollars, but tens of millions."[38] The interviewee also observed that the level of individual and institutional enthusiasm was not enough for the US SKA Consortium to continue its involvement through a projects-based approach either. Nonetheless, individual American scientists and engineers from NRAO are continuing their involvement with SKAO through an agreement for the development of software systems, while individuals from NASA Jet Propulsion Laboratory and NVIDIA corporation are contributing to the construction of the "central processing 'brain' of the SKA."[39] Finally, researchers from the Massachusetts Institute of Technology Haystack

Observatory are part of a global consortium on Low-Frequency Aperture Array element.[40]

SPIRAL 2 (Second-generation System for On-line Production of Accelerated Radioactive Ions)

SPIRAL 2 is a multinational effort to upgrade a French nuclear science laboratory, the Large Heavy Ion National Accelerator (GANIL). It seeks to expand research into the physics of radioactive ion beams, with implications for atomic and condensed matter physics, radiobiology, and other fields. The scientific and technical development of SPIRAL 2 is an international effort of research institutions in nine countries, including the US.[41] GANIL operates as an Economic Interest Group (EIG) – a consortium of French public research organizations. It has own secretariat and the French Alternative Energies and Atomic Energy Commission (CEA) serves as its regulator. France is funding 80% of the SPIRAL 2 upgrade, with the remainder to come from international partners.[42]

SPIRAL 2 and its predecessor, SPIRAL 1, are an example of layering novel organizational structures of a scientific laboratory onto existing ones.[43] Moreover, SPIRAL 2, along with several other projects, is seen as a stepping stone towards an even more powerful next-generation facility, European Isotope Separation On-Line post-accelerator facility (EURISOL).[44] Its American counterpart will be the Facility for Rare Isotope Beams (FRIB), currently nearing completion by DOE at Michigan State University.[45] A different legal form for SPIRAL 2 may be necessary in its operational phase, in order to accommodate these international partnerships.[46]

GANIL and Argonne National Laboratory in the US have a non-proprietary Cooperative Research and Development Agreement (CRADA). Argonne, in partnership with three American universities and two companies, is contributing to the design and construction of some equipment for the new instrumentation.[47] Collaboration between Argonne and GANIL started in the 1990s and was initially based on joint experiments rather than instrumentation. The experience of the Argonne collaborators in both accelerator and nuclear science, along with the "close" and "friendly" relationships lie at the basis of this collaboration.[48] A DOE grant is currently covering the work of the American collaborators.

Differences in administrative policies and regulations under which the French and American national laboratories operate have sometimes complicated this collaboration. For example, the mandatory retirement age in France led a GANIL researcher to move to MSU in order to continue work on the S3. In another example, the DOE contribution to joint work on an instrument appears disproportionately high because the costs of labor are included in the budget. In contrast, French scientists have national-level positions and their wages are budgeted separately, making the French contribution appear lower. The difference in manpower costs was also reported to pose challenges to the short-term employment of the French postdoctoral researchers in the US.[49]

CLARIN (Common Language Resources and Technology Infrastructure)

CLARIN integrates Europe's existing repositories of linguistic data and facilitates the sharing and use of the data by users from the social sciences and humanities.[50] It serves as a single entry point to data with simultaneous access to multiple interoperable systems. CLARIN was set up as an ERIC in Utrecht (the Netherlands) in 2012 by six EU countries and an IGO – the Dutch Language Union. Each member country funds national linguistics data centers and pays dues to CLARIN. As a distributed RI, CLARIN's governance structure consists of a general assembly made up of representatives of the ministries of the member countries and assisted by a scientific advisory board. Day-to-day management is in the hands of a four-member board of directors headed by an executive director. Becoming an RI and an ERIC, according to the respondents, made the previously fragmented CLARIN network more organized and committed to the common goals.[51]

Even though computational methods entered the humanities in the 1950s, closer ties between research groups only developed in the 1980s, when "a need for standardization, interoperability and data reuse emerged with the spread of computers."[52] EU-funded initiatives for humanities research in the 2000s stimulated wider collaboration between European research organizations and between 2008 and 2011,[53] a €4.1 million EU preparatory phase grant enabled a collaboration of 35 institutions to set up CLARIN. CLARIN membership currently extends to 21 members, three observers, and an American participant – Carnegie Mellon University (CMU). The legal status of an ERIC enables CLARIN to sign agreements with third parties, such as an American university, without the US becoming a member.

CMU provides data and technical expertise to CLARIN through its program TalkBank, which was established with NSF funding in the 1990s. It is cyberinfrastructure with a focus on spoken human communication, and comprises data repositories on child language, multilingualism, conversations, and other types of data, in 34 languages.[54] CMU researchers had previously collaborated on building language data repositories for the German and Danish institutes that later became CLARIN members.[55] Those linkages led to an invitation to CMU to join CLARIN.

There are several challenges to this partnership. Firstly, the annual dues that TalkBank is required to pay to CLARIN are not covered by the grants that fund it. Secondly, access to some of the CLARIN data is restricted, creating asymmetries in the relationship with the open-access US-based language bank.[56] Even without such barriers, differences in ethical (human subjects), legal (copyright), and technical (format) aspects also pose barriers to sharing data.[57]

DANUBIUS (International Centre for Advanced Studies on River-Sea Systems)

DANUBIUS has been on the ESFRI roadmap since 2016 and completed the EU-funded planning phase at the end of 2019.[58] Once it is operational in 2022 as an ERIC, DANUBIUS will be a "one-stop shop" for environmental, social, and economic scientists. It will have nodes responsible for data collection, analysis, and modeling of river-sea systems. Thirty institutions from across four nations, including two RIs in environmental sciences, are driving the effort, which is led by Romania.[59]

DANUBIUS builds upon existing laboratories in Germany, Italy, the Netherlands, and the UK, with a multi-purpose hub to be built in Romania and a technology transfer office in Ireland. By adding these features, DANUBIUS mirrors the EU policy priorities for environment and regional development. Some construction costs and operational funding are expected to be covered by EU structural and investment funds.[60] The EU preparatory grant is funding a DANUBIUS project that is organized as a consortium of 30 institutions from 16 countries.[61] Its executive body is a steering committee within a general assembly that will assist a project coordinator in managing the project. There are also a Scientific and Technical Advisory Board and a Board of Governmental Representatives from the member countries.

The nature of US participation in DANUBIUS, if any, is however not clear. One American organization was listed as a partner of DANUBIUS on the project's website, but a representative of that organization said that none of its current scientists were aware of such a collaboration, suggesting instead that a former employee might have been involved.[62] After the completion of the EU-funded project, the American institution was removed from the website and no information on further relations with the US or a separate American instruction was mentioned in the final report.[63]

Summary: Institutional set-up of transatlantic collaboration on European RI

Although these organizations are all multilateral bodies, their specific organizational designs vary considerably in form and complexity, depending on the nature of the research area, the institutional bases from which they developed, and the individual histories, traditions, or connections to certain countries. A similarity was observed in their dual structures – the participating governments and funding agencies carrying out decisions on one level and the scientific communities collaborating on another. Nonetheless, the legal status provided by an IGO, ERIC, EIG, or a non-profit company integrates multiple organizational layers of an RI (e.g., scientific, decision-making, administrative) into a single entity, enabling, among other things, its engagement with societal actors and thereby allowing the multinational research organization to fulfill its mission.

Funding came up frequently in our interviews, since multinational RIs are funded by the participating countries. Funding allocation goes hand-in-hand with priority-setting. As noted by the interviewees from CLARIN, SKA, and CTA, prioritization of scientific ideas by ESFRI had an impact on their further development. Namely, being included on the EU list of RI raised the profile of those projects in the individual countries and allowed them to secure national funding: "In Europe, the ESFRI projects are taken seriously by the governments. It is sort of a box to be ticked."[64] Similarly, the Decadal Survey and the P5 were referred to as important prioritization exercises in the US, on a par with inclusion among ESFRI priorities in Europe.[65] Our first finding suggests that multinational RIs are embedded into formal institutions and practices (funding, priority-setting, organizational forms, dual managerial/governmental and scientific structures). Communication and leadership, sometimes by a single individual, is paramount in navigating between and among these institutional levels. The four cases also demonstrated that despite formal agreements among the participating countries, individuals are able to make their way through the multinational bureaucracies and continue collaboration via other available means (contractual agreements, project-based collaborations, etc.).

Most of the multinational RIs that we studied did not arise de novo. The SKA, for example, builds on a "family" of telescopes with increasing capacity. The physical size, cost, and diversity of expertise required in the development of these instruments is such that national governments have been persuaded to collaborate. CTA and SPIRAL 2 also build on the infrastructure of previous generations and established collaborations. Hence, the projects in astronomy and physics that we studied demonstrate layering and build upon existing system of facilities, aiming to become new-generation instruments. CLARIN builds upon existing linguistics data repositories in the participating countries. The partnerships between the European and American researchers in these four studied cases also build upon their previous collaborations. DANUBIUS relies on laboratories in partner countries, while establishing a hub in Romania and adding some features that mirror the EU policies of regional development, sustainability and economic cohesion between various regions of the EU. This leads us to our second finding, that multinational RIs build on established, often national, infrastructural bases.

An important question about these transatlantic partnerships is what motivates the various parties. This question was posed to the informants from the coordinating offices in Europe and their American partners. Several European representatives from the astronomy and physics facilities recognized the American partners' expertise and track records in constructing and running similar instruments.[66] Similarly, concerning the motivation to participate in e-infrastructure, the informants from the European coordinating office of CLARIN pointed out the importance of the American partners' expertise and reputation in the field.[67] They saw closer cooperation with an American RI as an "experiment to work with organizations outside of Europe," as well as "access to more data, tools, and expertise."

American collaborators reported that participation in the state-of-the-art physics and astronomy projects allowed them to test ideas, which would not have been possible on their own, due to funding and technological constraints.[68] Participation also allowed some of them access to the newly developed tools once they were operational; these were part of the transactional relationships reported in CTA – as when the American partners secured observation times in exchange for their contribution to the instrument design.[69] Mutual advantages are therefore paramount. As one interviewee pointed out, "each institute [should get] something from it, like a postdoc, or a bit of equipment."[70] One US-based informant from the CTA remarked on the importance of the American tradition in high-energy gamma-ray arrays, the US-led development of the Cherenkov atmosphere technique, and the passion and enthusiasm of individuals working with this type of science.[71] The American participation in the S3 instrument for SPIRAL 2 was reported to be motivated by a chance to contribute to further advancement of science vis-à-vis the development of a novel instrument.[72]

Similarly, the US-based informant cited an "ideological commitment" to the idea of unified access to data and a desire to stay updated on the European standards for computational linguistics, as well as possible access to data on some of the European languages.[73] For some individuals, participation in large-scale global initiatives may also provide additional research funding and an opportunity for leadership as an individual and as an organization.[74] Our findings demonstrate that multinational RIs may be seen as tangible expressions of science diplomacy. Diplomacy implies attaining mutual benefits – that is evident from the nature of a multinational RI when every member or participant benefits from contributing a part, be it monetary or knowledge of a particular technology for developing a novel instrument.

During a short conversation with one of the authors, the PI of DANUBIUS explained that an American institution had been approached with a proposal to cooperate. It was not specified what kind of cooperation was envisioned, but the potential US participants were reported to have expressed willingness to become involved in the future when the project is "more developed" in Europe: "We [Europeans] do not want to waste their [the Americans'] time until then."[75] The listing of a US institution on the website could have been intended to bolster the reputation of DANUBIUS, as the project is being established.

Concluding remarks

This study demonstrates that even without formal collaboration frameworks, science diplomacy between American and European scientists can be seen at the grassroots level in these cases of scientific cooperation. Still, structural differences and scarcity of resources at national levels may at times act as bottlenecks to transatlantic collaboration on RIs. Nonetheless, governments and funding agencies exercise their own types of science diplomacy through policy sharing and learning. For example, the EU-wide roadmapping exercise has been incorporated in the national practices of many of its member states. Moreover, mid-scale RI policy is gaining momentum in the US,[76] and ERIC is considered a model for globally distributed RIs.[77] Although the ERIC framework poses some barriers to non-EU (e.g., US) participation since countries participating in the ERIC need to submit to the jurisdiction of the EU, European RIs set up under the framework may enter into agreements with institutions in non-EU countries, as demonstrated by CLARIN and CMU.

As our study has shown, some RIs are established with diplomatic missions in mind.[78] Nevertheless, even those build upon established scientific foundations. Policy priorities in the case of DANUBIUS go along with, if not before, the actual scientific mission.[79] Although it is only in its early stages and not yet meeting its scientific aims, DANUBIUS is already seen by the EU officials as a science diplomacy bridge between the EU and Southeast Asia.[80]

Science diplomacy varies across different scientific fields, each of which has distinct traditions for collaboration between groups and individuals. Although every branch of science is collaborative, there are differences in how RIs in these different branches are constructed technologically, scientifically, and organizationally, due to discipline-specific factors and traditions. However, as each of the cases of European-American collaborations on RI show, the ambition to reach the frontiers of science is at their core. SD

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Annex I: Presentation of cases

	CTA	SKA	SPIRAL 2	CLARIN	DANUBIUS
Academic area	Astronomy	Astronomy	Nuclear physics	Linguistics	Environmental sciences
Headquarters location	Bologna (IT)	Lower Withington (UK)	Caen (FR)	Utrecht (NL)	Murighiol (RO)
Member countries	AU, AT, CZ, FR, DE, IT, JP, SI, ES, CH, UK (plus ESO)	AU, CA, CH, CN, FR, DE, IN, IT, NL, NZ, ZA, ES, SE, UK	FR (with participation of BE, CZ, DE, IN, IT, RO, PL, SE, US)	AT, BG, CY, CZ, DE, DK, EE, EL, FI, HR, HU, IS, IT, LT, LV, NL, NO, PL, PT, SI, SE	RO (with prospective members BG, DE, EL, ES, IE, IT, MD, NL, UK)
ESFRI roadmap entry	2008	2006	2006	2006	2016
EU Preparatory Phase Funding (€ million EU contribution) and timeline	5.2 (2010-2014)	5.5 (2008-2012)	3.9 2007-2012	4.1 (2008-2011)	4 (2016-2019)
Construction/ implementation	2019-2024	2020-2027	2010-2019	2011-2015	2012-2022
Operation start	2024	2027	2020	2012	2022
Capital value, € mln	400	1000	281	n/a	300
Construction costs, € mln	297	674	266	n/a	222
Operating budget, € mln/year	20	77	6	14	28
Legal status of RI	Public company under the German law in 2014; in process of applying to ERIC	International treaty organization in 2019; public company under the UK law between 2011-2019	A project of GANIL that is established as an Economic Interest Group (EIG)	ERIC, 2012	Currently applying to ERIC
Type of partnership with US-based scientists	A consortium of 24 American research organizations is contributing a prototype design, the scientific justification, and simulations.	A consortium of 14 American research organizations withdrew in 2011, but contributed to the telescope design. Currently individual American academic and industrial partners are involved in prototyping and software development.	A DOE lab, a university, and two industrial partners are contributing expertise to the design and construction of an experimental Instrument.	A US organization provides service to users and contributes expertise.	Nature of relationship with a US-based institute mentioned on the website was not determined.

Sources: ESFRI Roadmap 2016, 2018, websites of the RIs.

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12. This distinction is roughly based on costs of projects, with those over 1 billion dollars or euros generally being labelled megascience or Big Science projects, and small and medium-scale ones ranging from several million to hundreds of millions of dollars or euros.
13. Documentary sources were complemented by seven semi-structured interviews with informants from the RIs. One respondent provided written answers. Additionally, two unrecorded phone conversations, one interview with an external expert, and personal communications during a conference provided information. Interview questions addressed: (1) the RI's background and history, (2) motivations for collaboration, and (3) factors that enabled or challenged the collaborations. Interviews were recorded and transcribed and coded for further analysis. We use the words "informant," "respondent," and "interviewee" interchangeably.
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