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## « A Multi-Level Perspective on Ambidexterity: The Case of a Synchrotron Research Facility »

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# A Multi-Level Perspective on Ambidexterity: The Case of a Synchrotron Research Facility\*

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## Abstract:

We investigate the case of a large scale user oriented research infrastructure, to explicate the repertoire of management strategies that support its organizational ambidexterity. Adopting an ecosystem perspective, our case study unveils, beyond the generic exploitation / exploration tension the multi-level nature of ambidexterity through specific tensions associated to different management levels: (1) responsive *versus* proactive orientation towards users (2) modular *versus* architectural technology innovations; (3) competitive *versus* cooperative orientation towards other organizations. We conclude that ambidexterity is a systemic capability emerging through interactions between nested tensions. Appropriately managing a tension at one level helps to release the innovative energy of tensions at other levels. Synergistic evolution of tensions creates thereby multi-level innovation dynamics.

## Keywords:

Ambidexterity; technology management; co-opetition; user-producer interaction; research infrastructure.

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## I. Introduction

*"The test of a first-rate intelligence is the ability to hold two opposed ideas in mind at the same time and still retain the ability to function." (F. Scott Fitzgerald, The Crack Up, 1945)*

This quote illustrates in our paper the ability of synchrotron scientists and engineers to manage a large scale research infrastructure. While on the one hand synchrotrons have to reduce uncertainty and complexity in order to optimize their operation and minimize risks, on the other hand they have to cultivate them in order to strengthen their innovation capacity. Based on the case study of the French synchrotron Soleil, we show that, given the complex and uncertain environment in which this organization operates, the appropriate management of different tensions, a capability called organizational ambidexterity is a central feature of its sustained innovative performance (Duncan, 1976; Tushman & O'Reilly 1996; March, 1991; Smith & Lewis, 2011). We investigate through the case of Soleil the repertoire of critical management strategies that support organizational ambidexterity.

As non-profit research organizations, synchrotrons have the goal to produce and diffuse new knowledge through scientific publications. As user dedicated research facilities they are of distinctive value for fundamental and applied sciences. By visualizing the structure of matter at molecular and atomic levels, synchrotron radiation enables researchers in various scientific disciplines to conduct experiments that otherwise would be well beyond their individual laboratories' reach. Similar to other complex technological systems, synchrotrons are characterized by high capital and technology intensive investments even though their technological environment is characterized by rapid obsolescence. In such an environment, the design of synchrotrons remains in a state of continuous flux and only ends with their operational life (30-35 years on average). Synchrotrons need therefore to be adaptable and extendable. In the course of time they undergo incremental but also substantial transformations.

We consider that the synchrotron we focus at, like many organizations, is characterized by outward and inward oriented management processes to support its innovation dynamics. The external environment refers to the orientation of Soleil towards scientific users and interactions with them. It relates, also, to Soleil's inter-organizational relationships with other synchrotrons through network and community based organizational models which play an influential role in knowledge development processes. Finally, the internal environment corresponds to technology management mechanisms and coordination/integration processes between synchrotron members.

Beyond the generic exploitation *versus* exploration tension, our case study unveils the multi-level nature of ambidexterity through specific tensions associated to each management domain. The user perspective highlights the responsive *versus* proactive orientation towards users in satisfying their current and future needs. The inter-organizational perspective underlines the competitive *versus* cooperative orientation towards other synchrotrons in shaping individual and collective technological trajectories. The technological perspective envisages modular *versus* architectural change processes as critical in ensuring both efficiency and sustained innovation.

This study makes two contributions to the ambidexterity literature. First we develop a more comprehensive approach to ambidexterity by making explicit through the case of Soleil, multiple innovation tensions that each requires different and dedicated management strategies. We also show that ambidexterity is a systemic capability emerging from interactions between nested tensions.

In the following we first present the theoretical and analytical background. Next we describe our empirical case study and methodological approach. We then elaborate our findings. Finally, we discuss our results and conclude.

## **II. Theoretical Background**

Organizational ambidexterity is defined as the ability to manage challenging tensions by being capable to develop jointly contradictory knowledge processes or performance objectives with equal dexterity (Smith & Lewis, 2011; Andreopoulos & Lewis, 2009). It requires from organizations to transcend paradoxes by considering the complementary and synergistic nature of their contradictory elements (Gibson & Birkinshaw, 2004). Ambidexterity refers thus to the ability of organizations to leverage paradox *"in a creative way that captures both extremes"* (Eisenhardt, 2000). As suggested also by Andriopoulos & Lewis (2009) *"managing paradox does not imply resolution or eliminating the paradox, but tapping into its energizing potential."*

Following the seminal works of Duncan (1976) and March (1991), research on ambidexterity has been essentially addressed through mainly the tension between exploitative and explorative innovation modes. Whereas exploration implies experimentation with new alternatives, trial and error, risk taking and play, exploitation involves improving existing competencies and technologies, disciplined problem solving, refinement, selection, efficiency (March, 1991; Gupta *et al.*, 2006). Each builds therefore on different cognitive mindsets, different learning modes and call for different organizational structures. Hence ambidexterity requires managerial processes where both activities are appropriately deployed and integrated (Simsek *et al.*, 2009; Gupta *et al.* 2006). These processes can incorporate structural separation (Duncan, 1976; Benner & Tushman, 2003), temporal cycling (Tushman & O'Reilly, 1996; Burgelman, 2002; Gupta *et al.*, 2006) or contextual integration (Gibson & Birkinshaw, 2004) as organizational design approaches to manage ambidexterity contingent on the environment (Raisch & Birkinshaw, 2008).

Recently scholars called for ambidexterity research to devote more attention, beyond organizational design aspects, to its multiple dimensions in order to better reflect its systemic nature and understand its antecedents and outcomes (Gupta *et al.*, 2006; Raisch & Birkinshaw, 2008; Raisch *et al.*, 2009). The multifaceted nature of ambidexterity and the collective processes that enable it necessitate therefore adopting a more holistic approach.

The open innovation perspective (Chesbrough *et al.*, 2006) can be a fruitful framework to develop a more holistic approach to ambidexterity. This perspective has emphasized the importance of both internal and external knowledge management processes to improve innovativeness and support ambidexterity (Belderbos *et al.*, 2010; Ferrary, 2011). Interaction

with customers (Neale & Corkindale, 1998; Desouza *et al.*, 2008; Foss *et al.*, 2011), between competitors (von Hippel, 1987; Hamel *et al.*, 1998; Cassiman *et al.*, 2009; Gnyawali & Park, 2011) or within networks/communities (Franke & Shah, 2003; Owen-Smith & Powell, 2004) have been shown to be important innovation sources. Internally, particularly for S&T intensive systems, technology management and design capabilities have been highlighted as critical for innovativeness (Ulrich, 1995; Henderson & Clark, 1990; Brusoni & Prencipe, 2001).

Nevertheless, both internal and external innovation management processes are often underpinned by tensions. Concerning customer orientation strategies, scholars have distinguished two opposing orientations: responsive and proactive (Day, 1994; Slater & Narver, 1998, 1999; Narver *et al.*; 2004; Connor, 1999; Jaworski *et al.* 2000; Hult *et al.*, 2005; Ketchen *et al.* 2007). Focusing more explicitly on interactions between organizations and customers Daneels (2003) and Andriopoulos & Lewis (2009) have shown the importance for firms to combine loose and tight coupling with customers to sustain innovation capabilities. Whereas the focus of a responsive strategy is on efficient satisfaction of immediate customer needs, a proactive strategy is associated with long term orientation towards future and latent user needs and developments focusing on the creation of new markets. A responsive orientation helps to better fulfill varying needs of different customers. A proactive approach is nevertheless also necessary to keep open to opportunities to leverage competencies to new customers and engage in innovations that are beyond the immediate needs and competency scope of current customers. But, considering the key contributions that expert customers and lead-users can make to exploration, a proactive orientation can also go as far as integrating them in the innovation process (Berthon *et al.* 1999, Prahalad & Ramaswamy, 2000; Magnusson *et al.* 2003; von Hippel, 1976; Riggs & von Hippel, 1994; von Hippel, 1986; Thomke & von Hippel, 2002).

Co-opetition, where firms or members of a network/community simultaneously cooperate and compete is also a critical aspect of an open innovation strategy since it is based on the dynamic interdependence between actors operating in the same market or activity domain and having both distinct and common interests. Co-opetition between firms has been stressed as an important source of value creation (Brandenburger & Nalebuff, 1996). Competition between firms focuses on the development of distinctive competencies to offer different or superior products / services. This is often also a pre-condition in order to get involved in networks and communities. Similarly, members of a community often engage into competition and try to outperform others through new ideas and innovations (Hutter *et al.*, 2011). Competition is thus critical for unlocking and revealing the individual potential of firms or community / network members and to spur innovations. On the other hand, organizations cooperate to derive mutual benefits through joint value creation. Cooperation can improve coordination and use of resources between competing organizations; contribute to leverage internal capabilities by combining them with external complementary resources both for exploitative and explorative purposes (Rothermeal & Deeds, 2004; Yamakawa *et al.*, 2011). Freely revealing information, intense interaction and knowledge sharing can significantly improve the collective innovation capacity of the whole community and the system concerned (Von Hippel, 1987; Teece, 1992; Dyer & Singh, 1998; Gilsing &

Nooteboom, 2006; Ritala et al., 2009; Gnyawali & Park, 2011). Particularly in S&T intensive environments where technology cycles are short, R&D costs are high, where there are strong technical and cognitive complementarities and where the establishment of standards play a critical role in the market success of technologies, the interplay between competition and cooperation and the capability to find a healthy balance between both can be decisive for organizational ambidexterity.

Customer orientation and co-opetition strategies define how openness can be managed to contribute to organizational ambidexterity. An additional critical capability relates to internal processes both to guarantee operational efficiency and ensure effective change. Organization and innovation scholars have stressed the tensions that have to be conciliated in dynamic and complex environments between static-dynamic efficiency (Ghemawat & Ricart I Costa, 1993), efficiency-flexibility (Adler et al., 1999) or reliability-versatility (Hackett et al., 2004) of production systems. Particularly in the case of S&T intensive production systems technology management strategies represent a key factor in supporting organizational ambidexterity.

Research on complex technology systems (Hobday et al., 2000; Hobday & Rush, 1999; Etirahj & Levinthal, 2004) has highlighted the critical role of modular and architectural design strategies (Brusoni & Prencipe, 2001; Etirahj & Levinthal, 2004; Hobday et al. 2005) for the dynamics of innovation. Modularity involves system decomposability and enables flexibility and organizational modularity to manage change (Sanchez & Mahoney, 1996). Benefits related to modularity are for instance the possibility to uncouple, at least partially, learning performed in different sub-systems; to work simultaneously on the design of several sub-systems to speed up the innovation process; to increase an organization's overall capacity to absorb innovations; to decrease the need for hierarchy; and to enable the implementation of a wide variety of functionalities and services. In nearly decomposable systems, modularity generates openness and diversity, freedom and indeterminacy (Thompson, 1967). The architecture, on the other hand, in its coordinating and structuring roles promotes the relative stability and closeness of the system through standardized interfaces and selective determinacy. In contexts where organizations operate in variety and change intensive contexts tensions between modular and architectural logics can thus become inevitable (Henderson & Clark, 1990). Therefore ambidexterity requires to appropriately balance modular and architectural innovations over time and to harness beyond static system integration capabilities where only modules evolve without changing the architecture, dynamic system integration capabilities where both modules and the architecture change (Brusoni & Prencipe, 2001).

Studying a complex structure such as a synchrotron provides us interesting insights on ambidexterity through a multi-level perspective (Smith & Tushman 2005; Sidhu et al., 2007; Aspara et al. 2009; Simsek, 2009). Contradictory forces underlying ambidexterity can in fact be polymorphe. Ambidexterity may be required in distinct domains, tensions may relate to different management processes and may be found at different ontological levels (individual, team, project, firm, inter-organizational). As such, ambidexterity can be defined as a capability structured by the interplay between different processes, domains and levels (March 1991, Smith & Tushman 2005; Andriopoulos & Lewis, 2009; Simsek, 2009).

In the following, we show through the case of Soleil how ambidextrous innovation capability emerges from the management of distinct but nested organizational tensions: responsive / proactive orientation towards users, modular / architectural innovations and cooperation / competition at the inter-organizational level.

### **III. The empirical case**

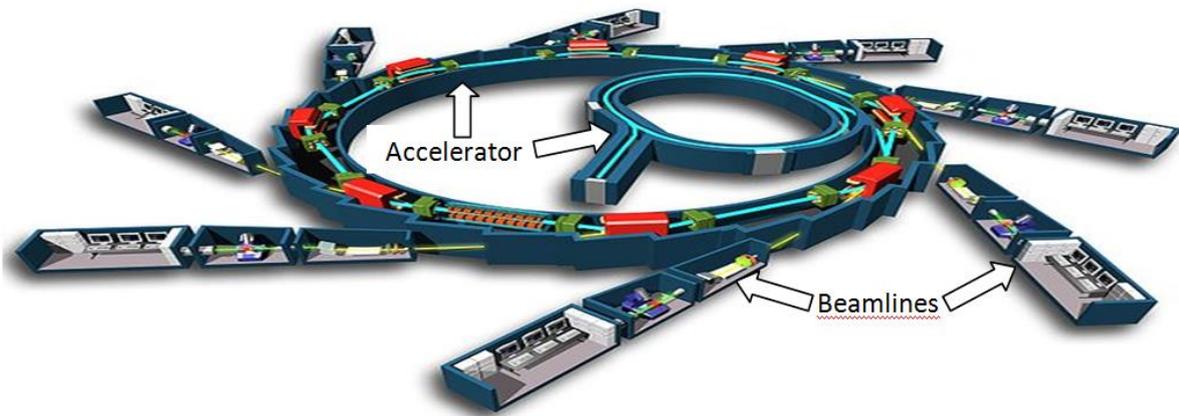
#### **1. The case of a large scale research facility**

Soleil is a French synchrotron radiation source, a large-scale research facility dedicated to scientific users to conduct experimental projects. Soleil hosts on average 3500 scientific users yearly (Soleil, 2012). As a public company Soleil's operation is financed by its two shareholders, the French National Centre for Scientific Research (CNRS) and the French Alternative Energies and Atomic Energy Commission (CEA) whose contributions are proportional to their use of the synchrotron (72% and 28% respectively). User hosting is also the object of a special European Community infrastructure access financing program. Additionally, Soleil participates actively to collaborative call for proposals and cost-sharing research partnerships with other synchrotrons to contribute to technological advances. The total Soleil workforce consists of 357 employees provided by the CNRS, the CEA and universities or directly recruited by Soleil. Thesis, doctoral, and post-doctoral students also participate in research programs, including those in the field of synchrotron technologies. 80% of the staff has scientific or technical vocations and 20% works in administrative or managerial activities.

The main mission of Soleil is to provide S&T services to the scientific community through its experimental platform. Soleil host a large number of scientific users from different disciplines with highly diversified and singular experimental needs. Access to Soleil by users is based on the academic model. Users have free access to beam time on beamlines (laboratories exploiting the radiation source) provided that they publish their results (open science norm) and submit their experiment projects to program committees for evaluation and acceptance. Once projects are accepted users are hosted on-site and accompanied by beamline scientists and engineers to run their experiments.

A synchrotron system is composed physically of two main parts: the accelerator which is the source of radiation and the beamlines (laboratories) connected to the accelerator which uses the radiation as an input to run scientific experiments. The organizational structure of a synchrotron reflects the distinctive functions of the accelerator and the beamlines. The Accelerator Division is organized around several technology competency units (e.g. magnetism and insertion devices, diagnostics, accelerator physics, operation) and includes physicians, geometers, engineers in charge of the development and the operation of the accelerator complex. The Experience Division is structured around several beamline laboratories. Each beamline is a small team organized around 4-5 members. It includes a scientist-manager, other scientists and engineers and often a post-doc and an associate external researcher.

**Figure 1: A graphic representation of a synchrotron**



The management of a large scale infrastructure supporting scientific research requires from synchrotron scientists and engineers to be involved in both exploitation and exploration. The ability to propose outstanding experiment solutions depends on keeping the infrastructure innovative for the scientific user community through cutting edge developments while securing and improving its efficient operation. This capability is based on three critical management domains related to users, the technological system and inter-organizational relations.

Beamline teams are in direct contact with scientific users and are involved both in service and research activities. Their success is judged according to standards in the scientific community through publications of experimental results in refereed, high impact journals and the visibility of their beamlines in the S&T community. Appropriately satisfying the needs of a large and heterogeneous user base requires from beamline teams to cultivate a quasi-industrial logic in conducting experiments. In parallel, the evolution of scientific needs in terms of experimental conditions and instrumentation motivates to continuously overcome and push the boundaries of technological possibilities. Experimental teams enjoy a great deal of autonomy and deploy entrepreneurial spirit in their research projects as long as these are useful to the user community.

Although the Accelerator and the Experience Divisions are autonomous in their internal organization and responsibilities, they are highly interdependent in their operation and technological design. The synchrotron is comprised of many interconnected sub-systems, electronic and IT based control units, and a variety of sophisticated components and materials. Its architecture is highly elaborate and includes multiple design possibilities. Many sub-systems are customized to respond to the specific needs of beamlines to allow different types of experiments. The accelerator being the common technological platform, the development of the synchrotron is therefore a collective and reciprocal process where innovations at the accelerator innovations create new experimental possibilities and beamline developments motivate accelerator changes. These interdependencies require from synchrotron members to continuously guarantee operational reliability on the one hand and variety and renewal on the other hand.

Soleil operates also in an environment where both competition and cooperation with other synchrotrons co-exist in the knowledge production process. The science policy environment is oriented towards more competitive forms of science funding at the national and European levels. The increasing number of synchrotrons at the European level (most European countries have built at least one synchrotron for their national user community) has also triggered competition and the need for differentiation and specialization across synchrotrons. At the same time the heterogeneity of knowledge domains and knowledge accumulation contexts, the interdependencies, complementarities and synergies between different synchrotrons but also between scientific users and synchrotron members makes knowledge production a truly collective process. Scientific advances require multidisciplinary and capital intensive research modes driving towards networking of infrastructural resources, close collaboration between synchrotrons to support knowledge creation. Synchrotrons share the characteristics of both epistemic communities and communities of practice. As such they share a common knowledge base and common professional values and norms. Soleil adopts network and community based organizational models to improve collective operational efficiency and develop new technological trajectories.

## **2. Methodological approach**

The in-depth case study on the Soleil synchrotron has been conducted within a larger project called EvaRIO (*Evaluation of Research Infrastructures in Open innovation and research systems*) realized by a team of researchers at the BETA between 2010 and 2013, and supported through the Infrastructure sub-program of the European Commission during the 7<sup>th</sup> Framework Program. During our Soleil case study we combined information from different sources including the Soleil web site, Soleil annual reports and the Soleil Journal (from N° 1 published in January 1997 until N° 22 published in November 2012). This documentation sources have been complemented by information collected directly at Soleil through targeted interviews. A series of 25 semi-structured interviews have been conducted, with an average duration of 2 hours, with different type of actors: 8 with members of the Soleil top management team, 6 with beamline leaders and scientists, 2 with instrumentation suppliers, and 9 with beamline users (of which 2 were private companies). Conversations during lunch and/or dinner time provided us further with highly valuable information. The interviews focused on the following topics: the history, financing, organization, strategy, outputs and impacts of the research facility. Specific topics addressed included: relationships and cooperation with scientific users and their role in the innovation process; internal technology and innovation management approaches, evolution of research themes and their organizational consequences, cooperation and competition with other synchrotrons; human resource policies and practices. To avoid loss of information, each interview was tape recorded, transcribed in full verbatim, under the conditions of anonymity and confidentiality of information. Interviews were conducted by at least two BETA researchers. However in the case of framing interviews the aim of which was to give an overview of the RI, between four and five people from the EvaRIO project were present. So the majority of the EvaRIO project team attended one interview or the other. We collected about 46 hours of recording time. We undertook a rigorous content analysis of the transcripts. This analysis helped us to modify and refine our preliminary conceptual/theoretical framework inspired by the exploration /

exploitation management literature and more particularly to develop our multi-level approach to ambidexterity. The quotes cited in the following parts of the paper are used to illustrate our findings.

## **IV. Findings**

Our case study led us to envisage ambidexterity as a multilevel construct related to key dimensions in the management of a complex organization, the synchrotron. These relate to its external users, its technological infrastructure and the community of which it is part. Each of these dimensions has been found to involve a distinct tension: responsive-proactive orientation towards users, modular-architectural technological changes and competitive-cooperative attitude towards the community. Furthermore, by focusing on short and long term innovation processes we conceived exploitation and exploration as two ends of a continuum (March, 1991; Gupta *et al.* 2006) and distinguished pure and balanced innovation modes. The combination of level specific tensions and innovation modes allowed us to characterize at each level four complementary management strategies that support the organizational innovation dynamic.

### **1. Beamlines: User oriented ambidexterity**

Beamlines who are in direct contact with scientific users pursue to broad missions. On the one hand, they have to provide valuable services to scientific users. Service activities are considered as necessary to ensure user satisfaction and contribute to the success of challenging experiments. On the other hand, beamline teams have to sustain their technological innovativeness. Significant efforts are invested to search for new applications for existing beamlines and develop new experimental systems. To fulfill these missions beamlines combine a responsive and proactive orientation towards users. While in the short term a responsive orientation dominates, reflecting the nature of services required (standardized and customized), in the long term beamline's adopt also a proactive orientation towards users (initiating new applications and designing new beamlines).

#### **1.1. Standardizing services**

The assistance provided to scientific users during experiments can be a very time-consuming and constraining task for beamlines which are operated by small teams. Therefore, when demand for a given experimental setting is high and experimental conditions are relatively stable an important aspect is to improve the productivity of the user support process. Exploitation of economies of speed, scale and scope orient in this context the beamline design strategy.

Service standardization, when appropriate, represents a common strategy for all beamlines. Whenever possible, they are designed to run on a turnkey basis and with user-friendly interfaces. Rationalization, automation, flexible sample handling systems, powerful measurement and data processing techniques are used to accelerate the experiment process and ensure high-throughput in order to create the possibility for large user turnover and for

access to non-expert users. For beamline systems which are in their mature phase efforts are therefore focused on exploitative innovations to improve efficiency. "*Crystallography is around for a long time...it's difficult to find something truly new and innovative setting. Now the focus is on how to apply the new technologies to do the same things better and faster. We are principally fine-tuning our system.*" (Beamline manager) The focus on exploitative efficiency helps to save time and resources, to minimize interactions with users and enables beamline teams to invest efforts on explorative and challenging experimental projects and on the long term development of beamlines.

## **1.2. Customizing services**

More sophisticated experimental projects require from beamlines to be innovative mediators between users and scientific instruments. They often entail improvisation in the sense that they combine design and execution (Miner et al. 2001; Baker et al., 2003) of experimental setups. The success of exploratory experiments depends critically on beamline scientists' and engineers' tacit knowledge to handle instruments and parameters and their expertise in interpreting and analyzing results. "*The beamline team knows the instruments inside out. They see a lot of projects. They have hindsight, which we don't as a user. They give us technical advice on things we do not even see. It's a fact that I benefit from their knowledge. The interactions with them are really essential. Infra-red experiments are not at all something standard or automatic; it's a domain with lot of evolutions.*" (Beamline user)

This creative assistance is accompanied by close interaction between users and beamline scientists in order to customize the experimental process. Users interact already with beamline scientists before accessing the synchrotron in order to improve project proposals and increase their chance to be accepted. Dialogue is also required to customize scientific instruments. Finally, beamline members because of their critical contribution to the experiment process participate with users as co-authors to the publication process. "*The user needs more than a technician to run the experiment. He often needs a scientist to bring his knowledge and who has a visibility in the scientific community...Often we become collaborators with our users when they need support. We consider this as our research, as part of our scientific activity of ... We invest our time to help users all along the process to achieve the publication phase. Once we support them, we appear as co-authors on the paper because users recognize our contribution.*" (Beamline manager)

## **1.3. Leveraging competencies**

Except for specifically designed beamlines for a given user community (e.g. biocrystallography), beamlines' research resources can potentially be used in a broad range of scientific fields and applications. Experimental systems are often multi-purpose or are subsequently adapted to fill needs other than their initial purpose (Rosenberg, 1992; Shinn and Joerges, 2002).

To leverage existing competencies (Daneels, 2007; Harvey et al. 2002) beamline managers adopt a proactive attitude to sense new applications. They insist on their role as gatekeepers to recognize the potential of atypical user proposals which otherwise would get rejected. Quit

often once users have been able to conduct such singular experiments they can diffuse the information to other users and initiate thereby a scientific community around these applications. In parallel, beamline manager dedicate their own research time to the exploration of new experimental possibilities: "*We are instigators, awakeners. We have our own research time. We use it to see if a subject is really worth, we make preliminary experiments and when we submit a project to the Program Committee we show the preliminary results. This contributes to the acceptance of the risky project ... 'there are results, its promising', ... so they give us beamtime.*" (Beamline manager)

Beamline managers favor also when appropriate multidisciplinary teams in order to develop interactions and improve communication with users from different disciplines. They insist on their bridging role across scientific disciplines as being critical to the leveraging process. They conceive beamlines as a forum to enable dialogue and create synergies among users from different scientific domains. This is facilitated through intense collaboration between beamline scientists and users. "*The right way is to motivate and convince users in an interdisciplinary way. Good projects are created by people who have complementary activities...I have two branches on my beamline. I have biologists in one branch and physicians in the other. They talk to each other. There are projects which have been launched in this way ... There are catalytic effects. We are a competency and instrumentation hub..... Beamlines or techniques complement each other but also disciplines complement each other.*" (Beamline manager). This way, beamlines connect formerly separated actors and serve to expand and foster collaboration networks (Hussler et al. 2016).

#### **1.4. Co-designing with users**

Long term beamline developments are based on both responsive (demand pull) and proactive (technology push) attitudes towards users. Extensive input from users on their future scientific needs helps to align research programs and orient instrument and beamline development projects. User workshops with scientific communities are regularly organized to gain insight on user expectations and on the changing scientific landscape. Also scientific committees involving expert users contribute to the reviewing process of beamlines every three to four years and influence thereby beamlines' explorative efforts. Direct personal interactions during experiments influence also future beamline developments.

Beamlines adopt also a proactive attitude toward users by selectively involving expert users and users from external research institutes in instrument and/or beamline developments. "*I had a request from a physician. I met him and he said 'I miss the instrument'. But we didn't have it. I knew that my colleague was a good scientist and that he had a challenge and the financial means. I worked hard to have a strong collaboration ... I explained my case to the Soleil top management and they understood it's potential ... This was for me a strong collaboration. We needed each other. I couldn't work without him and he couldn't work without me.*" (Beamline manager) Co-operation with users can go as far as hiring them as associates. A case in point is the partnership with the INRA, a public research institute on agricultural research. Expert users from the INRA are involved in the in-house research activities of several beamlines. "*When one of our researchers [from INRA] integrated the beamline, he built 50% of the UV imaging installation.... Our researchers are actively*

*involved on beamline development projects."* (INRA partnership manager) Although being INRA employees, Soleil associates report professionally to the beamline managers. The INRA co-finances beamline instrumentation and provides PhDs and Post-docs who devote their research to beamline projects. *"The partnership agreement is ambitious; it goes far beyond punctual collaboration [like in the case of an experiment]. With associate researchers we work on a research theme during at least 5 years and provide them privileged access to beam time ... We are in a win-win relationship with advantages for both parties. We offer them beam time, bring them expertise and a technological infrastructure that they cannot afford in their institute...They bring us their specific expertise and time."* (Soleil partnership manager)

**Figure 2: User oriented ambidexterity**

Exploitation	Innovation		Exploration
Responsive	Responsive	Proactive	Responsive /Proactive
Standardizing services	Customizing services	Leveraging competencies	Co-designing with users

## 2. Synchrotron system: technological ambidexterity

Whereas interactions with users shapes innovation management processes of beamlines, at the synchrotron system level, the technological infrastructure which connects the accelerator (producing the radiation) and the beamlines (using the radiation for experiments) is the main innovation structuring factor. The technological challenge of a synchrotron is to combine during its life cycle three main objectives which are besides ensuring efficient operation, to remain a variety but also change intensive organization. As we show these triple motivation is achieved by appropriately managing over time modular and architectural innovations. In the short term these three aspects are principally supported by modular innovations (operational optimization and versatility of the infrastructure) whilst keeping the architecture as much as possible stable. In the longer term, the architecture evolves also and innovations have to be coordinated and integrated (infrastructure upgrading and synchronizing).

### 2.1. Optimizing efficiency

Improving operational efficiency of the infrastructure is considered by the accelerator team as a key mission towards beamlines. Because unexpected beam interruptions and poorly controlled beam dynamics (e.g. instability) can involve significant losses for beamlines / users in terms of money, time and opportunity, a key determinant of efficiency is the reliability of the system.

To optimize reliability the accelerator group combines several mechanisms. Regular synchrotron shutdown periods are planned over the year for maintenance, repairs, upgrades of components and subsystems. Advanced monitoring techniques are developed to precisely control separately delicate parts of the system to locate more easily and detect timely problems. The objective is thereby to reduce recovery time by making reparability easier.

Risk reduction is additionally ensured through several flexible design principles. First, whenever possible, standardized modules are used in order to facilitate the market supply process. Second, redundancy is created by installing backup solutions or spare systems in different critical parts of the accelerator (e.g. the electric power supply system) to avoid beam interruptions. A third design principle used is the additionality of identical modules to create a scalable functional unit in order to make the system resilient to failures of one or several modules. This also facilitates maintenance since only failed modules are replaced and not the whole system, but also speeds up the substitution old generation modules by new ones. *“The solid state amplifiers used in our accelerator to generate the drive power [to maintain beam stability] have been developed in-house and are a technological leap. We used until recently, klystrons as amplifiers. The system was not flexible...when it broke down which happened quite frequently, users could not run experiments. Changing a klystron required many days. To alleviate this problem we developed a system with many transistors, each providing a small power. If one of them blows up, it’s not a big deal because it’s only one thousandth of the total power and we can still continue to work.”* (Accelerator engineer) A fourth mechanism relates to the progressive system add-ons dedicated to beam control and corrections during operation. Beyond passive control systems reflected in the initial built-in design parameters of the synchrotron to suppress exogenous vibration sources, the accelerator group develops active systems to control endogenous instability sources. Such "plugged-in" active systems respond to more stringent stability conditions required over time by beamline experiments.

## **2.2. Increasing diversity**

Although all beamlines exploit the same accelerator platform to access to the radiation source, different beamlines use different radiation properties (wavelengths from UV to X-rays) to respond to heterogeneous user needs. The design logic consists therefore in using the same common architecture for all beamlines and to apply the principle of process modularity through “late point” differentiation (Feitzinger & Lee, 1997; Sanchez, 1999; Tu et al. 2004) in order to produce beamline dedicated beam properties. This is made possible through customized modular interfaces (e.g. undulators) between the accelerator system and the beamlines which generate beamline specific radiation sources. Such an approach helps to develop new beamlines by exploiting to a large extent the existing accelerator system. *“If we install a new beamline or upgrade an existing one, we generally develop a new undulator with unique specificities. This provides us a great flexibility. We have different types of undulators and there are a lot of possible developments. Undulators may have different lengths, use different materials ... They generate radiation in new ways....We invent new ones continuously....”* (Accelerator system engineer) This late differentiation process has allowed, since Soleil's creation, the progressive installation of 30 different beamlines around the accelerator system.

Late differentiation reflects however only part of the innovation potential of the accelerator system to increase experiment diversity. Upstream or early differentiation, through the development of several accelerator operating modes by precisely controlling electron injection patterns, constitutes a complementary diversification mode to create new experiment possibilities (e.g. study of the dynamic properties of materials). But the latter design logic

doesn't promote anymore versatility (simultaneous diversity), like in the case of early differentiation, but only sequential diversity. Early differentiation requires the temporal planning of modes where some beamlines have to pause to give the possibility to others to use some specific modes. In order to improve simultaneity, efforts are made at two levels: accelerator engineers develop hybrid operational modes which suite to the needs of a larger set of beamlines or adapt downstream the modular interfaces in order to provide beamlines the possibility to use a greater variety of operational modes.

Together, the two differentiation principles provide the synchrotron the properties of a highly flexible system, which has the capacity to adjust to a growing range of uses by keeping the architecture as far as possible stable.

### **2.3. Upgrading progressively**

In the long term it becomes also essential to search for significant architectural performance improvements in order to be able to respond to changing user needs. Architectural innovations, because of their systemic nature increase the complexity and uncertainty of the managerial process. They often involve technologies with uneven rates of change and generate unpredicted emergent properties at the system level. Architectural modifications can have destabilizing effects on the system because of poorly understood cause-effect relationships. For the accelerator group, the motivation in pushing the performance frontier is thus to have an adaptive and controlled approach to complexity by opting for a sequenced architectural upgrading strategy capable to integrate paradoxical specifications (e.g. beam brilliance versus stability).

The accelerator group follows therefore a "time-paced transition" process (Brown & Eisenhardt, 1997). Architectural changes follow discreetly planned stages. At each stage the need for system integration requires a reflective learning process supporting the continuous articulation between theoretical conjecture and practical observation. The innovation process involves constantly moving back and forth between these two poles in identifying and analyzing emerging systemic properties. Elaborate theoretical and simulation models help to clarify some of these emergent proprieties. Others emerge only with a hands-on approach. Therefore architectural upgrades require frequent and longer synchrotron shutdown periods to conduct operational tests.

This process is illustrated by the ultimate beam intensity targeted (500mA) by Soleil to provide the basis for unprecedented experimental opportunities. This strategic plan, collectively agreed by Soleil members (top management, beamline managers and the accelerator group) during its design phase, although judged as very ambitious, provided a long term and common perspective for a gradual approach in structuring the innovation process. Right from the design stage, successive R&D projects were launched to better understand the implications of increasing levels of beam intensity on system behavior. Along successive projects, the accelerator group has been confronted to many puzzles. Several observations were contrary to initial guesses and provided paradoxical findings. Over time the different accelerator competency teams (each being responsible for a given functional part of the accelerator) had to behave in a responsive way and reorient their R&D activities according to

new emergent issues to support the systemic learning process. At the time of our interviews the beam intensity level validated for beamline operation had progressively increased from 300Ma to 430Ma and during 2015 the accelerator began finally to operate with a stored current of 500 mA.

#### **2.4. Synchronizing innovations**

While beamlines' exploration efforts are focused on experimental innovativeness, the challenge for the accelerator group is to contribute to the architectural upgrading of the accelerator system to enable such innovativeness. "*The operational domain of each beamline is decided to 95% within the machine and more precisely through magnetic systems around the storage ring.*" (Synchrotron manager) An important element in the coordination of innovation processes between the accelerator group and the beamlines is that they differ in their development time horizons. Whereas the accelerator system has an operational life-cycle extending up to 35 years, beamlines operate on a time horizon of 6-7 years. Exploration at the accelerator system level is thus heavily focused on dynamic system integration by combining modular and architectural innovations (Henderson & Clark, 1990; Brusoni & Prencipe, 2001; Prencipe, 2000; Brusoni et al., 2001).

By balancing and combining modular and infrastructural changes Soleil sustains its innovation dynamic through the reciprocal exploration dialogue between beamline teams and the accelerator group. Through interactions with users, beamlines channel their prospective needs to the accelerator group, thereby orienting explorative efforts within the accelerator group. On the other hand, the accelerator's architectural evolution is a crucial driver in orienting the explorative projects of beamlines. As the accelerator system evolves to meet the changing requirements of beamlines and in turn beamlines develop new research and experimental programs to benefit from the progressive upgrading of the accelerator system, new exploration cycles and feedback loops are triggered.

This synchronization is supported by flexible project based working practices (Hobday et al., 2005) to align and articulate exploration (Fujimura, 1987; Hoegel et al., 2004) between beamline teams and the accelerator group. A common frame of reference, a strong mutual absorptive capacity (Cohen & Levinthal, 1990) among synchrotron members with a broad skill base and similar level of background S&T knowledge facilitate the creation of flexible project based teams which evolve and are recomposed according to the emergence of new challenges. These qualities minimize the need for hierarchical intervention in the exploration process (Siggelkow & Levinthal, 2003). Synchronization is rather based on a dynamic balance between autonomous search (modular) and team based (integrative) coordination efforts (Sanchez & Mahoney, 1996; Siggelkow & Levinthal, 2003; Westerman et al., 2006; Puranam et al., 2006). To synchronize different innovation processes between the accelerator system and the beamlines, early project coordination helps to define collectively the framing objectives and milestones. Expected critical interdependencies are internalized by beamlines and the accelerator group to orient innovation processes in different parts of the synchrotron. As exploration unfolds, when local innovations and unforeseen interdependencies introduce new design problems they motivate mutual innovative adjustments. Coordination is thus ensured through regular meetings and information exchange to reorient learning efforts across

different trajectories, reconfigure interfaces, reorganize teamwork and redefine the autonomy zone of beamlines and the accelerator group.

**Figure 3: Technological ambidexterity**

Exploitation	Innovation		Exploration
Modular	Modular	Architectural	Modular / Architectural
Optimizing efficiency	Increasing diversity	Upgrading progressively	Synchronizing innovations

### 3. Inter-organizational ambidexterity

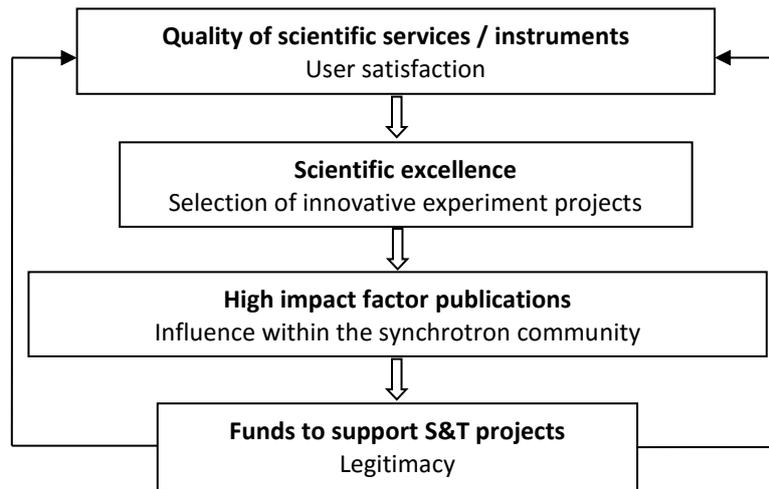
Soleil's innovation management strategies finally mirror its dynamic positioning within the synchrotron community. This positioning is structured by the cooperative and competitive attitude of Soleil towards other synchrotrons. At the more exploitative side, synchrotrons compete through scientific excellence to attract innovative experimental projects. In parallel, they engage in cooperation with other synchrotrons to improve their collective efficiency and better respond to user needs by pooling their complementary resources. Also when exploration is prioritized, competitive and cooperative forces co-exist and interact in the emergence and development of new technological trajectories. Synchrotrons compete to sustain their distinctiveness within the synchrotron community and cooperate to share high R&D costs and combine their competencies within complex projects.

#### 3.1. Striving for excellence

*"If we analyze the overall satisfaction of the user, this includes how he or she was treated and the quality of the working process, the service we provide."* (Beamline manager) Synchrotrons strive continuously for scientific service excellence to remain attractive for users. Excellence derives from the combination of scientific and technological support quality which as we have stressed in the two preceding sections results from the ability of beamlines to appropriately balance responsive and proactive attitudes towards users and modular and architectural technological innovations.

Scientific service excellence, experimental innovativeness and quality of scientific production create legitimacy to continue to obtain the public funds necessary to support the explorative capacity of synchrotrons in order to nurture their future competitiveness.

**Figure 4: Scientific value creation by synchrotrons**



Since academic publications are the ultimate performance measure for scientists, assisting users throughout the experimental and publishing processes is an important part in the attractiveness of synchrotrons. Besides, beamlines have to operate continuously at the technological frontier and act as pioneering technology adopters to attract innovative user projects. *"Users go everywhere. They know the advantages of one beamline compared to those in other synchrotrons. They are quickly informed when we buy a new detector. They come more often because there is a new instrument to discover."* (Beamline manager)

Attracting challenging and innovative projects contributes to the quality of scientific outputs and improves the visibility of synchrotrons within the broader community. *"There is competition among synchrotrons so they have an interest to attract projects like ours, it is a high impact project ... Synchrotrons are pretty good in general but an additional selection criterion is the quality of the people. At Soleil we are now collaborating with a beamline scientist. I knew that he was using an innovative x-ray diffraction technique with a lot of expertise. He is so good that he will be on the paper."* (User) The competitive relationship between European synchrotrons is also evidenced by the fact that even if they have the mission to provide access priority to their national user community, they strive to increase in size and diversity users from all over the world. Particularly the presence of users from countries where synchrotrons already exist is presented by the Soleil staff as a proof of the attractiveness of their organization (Soleil, 2012).

### **3.2. Networking**

The motivation behind the organization of collaborative multi-synchrotron networks is the ability to combine experimental systems dispersed across different synchrotrons for the purpose of creating and delivering new experimental possibilities and services to scientific users and which would be beyond the capabilities of a single research infrastructure. The strength of such networks is to pool its members' complementary resources and activities, and to allow each synchrotron to leverage its particular and specialized set of capabilities. The network creates in that sense greater combinatory flexibility (Snow et al., 2011) and increases the opportunities to run innovative and challenging experiment projects by exploiting collectively the assets and competencies of the network.

Supported financially by national and European policies on research infrastructures, synchrotrons have for instance engaged institutional and organizational changes to coordinate in a more systematic way multi-site access modes for users to existing synchrotrons. *"The concern is to rationalize at the European level user access to core research centers in life sciences and the different experimental fields and techniques they offer ... This multi-partner rationalization process is very useful for us. It helped us to organize our thoughts on our operational model, the one which could emerge. For instance Biostruct-X as a multi-partner platform [a networked infrastructure of national synchrotrons equipped with different X-ray techniques and dedicated to structural biology research] has been a driver for our structuring."* (Valorization manager)

The network organizational form is also motivated to support the standardization of experimental procedures and operational approaches across synchrotrons. Common standards are required to create a similar environment across synchrotrons in order to guarantee reproducibility / comparability of experiments conducted by users. Standardization processes are based on the initiation of common projects involving a consortium of synchrotrons and headed by a leading synchrotron. *"For instance there was a project led by the ESRF (one of the first European 3<sup>rd</sup> generation synchrotrons and located close to the city of Grenoble in France) to develop a common software to collect data in biocrystallography. The software is now the same for all synchrotrons and helps biologists to see the same information even if they use different equipment."* (Beamline manager) In the standardization process an important aspect relates also to the distinctive positioning of Soleil within different related projects in order to shape or influence consortium decisions with respect to Soleil's own strategic choices.

### **3.3. Differentiated positioning**

A critical factor contributing to the networking capability of Soleil relates to its long term investment choices to sustain its differentiated positioning compared to other synchrotrons. In that respect, the overall design phase of Soleil is illustrative of how it served as a momentum to establish the characteristics of Soleil, to shape its identity and orient its future trajectory within the broader synchrotron population. This phase was guided by the intention to provide the research facility a distinctive position among "3<sup>rd</sup> generation" synchrotrons and define its own competitive path. Its parameters have emerged through explorative efforts by considering significant developments (both internal and external) in critical technological domains as well as foreseeable technological advances. The objective was to confer Soleil, as one of the first "intermediary energy sources", a larger and unique set of radiation properties compared to already existing "low energy" and "high energy" 3<sup>rd</sup> generation synchrotrons and to create new experimental possibilities in a temporarily uncontested strategic space. *"We are still one of the leaders and try to maintain our position at the top. By designing Soleil, we placed our bets on very specific experiments. We invested in some domains on highly sophisticated technologies. We made a lot of efforts to start on very good bases and we build further upon. We have a machine with which we can go very far. Extending the design phase by several years has been a good thing. It helped to explore more and make important changes."* (Synchrotron manager) Several technological sub-systems implemented at Soleil, were the

first of their kind in the world of synchrotrons and were based on in-house research projects conducted within the LURE (the former 2<sup>nd</sup> generation French synchrotron) since 10-20 years.

During this design phase, explorative efforts drew also the greatest possible advantage from existing technologies in order to limit risks and appropriately allocate internal development efforts to distinctive high added-value parts. A progressive approach has often been adopted. This is for instance illustrated by the decision of Soleil to start its operations with a standard beam intensity of 200mA, and subsequently improve it through internal developments up to 500 mA, enabling the synchrotron to occupy a unique position within the community. The same strategy holds for undulators. *"We had to be sure of what we were doing. We went stepwise. We didn't want to do everything at once, to realize that it didn't work. On some parts we decided first to take existing standards. We didn't have the budget to develop very advanced undulators from the start. At the beginning we used classic undulators existing in the market, and then we rapidly innovated. We develop now regularly new types of undulators in-house."* (Synchrotron Manager).

Partnerships with other institutes and universities, with high-tech companies are also a key element to support the differentiation process. Soleil scientists and engineers have to motivate their partners to engage in ambitious developments and convince them to accept risky projects. This is often done by supporting challenging projects through Soleil's design and system integration expertise. As stated by one local high tech company *"We started to develop optics because of Soleil. Their requirements are often very difficult to achieve. Often it's something we have never done before. This improves our activity and provides Soleil with high quality components that we could not get elsewhere. It contributes to Soleil's competitive position at the international level."* (Supplier)

### **3.4. Innovation communities**

Referring to the first three 3<sup>rd</sup> generation hard X-ray machines, Haensel (1994) stressed the processes of mutual influence and shaping within the community of synchrotrons: *"Over the long run the three projects ran parallel and profited enormously from each other [...]. There are numerous examples of worldwide cross-fertilization. [...] where the first steps have been done on one side of the ocean and the systematic development on the other."*

This interactive innovation process hints to the continuous interplay between competition and cooperation within synchrotron communities and between their members. Synchrotrons evolve along technological trajectories (Dosi, 1982). Acting in a common perspective as user oriented research infrastructures, their S&T objectives and efforts are shaped by both common expectations and individual strategies. By orienting existing technological trajectories and contributing to the emergence of new ones, synchrotrons compete to serve as a point of reference for the development of other synchrotrons. In parallel, they engage in frequent explorative cooperation to stretch and leverage their innovation capacity.

Scientific entrepreneurs are characterized by their competitive spirit. Their role is to sense new opportunities, take risks, enroll new actors and attract resources to promote innovative projects (Hallonsten, 2009). This dynamic is for instance supported by international competition for human resources between synchrotrons to attract talented scientists. *"We have*

*a fairly high rate of foreign synchrotron scientists. It's part of our willingness not to be confined to France or even Europe but to seek talents wherever they are. There is a real competition at this level.... When a new synchrotron or a new beamline has to be designed there is a need for distinctive talents.*" (Human resource manager) During the emergence and development of new beamline generations, efforts engaged to shape and institutionalize new user communities are part of the competition process. *"From the beginning, we worked at the European and international levels. We engaged strong international partnerships with several potential user communities and their institutes...We created a network, developed and promoted the infrastructure required to gain recognition for our new experimental environment and get the necessary resources."* (Beamline Manager) Competition can also be more direct. Quite often different synchrotrons launch independently similar projects and use their skills and creativity to solve challenging problems which are in the interest of the whole community. Such community based innovation contests between synchrotrons serve in fact to increase the variety and potential of innovative approaches (Bullinger et al., 2010; Hutter et al., 2011)

Cooperation on the other hand is driven by the mutual motivation of synchrotrons to access to each other's S&T capabilities and to pool resources given the complexity and the high R&D costs of research infrastructure projects (Gnywali & Park, 2009; 2011). *"Each synchrotron is different but there are also strong similarities. When we carry out an innovative project which is highly complex, no one has the critical mass of competencies to fulfill the project. Thus we know that, we have a benefit to put in place partnerships."* (Synchrotron manager) Joint technology developments can be of varying scope, ranging from bi-lateral projects to consortiums in order to support whole infrastructure projects (ESRF being a case). On-line collaboration forums provide also the synchrotron community a virtual platform to exchange and circulate new ideas. Best practices and state-of-the-art technologies or processes disseminate among synchrotrons and serve as springboards for new innovations. *"It's very communicative. There is information exchange between the different synchrotrons and technical developments are relatively quickly adopted and further developed at other places."* (User) Diffusion is supported through the personal and informal network of scientists but also through institutionalized community initiatives (colloquiums, workshops, training programs). Inward and outward innovation transfer processes between synchrotrons showcase also that they can be important inputs for both individual and collective innovativeness. They reflect the cumulative and synergistic nature of innovations within the community and along technological trajectories.

In a long term perspective the history of synchrotrons (Haensel, 1994; Hallonsten, 2009) is replete of examples evidencing the role of co-opetition in the emergence of new technological trajectories. For instance in early synchrotron applications the co-opetitive use of synchrotron radiation by chemists on high energy physics accelerators, valuing what was initially considered as negative externalities by physicians paved the way to 2<sup>nd</sup> generation facilities optimized for synchrotron radiation. Also intense co-opetitive development efforts dedicated to 3<sup>rd</sup> generation technologies allowed low or intermediary energy storage rings to conduct hard X-ray experiments which were previously thought to be confined to high energy storage rings. These transitions and differentiation processes are mirrored in the dynamics of the

reconfiguration of inter-organizational networks and of co-opetition among scientific communities (e.g. physicians-chemists), within a given synchrotron generation (low, medium and high energy accelerators) and next generation technologies (ultimate third generation synchrotrons, free electron lasers).

**Figure 5: Inter-organizational ambidexterity**

Exploitation		Innovation		Exploration
Competition	Cooperation	Competition	Cooperation / Competition	
Striving for excellence	Networking	Differentiated positioning	Innovation communities	

## V. Discussion and conclusion

In this contribution, we investigate the case of a large scale user oriented research infrastructure, the French synchrotron Soleil, to explicate the repertoire of management strategies that support its organizational ambidexterity. The specificity of this organization in terms of its business model, strategies and competitive dynamics (Avadikyan et al., 2014) provides us with an original way to manage ambidexterity (Markides, 2013).

In their recent agenda for future research on ambidexterity, Tushman & O'Reilly (2013) propose to open the field of study to the firm's larger ecosystem. The reason is to be able to better understand the phenomenon of innovation which is not only housed within the firm but also and increasingly so outside its boundaries. In that perspective, our research provides key elements for the management of ambidexterity.

The Soleil case study outlines the fact that an organization closely interacting and co-evolving with its ecosystem requires to manage multiple tensions and develop therefore an organizational ambidexterity which is multi-level. These tensions relate to how the organization manages and orients itself towards both its internal and external environments. Outwards tensions are reflected in the orientation towards users (responsive *versus* proactive) and the broader synchrotron population of which the organization is part of (cooperative *versus* competitive). Inwards, tensions relate to the dynamic management of the technological system (modular *versus* architectural) allowing the organization both to respond to the evolution of user needs and to dynamically position itself within the broader community.

**Table 1:**  
**Innovation modes, level specific tensions and corresponding management strategies**

<b>Level &amp; Perspective</b>	<b>Innovation modes</b>	<b>Level specific tensions</b>	<b>Management strategies</b>
Beamline & User	Exploitation ↓	Responsive	Standardizing services
		Responsive	Customizing services
	Exploration	Proactive	Leveraging competencies
		Responsive & Proactive	Co-designing with users
Synchrotron & Technology	Exploitation ↓	Modular	Optimizing efficiency
		Modular	Increasing versatility
	Exploration	Architectural	Upgrading progressively
		Modular & Architectural	Synchronizing innovations
Synchrotron population & Inter-organizational	Exploitation ↓	Competition	Striving for excellence
		Cooperation	Networking
	Exploration	Competition	Differentiated positioning
		Competition & Cooperation	Innovation communities

Two observations are worth highlighting with regard to our findings:

First, although the innovation dynamic is characterized by the generic tension between exploitative and exploratory activities, the way this generic tension is managed and ambidexterity is sustained depends on level specific tensions and how they are addressed through the repertoire of strategies and corresponding management processes deployed by Soleil:

- User oriented ambidexterity testifies the necessity to pursue both responsive and proactive orientation strategies towards users. Both orientations are key aspects in the production of experiments and the innovative development of beamlines. Responsive orientation is based on closer tailoring of experiments and services, better understanding of users' immediate and future needs in order to appropriately delineate exploitative and explorative beamline efforts. Proactive orientation is nevertheless also necessary for ambidexterity. On the one hand such an orientation helps to leverage existing competencies to new user communities. On the other hand, it reflects the necessity for beamline scientists to engage in independent S&T research that is beyond the expertise and competency scope of existing users but which can open up new experimental opportunities. Considering however the key innovative contributions that scientific users can make on research instrumentation (Price, 1984; Rosenberg, 1992; von Hippel, 1976; Riggs & von Hippel, 1994) beamline managers can go as far as co-opting them as beamline members in the exploration process (Berthon *et al.* 1999, Prahalad & Ramaswamy, 2000; Magnusson *et al.* 2003). Therefore depending on the nature of experiments and beamline development activities, responsive and proactive orientations can promote interaction modes with users that are either loose (standardized services, competence leveraging or independent research) or tight (customized services and co-design of beamlines).

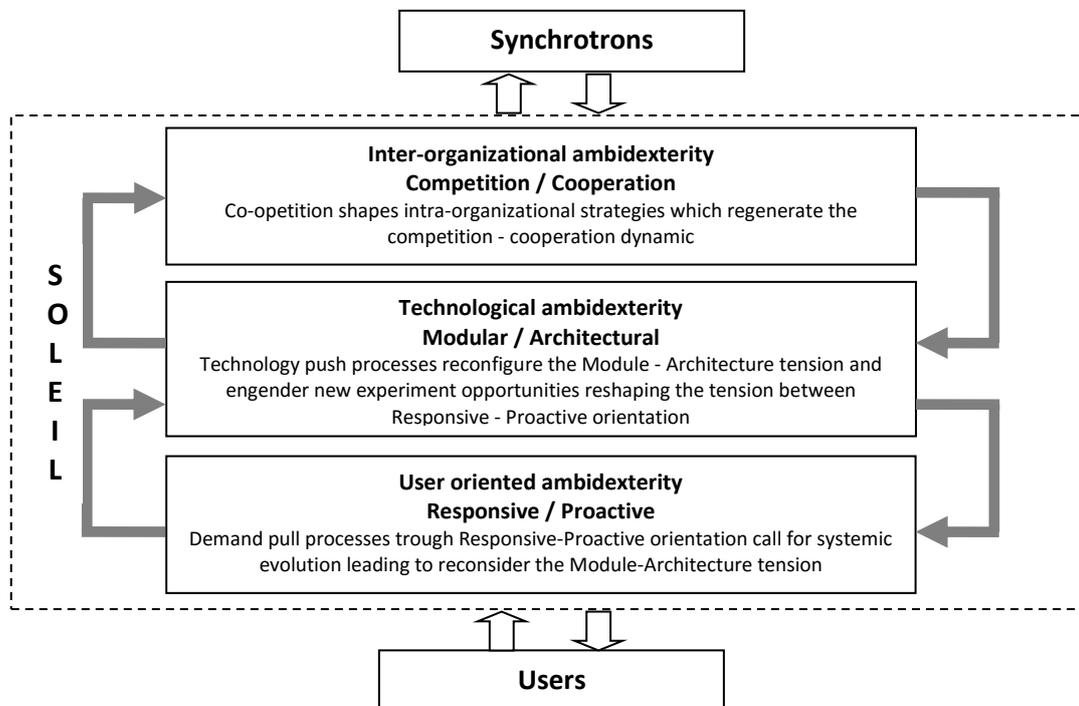
- Technological ambidexterity relates to the capability to appropriately manage and balance modular and architectural innovations within complex technological systems in rapidly evolving environments. In the case of Soleil, managers have to ensure the reliability of the common and shared experimental infrastructure and preserve at the same time its ability to evolve in order to satisfy new and emerging experiment needs. Technological ambidexterity is at the heart of the dynamic integrative capability (Sanchez & Mahoney, 1996; Brusoni & Prencipe, 2001; Etirahj & Levinthal, 2004; Hobday et al. 2005) of Soleil's accelerator scientists and engineers. They have to guarantee the highest operational efficiency of the complex system by controlling its multiple interdependences and think continuously about how to tailor and develop the accelerator according to the specific and evolving beamline requirements. This is done in the short term by tapping into the potential of modular innovations to guarantee the optimized operation of the synchrotron and generate differentiation (versatility) by exploiting as far as possible common elements of the accelerator. In the long term, the need to accommodate new experimental systems requires also architectural changes. The complex, uncertain and ill-understood environments in which these changes take place require from synchrotron members to adopt a progressive and stepwise approach to innovations and collectively synchronize and coordinate their exploratory efforts and modular and architectural innovations.
- Finally, inter-organizational ambidexterity refers to the spirit of competition and cooperation that drives interactions between synchrotrons. These interactions are shaped through the S&T networks and communities of which Soleil members are part of. They are characterized by open science norms, mission oriented activities to serve science and reciprocity in knowledge sharing to cope with mutual challenges (Dasgupta & David, 1994; Haeussler, 2011) and by peer emulation and innovation contests (Bullinger et al. 2010; Hutter et al., 2011). Through co-opetition synchrotrons create collective exploitative and exploratory benefits and at the same time leverage internally these benefits to create distinctive competencies. Co-opetition improves S&T services provided to scientific users through networking platforms, increases experimental variety through combination and differentiation and accelerates the emergence and development of new technological trajectories through the collective effort of innovation communities.

Second, the Soleil case evidences that in an open innovation context ambidexterity has to be conceived as a systemic capability. Soleil's ambidexterity is an emergent systemic capability shaped by the co-evolutionary interplay between three nested levels each characterized by a specific tension. Because, the different levels interact with each other, tensions emerging and addressed at one level have implications on the management of tensions at other levels. This embedded multilevel system is characterized by reciprocal influences between different management levels that together shape the synchrotron's ambidexterity and innovation dynamics. Considering for instance the inter-organizational level, co-opetition shapes intra-organizational development opportunities and trajectories which in turn regenerate inter-organizational co-opetition processes. A similar dynamic operates between the accelerator system and the beamlines: technology push innovations addressing the module-architecture tension open up new experimental conditions and opportunities reshaping the tension between responsive-proactive strategies. Finally, demand pull pressures emanating from

users/beamlines through responsive-proactive orientation call for innovative efforts at the synchrotron system level leading to reconsider the module / architecture tension. Therefore, lower level specific tensions become "manageable" or are redefined by addressing higher level specific tensions and the latter are reshaped by tensions emerging at lower levels. Appropriately managing a tension at one level helps to release the innovative energy contained in tensions at other levels. Synergistic evolution of tensions creates thereby multi-level innovation dynamics.

Ambidexterity is therefore the interdependent outcome of managerial processes combining user orientation, technology development and inter-organizational processes. It is sustained by the combination and interaction of internal and external innovation sources, that is, downstream with the scientific user community and upstream with the larger synchrotron community. Interaction modes between beamlines and the user community nurtures and structures the main mission of Soleil as a user dedicated research facility and orients thereby the internal technological system and the positioning of Soleil within the broader synchrotron environment. Interaction with the external synchrotron community reflects the processes through which Soleil continuously both contributes to and benefits dynamically from external knowledge of similar entities. This dynamic is supported internally by the capability of synchrotron members to manage their technological system through the combination of modular and architectural forms of innovation processes. Soleil's internal structure is conceived therefore as an evolving interface, where the external user and synchrotron environments intersect, and where appropriate strategies, processes and organizational forms are shaped to balance and cope with exploitative and exploratory forms of innovation.

**Figure 6: Multi-level ambidexterity**



## **Implications for theory and practice**

The analysis of ambidexterity management through the case of Soleil has several implications for innovation management theory and practice. Research on organizational ambidexterity can no longer be satisfied today by only describing situations of tension between exploitation and exploration. It should now explain the organizational phenomenon at work for managing ambidexterity (Khanagha et al., 2014) and the nature of integration processes within (Chen et al., 2015) and across organizations that such ambidexterity requires (Lavie et al., 2010; Kauppila, 2010).

First, in order to improve our understanding of the prerequisites of ambidexterity, it could be useful to invest in research considering ambidexterity management in the context of an innovative firm's larger ecosystem. Given the importance of outside innovation sources and the combination of internal and external knowledge developments in the innovation process there is the need to investigate in more depth the managerial, organizational, cultural implications for ambidexterity in this broader context. As O'Reilly & Tushman (2013) stress in a recent paper "*...if the locus of innovation is increasingly moving outside incumbent firms, the demands for firms to explore and exploit are both accentuated and made more difficult.*" (pp. 333).

Second, combining ambidexterity and open innovation topics could provide new insights on characteristics of ambidextrous organizations (Snow et al., 2011; Hafkesbrink & Schroll, 2014). In such a broader framework how firms manage and combine exploration and exploitation through inward (access to new ideas, knowledge absorption, technology adoption) and outward (collaboration, knowledge transfer, dissemination) oriented processes become critical. As our paper stresses this approach requires considering ambidexterity as a multi-level construct involving multiple and interacting tensions as firms span the boundary of their innovation process to involve outside actors.

A possible research orientation would be to focus on the role of communities of knowledge in ambidexterity management (Cohendet & Simon, 2007; Snow et al. 2011). Innovation activities involve increasingly multiple knowledge communities ("community of communities"). There is therefore the need to better understand how organizational communities interact and exchange with different external communities (e.g. customers, users, suppliers), with their external counterparts (within the same knowledge or practice domain) and also how "community of communities" manage and coordinate their activities to support and balance exploitation and exploration and cope with the multiple tensions that characterize their ecosystem. Our single case study contributed to the extent literature on communities by focusing and offering some liminal insights on the management of ambidexterity. These should be refined and elaborated through additional analysis and case studies.

Although our case study concerns a particular type of organization, the complex, rapidly changing and innovative environment within which Soleil operates and the organizational and managerial repertoire of processes that are combined to support effectively and efficiently its continuous innovation and excellence imperatives can have practical implications for

managers working in S&T intensive environments. From a broad viewpoint, managers have to conceive ambidexterity as a systemic and multi-level capability. Because tensions interact, creating and addressing tensions at one level often impacts the management of tensions at other levels. More specifically, the Soleil case can be useful for managers working in S&T intensive industries in stimulating reflection and debate about how to combine internal knowledge management processes and interactions with outside actors and communities (users, competitors) to enhance the innovative capability of their organization through ambidexterity.

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