A Multi-Level Perspective on Ambidexterity:  
The case of the SOLEIL Synchrotron Research Facility  
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I. Introduction  
Sustained long term success requires from organizations to effectively balance exploitative and explorative innovation activities and excel at both, a capability called organizational ambidexterity (Duncan, 1976; Tushman and O'Reilly 1996). The ability to be ambidextrous requires however from organizations to embrace and appropriately manage the tensions that arise from simultaneously conducting both types of learning activities (March, 1991; Smith and Lewis, 2011).  

We investigate the case of a large scale user oriented research infrastructure (RI), the French synchrotron Soleil, to explicate the critical management processes that support its organizational ambidexterity. Operating and evolving in a highly S&T intensive, uncertain and continuously changing environment, organizational ambidexterity is a central feature of synchrotrons and of their innovation and dynamic capabilities. Applying the existing theoretical framework on ambidexterity research (Raisch and Birkinshaw, 2008; Simsek et al. 2009) to our case study we provide a multi-level perspective on exploration-exploration (Andriopoulos and Lewis, 2009) and focus on processes through which critical tensions are managed to support organizational ambidexterity. More specifically our work informs three critical tensions that relate to the synchrotron's orientation towards external users, to its technological system and its positioning within the broader synchrotron community.  

As research facilities, synchrotrons host a large number of scientific users from different disciplines with highly diversified and evolving experimental needs. Appropriately satisfying the needs of this large and heterogeneous user base requires from synchrotrons both to cultivate an industrial service approach by increasing exploitative productivity in conducting experiments and at the same develop though exploration new experimental patterns to respond to new and changing user needs. Also similar to other complex technological systems, synchrotrons are characterized by capital, technology and knowledge intensive investments. Because of their long operational life cycles (30-35 years on average) they involve important feedback loops from operations into design innovation and development. They often necessitate the integration of important and sophisticated technological changes to accommodate increasingly diversified set of experimental possibilities. They need therefore to frequently renew the technological infrastructure through innovative exploration to avoid obsolescence while improving its exploitative reliability which requires to operate in a rather stable task environment. Finally, a synchrotron's exploitative and explorative activities are critically oriented and supported through its positioning within the larger synchrotron
community. Synchrotrons have both to cultivate individual differentiation to develop distinctive capabilities in a highly competitive landscape to remain attractive towards users and contribute to the collective performance of the whole community to contribute to its long term innovativeness.

This study makes several contributions to the ambidexterity literature. First our results provide a richer analysis of how exploitation and exploration efforts interact with each other. We show that these efforts are more often than not interlaced and that innovation activities beyond pure exploitation and exploration efforts are critically based on exploitative exploration and explorative exploitation processes. Our case study provides thus a framework contributing to a better understanding of the antecedents and processes of ambidexterity. We also develop a more comprehensive approach to ambidexterity by making explicit through our case study, multiple innovation tensions that each require different and dedicated management approaches. We finally contribute to the multi-level perspective on organizational change, by showing 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 contained in tensions at other levels. Synergistic evolution of tensions creates thereby multi-level innovation dynamics.

In the following we first describe our empirical case study and methodological approach. Next, we present the theoretical and analytical background based on ambidexterity research. We than elaborate our findings and finally discuss our results and conclude.

II. The empirical case

1. The synchrotron: a large scale research facility

A synchrotron is shorthand a very powerful microscope where various scientific experiments are carried out using radiation produced by electron accelerators. The properties of synchrotron radiation, its extreme brilliance and precision, are used to probe, analyze and experiment on the structure and dynamics of matter with ultra precise resolutions at the spatial (down to subnanometer) and temporal (down to hundreds of femtoseconds) scales.

The emergence of synchrotron radiation use dates back to the 1940s-1950s when a small community of scientists (physicians and chemists) discovered its value to explore the structure of matter. Since then synchrotron radiation facilities have developed through successive generations. The 1st generation synchrotron radiation was produced by storage rings built for high energy physics. In the 1970s, 2nd generation synchrotron storage rings were developed for the specific purpose of optimizing the production of radiation, given the increasing demand by scientists for synchrotron radiation. Critical technological developments paved then the way to the transition towards 3rd generation synchrotron facilities with unprecedented performances achieved in terms of beam brilliance, stability, lifetime and size and opening up new experimental possibilities (Hallonsten, 2009).

A synchrotron is composed of two main parts: The accelerator system and the beamlines. The accelerator system with its electron storage ring producing the synchrotron radiation is comprised of many interconnected elements including, numerous sub-systems, control units,
components and a variety of materials. Its system architecture is highly elaborate and includes multiple design possibilities. Sub-systems are themselves complex and many are highly customized to respond to the specific needs of experimental labs. Although all synchrotron accelerator systems perform the exact same task, producing radiation for different beamlines, every accelerator is built with unique designs, optimized with regard to its size and its exact parameters. Therefore an accelerator system is always optimized as a whole and though the function of two accelerator systems is the same, they are never identical (Hallonsten, 2009).

The beamlines on the other hand amount to genuine laboratories where samples are prepared, probed and, data collected and processed. Each beamline is managed by a small team of scientists and engineers who are in daily contact with external users. Different experiments require different radiation properties. Thus each beamline is specialized on a given energy domain and on one or several experimental techniques. Beamline technologies and experiments have significantly evolved through time. The evolution of accelerator technologies have created the possibility to expand and refine the set of experimental techniques. Developments concerned optic systems in order to improve focus, detector systems to make best use of the information provided by the radiation, sample handling, computer systems for data analysis, and user-friendly experimental systems.

The organizational structure of synchrotrons reflect the distinctive positions of the accelerator system and the beamlines. The Accelerator Division organized around several technology competency units is composed of mainly physicians, geometricians and engineers in charge of the development and the operation of the accelerator system. The Experience Division includes the beamlines and several common R&D laboratories in order to coordinate and satisfy the specific and common instrumentation needs of beamlines. In between these two main organizational units, other Divisions play a transverse role focusing on development and engineering work in domains critical both to the accelerator system and the beamlines.

Access to beamlines by external users is mostly based on an academic model. It is obtained through a selection process based on the quality of research projects submitted by users and peer-reviewed by scientific committees (generally one for each scientific domain). Once projects are accepted users are hosted on-site and accompanied by beamline scientists and engineers to run their experiments free of charge. This academic access mode represents de facto a grant to academic research and is subject to the publication of experiment results.

2. The case of Soleil and the methodological approach

Soleil is a French third generation synchrotron radiation source. It has been opened to the external scientific user community in 2008. As of 2014, 26 beamlines were installed around the storage ring with the objective to reach 29 beamlines in 2015. The total budget (construction and setting up) for SOLEIL from 2002-2012, reached 634M€.

Soleil hosts each year on average 3500 users on its beamlines (Soleil, 2012). Between 2008 and the end of 2012, nearly 1,200 different external laboratories have had access to SOLEIL. For the year 2013 alone, Soleil had 4000 visits, by scientists from 690 different laboratories. Of these, 486 labs were using SOLEIL for the first time (Soleil, 2014). Although Soleil was build to respond in priority to the needs of the French scientific user community, the
synchrotron also host projects submitted by scientists from other countries. For instance in 2012 foreign laboratories have used 29% of the beam time (23% for European laboratories) with proposals received from 36 countries (Soleil, 2013). In 2013, scientists from the USA joined the top five foreign users of SOLEIL, alongside the UK, Germany, Italy, and Spain. The latter criterion is very important for a synchrotron since it clearly illustrates its attractiveness. Demand pressure is very high for some beamlines. Acceptance rates can thus be as low as 21% and the average rate is close to 38%.

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 the BETA between 2010-2013 and supported through the Infrastructure sub-program of the European Commission during the 7th Framework Program. During our Soleil case study we combined information from different sources including the Soleil website, Soleil annual reports (Highlights, 2010, 2011, 2012) and the Soleil Journal (from N° 1 published in 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 management team, 6 with beamline managers, 2 with instrumentation suppliers and 9 with beamline users of which 2 were private companies. Additional conversations during lunch and/or dinner time provided us further with highly valuable information. To avoid loss of information, each interview was 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 BETA were present. So the majority of the BETA team attended one interview or the other. We collected about 46 hours of recording time, which corresponds to 268,442 words, once transcribed.

III. Theoretical Background

Exploration and exploitation refer to very different knowledge processes and call for different cognitive mindsets and organizational processes. Exploration implies experimentation with new alternatives, trial and error, risk taking, variation and play while exploitation involves extension of existing competencies and technologies, disciplined problem solving, refinement, selection, efficiency (March, 1991; Gupta et al., 2006).

Organizational ambidexterity can thus be defined as the ability of an organization to manage challenging tensions by being capable to develop jointly contradictory knowledge processes or performance objectives with equal dexterity. It requires from organizations to transcend paradoxes by perceiving them as complementary, synergistic and interwoven (Gibson and 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 and Lewis (2009) "managing paradox does not imply resolution or eliminating the paradox, but tapping into its energizing potential."
Scholars on ambidexterity have proposed several solutions to manage exploitation-exploration tensions (Simsek et al., 2009). A dominant approach has been the separation of both activities (Gupta et al. 2006). The structural view refers to ambidexterity as the simultaneous pursuit of exploitation and exploration by separate and specialized organizational subunits each with distinct routines and cognitive mindsets to support a given type of learning (Duncan, 1976; Benner & Tushman, 2003). Temporal ambidexterity reflects an alternative balancing mechanism where organizations cycle between exploitation focusing on efficiency related innovations and exploration when attention shifts to breakthrough innovations (Tushman & O’Reilly, 1996; Burgelman, 2002; Gupta et al., 2006). Both approaches however require higher level integrative efforts to coordinate exploitation-exploration and to avoid competency/failure traps.

A third perspective that has been proposed is contextual ambidexterity (Gibson and Birkintshaw, 2004). This view adopts an integrated perspective to the management of exploitation-exploration where the context is dynamic and flexible enough for both activities to be conducted within the same organizational unit/individual. Contextual ambidexterity emphasizes behavioral and social characteristics to cope with contradictory knowledge processes. Integrated pursuit of exploitation-exploration is seen as part of an organization's culture, its formal and informal structures and its members' ability to think and act ambidextrously. Gibson and Birkintshaw (2004) have argued that an organizational context characterized by stretch, discipline, support, and trust (Ghoshal and Bartlett, 1994) facilitates ambidexterity because it involves a joint emphasis on high performance and social support.

Recent reviews called for ambidexterity research taking into account its multiple dimensions and spanning multiple levels of analysis to better reflect its complexity and have a more holistic understanding of its antecedents and outcomes (Gupta et al., 2006; Raisch and Birkintshaw, 2008; Raisch et al., 2009).

Contradictory forces underlying ambidexterity can be multi-faceted and concern distinct domains related for instance to markets/customers, technologies, partnerships/networks (Smith and Tushman 2005; Sidhu et al., 2007; Aspara et al. 2009; Simsek, 2009). Also exploitation/exploration tensions may be found throughout different organizational levels, ambidexterity being a capability emerging through the complex interplay of tensions disposed at these various levels (March 1991, Smith and Tushman 2005; Andriopoulos and Lewis, 2009; Simsek, 2009). Through a multiple case study Andriopoulos and Lewis (2009) have shown that ambidextrous innovation processes are based on the management of nested and interwoven paradoxes across different levels and that consistent interactions across them create and sustain organizational ambidexterity.

Our case study led us to conceptualize ambidextrous innovation capability as emerging from the management of idiosyncratic tensions underlying the exploitation-exploration process across three distinct but interdependent levels: user oriented ambidexterity, technological ambidexterity and positioning ambidexterity (Table 1). In the following we present in more detail each level before illustrating them through the Soleil case.
Table 1: Multi-level ambidexterity, related tensions and management processes

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IV. Findings

1. Beamline level: User oriented ambidexterity

1.1. The tension between responsiveness and proactivity

Management scholars have widely recognized the important role of market orientation strategies. Two broad orientation strategies have been distinguished: responsive and proactive (Day, 1994; Slater and Narver, 1998, 1999; Connor, 1999; Jaworski et al. 2000; Hult et al., 2005; Connor, 2007; Ketchen et al. 2007;). Whereas the focus of a responsive strategy is on short term satisfaction of existing and immediate customer requirements, a proactive strategy is associated with long term orientation with a focus on the anticipation of future needs, the discovery of new market opportunities and the development of competencies necessary to respond to emerging demands.

For Narver et al. (2004) in the responsive market orientation the product design process is addressed in order to respond to expressed needs of customers and the proactive orientation takes into account their latent needs. In the second case, the requirements are not directly expressible for the customers and hardly explicitly formalizable for the designer, insofar as they are often unconscious. According to the authors: “for any business to create and to sustain a new product success, a responsive market orientation is no sufficient... Such a business is vulnerable ... for relying on customers’ best guesses for new products, many or most of which may have little long-term economic value for either party... A business that relies solely on customers’ expressed needs to develop its new products creates no new insights into value-adding opportunities for the customer and thereby creates little or no customer dependence and foundation for customer loyalty.” p.334

Formal information systems as they exist in quality assurance, for example, are a useful source of information to develop detailed specifications to support a responsive market orientation. Conversely, it is often through the detailed observation of user behavior, direct interaction and close communication with them, that it become possible to capture the unexpressed needs of the customers and that the designers get able to identify latent needs to create value. But a crucial complementary aspect is the capability of designers to proactively
and independently explore new products/technologies to discover opportunities of which customers are not aware about. This proactive orientation is a way both to value the designers' distinctive knowledge and experience in designing products and to extend their knowledge base. Focusing explicitly on interaction modes between organizations and customers through the concepts of loose and tight coupling (Orton & Weick, 1990), Daneels (2003) and Andriopoulos & Lewis (2009) have shown the importance for firms to combine these interaction modes to support their responsive and proactive customer orientations.

If we transpose this market orientation perspective to the synchrotron case, “customers” correspond to scientific users who conduct experiments which are a necessary condition for scientific publications. "Products" are the technologies and services upon which the success of experiments directly depend.

In the following we explicit four key strategies which structure the user orientation of beamlines:

- When the scientific communities are highly structured and stable in their use of the beamlines, the management of beamlines is structured around the logic of exploitative responsiveness and efficiency: the standardized service strategy (§ 1.2.1)

- The beamline managers need often to develop a more customized approach to adapt the experiment process to the singular needs of scientists. The challenging nature of experiments requires therefore a responsive explorative approach: the customized service strategy (§ 1.2.2)

- Beamline managers intend also to identify latent needs within research communities who have little experience to appeal to the synchrotron service. In a proactive logic, the objective is to exploit existing beamline capabilities to develop new applications and to attract new user communities: the competence leveraging strategy (§ 1.2.3)

- Finally, close and long-term partnerships with lead users combine responsive and proactive market orientation perspectives. The aim is to associate creatively expert users' competencies in specific domains and beamline managers distinctive capabilities: the co-design strategy (§ 1.2.4)

1.2. Management of the user oriented ambidexterity

1.2.1. The standardized service strategy

A motivation in designing and operating beamlines is to improve the efficient productivity of the user support process during experiments by exploiting economies of speed, scale and scope (Nightingale, 2000). The mediation between the capabilities of scientific instruments and the requests of users and their assistance during experiments can be very time-consuming for beamline teams having a very heavy workload. Therefore, for beamlines where demand is high and experimental conditions are relatively homogeneous and stable an orientation towards automation and standardization represents a natural trajectory.
Crystallography experiments are a case in point. Overwhelmingly used by biologists, crystallography beamlines conduct rather “measurements” than “experiments”. The experimental systems are designed to run on a turnkey basis and with user-friendly interfaces. Rationalization, automation, 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. As stressed by the crystallography beamline manager "the experiments are more or less identical, the specificities concern rather the object (the crystal sample). It’s rather rare that we have to modify the line to run the experiment. The technology is quite generic...The experiments take in general two minutes with about 200-300 crystals daily. We work during 6-8 weeks with the same equipment configuration and require just a daily preventive maintenance to guarantee their smooth operation." Therefore, for beamlines, standardization of services, when possible, represents a common strategy to improve efficiency and to save time. Furthermore, since beamline technologies are in their mature phase, the focus is principally on exploitative innovation. "Crystallography is around for a long time...it's difficult to find something truly new and innovative. Now the focus is on how to apply the new technologies to do the same things better and faster. We are in a logic of fine-tuning" (Beamline manager).

1.2.2. The customized service strategy

Although standardization represents an effective way to increase the efficiency of experiments, it is more difficult to implement when experiments are more exploratory and entail naturally improvisation and bricolage during the experimental process (Weick, 1996; Baker et al., 2003). Exploratory experiments require longer beamtime (typically several weeks), necessitate sample preparation, playing with instruments and experiment parameters, expertise in interpreting and analyzing results. For users, tapping into beamline scientists’ and engineers’ tacit knowledge is a key factor in successfully running difficult experiments. “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)

Difficult experiments require from beamline teams to be innovative mediators between users' needs and the capabilities of instruments. This kind of valuable support is thus to be differentiated from the basic support provided by beamlines to first time users. Through the creative assistance they provide to users, beamline scientists contribute also to the scientific output as co-authors in prestigious journals. This aspect is stressed for instance by the SMIS beamline manager: "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.... At Soleil most of our colleagues are really involved...Often we become collaborators with our users when they need support for their experiments. We consider this as our research, as part of the scientific activity of our beamline for which we are responsible...We will invest our time to help users all along the process to achieve the publication phase. Once we support them, we help them in processing and interpreting the data, we got our names in the
publications. We appear as co-authors because users recognize our action and if it is published in a high quality journal it is a good thing.” (Beamline manager). The involvement of beamline teams is sometimes so important that it can sometimes generate tensions. “We cannot present always the results as our own scientific research. The difficulty to evaluate our scientific activity lies there. It’s our choice. My beamline must be productive. If I’m not involved in interacting with users, in monitoring the experiment, in writing the paper, my beamline will not be productive.” Beamline scientists require personal recognition and to be considered as scientists able to conduct their own in-house research. But because of the lack of time to develop their personal research some of them can decide to look for an academic position as a professor.

Customized experiments create also the opportunity to develop tight relationships between scientific users and beamline scientists. Cooperation is manifested through common research proposals for beamline access. In fact, challenging experiment projects represent an opportunity for both users and the beamline team to foster through collaboration their explorative innovation efforts to develop, in promising experimental domains, dedicated specific methodologies and instruments. “Physics experiments require the development of highly specific instruments which take me a lot of time. Let me give you an example. Scientists want to study more and more the new chemical materials that we find in the core of the Earth. In order to do that we need extremely high pressures and temperatures to create the right conditions. I had a request from a physician at the CEA. I met him and he said ‘I miss the instrument’. But we didn’t have it. It was a completely different instrument. 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 and to make Soleil visible in the project...I explained my case to the Soleil managers and they understood it’s potential...This is for me a strong collaboration. We did it. We were very happy to work together. We needed each other. I couldn’t work without him and he couldn’t work without me.” (Beamline manager)

1.2.3. Competence leveraging strategy

Beamlines are composed of research resources that are amenable to uses for a broad range of potential scientific fields and applications. Quite often experimental instruments and systems are designed as multi-purpose technologies or are subsequently adapted to fill needs other than their initial purpose (Rosenberg, 1992). They have in that sense a generic character and their exploitation in a given time does not necessarily reflect their alternative capabilities.

Technology leveraging requires a proactive entrepreneurial process to sense new scientific application areas. This process involves both de-linking the technology from its current applications and re-linking it to new user communities or new research domains (Daneels, 2007). Beamlines conduct autonomous in-house research in order to imagine and learn about new applications: "We are instigators, awakeners. We have our own research time for our projects. Sometimes we use it to see if a subject is really worth, we make preliminary experiments and when a project is submitted 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 it beamtime" (Beamline manager). Beamline scientists
also monitor, as gatekeepers, atypical and risky project proposals by would-be synchrotron users which could open up promising research directions.

A multidisciplinary approach is often cultivated within beamline teams to improve communication with potential users. Beamline managers invest significant efforts to convince new users of the utility of their techniques and to understand precisely their needs. They initiate tight interaction with them during the project proposal stage to secure the necessary financial, human and technical resources to run the experiment. Beamline managers insist on their bridging role across scientific disciplines and synchrotron techniques as being critical to the leveraging process. They conceive beamlines as a forum to combine ideas and create synergies. New applications emerge when user teams from distinct disciplines come to run their experiments, meet each other and discover opportunities for a common project. "The right way is to motivate and convince people in an interdisciplinary way, a biologist with a doctor, sometimes with an intermediary, a biochemist or a bio-spectroscopiste. Good projects are created by people who have complementary activities" (Beamline manager). The fact that a synchrotron concentrates in a single space a multiplicity of distinct experimental capabilities creates favorable conditions for cross-fertilization. For many research programs new investigation possibilities are opened up through the combination of complementary synchrotron techniques. "I have two branches on my beamline. I always have biologists on my microscope. I have physicians in the other experiment room. They talk to each other. There is a project which has been launched in this way by two external users.... There are catalytic effects. We are a competency and instrumentation hub. It's an important element in our creation process .... Disciplines complement each other but also techniques complement each other. It's not always simple to coordinate our activities across beamlines, but it's important. This is what motivates me...to search for combinations with different techniques to gain more information..." (Beamline manager). Beamline managers hold therefore a boundary position and act as orchestrators to orient projects towards the appropriate bundle of beamlines. As such, beamline scientists cultivate what Shinn and Joerges (2002) define a transverse S&T culture. They "operate out of an interstitial arena" and engage permanently in boundary crossing to broaden the adoption of their ideas and instruments by new users, disciplines and research fields.

1.2.4. The co-design strategy

The emergence, design and continuous development of beamlines result from different interaction processes between the user community and the beamline teams. Extensive input from current and potential users on their future scientific needs help to orient the long term strategies of beamlines, to develop innovative instruments and prepare new scientific programs. To facilitate communication and information sharing, user workshops with different scientific communities are regularly organized to gain insight on user expectations and to anticipate the changing scientific landscape. These workshops serve as promotion and selection mechanisms for new instrument concepts in building new beamlines. Also scientific committees involving expert users contribute to the reviewing process of existing beamlines every 3-5 years. Feedback from users on their satisfaction regarding the scientific and technical support provided by beamlines serve as an input to orient beamline's innovative
efforts. Direct personal interactions, through the flow of users during experiments represent also important information sources and influence future beamline developments. Punctual collaborations with expert users help to test newly developed instruments before opening them to the larger scientific community. Such collaborations provide mutual benefits. Lead-users get the opportunity to launch pioneering experimental projects on leading-edge instruments. In turn, beamlines benefit from the competence of lead-users to further improve and refine instruments.

Through long term collaboration beamlines implement also co-design strategies, when appropriate with expert users or research institutes. Soleil employs around 80 external associate researchers who are directly involved with permanent beamline scientists and engineers in the co-development of beamlines. A case in point is the partnership with the INRA, a public research institute on agricultural research, to attract talented users and actively involve them on beamline related R&D efforts. Associate researchers from the INRA are involved in three Soleil beamlines. Although being INRA employees, they are at the disposal of Soleil and report professionally to the beamline managers. The INRA co-finances beamline instrumentation and provides PhDs and Post-docs who devote their research to long term projects. "The partnership agreement [with the INRA] is highly formalized and very ambitious; it goes far beyond a punctual collaboration. With associate researchers we work on a research theme or technique during at least 5 years and provide them privileged access to beamtime...We are in a win-win relationship with a significant advantage for both parties. We offer them beamtime, bring them expertise and a technological infrastructure that they cannot afford in their institute...They bring us of course their expertise, and also their work time which adds to that of the Soleil permanent staff." (Soleil partnership manager). The partnership helps INRA users to improve the project bidding process, allows to better focus on their development needs and speeds information flow and knowledge transfer between the two organizations: "The gain for our institute [the INRA] is substantial...beyond improving the acceptance rate of our experiment proposals, we are very quickly informed about beamline improvements. When they installed the imaging branch at the DISCO beamline, we have been one of the first users. Very often when there are technical improvements we have the opportunity to bring our own samples from the INRA to test these improvements". Particularly, the partnership highlights the critical role that associate user scientists play in the beamline innovation process (von Hippel, 1976) : "When one of our researchers integrated the DISCO beamline, being trained in imaging experiments, he built on its own 50% of the UV imaging installation on this beamline...this was initially. As beamlines improve their technologies every 6 month, our researchers are actively involved in this process. For instance one of our staff is very good at sample handling robots. Our staff contributes therefore to many innovations and improvements." (INRA Partnership manager).
2. Synchrotron level: technological ambidexterity

2.1 The tension between modular and architectural innovations

The second level concerns the dynamic management of the technological infrastructure to respond to the evolving needs of users and maintain a high level of technological innovativeness. This dynamic is based on a crucial feature of synchrotrons: the balance between modular and architectural innovations.

Modularity involves not only system decomposability, but also loose coupling between modules. Modularity is a strategy to master complexity, which can be especially useful in noisy environmental contexts like innovation processes. For example, research on complex products and systems – CoPS - (Hobday et al., 2000; Hobday & Rush, 2000; Etirahj & Levinthal, 2004), on technology platforms/architectures (Davies et al. 2007; Hobday et al. 2005; Brusoni & Prencipe, 2001; Etirahj & Levinthal, 2004) insisted on the importance of system integration capabilities and the role of modularity and architectural complexity in shaping innovation processes.

In this perspective, Sanchez & Mahoney (1996) defend the idea that technological modularity enables organizational modularity to manage and design the system. If we assimilate the interfaces between the “machine” and the beamlines to the system's architecture and the machine and beamlines to modules, then this confers, according to Sanchez & Mahoney, a certain number of benefits to the innovation process:

- it becomes possible to uncouple, at least partially, learning performed on the machine to that performed on beamlines;
- it becomes possible to work simultaneously on the design of several beamlines, which speeds up the design process;
- a disturbance on one beamline may not necessarily call into question the functioning of the entire synchrotron;
- It increase synchrotron's overall capacity to absorb beamline and machine level innovations;
- It decreases the need for hierarchy;
- It enables the implementation of a wide variety of functionalities and services.
Nevertheless, in a context of fast technological obsolescence, characterized by continuous innovation, a tension between the evolution of architecture and evolution of modules is inevitable (Henderson and Clark, 1990). Therefore, having to deal with complex and uncertain technological systems, accelerator scientists' and engineers' system integration capabilities (Henderson and Clark, 1990; Hobday et al., 2000, Brusoni and Prencipe, 2001; Brusoni et al., 2001) critically orient and support technological ambidexterity.

Indeed, in a loosely coupled system the architecture in its coordinating role leads to the relative stability and closeness of the system, to standardized control and system determinacy. At the same time modular innovativeness and their distinctive environments provide systemic openness, diversity, discretion and indeterminacy [Thompson (1967)].

The achievement of such (technological) ambidexterity depends on how modular and architectural innovations are combined through system design, engineering and integration capabilities. The accelerator systems' evolution can here be assimilated to a "time-paced transition" (Brown and Eisenhardt, 1997) based on organizational change through sequenced steps. A critical question with respect to system integration in a fast changing and uncertain environment is therefore how different organizational units balance autonomous and coordinated explorative efforts (Siggelkow and Levinthal, 2003; Westerman et al, 2006; Puranam et al., 2007).

We identify four key strategies which play an important role in dealing simultaneously with the necessity:

- to guarantee the reliability of the synchrotron in a noisy environment: the optimization strategy (§2.2.1);
- to support the experimental diversification of beamlines: the versatility strategy (§2.2.2);
- to maintain machine innovativeness while preserving core functionalities of the beamlines: the upgrading strategy (§2.2.3);
- to manage the differential life cycle between the machine and the beamlines: the system evolution strategy (§2.2.4).

2.2 The management of technological ambidexterity

2.2.1. Optimization strategy

An accelerator system is composed of highly interdependent components and subsystems. Each element plays a pivotal role and the weakest part often determines the performance of the entire system. Dysfunctions at the accelerator level can thus have detrimental effects on experiments conducted by beamlines. In fact, unexpected beam interruptions and poorly controlled beam dynamics often involve significant costs in terms of money, time and lost opportunity for beamlines and users (Hardy, 2009). Technical disruptions can break down both ongoing experiments and cancel those that were planned. Even if a failure is resolved rapidly, continuing the same experiment may be lost because the samples on which it was based on can no longer be used. Hence, improving the reliability of the accelerator (e.g. beam availability, beam stability) is a critical collective performance indicator.
The accelerator team generally combines several mechanisms to reduce the risk of failure and improve reliability. Regular accelerator dedicated time is planned for maintenance, repairs, upgrades and testing of new components and subsystems over the year during synchrotron shutdown periods. Advanced monitoring techniques are developed to precisely control delicate parts of the storage ring. These techniques allow to anticipate in good time the problems and to act before a failure occurs through preventive actions.

Risk reduction is also ensured through several design mechanisms. A first mechanism is redundancy. It is provided through backup solutions or spare systems which are used to avoid unexpected beam interruptions. Operationally, sophisticated backup solutions are developed and implemented to improve for instance the quality of electric power supply systems, which are critical for the smooth operation of beamlines and the cost they involve in case of beam interruptions. They concern the power system of the whole facility but also different critical parts of the accelerator. In all cases, in the event of a breakdown of the original power supply system, power is delivered by switching to the spare power supply equipment.

A second mechanism is stack modularity (Ulrich and Tung, 1991). It consists to duplicate identical modules and to connect them together to create a functional unit. This system has the advantage to add flexibly the individual performances of the modules. Furthermore, it is less sensitive to system failures because of its resilience. On the one hand the failure of one or several modules doesn't induce the failure of the system and impacts only marginally its performance. On the other hand it facilitates its maintenance since it makes possible to replace only the failed modules and not the whole system. Stack modularity has been applied as a design principle by Soleil engineers in the development of an innovative solid state amplifier for the radiofrequency system which has the role to compensate the energy lost by electrons in emitting the radiation on each rotation by accelerating them and ensuring that they follow the correct path (fixed orbit).

Beyond, modularity which improves the tolerance to failures, Soleil engineers give also close attention to improve beam stability by better monitoring and correcting beam dynamics through both passive and active control systems during operation. Passive control strategies are reflected in the initial design parameters of the synchrotron to minimize all potential beam vibration sources. Additional active systems (high precision beam monitoring and feedback techniques) are developed progressively and integrated into the system when new sources of instabilities are discovered through experiential learning to correct beam dynamics in terms of position, divergence and size.
2.2.2. Versatility strategy

Since the creation of the synchrotron progressively 30 beamlines have been installed around the storage ring. Each beamline exploits different properties of the radiation using different wavelengths (from UV to X-rays) to run specific experiments using appropriate instruments and methodologies. But, all beamlines are provided by the same unique radiation source generated by the machine. Therefore, the design logic consists in using the same common architecture for all beamlines and to use the principles of late differentiation and bus modularity (Ulrich and Tung, 1991) to produce beamline dedicated beam properties. In fact, the connection between beamlines and the storage ring takes place through beamline specific magnetic systems (e.g. undulators, wigglers, dipoles) which provide the possibility to generate highly customized radiation sources. These magnetic systems play thus the role of dedicated modular interfaces between the accelerator system and the beamlines. As stressed by a machine engineer: "If we install a new beamline or change an existing one, we always develop a new undulator. The flexibility is provided by the possibility we have to dismantle an undulator dedicated to a beamline and to install a new one with new specificities. We have different types of undulators and there are a lot of possible developments. For instance undulators may have different lengths, use different materials... They allow to generate the radiation in new ways....We invent new ones continuously.... In order for instance to produce X-rays with intermediary energy machines like in the case of Soleil, we developed innovative in-vacuum undulators, also cryogenic undulators to increase the current. Beamlines can also change the use of undulators by adding new measuring instruments."

But late differentiation reflects only part of the innovation potential to increase the diversity of the system. Upstream, the creation of several machine operating modes by precisely controlling electron injection patterns (differentiated by electron bunch size and electron intensity level), constitutes a complementary innovation mode to respond to the experimental needs of the beamlines concerning for instance the study of the dynamic properties of materials.

This early differentiation design principle is also an important source of experimental diversification. But this diversity is no more simultaneous like in the case of early differentiation but sequential. In fact early differentiation requires the temporal planning of modes and therefore privileges some beamlines at the expense of other beamlines which cannot use them and have therefore to pause. In order to improve simultaneity efforts are thus made at two levels: machine engineers develop hybrid operational modes which suite to the needs of a larger set of beamlines; beamline managers adapt in innovative ways their instrumentation in order to be able to use a greater variety of operational modes.

Together, these characteristics provides the synchrotron the properties of a highly versatile system, that is the capacity to adjust to a growing range of uses without compromising the performance of experiments.

2.2.3 Upgrading strategy

It is essential for the benefit of beamlines’ research activity in the long term to explore, upstream at the accelerator system level, for significant performance improvements. However,
pushing forward the frontier of the accelerator system's technological capabilities often involves noticeable modifications in different parts of the machine and are therefore likely to call into question the coherence of the whole system.

Innovation processes at synchrotrons are characterized by complex interactions and by systemic uncertainties arising from the need to integrate highly interdependent technologies performing various functions. Innovation processes in this context often involve technologies with uneven rates of change, generate unpredicted emergent properties at the system level and are characterized by ill-defined cause-effect relationships.

Changes on the machine might have negative effects on the operability of beamlines. Efficient operation requires stability and experiential learning whereas frequent changes can have destabilizing effects through increased uncertainty. The motivation in pushing the performance potential frontier of the accelerator is hence to have an adaptive and controlled approach to risk and complexity through time and to develop a progressive system capable to integrate paradoxical specifications (e.g. beam brilliance versus stability).

This is why accelerator physicians and engineers opt for a sequenced upgrading strategy. The accelerator systems' evolution can here be assimilated to a "time-paced transition" (Brown and Eisenhardt, 1997). Important changes follow discreetly planned stages. Therefore in a long term perspective (through successive stages) the accelerator team seeks for a balanced exploration-exploitation approach to avoid the risk of costly search activities.

In fact, at each stage, before validating the operation of the synchrotron at a higher performance level, the quest for system integration requires a reflective learning process supporting the continuous articulation between theoretical conjecture (exploration) and practical observation (exploitation). The innovation dynamics involves constantly moving back and forth between these two poles in identifying and analyzing emerging properties. Elaborate theoretical and simulation models help to identify some of these emergent proprieties. Others emerge only through actual exploitation. Therefore the upgrading process involves more frequent and longer accelerator shutdown periods to conduct dedicated operational tests.

This process is particularly well illustrated by the theoretical beam intensity targeted (500mA) in the long term by the Soleil accelerator, and providing the basis for unprecedented experimental opportunities for beamlines. This strategic plan, collectively agreed by beamline managers and accelerator scientists / engineers was judged as extremely ambitious in that it required developing challenging approaches to control beam dynamics at such high beam intensity. It provided however a long term and collective perspective for a gradual approach along which to balance and synergistically combine the explorative and exploitative efforts of the accelerator team. Right from the design stage, successive projects were launched to better understand the implications of increasing levels of beam intensity on system performance dynamics. Through the numerous studies and tests that were launched along the successive projects the accelerator team has been confronted to many puzzling facts. Several observations were contrary to initial guesses and provided paradoxical findings. Therefore through time the different accelerator units within their competency domain (each being responsible for a given functional part of the accelerator) had to behave in a responsive way
and reorient their research activities according to new emergent issues to support the integrated learning and innovation process. At the time of our interviews the beam intensity level validated for user operation had progressively achieved 430Ma and the project team still conducted numerous studies with the perspective of a transition towards a stored current of 500 mA offered to beamlines in the near future.

2.2.4. Decoupling strategy

Since the creation of Soleil, 30 beamlines have been progressively installed and activated around the storage ring. This process of new beamline development and creation should continue during synchrotron's operational life span, that is approximately 30 years. In fact beamlines are in perpetual evolution. An annual investment budget is allocated to their rejuvenation, new beamlines replacing older ones every 8-10 years. "We have established beamline committees. Every 4 year a committee of experts composed of expert users and scientists from other synchrotrons examines where a given beamline is, looks if it's not outdated, where improvements should be made. We started the first beamlines in 2008. Hence, perhaps in 10 years we should stop it and do something completely different ... We know that for each beamline to be competitive, it will require continued investments from the very beginning of its operation ... we can take some existing technological elements but we need to replace quickly those that are outdated...." (Synchrotron manager, 1) Beamlines' innovation efforts reflect the necessity to develop independently local improvements in order to differentiate their experimental capabilities from other beamlines and contribute thereby to the synchrotrons experimental variety and distinctiveness. Each beamline develops its own autonomous search strategy to be able to respond to future user expectations through demand pull exploration and by creating new experimental opportunities through technology push.

The challenge for synchrotron managers is to maintain consistency over time despite the dynamic nature of the system and its tendency to diversify. Exploration at the accelerator system level is thus heavily focused on system integration innovations (Henderson and Clark,1990; Prencipe, 2000; Brusoni et al., 2001). "The operational domain of each beamline is decided to 95% within the machine and more precisely either through magnetic dipoles or the undulators around the storage ring." (Synchrotron manager) Therefore, innovation at this level, is concerned with adjusting systemic interdependencies and technological imbalances in order to resolve tensions and gaps emerging from synchrotron's progressive expansion.

Sanchez and Mahoney have defended the following principle: when the physical architecture of a product is modular, the organization responsible for the design of this product is likely to become modular too. In our case, synchrotrons modularity leads to the modularity of the organization in charge of the synchrotrons strategic management. As the team of engineers responsible for the design of the machine have a high capacity to absorb innovation needs by the beamlines (Cohen & Levinthal, 1991), the need for hierarchical mechanisms remains limited. In this context it becomes possible to decouple architectural learning (which operates on a time horizon of 30 years) from modular learning (which operates on a time horizon of 8-10 years).

This modular organization is however supported whenever necessary by communication and coordination through project led management mechanisms (Hobday et al., 2005) to align and
articulate innovative efforts (Fujimura, 1987; Hoegel et al, 2004) between beamlines and the accelerator system. Early coordination predefines objectives in terms of performance, schedule (milestones), and budget. Expected critical interdependencies are internalized by different units to synchronize, orient decentralized innovation processes. As exploration unfolds, local innovations and unforeseen interdependencies, changes in the external environment may introduce new design problems and require mutual innovative adjustments. Continuous coordination and information exchange is thus established through regular meetings to reallocate and reorient learning efforts across different technological trajectories, redefine interfaces, reorganize teamwork and the autonomy zone of different units in the face of changes.

By balancing and combining decentralized and coordinated exploration a synchrotron system remains during its life cycle in a more or less continuous co-innovation dynamic through the reciprocal exploration dialogue between beamlines and the accelerator system. Through interactions with users and their own autonomous research ambitions, beamlines channel their future exploitation needs to the accelerator staff. In that sense future exploitative needs of beamlines trigger and orient the explorative efforts within the accelerator system. On the other hand the increasing potential of the accelerator is a crucial driver of the explorative efforts of beamline managers both in terms of experimental and beamline development projects. As the accelerator system evolves to meet the changing requirements of beamlines and in turn beamlines develop new instruments, tools and experimental programs to benefit from the increasing performance of the platform, new learning cycles and feedback loops are triggered: innovative design changes on the accelerator lead to alterations on beamlines and vice versa.

**Figure 2: Technological ambidexterity**

### 3. Networking ambidexterity

#### 3.1. The competition-cooperation tension

The two previous parts focused on the internal ecosystem allowing Soleil's innovative development. It is indeed on the articulation of these internal levers easily accessible and powerful for action that the innovation and creativity of the infrastructure is based. The management of critical tensions - responsive-proactive strategic orientation towards users and the modular-architectural renewal of the technological system - constitutes a breeding ground
around which Solei researchers and engineers collectively legitimize the evolution of their organization.

But beyond this internal system, Soleil is part of an external ecosystem which critically orients and strengthens its momentum for change and innovation. Soleil is indeed linked to other similar structures that contribute to its change as much as they are influenced and transformed by Soleil. This ecological relationship is essentially shaped by both cooperation and cooperation with other synchrotrons. Key factors that drive this co-opetition process are related to the search regime and the industrial dynamics of science (Hallonsten, 2009; Bonaccorsi, 2008) that characterize synchrotrons: rapid growth rate of users and experimental applications, increasing diversity, intensity and cost of S&T activities, importance of S&T standards and technical and cognitive complementarities.

To give a full account of how synchrotrons position themselves within their environment requires investigating the competition and cooperation mechanisms that structure exploitation-exploration activities (Gilsing and Nooteboom, 2006; Fernandez et al., 2014) and ultimately benefit the user community.

Previous research has largely acknowledged the importance of co-opetition as an important source of value creation (Brandenburger & Nalebuff, 1996). Particularly in complex and dynamic environments, such as in high technology industries the strategic interplay between competition and cooperation and the capability to address the related tensions has been found to be critical for organizational learning and innovativeness (Von Hippel, 1987; Teece, 1992; Dyer and Singh, 1998; Ritala et al., 2009; Gnyawali and Park, 2011). Innovative capabilities of synchrotrons derive from the dynamic interplay between collaboration and competition by capitalizing and reinforcing the benefits of both competition and collaboration (Teece, 1992; Gnyawali and Park, 2011). These benefits result from the combined exploitation of distinctive and shared existing resources and competencies and exploration in that co-opetition contributes synergistically to the differentiated and collective innovation capabilities of synchrotrons. We again distinguish four strategic dimensions to show how co-opetition shapes exploitation and exploration activities within the external ecosystem.

- cooperation between synchrotrons is essential to improve their collective efficiency. This exploitative or operational cooperation is based on the adoption of common or standardized platforms: platform strategy (§ 3.2.1)

- Parallel to the platform strategy, synchrotrons strive individually to improve their scientific service performance through both excellence and differentiation to attract users: user attraction strategy (§ 3.2.2)

- Beyond cooperation around common platforms, synchrotrons search for and establish common explorative projects to combine their distinctive and complementary competencies: the technology partnership strategy (§ 3.2.3)

- Finally synchrotrons compete in a long term perspective to build a differentiated and uncontested positioning within their external eco-system: the option creation strategy (§ 3.2.4)
3.2. The management of networking ambidexterity

3.2.1. The standardized platform strategy

Since the 80s, the number of synchrotrons has risen worldwide. The scientific user community have increased both in volume and diversity. The motivation to manage more efficiently the increasing number of users have in parallel been accompanied by more systematic cooperative approaches to improve the operation and use of synchrotrons. The development of common standards, the creation of multi-facility platforms, and the diffusion of best practices all aim to increase the collective and individual exploitation capacity of synchrotrons.

Firstly, the development of common standards intends to create a similar environment across synchrotrons in order to guarantee reproducibility and comparability of experimental results. A noticeable example are bio-crystallography techniques where collective efforts have been undertaken to standardize computer interfaces, develop common operating procedures and automated tools in order to diffuse more largely the use of these techniques among structural biologists. "We work often with other synchrotrons. For instance there is project led by the ESRF 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 equipments. Other similar design studies exist at the European level to elaborate common IT tools and instruments" (Beamline manager).

Secondly, the distinct experimental systems dispersed across multiple research facilities and the need to combine them to carry out innovative experimental projects motivate synchrotrons to develop integrated access possibilities through the creation of multi-site user platforms and to coordinate their operational management. Soleil is for instance part of the European Biostruct-X project for structural biology research which is a networked infrastructure between national synchrotrons equipped with different X-ray techniques. Here "the concern was to say ...we must rationalize at the European level access to core research centers in life sciences and the different experimental fields and techniques they offer. Synchrotrons were naturally part of these core centers ... This multi-partner rationalization process was very useful for us. It helped us to organize our thoughts on our operational model, the one which could emerge. Biostruct as a multi-partner platform has been thus a driver for our structuring" (Valorization manager).

Thirdly, since synchrotrons share a common S&T background, the rapid diffusion of best practices is an inherent characteristic of the community. This diffusion is supported through various institutionalized initiatives (colloquiums, seminars, workshops, training programs, forums and discussion sites) or the personal network of scientists. There is a strong incentive to diffuse knowledge, technologies and organizational practices across synchrotrons since they both contribute positively to the reputation of the innovating synchrotron and improve performance at the collective level. "It's a very communicative community. There is information exchange between the different synchrotrons and technical developments are relatively quickly roaded out to other places. For instance the micro-diffractor at the EMBL or at the ESRF, that’s now a product that you can have also at other synchrotrons. So the technologies spread relatively quickly" (User). Collaboration forums for instance bring
together people from the accelerator community to help them exchange ideas about
accelerator operation, organization, maintenance, and establish benchmarks by facilitating
comparisons of methods, efficiencies, costs, reliability, beam quality and other performance
measures. Another noticeable example is TANGO, a free open source device-oriented toolkit
adopted by several synchrotrons for controlling operational hardware and software. In
developing TANGO each facility relies on the experience of others to further improve the
system and to add new applications according to its needs. The synchrotron community
becomes thereby a breeding ground which is continually fed with new applications by using
an ever expanding and flexible toolkit.

3.2.2 User attraction strategy

Beyond the platform strategy to improve the collective efficiency of infrastructural services
synchrotrons have to strive individually for excellence to remain attractive for users.
Publications are the ultimate measure of research performance both for scientists using the
research infrastructure or for managers who administer them.

Through scientific service quality synchrotrons aim to attract the best users and benefit from
their challenging and pioneering projects to increase experimental innovativeness. Even if
domestic synchrotrons provide access priority to their national scientific user community, a
synchrotron's attractiveness is mainly evidenced by the increase in size and diversity of user
communities from countries where synchrotrons already exist. Oversubscription rates reflect
the reputation of the facility in the user community and contribute to the increasing quality of
projects accepted. Therefore synchrotrons are competing to host the most promising research
projects, and users are aware of this situation: "You know there is competition among
synchrotrons so they also have an interest to attract projects like ours, it is a high impact
project, so it is also very good for Soleil." (User)

Service excellence by synchrotrons depends on a variety of technical, scientific and
organizational elements (Soleil, 2010; 2011; 2012; Hallonsten, 2013). For example, users look
for the best performing instrumentation because it offers them more opportunity to advance
their research. "Users coming here, go also to Switzerland, to the ESRF, Diamond,...they go
everywhere. Users know very well the advantages of one beamline compared to others. They
are quickly informed when we buy a new detector. As it happens, they come more often
because there is a new instrument to discover...they are very geek, very fashion..." (Beamline
manager)

Users also know that support activities throughout the experimental and publishing processes
are important to the success of their projects (see § 1.1.2). "What is essential is tutoring,
supervising and supporting. There is the performance of the instrument but also the service
we provide....If we analyze the overall satisfaction criteria of the partner, the user, it includes
how he or she was welcomed, treated, and the quality of the working process." (Beamline
manager). Indeed, the quality of scientific services relates to support provided to users prior
to, during and after experiments. It may concern the definition of experiment proposals before
submission, orientation towards appropriate beamlines, preparation and use of scientific
instruments and interpretation of experimental data. Service quality may also be improved
through more flexible and diversified access modes to better respond to specific user needs.
In turn, innovative experimental projects contribute to the quality of scientific outputs and improve the visibility and influence of synchrotrons within their broader community. Such visibility of synchrotrons follows from the fact that the synchrotron on which the experiments have been run is either acknowledged or the beamline team that contributed to the experiments appears as a co-author. "I mean European synchrotrons are pretty good but what starts to be an additional selection criteria is really the quality of the people at the beamlines. You have the local context...you have to distinguish, if it’s a standard case that’s always okay you can really manage it, but if something is really at the very edge then you need not only the fantastic instrumentation but also the competence and the support... In the case of Soleil for example 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 there. He is so good and he was so helpful that he will be on the paper. It goes far beyond just providing technical support" (User)

Attractiveness, reputation, visibility and influence through service excellence, experimental innovativeness and quality of scientific production create legitimacy for synchrotrons to continue to obtain the resources necessary to sustain their efforts to further develop and improve their research facility. Being competitive at the exploitative stage is thus a crucial factor to support the explorative capacity of synchrotrons to nurture their future competitiveness both through in-house S&T projects and by attracting collaborative partners.

The purpose of synchrotrons and beamlines is to achieve the implementation of the virtuous circle described in Figure 3

**Figure 3: Scientific value creation by synchrotrons**

- Quality of scientific services / experimental systems
  - Attractiveness / reputation

  **Scientific excellence**
  - Selection of high quality projects
  - Experimental innovativeness

  **Number of publications with high impact factor**
  - Visibility and influence within the synchrotron community

  **Funds to support S&T projects**
  - Legitimacy

### 3.3.3. Technological partnership strategy

Collaborative initiatives motivated by mutual benefits help to combine synchrotrons’ distinctive resources and capabilities to create, access, acquire, and leverage knowledge in pursuing innovation projects which involve high risks and require heavy investments. "Synchrotron infrastructures are not all the same but there also similarities. When we want to carry out innovative projects which are highly complex, no one or very few have the critical
mass of competencies to fulfill the projects. These can concern microelectronics, the mastering of some materials or production processes. Thus we know that, we have a benefit for instance at the European level to put in place partnerships like a Memorandum of Understanding on specific topics." (Synchrotron manager)

The fact that synchrotron scientists and engineers have worked in several synchrotrons during their career and highly value the strong interpersonal links they have built over time with other synchrotron creates trust based relationships and facilitates these inter-synchrotron partnerships.

A noticeable case is the long term cooperation between Soleil and the ESRF, one of the first and world’s largest 3rd generation high energy synchrotron. With its ambitious S&T developments and rich experience ESRF, already a collaborative European initiative, has played a highly influential role in the technical choices adopted by Soleil for its accelerator system. Through such collaboration Soleil had access to ESRF’s advanced infrastructure and expertise for prototyping and testing new equipment. Challenging and unprecedented in-house development projects engaged at the LURE to prepare Soleil and later at Soleil have in turn benefited the ESRF.

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Similar mutually beneficial collaborations on R&D projects have also been launched between Soleil and other synchrotrons. "At the LURE we began a specific beamline equipment plan to design and prepare Soleil. During this period we built a beamline called LUCIA at the Swiss synchrotron SLS in Zurich, which is also a 3rd generation synchrotron, similar to Soleil. It has been first installed there. We benefited from their infrastructure, pooled our competencies and saved a huge amount of time and money. Afterwards, they exploited there our developments and developed on their own other specific features. Before Soleil opened we repatriated the beamline but not all of it and we also continued to improve the beamline at Soleil" (Synchrotron manager)
These collaborations are based on the implicit agreement to reciprocate and pool knowledge between partners during the project or in a more long term perspective (Von Hippel, Nooteboom, ). They help to combine the distinctive and complementary competencies of research facilities and share the cost of technologies to be developed and/or deployed. By freeing up resources and creating collective capabilities they also engender new differentiation potential and new competition fields. As such the risk of spillovers become less an issue because both partners improve their innovative capabilities and competitive advantage.

3.3.4. The option creation strategy

The history of synchrotrons (Haensel, 1994; Hallonsten, 2009) shows that the interplay between competition and cooperation has always been an important driver in the differentiation processes between synchrotron communities and technological generations. 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 2nd generation facilities optimized for synchrotron radiation. Also intense co-opetitive development efforts on several technologies (e.g. IDs, lattice design) allowed low or medium third generation energy storage rings to conduct hard X-ray experiments which were previously thought to be confined to high energy storage rings. From a long term perspective these differentiation processes mirror the dynamics of the reconfiguration of networks and of co-opetition among scientific communities (e.g. physicians-chemists), synchrotron types (low, medium and high energy accelerators) and next generation technologies (ultimate third generation synchrotrons, free electron lasers). Since the high energy physic infrastructures, significant progress in particle accelerators and experimental techniques has led to the emergence of radically new technological trajectories and completely new user communities.

In the case of Soleil, the planning and design processes from the mid 90’ onwards was guided by the intention to provide the new research facility, expected to replace the existing “2nd generation” LURE facility, a distinctive and sustainable position among “3rd generation” synchrotrons. Its systemic design parameters (e.g. electron energy, total current, emittance) have progressively emerged and been fixed through explorative efforts by considering the significant and constant developments (both internal and external) in critical technological domains related to accelerator facilities as well as foreseeable advances in a large set of domains. These developments and advances provided Soleil the capability to cover a wide wavelength spectrum (photon energy range) and offer, as one of the first “intermediary energy sources”, a larger set of radiation properties than in already existing “low energy” and “high energy” 3rd generation synchrotrons (Couprie, 2013; Couprie et al., 2010). Explorative efforts oriented the differentiated positioning and path dependent trajectory of Soleil by structuring its strategic identity within the population of synchrotrons and shaped its future orientation, what it can do and not do (Hackett, 2005). From this point of view, these technological developments allowed Soleil to create a new demand in a temporarily uncontested strategic space.
This process of emergence of new technology generation is similar to a dynamic of new option creation (Bowman & Hurry, 1993; Noteboom, 2000; McGrath et al, 2004). The existing tension between the phases of competition and collaboration between different synchrotrons led, initially, to the development of possible new technological trajectories as many opportunities to choose that the organization can enable. In a second step, the process of collaboration will lead to lock-in an option to be exercised at the expense of others. Luehrman (1998) insists on the fact that real options phenomenon involves creating a series of prior decisions necessary for their emergence. Bowman & Hurry (1993) talk about option chain where real options are the results of previous actions. Regarding Soleil, this is precisely in the crossing points between competition and cooperation that selection of new technological trajectories takes place among the possible real options portfolio. This strategic tension, characterizing a « co-opetition » situation, combines proliferation phenomena and disappearance of technological solutions, well-known phenomena in the literature on Real Options. The following quote illustrates this dynamic creation of new technological trajectories: "We can still be considered today as one of the best synchrotrons. We are still one of the leaders and try to maintain our position at the top. We placed our bets on very specific experiments by investing in some domains on highly sophisticated technologies rather than on high output. We have a very stable machine. We made a lot of efforts to start on very good bases and we can built 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 make important changes. We introduced for instance the possibility to install long beamlines which is now critical for some experiments. The challenge now is to develop experiments at the nano and femto levels. It's not the same technology and not the same physics. We also hope to develop the ultimate storage ring. If we succeed then the battle is won." (Synchrotron manager)

The inherent generic property of synchrotrons as research technologies towards continuous differentiation (Shinn, 2005) is in fact what motivates synchrotron scientists and engineers to engage in unprecedented explorative projects. It explains the key role played by scientific entrepreneurs whose role beyond attracting new users is to create and develop distinctive and unique experimental trajectories. This dynamic is usually accompanied by international competition for human resources within the small world of synchrotrons and by efforts to improve the attractiveness of facilities for talented beamline scientists. "We have a fairly high rate of foreign scientists. We recruit beamline scientists from varied countries. It's part of the willingness of Soleil not to be confined to France or even Europe but to seek talents wherever they are. We look for opportunities, since after all in the world of synchrotrons there is of course cooperation but also real competition...we do it all. It’s often related to innovative projects when a new synchrotron or a new beamline is designed or built there is a need for distinctive talents" (Human resource manager). In fact, synchrotron researchers and most particularly young scientists are attracted by the challenging research prospects offered by the facilities. Therefore the possibility to conduct actively in-house research is very often an important choice criterion in joining a facility (Simoulin, 2012). At Soleil, beamline scientists beyond their time dedicated to support users try to devote 40% of their time to in-house research. As shown in the preceding sections privileged relationships with expert users and
partnerships with external academic establishments on explorative projects represent also key inputs in the differentiation process of synchrotrons.

**Figure 4: Networking ambidexterity**

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**V. Discussion and Conclusion**

Since numerous years, organizational ambidexterity is presented as a way to cope with uncertain environmental context as in the case of creation and innovation processes. We usually distinguish architectural from contextual ambidexterity. The first case implies separation of organizational units in charge of exploration, from them who deals with exploitation. In the second case, exploitation and exploration are integrated: the same organizational unit is able to switch between the two modes depending on the context.

Andriopoulos and Lewis (2009) achieved a comparative analysis of 5 new product design case studies. They show that contextual ambidexterity brings out three nested innovation paradoxes: strategic intent (profit-breakthrough), costumer orientation (tight-loose coupling), and personal drivers (discipline-passion). However, Soleil organization, aggregate numbers of specific characteristics which differentiate our case from those presented by Andriopoulos and Lewis:

- This organization is a research infrastructure whose purpose is not making profit but the production and diffusion of knowledge through scientific publications;
- it involves a very significant investment in fixed sunk costs even while technological obsolescence is very fast;
- the design of this infrastructure does not stop with the beginning, but with the end of its exploitation: it is difficult to distinguish the management activity from the infrastructure design activity;
- the great complexity and diversity of problems treated by this organization led it to adopt a structure in which very different organizational subunits have weak hierarchical links even in a context as the technology integration is very strong.

Baker *et al.* (2003) suggested that in conditions of high uncertainty, knowledge intensive organizations use convergence between design and execution as a management mode, in complement to the design-then-execution organizational framework. This hybrid management approach plays in RIs an important strategic role to sustain ambidexterity. The combined
scientific, engineering, managerial and operational responsibilities of RI researchers require from them both a short-term and a long term orientation and the parallel pursuit of an industrial logic of exploitative efficiency and a scientific attitude towards creative exploration and purposeful search and improvisation.

Our case studies led also to the emergence of three paradoxes concerning the strategic management of the organization: scientific user perspective (responsiveness versus proactivity), technological perspective (modular versus architectural innovation), scientific policy perspective (collaboration versus competition). We do not claim that this is the only tension that exist in the management of a this synchrotron. But if we put them forward, it is because we think that these tensions are important in orientating strategies implemented in the organization. Note that unlike Andreopoulos and Lewis results, our generic tensions are not a simple translation or operationalization of the exploitation/exploration tension. In our conceptualization second order tension are independent from the first order tensions.

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Two observations are worth highlighting because they enriches the concept of ambidexterity

**Ambidexterity can be multi-level**

First, we observe that the tensions inherent to the search of ambidexterity are solved by a specific infrastructure management. This structure contains three embedded management levels in interaction but retaining considerable autonomy. It is as if we had conducted a systemic decomposition of the organization. Scientific experiment management, regarding the beamlines, operates in the technology management framework that affect the whole synchrotron. The latter two management levels are in their turn conducted within a scientific
Our multi-level analysis shows that a synchrotron's innovation ambidexterity is an emergent systemic capability shaped by the co-evolutionary interactions between three overlapping and interdependent levels. In fact, a synchrotron evolves through (1) interactions with external users; (2) coordination between beamlines and the accelerator system; and (3) interactions with other synchrotrons. Innovation dynamics is here related to the capacity to achieve what Simsek et al. (2009) define as reciprocal ambidexterity: "a synergistic fusion of complementary streams of exploitation and exploration that occur across time and units". Considering for instance the meta-infrastructure level, co-opetition between synchrotrons illustrates how inter-organizational or collective exploitation-exploration dynamics determine intra-organizational exploitation-exploration strategies and reciprocally how intra-organizational exploitation-exploration strategies generate inter-organizational or collective exploitation-exploration processes (Homqvist, 2004). A similar dynamic operates between the infrastructure and the experimental labs where exploitation-exploration processes reciprocate: technology push innovations reconfiguring the collective performance-diversity tension open up new experimental conditions and opportunities reshaping the tension between responsive-proactive strategies; demand pull pressures emanating from beamlines/users through responsive-proactive orientation call for innovative efforts at the infrastructure level leading to reconsider the collective performance-diversity tension.

Figure 5: Multi-level ambidexterity
Ambidexterity can involve dual tensions

Second, our observation tend to emphasize the importance of complementary tensions in the definition of ambidexterity. In everyday language, ambidexterity refers to an individual who is not lateralized, it is as much as right-handed left-handed. Following the work of James March about the exploration exploitation dilemma, the concept of ambidexterity has been applied to organizations. In this context, ambidexterity refers to the ability of an organization to exploit its skills and proven practices in the manner of a bureaucracy and the same time explore new fields of knowledge and breakthrough solutions through organic structures. In the case of Soleil, the exploitation / exploration tension is present at all levels of the organization. This presence reflects the need for organizational ambidexterity.

However ambidexterity can also mean for an organization to have the ability to implement conflicting orientations that are not only limited to variations of the exploration/ exploitation tension. Our findings show that at each systemic level appears specific tensions that give a new "color" to the ambidexterity:

- **User oriented ambidexterity**, testifies the necessity of reconciling two user orientations that are in opposition. The responsive orientation addresses the expressed needs of users, whereas the proactive orientation addresses the latent needs of users, even for scientific communities that are not yet synchrotron users. Both responsive and proactive orientations towards users are key aspects in the production of experiments and the innovative development of experimental labs. As evidenced by our case study to support both orientation strategies beamline teams rely on tight-loose coupling with users. Tight coupling leads to closer tailoring of experiments and services, better understanding of users’ needs, easier forecasting of demand, and closer relationships. Considering the key innovative contributions that experimental scientists can make on research instrumentation (Price, 1965, 1984; Rosenberg, 1992; von Hippel, 1976; Riggs & von Hippel, 1994) tight coupling in the case of synchrotrons can go as far as co-opting them in the innovation process (Berthon et al. 1999, Prahalad & Ramaswamy, 2000; Magnusson et al. 2003) as lead-users (von Hippel, 1986; Thomke & von Hippel, 2002) and user-operators. Loose coupling with users is nevertheless also necessary for beamline teams to remain flexible both in the short and long term, and to keep open to opportunities to leverage existing competencies to the largest possible user base and engage in S&T research that is beyond the expertise and competency scope of current users.

- **Technological oriented ambidexterity** involves two orientations of technology management that are likely to enter in conflict. Indeed, the evolution of the synchrotron implies on the one hand, modular innovations to meet the growing variety of requirements in terms of experimentation and secondly, architectural innovations in the accelerator system to improve the overall performance of the synchrotron. This balance between modular and architectural innovations (Sanchez & Mahoney, 1996; Brusoni & Prencipe, 2001; Etirahj & Levinthal, 2004; Hobday et al. 2005) is at the heart of the integrative capability of synchrotron actors who have to think...
continuously about how to tailor the accelerator system according to the specific and evolving beamline requirements and at the same time control the complex systemic interdependences that guarantee its overall excellent operational performance. The accelerator system is therefore a constantly evolving construct and very often exhibits all along its design, construction and operational phases emergent properties and unpredictable effects calling for innovative solutions.

- Network oriented ambidexterity, emphasizes two opposite directions in terms of scientific policy. On the one hand, there is the need to capture the best scientific users, and to offer completely new services to sustain a leading competitive position. On the other hand, the need to improve the collective quality and efficiency of synchrotrons leads to collaborate with other synchrotrons. In fact co-opetition and the ability to address the tension between individual and collective performances are critical to the development of capabilities at both organizational and inter-organizational levels. Through co-opetition synchrotrons create mutual exploitative and explorative benefits and at the same time leverage these benefits by integrating internal and external knowledge bases to create distinctive competencies and trajectories. This co-opetition driven by the common mission of synchrotrons to act as user oriented facilities both improves S&T services provided to the scientific user community and increases experimental variety and innovativeness.

References


