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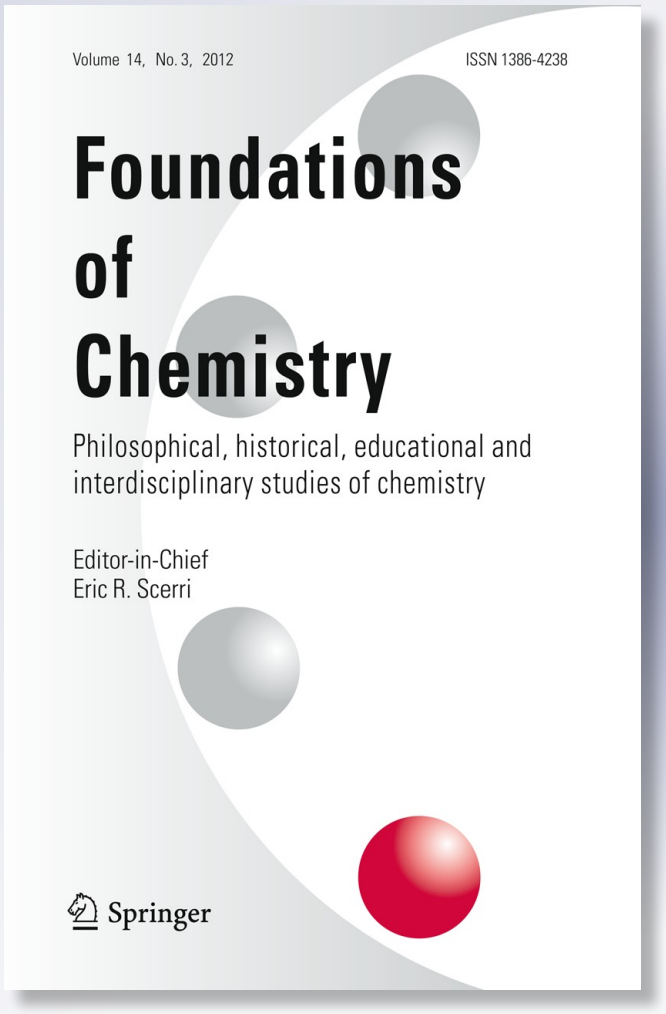

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Abstract Ilya Prigogine was not a systematic author: his ideas, covering a wide arch of areas, are dispersed in his many writings. In particular, his philosophical thought has to be reconstructed mainly on the basis of his works in collaboration with Isabelle Stengers: *La Nouvelle Alliance* (1979), *Order out of Chaos* (1984), and *Entre le Temps et l'Éternité* (1988). In this paper I undertake that reconstruction in order to argue that Prigogine's position, when read in the light of Putnam's internalist realism, can be characterized as an ontological pluralism. The main aim of this work is to show the striking parallelism between the philosophical views of Prigogine and Stengers and those of Hilary Putnam in *Reason, Truth and History* (1981). This task will lead me to critically review Prigogine's general scientific program: the attempt to establish the foundations of objective irreversibility.

Keywords Prigogine · Putnam · Ontological pluralism · Irreversibility

Introduction

In 1924, Werner Heisenberg went to Denmark to visit Niels Bohr and to work in his institute. In one of their frequent walks, they reached Helsingör and decided to take a quick promenade through the precincts of the Krönberg Castle. After telling the history of the castle, Bohr mentioned the legend of Hamlet and went on to say: "Isn't it strange how this castle changes as soon as one imagines that Hamlet lived here? As scientists we believe that a castle consists only of stones, and admire the way the architect put them together. The stones, the green roof with its patina, the wood carvings in the church, constitute the castle. None of this should be changed by the fact that Hamlet lived here, and yet it is changed completely. Suddenly the walls and the ramparts speak a quite different language" (Heisenberg 1971, p. 51). When recalling that comment, Prigogine says: "What is the castle of Krönberg, independent of the questions we put to it? The stones can speak to us of

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their molecules, of the geological strata they were quarried from, perhaps of the extinct species they contain in fossil form, of the cultural influences that worked on the architect, or of the questions that pursued Hamlet to his death" (Prigogine 1996, p. 39). According to him, none of these matters are arbitrary, nor do they permit us to sidestep reference to who poses the questions. Those words express his belief in the "important role intellectual construction plays in our concept of reality" (Prigogine and Stengers 1984, p. 292), and perhaps they are the clearest manifestation of a pluralistic view of reality.

As it is well known, Ilya Prigogine was not a systematic author. His ideas, covering a wide arch of areas, are dispersed in his many writings. In particular, his philosophical thought has to be reconstructed mainly on the basis of his works in collaboration with Isabelle Stengers: *La Nouvelle Alliance* (1979; from here on, cited as *NA*), *Order out of Chaos* (1984; from here on, cited as *OC*), and *Entre le Temps et l'Éternité* (1988; from here on, cited as *ETE*). In this paper I will undertake that reconstruction in order to argue that Prigogine's position, when read in the light of Putnam's internalist realism, can be characterized as an ontological pluralism. The main aim of this work is to show the striking parallelism between the philosophical views of Prigogine and Stengers and those of Hilary Putnam in *Reason, Truth and History* (1981). This task will lead me to critically review Prigogine's general scientific program: the attempt to establish the foundations of objective irreversibility.

Before beginning, I want to introduce a methodological remark. Due precisely to the non-systematicity of the work under analysis, I will follow the strategy of letting the authors to speak: we shall see philosophical ideas to progressively emerge from Prigogine and Stengers's own words. For this purpose, in spite of the fact that *Order out of Chaos* was presented as an enriched version of *La Nouvelle Alliance*—which was not translated to English—I will mainly follow the French-language books. The reason is that, although the themes contained in *Order out of Chaos* appear, under different forms, in the French-language books, in the English books they lose much of the subtleties of the original treatment: in several cases, the English version lacks the philosophical richness of the original French texts.

The end of omniscience

Prigogine and Stengers appeal to the dialogue between Einstein and Tagore as the best manifestation of the confrontation between two different conceptions of reality: whereas Einstein emphasized the independence of reality from the subject of knowledge, even from the existence of human beings itself, Tagore maintained that any reality, being ethical, philosophical or scientific, is relative to human spirit (*ETE*, p. 57). They regret that Einstein's position became the metaphysical choice of physics, and that it was identified with the ideal of scientific knowledge. That position incorporates the idea of a kind of knowledge that completely erases who describes the world, that preserves, at the very heart of science, the reference to God, the only being capable of endowing the knowledge of reality "in itself" with any sense (*ETE*, p. 59). From this perspective, scientists merely discover the laws of nature and describe the independent world.

In several places of their works, Prigogine and Stengers protest against the myth of omniscience, the chimera of the possibility of having access to the knowledge about the world that God would have if he existed (*NA*, Chapter 1; see also *OC*). According to the authors, classical science, although secular, "is still the prophetic announcement of a description of the world seen from a divine or demonic point of view" (*NA*, p. 129). This is

the science dreamed of by modern philosophers, as Descartes and Leibniz. It is this myth that gave birth to the many omniscient characters that populate physics along its history: Laplace's demon, capable of perfectly observing the position and velocity of each particle of the universe at any time and of deducing its evolution; Maxwell's demon, who can separate fast- and slow-moving particles in order to impose an anti-thermodynamic evolution on a system; Einstein's God, who does not play dice with subatomic particles (*NA*, pp. 95–96; *ETE*, p. 58). The ghost of those omniscient beings still overflies present-day science. For instance, most quantum chemists think that the complete reduction of chemistry to quantum mechanics is simply limited by technical constraints, which, in the future, will be gradually superseded.

By explicitly rejecting the myth, Prigogine and Stengers proclaim the end of omniscience (*NA*, Conclusion). According to them, we have to admit the impossibility of adopting a divine viewpoint, from which we could describe and deduce reality in itself "from the outside", as mere spectators. As stressed by the subtitle of *Order out of Chaos*, *Man's New Dialogue with Nature*, knowledge is a dialogue, in which we are both actors and spectators, in such a way that actors and spectators are co-defined, that is, "co-stabilized" in the process of knowing (see also *NA*, pp. 368–370).

Towards a new objectivity

For the traditional conception of science, "a description is objective to the extent to which the observer is excluded and the description itself is made from a point lying outside the world—that is, in fact, from the divine viewpoint to which the human soul, created as it was in God's image, had access at the beginning. At present, classical science aims at discovering the unique truth about the world, the unique language that will decipher the whole of nature" (*NA*, p. 92). This is the science that aspires to discover "universality" beyond phenomena, from God's eye viewpoint. This traditional conception of science is the target of the criticisms of Prigogine and Stengers, and for this reason they adopt Tagore's viewpoint: reality is not merely given; knowledge is a construction, a bold and daring invention, a creation of meanings (*ETE*, p. 12). Science should no longer be understood as a neutral and disembodied activity; it should become a result of a task that unifies, as any creative task, the freedom of creation and the rigorous exploration of the world (*ETE*, p. 31). In this sense, the authors recall what Maurice Merleau Ponty termed 'truth within situation': "So long as I keep before me the ideal of an absolute observer, of knowledge in the absence of any viewpoint, I can only see my situation as being a source of error. But once I have acknowledged that through it I am geared to all actions and all knowledge that are meaningful to me, and that it is gradually filled with everything that may *be* for me, then my contact with the social in the finitude of my situation is revealed to me as the starting point of all truth, including that of science" (Merleau-Ponty 1953, pp. 136–137).

Therefore, against the traditional conception of objectivity as independence of the observer, a redefinition of objectivity turns out to be indispensable: we must move away "from this rather naïve assumption of a direct connection between our description of the world and the world itself. Objectivity in theoretical physics takes a more subtle meaning" (*OC*, pp. 54–55). On this basis, Prigogine and Stengers accept Kant's starting point, his emphasis on the active role that man plays in knowledge: "Objective knowledge is not passive; it forms its objects. When we take a phenomenon as the object of experience, we assume, before any effective experience, that it has a legal behavior, that it obeys a given

set of principles" (*NA*, p. 143). The active role assigned to the subject in knowledge is clearly manifested when the authors speak of 'construction': "the reality studied by physics is also a mental construction: it is not merely given" (*OC*, p. 225); we cannot ignore "the important role intellectual construction plays in our conception of reality" (*OC*, p. 292). As Kant in his *Critique of Pure Reason*, they conceive the examination of nature as an interrogatory in a court of law, in the name of certain principles. Although, in experimentation the answer of nature is registered with precision, its pertinence is assessed in the light of the hypotheses that guide the experiment: nature is forced to answer in the same language as the question was posed (*NA*, p. 78). Nevertheless, in spite of this explicit adherence to the idea of an active subject of knowledge, Prigogine and Stengers let aside the transcendental character of Kantian philosophy, which leads to the denial of a diversity of possible viewpoints: "In agreement with the myth of classical science, Kant is after the *unique* language that science deciphers in nature, the unique set of assumption that condition physics, and that are thus to be identified with the categories of human understanding itself" (*NA*, p. 145). In other words, the authors reject the aims of universality that underlies classical science.

Against reduction

In opposition to the idea of a unique language, Prigogine and Stengers claim that "nature speaks with a thousand voices" (*NA*, p. 131). From this perspective, they interpret the quantum principle of complementarity as showing that "the various possible languages, the different points of view about the system are complementary; they all deal with the same reality, but they cannot be reduced to one single description. This irreducible plurality of perspectives on the same reality expresses the impossibility of discovering a comprehensive perspective from which the whole reality is simultaneously visible" (*NA*, p. 313). There are not all-embracing schemes to describe reality (*NA*, p. 292): "the wealth of reality […] overflows any language, any logical structure, any conceptual lighting" (*NA*, p. 313); "each language can express only part of reality" (*OC*, p. 255).

It is from this pluralistic position that Prigogine and Stengers conceive the interrelation between sciences (see Lombardi 1999b). They point out the protests raised, during the Enlightenment, by chemists and physicians against the way physicists reduced living processes to peaceful mechanisms and the quiet unfolding of universal laws (*NA*, p. 138). They also stress "the eloquent defense of chemistry against the abstract imperialism of the Newtonians" written by Venel in his article for Diderot's *Encyclopédie* (*NA*, p. 137; see also Bensaude-Vincent and Stengers 1993). It is also from this perspective that Prigogine and Stengers recall Hegel and his search of a new coherence opposed to scientific reductionism. To the assumption that differences are only apparent and nature is fundamentally homogeneous and simple, Hegel's philosophy opposes the idea of a hierarchy where each level presupposes and surpasses the preceding ones (*NA*, pp. 149–150). In this sense, the authors also acknowledge their debt to Bergson and his rejection of the traditional attempt of reducing the irreversible time of human existence to the time-motion of classical science (*NA*, p. 155).

In their opposition to reductionism, Prigogine and Stengers go beyond the boundaries of physics and admit the specificity and the autonomy of all the scientific disciplines: "far from proposing a single vision to other sciences, the physicist discovers, in his own domain, a multiple reality, which cannot be endowed with any sense without recognizing, at the same time, the irreducible diversity of the problems that other sciences must face"

(*ETE*, pp. 38–39). Nevertheless, the main interest of the authors is always directed to the relationship between irreversible thermodynamics and reversible mechanics. They accept Eddington's view (1928), according to which the description of the behaviors of the elementary parts of a system is not sufficient for understanding the system as a whole. It was precisely the second law of thermodynamics, with its distinction between past and future, "the first challenge to a concept of nature that would explain away the complex and reduce it to the simplicity of some hidden world" (*OC*, p. 8); the second law is the proof of the inadequacy of a conception of research identified with—in Eddington's words—"microscopic dissection of objects." Prigogine and Stengers are completely clear when they declare that every attempt to "derive" irreversibility from dynamics is necessarily condemned to fail (*OC*, p. 16), since "[o]ur universe has a pluralistic, complex character" (*OC*, p. 9).

Putnam and his internalist realism

"An ant is crawling on a patch of sand. As it crawls, it traces a line in the sand. By pure chance the line that it traces curves and recrosses itself in such a way that it ends up looking like a recognizable caricature of Winston Churchill. Has the ant traced a picture of Winston Churchill, a picture that *depicts* Churchill?" (Putnam 1981, p. 1; italics in the original). With these words, which open the book *Reason, Truth and History* (1981), Putnam begins to build his argumentation to reject magical theories of reference, which assume a "magical connection" between a name and the bearer of that name. According to him, a word "in itself" is not a representation, it does not intrinsically refer to an extra-linguistic object. Let us consider now, says Putnam, a monkey that, by chance, types out a copy of *Hamlet*: the situation is the same as that of the ant, but regarding a much more complex representation. And he concludes: "it would be a striking demonstration of an important conceptual truth; that even a large and complex system of representations, both verbal and visual, still does not have an *intrinsic*, built-in, magical connection with what it represents—a connection independent of how it was caused and what the dispositions of the speaker or the thinker are." (Putnam 1981, p. 5; italics in the original).

For Putnam, the rejection of magical theories of reference is the first step toward breaking the dichotomy between the objective and the subjective views of truth and reason. This dichotomy leads to the unavoidable choice between two mutually exclusive alternatives. On the one hand, many philosophers hold some version of the "copy" theory of truth, according to which a statement is true just in case it corresponds to the subject-independent facts. This conception, in turn, presupposes the existence of an objective world completely independent of human mind, which admits the "One True Theory" as the only true description. On the other hand, some thinkers reject the "copy" theory of truth, and this leads them to adopt a relativistic perspective: schemes of thought, ideologies and even scientific theories are merely subjective. Putnam's aim is to find a middle way between those two philosophical positions. He calls his perspective '*internalism*' or '*internalist realism*', as contrasted with '*externalism*' or metaphysical realism, also referred to as "God's Eye point of view" (Putnam 1981, p. 49).

According to externalism, the world exists independently of our knowledge and theories, and consists of some fixed totality of mind-independent objects. Then, there is only one true and complete description of 'the way the world is', whose truth involves some sort of correspondence between words and objects and between sentences and facts (Putnam 1981, p. 49). By supposing that reference is a relationship between the words of the

language and the external, independent ontology, externalism needs a non-human point of view—God's Eye—to fix the reference of the language and, with this, the truth-value of its sentences.

As Pérez Ransanz (1999) argues, the key for understanding the disagreements between externalism and internalism is the concept of *object*. For the internalist, "«objects» do not exist independently of conceptual schemes. We cut up the world into objects when we introduce one or another scheme of description" (Putnam 1981, p. 52). The question 'What objects does the world consist of?' only makes sense to be asked within a theory or description (Putnam 1981, p. 49). In other words, objects depend on conceptual schemes in a strong sense, which includes existence. This means that conceptual schemes are not mere intermediary elements between subjects and objects; rather, they play an essential role in the constitution of objects. Therefore, even though there is a reality independent of the subject, ontology only arises from a conceptual scheme, which depends on practice, on the human goals within a particular field of research. Objects constituted by the *synthesis* between each conceptual scheme and the independent reality are the only objects. Objectivity does not mean independence from the subject, but is the result of our conceptual schemes applied to reality. This is "*objectivity for us*, even if it is not the metaphysical objectivity of God's Eye view" (Putnam 1981, p. 55; italics in the original): this is the only possible objectivity when we have given up the idea of God's point of view.

It is not difficult to see that internalism is rooted in Kantian philosophy, and Putnam himself acknowledges the influence: "although Kant never quite says that this is what he is doing, Kant is best read as proposing for the first time what I have called the 'internalist' or 'internalist realist' view of truth" (Putnam 1981, p. 60). For Kant, the subject-independent reality exists: such an existence is a postulate of reason. Nevertheless, that reality is a *noumenal* reality, which is not object of our knowledge. To think about an independent ontology makes no sense because there are no entities in the noumenal reality: the notion of a noumenal world is a kind of limit of thought, a condition of possibility and of intelligibility of our knowledge. As Torretti clearly explains in his careful study of Kantian philosophy, not only there is no biunivocal correspondence between things-in-themselves and objects of experience, but we should neither expect that our science tends to more accurate descriptions of those noumena (Torretti 2005, p. 664). In Putnam's words, "you must *not* think that because there are chairs and horses and sensations in our representation, that there are correspondingly noumenal chairs and noumenal horses and noumenal sensations. *There is not even a one-to-one correspondence between things-for-us and things in themselves*" (Putnam 1981, p. 63; italics in the original). This means that the ontology resulting from the synthesis between a conceptual scheme and the noumenal realm cannot be interpreted as an epistemologized ontology resulting from our contingent means of access to reality. The ontology so constituted is not an approximation to the "true" reality, the result of certain epistemic limitations that will be progressively removed with the development of science. The world resulting from the constitutive role of the conceptual scheme is the only meaningful ontology when the idea of the knowledge of God's eye is finally abandoned. The Kantian system is not an epistemology but a broad philosophical framework that establishes the necessary conditions for knowledge and, therefore, for any meaningful scientific discourse.

Summing up, the internalist notion of object has, as Janus, a double face. On the one hand, objects are not free inventions of mind, without an independent substratum imposing constraints. But, on the other hand, objects are neither entities purely external to the subject, which inhabit a ready-made world. Objects are produced, at the same time, by the subject and by the independent reality.

Ontological pluralism

Although, accepting the "Copernican revolution" of Kantian philosophy, Putnam does not adhere to the transcendental character that Kant ascribes to the categories. As Torretti (2008, p. 87) points out, one may admit that "there is no reason why the constitution of objects by the human understanding must follow precisely the patterns listed and described by him [Kant]." In fact, from his historicist position, Putnam introduces the thesis of conceptual relativity, according to which no concept—not even the most basic categories—has a single or absolute meaning or validity (Putnam 1987, p. 19). This implies that there are multiple human conceptual schemes, each one carrying its own system of categories and concepts. But since objects result from the synthesis between a conceptual scheme and the noumenal reality, the existence of different conceptual schemes leads to *ontological pluralism*, according to which there is not a single "true" ontology: we may inhabit different ontologies depending on our particular context. In this sense, Putnam's stance is close to neo-Kantian positions, in particular, that of Ernst Cassirer.

Ontological pluralism points in the same direction as the Duhem–Quine thesis of the underdetermination of theories by evidence, according to which there may exist incompatible theories that explain the same set of phenomena: we may have two empirically indistinguishable scientific theories that refer to completely different ontologies. Both theses have been used against scientific metaphysical realism, which assumes that science converges to the "true" description of the "real" ontology—the One True Theory. That realism is clearly described by Torretti: "«Scientific realists» believe that reality is well-defined, once and for all, independently of human action and human thought, in a way that can be adequately articulated in human discourse. They also believe that the primary aim of science is to develop just the sort of discourse which adequately articulates reality—which, as Plato said, «cuts it at its joints»—and that modern science is visibly approaching the fulfillment of this aim" (Torretti 2000, p. 114).

But although Putnam's internalism has been widely wield against metaphysical realism in the context of the problem of theory change, it has been much less discussed in a synchronic sense. Nevertheless, when we realize that theories—or even disciplines—presupposing different conceptual schemes are accepted at the same historical time and in the context of a single paradigm, we must also admit that different ontologies *may coexist* since each one of them is constituted by its corresponding conceptual scheme. And this is not an exceptional case, but a normal situation in science, as Bachelard (1932) points out with respect to the pluralism of chemistry. But to the extent that the different conceptual schemes cannot be reduced to each other, there is no reason to believe that one ontology has metaphysical priority over the others. Since the privileged viewpoint of God's Eye does not exist, there is not a single "true" ontology: all *pragmatically successful* ontologies have the same metaphysical status because all of them are constituted by equally objective descriptions. This is so because objectivity does no longer depend on the closeness to the "real" ontology viewed from God's eye, but on the success in supplying answers to the practical challenges of *human* science. As a consequence, the so-called "fundamental" theories cannot be conceived yet as describing, even in an approximate way, reality as it is in itself, since the noumenal reality is not an ontology to be described by science: "fundamental" ontologies are as constituted as "phenomenological" or "secondary" ones and, as a consequence, they are not endowed with a "higher" objectivity or a privileged metaphysical status.

This synchronic version of ontological pluralism has proved to be fruitful for facing situations that share a common feature: at the macro-level there is a property whose objectivity cannot be denied, but which cannot be explained in terms of an underlying

micro-level that lacks it. For instance, the problem of determinism in highly unstable systems consists in explaining the objective macro-indeterminism described by ergodic theory in terms of the objective micro-description given by the theory of deterministic chaos (Lombardi 2002). In the traditional discussion about irreversibility, the main problem is to account for the emergence of objective macroscopic irreversibility from and underlying reversible dynamics (Lombardi 2003; Lombardi and Labarca 2005a, b). In the case of the classical limit of quantum mechanics, the problem is to explain how a classical statistical description may emerge from the quantum realm, where probabilities show unavoidable interferences (Castagnino and Lombardi 2004, 2005). Moreover, when ontological pluralism has been applied to the problem of the relationship between chemistry and physics, it has allowed us to go beyond the epistemological autonomy of chemistry and to claim the ontological autonomy of the chemical world (Lombardi and Labarca 2005a, b, 2006; Labarca and Lombardi 2010). In all these cases, ontological pluralism makes possible to reject the arguments that endow the macro-ontologies with an apparent or secondary status: the macro-descriptions do not need to be referred to the micro-realm to be considered objective.

Prigogine and ontological pluralism

When the theses of Prigogine and Stengers and of Putnam are considered side by side, it is not difficult to notice an illuminating parallelism between them.[1] From both sides the possibility of a neutral knowledge of reality in itself is explicitly and definitively rejected: the end of omniscience proclaimed by Prigogine and Stengers can be easily identified with Putnam's rejection of God's Eye viewpoint. Therefore, objectivity is not independence from the subject of knowledge: whereas for Prigogine and Stengers it is the result of intellectual construction, for Putnam it is an objectivity-for-us. In fact, according to Putnam, we cut up the world into objects when we introduce a conceptual scheme, that is, a particular language or theory. With a more rhetoric style of writing, Prigogine and Stengers talk of a nature that speaks many languages: the scientist has to choose a language, in terms of which the system must answer to his questions (*NA*, p. 313). Nevertheless, they also use the terms "logical structure" (*NA*, p. 313) and even "conceptual structure" (*OC*, p. 3) to denote the element supplied by the subject for knowledge.

When these points of contact are noticed, it is not surprising that Prigogine and Stengers as well as Putnam acknowledge the influence of the *Critique of Pure Reason*, in particular, the active role of the subject in the constitution of knowledge. Nevertheless, in both cases the transcendental character of the Kantian philosophy, with its consequent universality, is left aside. Whereas Prigogine and Stengers explicitly reject the uniqueness of Kant's system of categories, Putnam takes for granted the existence of a multiplicity of conceptual schemes that leads to ontological pluralism.

As we have stressed above, although ontological pluralism has been mainly discussed regarding theory change, it has relevant implications in a synchronic version. In fact, ontological pluralism has been applied to argue for the autonomy of supposedly "phenomenological" physical theories and of supposedly "secondary" disciplines as chemistry. From this pluralistic perspective, the different theory-depending ontologies, non-reductively related to each other, are all equally objective, and there is no priority o dependence relation between them. Keeping this in mind, certain quotes from the books of Prigogine

[1] This claim does not imply to ignore other influences and philosophical relationships. For instance, consider the influence of Whitehead's thought on the theses of Prigogine and Stengers (Vihalemm 2007).

and Stengers seem to have been taken from the works where Putnam advocates ontological pluralism in science: "an essential characteristic of our scheme is that it does not suppose any fundamental mode of description; each level of description is implied by another and implies the other. We need a multiplicity of levels that are all connected, none of which may have a claim to preeminence" (*OC*, p. 300).

The striking parallelism between these two perspectives should not to hide the differences between them, which mainly rely on their distinct philosophical roots. In fact, the discourse of Prigogine and Stengers belongs to the continental tradition in philosophy, in particular to the strong French tradition. By contrast, Putnam introduces his theses in a clearly analytic framework, where linguistic matters play a central role. This difference has also repercussions in the language style: whereas Putnam's writing is sober and clear but bereft of literary value, the books of Prigogine and Stengers are written in a rhetorically suggestive style, where form and content reach a fertile synthesis.

Another point to consider is that referred to temporal precedence and possible influences. It is clear that Prigogine and Stengers could not know Putnam's book, published in 1981, when they wrote their *Nouvelle Alliance*, published in 1979. And it is reasonable to suppose that Putnam didn't read the *Nouvelle Alliance* before writing his *Reason, Truth and History*, since Prigogine and Stengers' book was presented—in my view, wrongly—as a popular science book. What is most surprising is that this situation of isolation lasted until much later, when both books become deeply read and highly influential. The only guess that I can venture for explaining this situation is based, again, on the different philosophical origins of the authors, and the unfortunately scarce dialogue between continental and analytic philosophy.

Prigogine's scientific program

Once an ontological pluralist perspective is found in the works of Prigogine and Stengers, a question immediately arises: How this philosophical stand influenced Prigogine's scientific work?

As it is well-known, the main concern of Prigogine was the so-called "problem of irreversibility", that is, the question about the relationship between macroscopic irreversibility and microscopic reversibility. This is one of the problems where the subtle relations between chemistry and physics are best manifested. In fact, whereas most chemical processes are irreversible in the sense that they cannot be time-reversed without energetic cost, the world of physics is described by laws that do not distinguish between the two temporal directions (see Earley 2004). Then, the assumption that chemical processes should be explainable, at least in principle, in physical terms is committed with facing the incompatibility between chemical irreversibility and physical reversibility.

Since 1977, when he was awarded with the Nobel Prize in Chemistry, Prigogine spent most of his academic life and his scientific efforts in trying to explain how macroscopic irreversibility can emerge from an underlying time-reversal invariant dynamics. As noticed by Bishop (2004), two stages can be clearly distinguished in his works. In the early years, from the 1960's to the mid 1980's, he developed an approach based on a similarity transformation that maps a classical or quantum unstable description into a probabilistic Markovian description, intrinsically indeterministic and irreversible (see discussion in Lombardi 2000). In the later years, under the influence of the theoretical contributions of Arno Bohm and Manuel Gadella, he adopted the rigged Hilbert space formalism to describe intrinsic irreversibility.

During the first stage, the work of Prigogine and his group relied on the Hilbert-space formalism, which encompasses both quantum mechanics and classical mechanics in the Koopman version (1931). By rejecting the idea that indeterminism and irreversibility are the result of a coarse-graining on the underlying deterministic and reversible dynamics, Prigogine proposes a formalism that aims at obtaining the probabilistic and irreversible description of unstable systems by a mere "change of representation". Given a system whose state is represented by a distribution function ρ, its classical or quantum evolution is represented by a unitary group U_t such that $U_t U_s = U_{t+s}$, and which applies on ρ as:

$$\rho(t) = U_t \rho(0) \tag{1}$$

The new representation proposed by Prigogine replaces the deterministically and reversibly evolving ρ with a new distribution function $\bar{\rho}^+$, which evolves according a Markov process described by an operator W_t^+:

$$\bar{\rho}^+(t) = W_t^+ \bar{\rho}^+(0) \tag{2}$$

W_t^+ has the following properties: (1) it preserves positivity (if $\bar{\rho}^+ \geq 0$, then $W_t^+ \bar{\rho}^+ \geq 0$ almost everywhere), and (2) the equilibrium distribution $\bar{\rho}_{eq}^+$ is stationary under $W_t^+ (W_t^+ \bar{\rho}_{eq}^+ = \bar{\rho}_{eq}^+)$ (Misra et al. 1979). In order to connect the two representations, it is necessary to define a similarity transformation Λ^+ such that:

$$\bar{\rho}^+ = \Lambda^+ \rho \tag{3}$$

where Λ^+ satisfies the following properties: (1) it preserves positivity (if $\rho \geq 0$, then $\bar{\rho}^+ \geq 0$), (2) it has a densely defined inverse $\left(\Lambda^+\right)^{-1}$, (3) it keeps the equilibrium distribution invariant $\left(\bar{\rho}_{eq}^+ = \Lambda^+ \rho_{eq} = \rho_{eq}\right)$, and (4) it preserves the measure in phase space $\left(\int_\Gamma \rho \mathrm{d}\mu = \int_\Gamma \Lambda^+ \rho \mathrm{d}\mu\right)$ (Misra et al. 1979). When these properties are satisfied, it can be proved that:

$$W_t^+ = \Lambda^+ U_t \left(\Lambda^+\right)^{-1} \quad U_t = \left(\Lambda^+\right)^{-1} W_t^+ \Lambda^+ \tag{4}$$

According to Prigogine and his coworkers, these equations show the "equivalence between a deterministic evolution and a genuinely stochastic evolution which displays the irreversibility expressed in the second law of thermodynamics" (Misra et al. 1979, p. 11). Moreover, Prigogine is interested in the cases where the equilibrium state is an attractor for the process described by W_t^+:

$$\left\| W_t^+ \left(\bar{\rho}^+ - \bar{\rho}_{eq}^+ \right) \right\|^2 = \left\| W_t^+ \bar{\rho}^+ - \bar{\rho}_{eq}^+ \right\|^2 \to 0 \quad \text{decreasing monotonically as } t \to +\infty \tag{5}$$

As a consequence, Prigogine and his coworkers have defined the desired relation that links the microscopic reversible description given by U_t acting on ρ with the macroscopic reversible description given by W_t^+ acting on $\bar{\rho}^+$. According to the authors, they have shown that the probabilistic description can be linked to the deterministic description by a "change of representation" brought about by an invertible similarity transformation involving "no loss of information" (Misra et al. 1979, p. 24).[2]

[2] In previous works I have argued that the problems of irreversibility and of time's arrow, even if related to each other, are conceptually different (Castagnino et al. 2003). When analyzed from this viewpoint, the scientific work of Prigogine succeeds in solving the problem of irreversibility, but not the problem of the arrow of time, which consists in establishing a theoretically based, non-conventional difference between the two directions of time. In fact, any time-reversal invariant law, as that represented by the unitary group U_t, leads to two time-symmetric solutions, one the temporal mirror image of the other. Then, by means

The main difficulties of Prigogine's works during the early years were of mathematical nature: the new operators used in the similarity approach do not have a precise definition in the Hilbert space formalism (see Bishop 2004). In the 1980's, Prigogine and his coworkers contacted the Austin group led by Arno Bohm; since then they adopted the rigged-Hilbert-space formalism, developed by Bohm and Gadella (1989), as their general mathematical framework. As it is well known, in usual quantum mechanics observables are represented by hermitic operators on a Hilbert space $\mathcal{H}$ which, as a consequence, have real eigenvalues. Therefore, if ω is an eigenvalue of the Hamiltonian H, the corresponding eigenvector $\Psi \in \mathcal{H}$ evolves unitarily and, thus, reversibly as:

$$\Psi(t) = U_t \Psi = e^{-i\omega t}\Psi \tag{6}$$

A rigged Hilbert space or Gel'fand triplet is a triplet of spaces:

$$\Phi \subset \mathcal{H} \subset \Phi^{\times} \tag{7}$$

where (1) $\mathcal{H}$ is an infinite-dimensional separable Hilbert space, (2) Φ is a topological vector space, dense in $\mathcal{H}$, and (3) $\Phi^{\times}$ is the antidual space of Φ such that the action of $\varphi \in \Phi^{\times}$ on $\phi \in \Phi$ is $\langle \phi \mid \varphi \rangle$ (Dirac's notation). In the particular representation of the rigged Hilbert space used by Bohm and Gadella, based on Hardy functions, the original group of evolution operators of standard quantum mechanics, U_t $(t \in \mathbb{R})$, is split into two semigroups $U_t^+ = e^{-iH_+ t}$ and $U_t^- = e^{-iH_- t}$, where the semigroup generators $H_\pm$ are the restrictions of the self-adjoint operator H to the subspaces $\Phi_\pm$. In turn, the operators on the spaces $\Phi_\pm^{\times}$ may have eigenvectors with complex eigenvalues. In particular, the spaces $\Phi_\pm^{\times}$ may also contain eigenvectors of the Hamiltonian having complex eigenvalues. For instance, there may exist a '*decaying Gamow vector*' $\Psi^D \in \Phi_+^{\times}$ and a '*growing Gamow vector*' $\Psi^G \in \Phi_-^{\times}$ such that they are eigenvectors of $H_+^{\times}$ and $H_-^{\times}$ (the restrictions of H to the subspaces $\Phi_\pm^{\times}$) with complex eigenvalues $z = \omega - i\,\Gamma/2$ and $z = \omega + i\,\Gamma/2$, respectively, with $\Gamma > 0$ (Bohm and Gadella 1989; Gadella 1997). Therefore, the Gamow vectors evolve as:[3]

$$\Psi^D(t) = e^{-iH_+^{\times} t}\Psi^D = e^{-i(\omega - i\Gamma/2)t}\Psi^D = e^{-i\omega t}\Psi^D e^{-(\Gamma/2)t} \tag{8}$$

$$\Psi^G(t) = e^{-iH_-^{\times} t}\Psi^G = e^{-i(\omega + i\Gamma/2)t}\Psi^G = e^{-i\omega t}\Psi^G e^{(\Gamma/2)t} \tag{9}$$

These expressions represent exponentially decaying and growing processes, respectively, with lifetime $\tau = 2/\Gamma$. This means that Ψ^D describes an irreversible evolution that tends to 0 for $t \to +\infty$, and Ψ^G describes an irreversible evolution that tends to 0 for $t \to -\infty$. On this basis, Prigogine and his coworkers conceive both Gamow vectors, $\Psi^D \in \Phi_+^{\times}$ and $\Psi^G \in \Phi_-^{\times}$, as representing decaying processes, directed to the future and to the past, respectively, and evolving according their corresponding semigroup of evolution operators: "The unitary group U_t when extended from the Hilbert space $\mathcal{H}$ to the space $\Phi_+^{\times} + \Phi_-^{\times}$ splits therefore into two semigroups, the forward semigroup $U_t^+, t > 0$, describing decay in

Footnote 2 continued
of an argument completely analogous to that developed above, one can define a similarity transformation Λ^- that leads to a distribution function $\bar{\rho}^-$, which evolves according a Markov process, described by an operator W_t^- and approaching equilibrium for $t \to -\infty$; and there is nothing in the theory that establishes a non-conventional difference between the two solutions (see Lombardi 1999a).

[3] Strictly speaking, it is not the Gamov vector but the expectation value $\langle \phi \mid \Psi^{\times} \rangle$ what evolves in time, since the vectors φ belonging to $\Phi^{\times}$ are *functionals* whose mathematical nature consists in *acting on* vectors ϕ belonging to Φ (see discussion in Castagnino et al. 2006).

the future, and the backward semigroup $U_t^-, t<0$, describing decay in the past" (Antoniou and Prigogine 1993, p 459).[4]

As we can see, in both stages of his work Prigogine could obtain, although by different theoretical means, an adequate link between the description of certain well-known irreversible phenomena and the traditional description of the reversible underlying dynamics. It is precisely at this point that one would expect that Prigogine applied his ontological pluralism to argue for the same degree of objectivity for both descriptions. For instance, from a pluralist perspective, the probabilistic and irreversible evolutions of highly unstable systems, as described by ergodic theory, are as objective as the deterministic and reversible evolutions in the underlying level, described by chaos theory. In fact, the (micro) description of chaotic systems is deterministic, meaning that, given the point representative of the initial conditions in phase space, there is only one trajectory that never intersects itself and that, as a consequence, represents a completely deterministic evolution. However, in ergodic theory one defines a (macro) description resulting from a coarse-grained partition of the phase space, where each cell of non-zero volume represents a macro-state of the system and each possible macro-evolution is defined by a possible succession of macro-states. It can be proved that, at this macro-level, chaotic systems have the statistical properties of a K-system. In a K-system, the only macro-states that can be univocally predicted are those that have probability zero or one independent of the macro-history of the system. This means that the macro-description of chaotic systems is indeterministic because the past macro-evolution of the system does not fix its future macro-evolution (see Schuster 1984).

The traditional view implicitly adopts God's eye perspective: unstable systems are objectively deterministic, and the statistical macro-description is a mere subjective appearance due only to our limited observational power. However, the statistical properties are not mere illusions, because they are generated by the micro-dynamics of the system. Ontological pluralism supplies the philosophical framework for admitting that the indeterministic macroevolutions are as objective as the underlying deterministic microevolutions. The states and evolutions of a physical system are not theory-independent; on the contrary, each theory constitutes a relative ontology when it cuts its own states and evolutions out of the same noumenal substratum. In chaotic systems, the micro-description defines an ontology with microstates represented by phase points, and deterministic evolutions represented by trajectories in phase space; the macro-description defines an ontology with macro-states represented by cells of non-zero volume, and indeterministic macro-evolutions with their transition probabilities between macro-states (for a detailed argumentation in this direction, see Lombardi 2002). In the same sense, ontological pluralism allows us to explain why the decaying irreversible processes described in the rigged-Hilbert-space framework are as objective as the reversible quantum evolutions described by traditional Hilbert-space quantum mechanics.

However, this is not the path followed by Prigogine. He could have argued that, since God's Eye does not exist, neither the irreversible description nor the reversible description has precedence over the other. On the contrary, he insisted in endowing the irreversible level with ontological priority. According to him, in the cases of high instability, the

[4] As the approach of the early years, this proposal neither solves the problem of the arrow of time. The reason is that, again, two time-symmetric solutions can be obtained: for any decaying Gamov vector with complex eigenvalue $z = \omega - i\,\Gamma/2$, there is a growing Gamov vector with complex eigenvalue $z = \omega + i\,\Gamma/2$, and there is nothing in the theory that establishes a non-conventional difference between the two solutions (see Castagnino et al. 2005, 2006).

evolution is inherently stochastic and irreversible (Misra et al. 1979) and, therefore, the Markovian description is more adequate than the deterministic one (Nicolis and Prigogine 1989). In this case, the concepts of phase-space point and of trajectory become "unphysical idealizations" (Misra and Prigogine 1981, p. 23): they have to be left over in favor of the "new elemental entities" described by $\bar{\rho}^{+}$ (Misra and Prigogine 1983, p. 422). An analogous position can be detected in his argumentation in the quantum context: instead of accepting both the reversible and the irreversible descriptions as equally objective, he claims that "we have to identify the irreversible time everywhere, or we will cannot understand it anywhere" (*ETE*, p. 195).

Summing up, Prigogine seems to have forgotten his philosophical claims in favor of the end of omniscience and the multiple reality. In his specifically scientific work he appears to be searching the "true" irreversible description of the world, traditionally ignored by mainstream science, whereas at the same time he disesteems the traditional reversible descriptions as inadequate idealizations. It is precisely this kind of argumentation that makes him the target of certain criticisms that, for instance, reasonably assert that no change of representation can ignore the impressive success of traditional statistical mechanics, formulated in terms of points and trajectories in phase-space (see Batterman 1991; Sklar 1993), and that the emergence of irreversibility from chaotic systems is claimed on the basis of inferring ontological conclusions from epistemic arguments (see Lombardi 1998a, b).

Final remarks

Although I worked on the critical analysis of the scientific and philosophical contributions of Prigogine during many years, only very recently I realized that his thought can be reconceptualized from an ontological pluralist framework, in the light of Putnam's internalist realism. Since that moment, I have revised my highly critical viewpoint and have reassessed Prigogine's philosophical theses.

From my new perspective I realized that, in his philosophical works, Prigogine takes a position that can be considered, in Putnam words, ontological pluralist. In fact, Prigogine and Stengers proclaim the end of omniscience and the need of conceiving objectivity as the result of the constructive role played by the subject in knowledge. Therefore, science is no longer the task of lifting the veil that hides the reality-in-itself, but a dialogue between man and a nature that speaks many different voices.

Although one can celebrate the entry of pluralism into the scientific community hand in hand with Prigogine's works, it is nevertheless necessary to admit the internal tension in his thought. In fact, when involved in the program of establishing the foundations of objective irreversibility, he seems to forget his philosophical stand. By contrast with his pluralistic claims, in the scientific context his discourse is closer to a more traditional reductionist viewpoint, according to which it is necessary to discover the single "true" description of the world. One may suppose that if Prigogine had not moved away from his ontological pluralism, he could have avoided certain conceptual criticisms and would have gained a stronger acceptance in the philosophical community.

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