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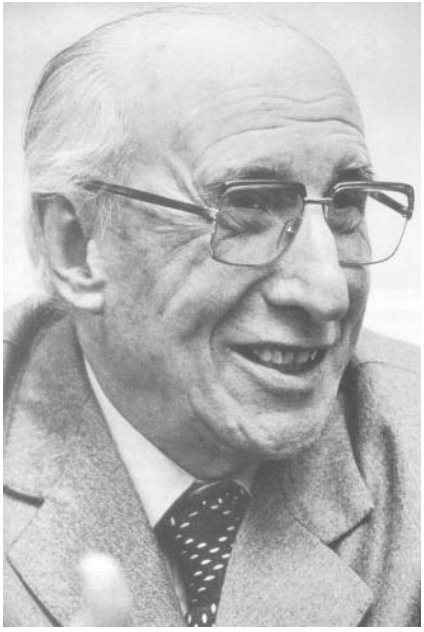

Professor LLUÍS SANTALÓ (1911–2001)*

On 22 November, aged 90, the great mathematician Lluís Antoni Santaló i Sors died in Argentina. He was an outstanding exponent of Integral Geometry, a great teacher and disseminator of scientific understanding, and a person of great human value. He had over 250 publications to his name, among which are books which have had considerable influence on our mathematic community, such as his *Geometría Proyectiva*. These lines are intended as an early sketch which can serve as the basis for the much fuller homages he deserves.

Girona

Lluís Santaló was born in Girona on 9 October 1911 at 15 Sant Pere Square. He was the fourth child of Silvestre Santaló Pavorell and Consol Sors Llach. In order of age, his three older siblings are Neus, Marcel and Joan; and his three younger ones, Dolors, Xavier and Maria.

A little while ago Maria explained to me how, when Lluís was young, they passed their hands over his head as a joke so that his science should inspire them, as his intellectual capacity was already recognised.

Lluís Santaló began to study in the *Grup Escolar*, where his father was the teacher. He went on to the Secondary School, which he always remembered in great detail. Xavier Duran [Dur] mentions a conversation with Santaló in which he recalled the meteorology practicals that they did at the School with the Physics teacher Mr. Camps. He also recalled with affection his first Mathematics teacher, Lorenzo González Calzada.

He was at school at the same time as the future great historians Jaume Vicens Vives and Santiago Sobrequés Vidal, among others.

At 16 he left to study in Madrid. It seems that his father decided on this, with the idea that, as he would have to go to Madrid to sit for a doctorate or a permanent post, it would help him to get to know the environment beforehand. He lived in the famous Residencia de Estudiantes (Students' Hall) in Pinar Street, following in the steps of his uncle Miquel and brother Marcel, who studied a Mathematics degree. Lluís Santaló intended to study Civil Engineering, but he soon switched to Mathematics like his brother. In the Faculty of Mathematics, he had teachers who would have a decisive influence on him, mainly Julio Rey Pastor and Esteve Terradas. Two great intellects. Two great mathematicians. The two had taught in Argentina, which would decisively affect Santaló's life.

Doing his military service at the same time as his coursework, he received his degree in 1934. Rey Pastor and Terradas advised him to go to Hamburg, which he did in 1934 with a grant from the *Junta para Ampliación de Estudios*. He had to resign his recently acquired job as a school-teacher. In Hamburg a friend of Rey Pastor's, the geometrician Wilhelm Blaschke, welcomed him.

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It is amazing to reflect on that small group of students of Blascke's. There were only 10, but Santaló and Chern were two of them! At the time Blaschke was starting to study geometrical probabilities, which was the start of what he himself would call Integral Geometry. He summarised the results in a series of numbered articles, which were all called Integral Geometrie. Number 4 was by Santaló. In 1936 Santaló published his doctoral thesis, sponsored by Pedro Pineda, on this question [S9]. While he was on holiday in Madrid, the Civil War broke out. As in so many cases, long-desired perspectives were smashed for ever.

Santaló returned to Girona and was posted to the Air Force in the Republican Army, concretely to Los Alcázares, near Cartagena. His first book was born from the notes he took then [S159], along with an interest in flying expressed in [S184],[S186],[S194].

Promoted to Captain, he spent a second stage of the war at the Barcelona School of Military Aviation, directed by Josep Canudas. From there his unit went into exile, with brief stops in Girona and Navata.

One of those strange coincidences of life, as Xavier Duran explains in his book [Dur], quoting Canudas, is that when the uncle of Santaló, Miquel Santaló, was Councillor in the Generalitat, he signed in 1933 the decree creating the Aeronautic Service although the Service possessed no aeroplane. Later a small plane was bought and Josep Canuda was made Director of the School where Miquel's nephew, Lluís Santaló, subsequently worked.

Co-founder of Esquerra Republicana de Catalunya, Mayor of Girona, Councillor in the Generalitat, and Minister, Member of Parliament and Vice-president in the Cortes, Miquel Santaló had no alternative but go into exile. He was to die in Mexico. It is no surprise that we can find in Girona today streets named after both Miquel Santaló and Lluís Santaló.

Once in France, Santaló was interned in the concentration camp at Argelers. According to Xavier Duran [Dur], Santaló did not remember how he escaped from this camp. From Colliure he wrote to Rey Pastor and Blaschke asking for help. He knew through his family that he could not go back to Girona.

Despite Blaschke being prepared to welcome him, the political situation in Germany advised against returning to Hamburg. However, Blaschke wrote on his behalf to Élie Cartan, who at once invited Santaló to give some lectures at the Institut Henri Poincaré in Paris. Once in Paris Santaló was arrested, but Cartan himself went to the prison to get him out. The lectures were held on 25, 28 and 30 March 1939, at Number 11, Rue Pierre Curie. The subject, of course, was integral geometry and geometric probabilities.

Though Rey Pastor had also answered Santaló's letter and sent him money for a passage to Argentina, visa problems prevented him leaving. According to Duran [Dur] it was Terradas who interceded with a bishop to get the visa processed. Finally he embarked in Bordeaux.

Argentina

On October 12 1939 Santaló reached Buenos Aires, where he was met by Manuel Balanzat, representing Rey Pastor. Balanzat later became a co-author and close friend of Santaló [S163] and [S174].

Rey Pastor took care of everything and found him a post at Rosario, in Santa Fe province. At that time the Institute of Mathematics of the Universidad del Litoral, directed by Beppo Levi [S208], was being set up. Santaló became deputy director.

He integrated rapidly into exile and émigré circles, becoming secretary of the Catalan Centre of Rosario. In 1945 he married Hilda Rossi, who remained with him for the rest of his life. Later he became an Argentine citizen. In 1947 their first daughter, Maria Inés, Tessi, was born.

One of my first conversations with Santaló comes to mind now. Around 1985 I asked him, when he was giving a course at the University of Barcelona, about the possibility of his returning to Catalonia. He answered that his life was in Argentina, his children and grand-children were there... but a touch of longing could be divined in his words. It was then that he asked me what Projective Geometry text-book I would recommend to my students. "The Santaló," I said and I suppose he thought I was trying to look good in his eyes, but it was true and even now, much later, I still think the same.

He spent 1948-49 with Hilda and Tessi in Princeton, on a grant from the Guggenheim Foundation. He also taught a course in Chicago, invited by M. H. Stone, who had been with Santaló in Argentina. As Claudi Alsina recorded many years later, Santaló left an indelible impression in Chicago. He coincided with Einstein at the Institute for Advanced Studies in Princeton.

Back in Argentina in 1949, he joined the University of La Plata, capital of the province of Buenos Aires. His second daughter Alicia was born. He directed his first thesis: *Propiedades infinitesimales de curvas y superficies en espacios de curvatura constante*, by Leticia Varela. He took part in the National Commission for Atomic Energy (CNEA), taught at the Army Higher Technical School, researched, travelled... always keeping up an intense, not to say frenetic, rhythm of work. His third daughter Claudia was born.

His membership of the CNEA allowed him to travel to Paris and visit Girona for the first time since going into exile. This must have been in about 1955, as he belonged to the CNEA from 1952 to 1957. Unfortunately he did not see his mother, for she had died in 1947.

In 1957 he was appointed Professor with tenure in the Faculty of Exact and Natural Sciences of the University of Buenos Aires.

The first public tributes to his career began in these years: the First National Prize for Culture, 1954; Prize of the Argentine Scientific Society, 1959; Membership of the National Academy of Exact and Natural Sciences, 1960.

In Buenos Aires his reputation as a fine teacher spread. He dedicated enormous effort to thinking about Mathematics teaching. He united profound knowledge of the subject with the ability to explain things in a straightforward way. He managed to make difficult things easy. He paid special attention to his students. He tried to change the traditional way of explaining the subject. He “invented” tutoring, in order to relate Mathematics teaching to aspects of the personality, desires, vocation and education of the student.

Most important honours in Spain

This section must open with the saying: better late than never.

- Corresponding Member of the Royal Academy of Exact, Physical and Natural Sciences of Madrid, 1955.
- Corresponding Member of the Royal Academy of Sciences and Arts, Barcelona 1970.
- Member of the Scientific Committee of the journal Stochastica of the UPC.
- Doctor *Honoris Causa* from the Polytechnic University of Catalonia (UPC), 14 July 1977. Introduced by Enric Trillas.
- Corresponding Member of the Institut d’Estudis Catalans, 21 December 1977.
- Prince of Asturias Prize for Scientific Research. 1983.
- Narcís Monturiol Medal for Science and Technology of the Generalitat of Catalonia. 1984.
- Doctor *Honoris Causa* from the Autonomous University of Barcelona, 13 June 1986. Introduced by Joan Girbau at a ceremony held in the Girona City Hall.
- Doctor *Honoris Causa* from the University of Sevilla, 1990. Introduced by José Luis Vicente. Promoted by Gonzalo Sánchez Vázquez, President of the Federation of Societies of Teachers of Mathematics in Spain and personal friend of Santaló.
- Honoured with the Medallion of the University of Valencia, 23 September 1993. Received by his daughter Tessi.
- Cross of Saint George from the Generalitat de Catalunya. 1994.
- Tribute of Alfonso X (The Wise), granted by King Juan Carlos and awarded by the Ambassador of Spain in Argentina. This tribute was proposed by Enric Trillas. 1996.
- Honorary Member of the Spanish Royal Mathematical Society, 22 January 1999.
- On July 27 2000 the University of Girona created the Santaló Chair, held by Carles Barceló i Vidal. The Rector of the University, Josep Maria Nadal, announced this before one of Santaló’s daughters on September 21 2000 in the Faculty of Exact Sciences, Engineering and Surveying of the National University of Rosario (Argentina), on occasion of the Session commemorating the 60th anniversary of the “Beppo Levi” Institute of Mathematics.
- Honorary Member of the Catalan Society of Mathematics, December 19 2000.

Integral Geometry

A few words to describe the field of Mathematics that enthralled Santaló.

Integral Geometry comes out of geometric probabilities. It has its roots in the famous problem of Buffon’s needle, which appears in his *Essai d’arithmétique morale,* 1777, and in Crofton’s formulas, c. 1868, in *On the theory of local probability*.

To simplify somewhat, the problem arises when, on trying to write Favourable cases/ Possible cases we find there are infinite possibilities, for example positions of Buffon’s needle in the plane.

These positions can be parameterised and identified again as points in the plane so that we then have as many positions as points. And what could be more natural than using area to measure, or “count”, the number of points?

As Santaló argues in [S173]: to apply the idea of probability to elements given by chance which are geometrical objects (such as points, lines, geodesics, congruent assemblies, movements or affinities), first a form of measurement for these assemblies of elements must be designed.

It seems that Santaló had in mind Bertrand’s paradoxes (the probability that a chord drawn at random on the circle of radius 1 is greater than $\sqrt{3}$), which arise from using, in a somewhat concealed way, different ways of measuring and different uses of the word “chance”. Poincaré was the first to clarify explicitly this point (H.Poincaré, *Calcul des probabilités*, Gauthier-Villars, 1912).

The geometrician feels attracted by the intrinsic geometric interest of questions that pose geometrical probabilities and tackles problems forgetting or ignoring whether there is or is not an underlying concept of probability.

The discussion on what measurement to choose is related to the group which determines the geometry of the problem, in the sense of Erlangen programme, by Klein. This is why in the studies of Santaló there are so many Lie groups.

Santaló argues that the basis of Integral Geometry consists of four words: probabilities, measurement, groups, geometry.

In fact, some of Santaló’s most important results come from measuring directly in the group. Talking in a general way, this is like identifying all the positions of a figure in the plane with the movements that take an initial set figure to each of the positions. The formulas that then appear are called kinematic formulas, to catch this idea of motion, even though the group is not specifically the group of movements.

While still at Hamburg, Santaló obtained in dimension two some preliminary results that would lead on to what became known as the kinematic formula.

In $\mathbb{R}^n$ we owe the kinematic formula to S.S. Chern (S.S. Chern*, On the kinematic formula in the euclidean space of n dimensions*, Amer. J. Math. 45, 1944, 744-752.)

To recall the fundamental kinematic formula of Santaló for non-Euclidian spaces we will give the expression in dimensions 2 and 3, since the general formula varies somewhat depending on whether the dimension is odd or even [S173] (note the beauty of these formulas).

For n=2

$$\int \chi(D_0 \cap D_1)dK_1 = (\varepsilon K)F_0F_1 + 2\pi(F_1\chi_0 + F_0\chi_1) + L_0L_1$$

For n=3

$$\int \chi(D_0 \cap D_1)dK_1 = 8\pi^2(V_1\chi_0 + V_0\chi_1) + 2\pi(M_1F_0 + M F_1)$$

where D_0, D_1 are domains with a regular boundary in the non-Euclidian space of curvature εK,ε = 0,1,-1; L, F, V, M denote length, area, volume and the integral of the mean curvature respectively, and χ is Euler's characteristic. Integral extended to all the positions of K_1.

Surprisingly, the case of n = 3 is the only case in which the kinematic formula does not depend on the curvature of space.

I would also like to highlight Santaló's formula for the measurement of hyperbolic straights. In [S36] he demonstrates

$$dG = \cosh p \, dp \, d\theta$$

where p is the distance from the geodesic or hyperbolic straight to a predetermined point of origin; and θ is the angle that this distance forms with a predetermined direction. The notation dG comes from "differential of geodesics". It is what we have to integrate to obtain geodesic measurements. I leave as an exercise the demonstration that the above expression is invariant for hyperbolic isometry. For example, the above calculations in the model of Poincaré are fairly complicated. However, Santaló did not work in the model and his astuteness enabled him to come out well without too many calculations. One day he said to me: "Free me from the mathematician who does not calculate". The point is that, to have the ability to avoid calculations, you must first have done calculations.

From here he showed that the following formula, formally the same as the Euclidean one, applied to the hyperbolic case

$$\int \sigma dG = \pi F$$

where σ is the length of an arbitrary chord of a C convex body of area F, and the integral is extended to the geodesics that cut the convex.

Santaló directed twelve doctoral theses in the Faculty of Exact and Natural Sciences of the University of Buenos Aires: those by L. Varela (1952), A. Ayub (1955), R. Luccioni (1963), C. Conton (1973), R. Noriega (1976), G. Keilhauer (1980), G. Berman (1980), F. Gutiérrez (1985), V. Molter (1985), L. Gysin (1987), F. Affentranger (1988) and A. Berenice (1988), all in the area of Geometry and especially in Integral Geometry.

Influence in Spain

Please accept my apologies in advance for any omissions in this section on Spanish authors. I will be grateful for any additions or amendments.

The first person to follow Santaló directly was Professor E. Vidal Abascal in Santiago de Compostela in the 1950s and 1960s. His work focused on Steiner's formula in spaces of constant curvature [7]. We should also emphasise [6],[8],[9],[10],[11],[12],[13],[14],[15],[16], [17].

In fact, as A.M. Naveira comments, the relationship between Santaló and Vidal dated back to the 1940s when he met a brother of Santaló, probably Marcel, who introduced them. In 1967, Santaló attended the II International Colloquium on Differential Geometry at Santiago de Compostela, where he gave the definition of absolute total curvatures which subsequently had such importance within Stereology. In 1978 he was also in Santiago, for the homage to E. Vidal on occasion of his retirement, and gave the opening address to the IV International Colloquium on Differential Geometry.

Going back to the 1950s we find the contribution of Professor J. Sancho de San Román, who worked on questions of Integral Geometry before devoting himself to Algebra [1],[2],[3],[4],[5], and E.G. Rodeja [14].

To give us some idea, we will use Vidal's formula which generalises Steiner's formula

$$L_\rho = 2\pi(sen(\rho\sqrt{k})/\sqrt{k} - F\sqrt{k}sen(\rho\sqrt{k}) + L\cos(\rho\sqrt{k})$$

where L, F are, respectively, the length and area of a curve over a surface of constant curvature k and L_ρ is the length of another curve at a distance ρ from the first one.

Professor Antonio Martínez Naveira, during his time in Valencia, also worked on Santaló's problems of integral geometry and achieved important results. Notable, for example, are [27],[28],[53],[54],[55],[56] and the results obtained with A. Tarrío, Professor at the University of A Coruña, in [57], [58] and [59].

For example, the densities of linear sub-spaces of $\mathbb{C}^n$ were studied. Formulas of the following kind were worked out

$$dP \wedge dP_1 \wedge ... \wedge dP_{2r} = \Delta^{n-r} dP(L_r) \wedge dP_1(L_r) \wedge ... \wedge dP_{2r}(L_r) \wedge dL_r$$

where $P, P_1, ..., P_r$ are $2r$+1 points of the holomorphic subspace L_r, and generalise formulas of Blaschke to the case of holomorphic subspaces.

In their wake came the studies by S. Segura Gomis and M.A. Hernández Cifre on complete groups of inequalities in which they closed earlier conjectures by Santaló, posed in [S106]. For example, see [48],[49],[50], [52] and the solution in [51] to the conjectures in [S106].

Concretely, if we have a convex body in space and we call the volume V, the area F, and the total mean curvature M, then

$$M^2 \geq 4\pi F, \qquad F^2 \geq 3VM,$$

The problem posed by Santaló in [S106], which we call complete systems of inequalities, consists of knowing whether, given three real numbers V, F, M satisfying the former inequalities, a convex body which has them as volume, area and total mean curvature, respectively, exists. In fact, in this case, another inequality is lacking and the general problem remains open. In [S106] Santaló studied this kind of problem in the plane. In [51] Segura and Hernández demonstrate, for example, that

$$(4R^2 - d^2)d^4 \leq 4\omega^2 R^4$$

and give a complete system of inequalities which involve (d,ω,R) (d = diameter, ω = width, R = circumradius.)

Still in Valencia we should note the contribution of Vicente Miquel who, along with A. Borisenko, studied the total curvature of convex hypersurfaces in hyperbolic space [33].

Santaló's relationship with geometricians in Barcelona stemmed from the lecture he gave at the First International Symposium on Statistics in November 1983 [S147]. He drew for me on a serviette his conjecture concerning hyperbolic convexes [26].

The fact that Santaló attended this Symposium in Barcelona, organised by E. Bonet, M. Martí and A. Prat, was probably due to his good relationship with the Polytechnic University of Catalonia, where Pere Pi Calleja, a mathematician closely linked to Rey Pastor, worked, and to the initiative taken by the mathematicians E. Bonet and E. Trillas, later good friends of Santaló's. In fact, C. Alsina, E. Bonet and E. Trillas, along with Miguel de Guzman, had kept up permanent contact with Santaló since the 1970s.

In 1977 Santaló had already been in Barcelona to chair the Scientific Committee and lecture at the First International Congress of Mathematics in the service of Humanity. He maintained contact with the Rosa Sensat group about Maths teaching, publishing two articles in the journal L'Escaire of the Department of Mathematics of the School of Architecture, [S142] and [S143]. He also had an interview published in this journal (L'Escaire, Vol. 15, 1985).

In October 1984 the Centre for Mathematical Research (CRM) was opened, with a course by Santaló on Integral Geometry in the affine plane, given in the University of Barcelona. Some notes for these were distributed [S147].

Meanwhile Eduardo Gallego and the author of this article closed the conjecture of Santaló and Yáñez, expounded in [S126], on hyperbolic convexes [26]. See also [25],[34],[35]. At present Gil Solanes has also obtained some interesting results [36].

For example, we should note that, in contrast with the Euclidean situation, it is proved in [36] that the asymptotic behaviour of the quotient (diameter/length) for convexes that tend to fill the hyperbolic plane takes any value of the interval [0,1/2]. In the Euclidean case it is marked on the lower side by 1/π.

In November 1991 Santaló was invited by J.M. Terricabras to give a course in the University of Girona under the aegis of the Ferraté Mora Chair. Among those of us attending were, among others, F. Affentranger, L.M. Cruz-Orive, A.M. Naveira, E. Gallego, C. Alsina, E. Trillas, Ortiz and X. Gual. From this meeting arose a productive scientific collaboration between X. Gual and L.M. Cruz-Orive.

Fernando Affentranger is a German-Spanish student of Santaló's who spent some time in Barcelona and even published in the journal of the Autonomous University [30], although his career is based in Germany [28],[29],[30],[31]. There is a curious anecdote about how we met. As the first article that Santaló gave to Fernando was our article [26], on his first trip to Barcelona to visit family, he asked how he could get in touch with Barcelona mathematicians. This was very easy because a cousin of his who lived next door, giving onto the same garden, was a mathematician and would be able to tell him. This cousin was me. They came to find me – and imagine Fernando's surprise when we were introduced!

Outstanding on the more applied side of Stereology is Professor L. M. Cruz-Orive and his Berne school. In Santander at present, he continues working intensively on applications of Integral Geometry with the student of A. M. Naveira, Ximo Gual Arnau. We should highlight articles [37],[38],[39] ,[40],[41],[42],[43],[44],[45],[46] by X. Gual, some jointly with A. M. Naveira and A. Tarrío. At present X. Gual is working at the Jaume I University in Castellón. Of L. M. Cruz-Orive's work we highlight [21],[22],[23],[24],[32].

To explain a little what Stereology is, we employ Santaló himself. In [S173], p. 282, he says of Stereology: Let us consider convex particles distributed in E_3. The determination of the measurement of the distribution of these particles on the basis of the measurement of distribution of their sections with random figures of a known shape (e.g. a convex body, a cylinder, a plane, a band or a line) is one of the basic problems of what is called Stereology, which is an intermediate field relating disciplines as widely varied as Biology, Mineralogy, Metallurgy and Geometry. Elias has proposed the following definition: Stereology deals with a complex of methods to explore three-dimensional space when it is only possible to know two-dimensional sections through solid bodies or their projections. The principal methods of Stereology are closely related to Integral Geometry, as some characteristic examples in this chapter will show.

To close this section on Santaló's relationship to Spanish mathematicians, let us also remember his course on Integral Geometry in the Complutense University of Madrid in February 1982.

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Some quotes

I have chosen some paragraphs written by Santaló which give an idea of him as a person and not only as a mathematician.

- Honoris Causa UPC. *This is the first academic function in which I am able to express myself in the language in which my understanding first knew things, named them and in which my spirit first showed its feelings and emotions, the language in which, when I was small, my mother told me stories and sang at the foot of my cradle. Clearly, this is Catalan.*
- Honoris Causa UAB. *Sometimes, fear is expressed that, with the necessary predominance in education of science and technology, based on mathematical reasoning, men are steadily losing their emotional faculties and becoming cold and rigid in their temperaments, refractory to emotional feeling and passion. Not at all. The fact of having one's mind prepared for clear logical and mathematical reasoning does not mean that this is to the detriment of feelings. One can think and believe, and one can reason and love.*
- Xavier Duran in [Dur] quotes the following words of Santaló concerning the importance of pushing forward talented students: *I think this is one of a teacher's main obligations. When you see someone who is intelligent, who is capable, he/she must be helped as much as possible to reach the maximum of his/her possibilities. The worst outcome is that someone who could achieve a lot does not do so because he/she has not found the right teacher or has not been guided. There must be a lot of people in that situation. It is the main thing that teaching, at any level of education, must avoid.*
- In [S176], talking of Mathematics and Art: *A lot of Mathematics is Art, in its creativity and also because it includes beauty, even though only initiates can admire this beauty, as also occurs with works of art and literature.*
- In [S176] talking of Mathematics and Philosophy. *If by science a systematised combination of knowledge is meant, which constitutes a branch of human knowledge, then Mathematics is the science par excellence.*
- In [S171] on education: *One teaches for good, for truth and to know and understand the universe.*
- Honoris Causa UPC. More on art: ...*Mathematics is art, as it is creation and it uses fantasy; it is science, because through it better understanding of the principles and causes of things is acquired; and it is technique because it provides methods and means for resolving problems and acting on Nature and its phenomena.*

We have quoted Santaló's book [S176] several times, as it is excellent and everyone can benefit from reading it. For example, S. Xambó has said that "reading it is a delight for any mathematician". But it is also a pleasure for non-mathematicians. The Rector of the University of Girona, Josep Maria Nadal, told me that he liked to sit with this book by Santaló beside the sea and meditate.

Let us end with the words that Professor J. Etayo of the Complutense used about Santaló. I find them very fitting. "It causes great happiness to find how values cultivated in simplicity and complete absence of pretentiousness end up being discovered by everyone else and highlighted in all justice".

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