

Research Article

# Period Doubling Phenomenon in Baryon Magnetic Moment Modelling and Its Correlation to Strangeness

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## Abstract

The period doubling phenomenon, first proven by M. I. Feigenbaum in 1980, describes the emergence of stable periodic sequences within an apparently chaotic system, where successive periods relate by a factor of two. This universal behavior has been extensively studied and confirmed both theoretically and experimentally. Given that both gravitational and electromagnetic systems exhibit  $1/r$ -nonlinearity, it is reasonable to expect that period doubling occurs in both. Analysis of experimental data from natural phenomena reveals that this process indeed takes place in both gravitational and electromagnetic systems, when the Planck time is used as the fundamental period. Additionally, gravitational systems possess three degrees of freedom, whereas electromagnetic systems exhibit four degrees of freedom—a distinction explored in prior studies. The objective of this article is to present an empirical model for baryon magnetic moments, incorporating one to three classical current loops derived via period doubling. The total magnetic moment is determined as the sum of these loops, with current defined as the ratio of the elementary charge to Planck time, considered the fundamental period, while the loop area is set by the Planck length. The elementary charge, essential for defining the fundamental magnetic moment, is obtained from the Planck charge through a doubling process in four degrees of freedom. The model's calculated values closely align with experimental data, reinforcing its validity. Furthermore, baryon strangeness appears to be strongly correlated with baryon magnetic moments, as derived from this approach, providing new insights into the structure of matter.

## Keywords

Baryon, Magnetic Moment, Period Doubling, Strangeness

## 1. Introduction

Mitchell J. Feigenbaum has shown that nonlinear dynamical systems exhibit a universal behavior known as the period doubling phenomenon [1]. In practical terms, this means that, over time, stable cycles can form within an apparently chaotic system, with each successive period maintaining a ratio of two starting from the fundamental period of the system.

Based on experimental data, period doubling occurs as a doubling of period space volume [2]. However, the total

volume formed by the periods cannot be directly measured. Instead, the measurement result provides a characteristic value for the volume, which corresponds to the geometric mean of the periods—in other words, the radius or diameter of a sphere representing the volume.

If there are 3 degrees of freedom, the characteristic measure corresponds to the cube root of the volume. If the periods are  $t_1$ ,  $t_2$ , and  $t_3$ , then the characteristic period  $t_c$  corresponding to

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the volume they form is given by  $t_c=(t_1t_2t_3)^{1/3}$ . For four degrees of freedom, the observed period is the fourth root of the product of the four individual periods.

If any physical quantity is related to a period, the doubling effect can also be observed in that quantity. In general, according to this model, the structure of elementary particles consists of two components: a mass component with three degrees of freedom and an electromagnetic component with four degrees of freedom [2].

The magnetic moment is an intrinsic property of the elementary particles, like rest energy and electric charge. It is traditionally associated with particle spin and a coefficient that characterizes the particle's internal structure. In this study the magnetic moment is described by a classical current loop, defined as the product of loop current and loop area.

This study aims to showcase the effectiveness of the classical current loop model, combined with the period doubling phenomenon, in modelling baryon magnetic moments. The unit magnetic moment is defined on the Planck scale, ensuring that the magnetic moment values derived from the doubling process remain fixed and cannot be adjusted. Lehto previously demonstrated, as noted in [2] and its cited references, that the period doubling process derives the electron's mass and elementary charge from Planck units, among other effects.

## 2. Methods

Period doubling phenomenon in nonlinear dynamical systems has been confirmed by mathematical analysis and various experiments. The period can be related to various physical quantities, including energy, length, elementary charge, and magnetic moment, which show doubling or halving behavior as a result.

The Planck scale magnetic moment, denoted as  $\mu_0=iA$ , is defined using a current loop with a diameter equal to half of the Planck length  $r=l_P/2=ct_0/2=2.026 \cdot 10^{-35}$  m. This definition corresponds to the ground state of a particle confined within a box. The loop current  $i$  is determined by the division of the elementary charge  $e$  by the Planck time  $t_0=(hG/c^5)^{0.5}=1.351 \cdot 10^{-43}$  s (considered as the unit period). The unit magnetic moment becomes

$$\mu_0 = \frac{e}{t_0} \pi r^2 = \frac{\pi}{16} e c^2 t_0 \quad (1)$$

showing that the period doubling behavior of  $t_0$  is directly related to the magnetic moment. The Planck time (period) is defined using  $h$  (not  $\hbar$ ), since energy is equal to  $hf=h/\text{period}$ . The numerical value of the unit magnetic moment is  $\mu_0=3.821 \cdot 10^{-46} \text{ Am}^2$ .

The observed number of period doublings – or magnetic moment doublings ( $n$ ) – for a single loop can be determined using

$$n = \frac{\log(\frac{\mu}{\mu_0})}{\log(2)} \quad (2)$$

from which

$$\mu = 2^n \cdot \mu_0 \quad (3)$$

where  $\mu$  is the measured magnetic moment and  $\mu_0$  the reference value. Equation (3) outlines the period doubling model of a particle's magnetic moment.

The theoretical values for the number of 3D doublings take the form  $n = N/3$ , derived from the cubic roots of  $2^N$ , where  $N$  represents the total sum of doublings across the three periods that form the period-space volume. For four-dimensional doubling the  $m$  values are of the form  $m=M/4$ , originating from fourth roots [2]. Both  $N$  and  $M$  are positive or negative integers. The elementary particles exhibit both three- and four-dimensional doublings, and the exponent of two in (3) is of the form  $n+m=N/3+M/4$  from the product of the 3D and 4D components. A dimension (D) represents a degree of freedom, like the four quantum numbers that define the energy levels of a hydrogen atom.

Examples: Electron-positron pair rest energy  $E_{ep}=1.022$  MeV is obtained from the Planck energy  $E_0=3.060 \cdot 10^{22}$  MeV (defined by  $h$ ) with  $n=-74.667$ . This results in  $E_{ep}=2^{-74.667}E_0$ , and  $N=3$   $n=224=32+64+128$  aligning with the superstability condition [1, 2], where the exponents are also powers of 2.

The ratio of the experimental rest energies of  $\Omega$  and proton is  $2^{0.833}=2^{0.333+0.500}=2^{1/3+2/4}=2^{1/3} 2^{2/4}$ , whereas  $\Lambda^0$  to proton is  $2^{0.250}=2^{0/3} 2^{1/4}$ .

The proton is the only stable hadron and possesses the largest magnetic moment of all hadrons. This analysis assumes that the smaller baryon magnetic moments  $\mu_B$  for the heavier baryons can be expressed as the proton magnetic moment  $\mu_p$  or its multiple augmented or diminished by an additional magnetic moment  $\mu_x$ :

$$\mu_x = n\mu_p - \mu_B \quad (4)$$

where  $n=1, 2, 4$ . When  $\mu_x$  is known,  $\mu_B$  can be calculated. Only  $\mu_x$  compatible with the period doubling process is accepted.

## 3. Magnetic Moments of Baryons

### 3.1. Proton

The PDG (Particle Data Group) value of proton's magnetic moment is  $\mu_p=1.4106 \cdot 10^{-26} \text{ Am}^2$  [3]. The corresponding observed number of doublings is

$$n = \frac{\log(1.4106 \cdot 10^{-26} / 3.8207 \cdot 10^{-46})}{\log(2)} = 65.001 \quad (5)$$

With the theoretical  $n=65.000$  the proton's magnetic mo-

ment becomes  $1.4096 \cdot 10^{-26} \text{ Am}^2$ , which differs from the PDG value by 0.07%. The model of the proton's magnetic moment consists of a single positive loop with 65 doublings from the unit Planck loop  $\mu_0$ . The total number of doublings in 3D is  $3 \cdot 65 = 195$ .

$$\mu_p = 2^{65} \cdot \mu_0 \quad (6)$$

The configuration of the 3D magnetic moment structure is not uniquely defined by the total observed number of doublings ( $N=195$  in this case). However, the most symmetric arrangement corresponds to  $N=195=65+65+65$ , where all three moments (forming the volume) have equal magnitudes.

### 3.2. Neutron

Although the neutron is electrically neutral, it possesses a negative magnetic moment  $9.662 \cdot 10^{-27} \text{ Am}^2$ . This phenomenon can be understood as having a negatively charged surface and a positively charged interior. The proton and neutron are approximately equivalent in size, thereby allowing the neutron's negative surface to be represented by a singular negative  $n=65$  loop. The magnetic moment  $\mu_n$  of the neutron constitutes the aggregate of the (negative) proton's magnetic moment  $\mu_p$  and the magnetic moment of the positive inside loop  $\mu_x$ :

$$\mu_x = \mu_p - \mu_n \quad (7)$$

where  $\mu_p$  and  $\mu_n$  values are PDG values. The numeric value of  $\mu_x$  is  $4.444 \cdot 10^{-27} \text{ Am}^2$ , yielding  $n=63.335$  from (2). The neutron's magnetic moment can be represented by a model that combines the magnetic moments of a negative 65-loop and a positive 63.333-loop. The model value of  $\mu_n$  is  $9.656 \cdot 10^{-27} \text{ Am}^2$ , which differs from the PDG value by 0.06%. Both loops illustrate the principles of the period doubling process in 3D.

### 3.3. Lambda

The lambda ( $\Lambda^0$ ) particle is neutral, like the neutron, but has a negative magnetic moment  $3.096 \cdot 10^{-27} \text{ Am}^2$ . Its internal magnetic moment can be calculated similarly to the neutron's magnetic moment, but with  $2\mu_p$ :

$$\mu_x = 2\mu_p - \mu_\Lambda \quad (8)$$

The value of  $\mu_x$  is  $2.512 \cdot 10^{-26} \text{ Am}^2$ , corresponding to  $n=65.833=66.333-0.50$  loop. The negative exponent (-0.5) associated with the 4D component signifies a reduction in the loop's magnetic moment by a factor of  $2^{0.5}$ , attributable to an increase in electromagnetic energy (higher energy, smaller loop).

The lambda particle's magnetic moment can be described by a model with two loops: a negative 66-loop and a positive 66.333-0.5 loop. The model value of  $\mu_\Lambda = 3.076 \cdot 10^{-27} \text{ Am}^2$ ,

which differs from the PDG value by 0.8%.

### 3.4. Sigma Plus

The magnetic moment of  $\Sigma^+$  is positive  $1.241 \cdot 10^{-26} \text{ Am}^2$ . The value of the required negative magnetic moment loop  $\mu_x$  is calculated using

$$\mu_x = 2\mu_p - \mu_\Sigma^+ \quad (9)$$

The value of  $\mu_x$  is  $1.580 \cdot 10^{-26} \text{ Am}^2$  corresponding to  $n=65.164=65.664-0.5$  loop. The EM part of  $\mu_x$  is again decreased by  $2^{-0.5}$ .

The  $\Sigma^+$  particle's magnetic moment can be described by a model with two loops: a positive 66-loop and a negative 65.667-0.5 loop. The model value of  $\mu_{\Sigma^+} = 1.237 \cdot 10^{-27} \text{ Am}^2$ , which differs from the PDG value by 0.5%.

### 3.5. Sigma Zero

The magnetic moment of  $\Sigma^0$  is positive  $8.132 \cdot 10^{-27} \text{ Am}^2$ . The value of the required negative magnetic moment  $\mu_x$  is calculated using

$$\mu_x = 2\mu_n - \mu_{\Sigma^0} \quad (10)$$

where  $\mu_n$  is neutron's magnetic moment. The value of  $\mu_x$  is  $1.119 \cdot 10^{-26} \text{ Am}^2$  corresponding to  $n=64.667$ -loop. The  $\Sigma^0$  particle's magnetic moment is modelled by three loops: a positive 66-loop, a negative 64.333-loop and a negative 64.667-loop. The first two components are the neutron loops. The model value of  $\mu_{\Sigma^0} = 8.125 \cdot 10^{-27} \text{ Am}^2$  differs from the PDG value by 0.2%.

### 3.6. Sigma Minus

The magnetic moment of  $\Sigma^-$  is negative  $5.859 \cdot 10^{-27} \text{ Am}^2$ . The value of the required positive magnetic moment loop  $\mu_x$  is calculated using

$$\mu_x = 2\mu_p - \mu_{\Sigma^-} \quad (11)$$

where  $\mu_p$  is proton's magnetic moment. The value of  $\mu_x$  is  $2.235 \cdot 10^{-26} \text{ Am}^2$  corresponding to  $n=65.665$ -loop. The sigma minus particle's magnetic moment is modelled by two loops: a negative 66-loop and a positive 65.667-loop. The model value of  $\mu_{\Sigma^-} = 5.817 \cdot 10^{-27} \text{ Am}^2$ , which differs from the PDG value by 0.7%.

### 3.7. Xi Zero

The magnetic moment of the neutral  $\Xi^0$  is negative  $6.313 \cdot 10^{-27} \text{ Am}^2$ . The value of the required positive magnetic moment loop  $\mu_x$  is calculated using

$$\mu_x = 4\mu_p - \mu_{\Xi^0} \quad (12)$$

where  $\mu_p$  is proton's magnetic moment. The value of  $\mu_x$  is  $5.011 \cdot 10^{-26} \text{ Am}^2$  corresponding to  $n=66.830=67.330-0.5$ -loop.

The  $\Xi^0$  particle's magnetic moment is modelled by two loops: a negative 67-loop and a positive 67.333-0.5 loop. The model value of  $\mu_{\Xi^0} = 6.153 \cdot 10^{-27} \text{ Am}^2$ , which differs from the PDG value by 2.5%.

### 3.8. Xi Minus

The magnetic moment of  $\Xi^-$  is negative  $3.287 \cdot 10^{-27} \text{ Am}^2$ . The value of the required positive magnetic moment loop  $\mu_x$  is calculated using

$$\mu_x = 4\mu_p - \mu_{\Xi^-} \quad (13)$$

where  $\mu_p$  is proton's magnetic moment. The value of  $\mu_x$  is  $5.314 \cdot 10^{-26} \text{ Am}^2$  corresponding to  $n=66.914=67.664-0.75$ -loop. The EM contribution to the loop's magnetic moment is reduced by a factor of  $2^{-0.75}$ .

The  $\Xi^-$  particle's magnetic moment is modelled by two loops: a negative 67-loop and a positive 67.667-0.75 loop. The model value of  $\mu_{\Xi^-}$  is  $3.165 \cdot 10^{-27} \text{ Am}^2$ , which differs from the PDG value by 3.8%.

### 3.9. Omega Minus

The magnetic moment of  $\Omega^-$  is negative  $2.02 \pm 0.05$  nuclear magnetons, equivalent to  $1.020 \cdot 10^{-26} \text{ Am}^2 \pm 2.5\%$ . The number of doublings is determined using the upper limit  $2.02+0.05=2.07$  nuclear magnetons ( $1.046 \cdot 10^{-26} \text{ Am}^2$ ) for  $\mu_{\Omega^-}$ . The required positive magnetic moment  $\mu_x$  is calculated using

$$\mu_x = 2\mu_p - \mu_{\Omega^-} \quad (14)$$

where  $\mu_p$  is proton's magnetic moment. The computed value of  $\mu_x$  is  $1.776 \cdot 10^{-26} \text{ Am}^2$  corresponding to  $n=65.333$  loop. The  $\Omega^-$  magnetic moment is modelled by two loops: a negative 66-loop and a positive 65.333-loop. Model value of the  $\Omega^-$  magnetic moment is  $\mu_{\Omega^-}=1.043 \cdot 10^{-26} \text{ Am}^2$  differing from the experimental value by 0.2%. Table 1 presents the collection of baryon magnetic moment loop models.

**Table 1.** Baryon magnetic moment models. Relation to strangeness  $S$ .

Baryon	Model loops ( $\mu_0$ )	EM component	PD-class	S
P	$+2^{65}$	0.000	65	0
N	$-2^{65.000}+2^{63.333}$	0.000	65	0
$\Lambda$	$-2^{66.000}+2^{66.333-0.5}$	-0.500	66	-1
$\Sigma^+$	$+2^{66.000}-2^{65.667-0.5}$	-0.500	66	-1
$\Sigma^0$	$+2^{66.000}-2^{64.333}-2^{64.667}$	0.000	66	-1
$\Sigma^-$	$-2^{66.000}+2^{65.667}$	0.000	66	-1
$\Xi^0$	$-2^{67.000}+2^{67.333-0.5}$	-0.500	67	-2
$\Xi^-$	$-2^{67.000}+2^{67.667-0.75}$	-0.750	67	-2
$\Omega^-$	$-2^{66.000}+2^{65.333}$	0.000	66	-3

Table 1 shows that certain baryons exhibit a negative exponent four-dimensional component in their doubling sequence, suggesting a decrease in magnetic moment as electromagnetic (EM) energy increases accordingly.

Baryon magnetic moments can be classified based on the magnetic moment of the primary loop (PD-class, the largest moment). Nucleons (P and N) fall under class 65, lambda ( $\Lambda^0$ ) and sigma ( $\Sigma$ ) baryons are grouped in class 66, and  $\Xi$  particles belong to class 67. This classification appears to align with the grouping based on particle strangeness ( $S$ ) in the Standard Model. The  $\Omega^-$  baryon is defined to have a strangeness of  $S=-3$ . In contrast, the period doubling model assigns it to

PD-class 66, corresponding to a strangeness of  $S=-1$ .

## 4. Origin of the 4D Component

Lehto [2] has demonstrated that the elementary charge originates from the Planck charge via the process of period doubling in four degrees of freedom. By comparing the Coulomb energy of the elementary charge to that of the Planck charge, it is found that  $m=9.75=39/4=(1+2+4+32)/4$  period doublings occur, which can be divided into  $2^0$ ,  $2^1$ ,  $2^2$  and  $2^5$  individual periods, representing superstable periods [1,

2]:

$$m = \frac{\log\left(\frac{e^2}{q_0^2}\right)}{\log(2)} = -9.75 = -\frac{1+2+4+32}{4} \quad (15)$$

The total number of doublings is  $M=4$   $m=39$ . The elementary charge squared becomes

$$e^2 = 2^{-9.75} \cdot q_0^2 \quad (16)$$

$$\text{where } q_0^2 = 4\pi\epsilon_0\hbar c \quad (17)$$

and  $q_0$  is the Planck charge. Charge squared represents the Coulomb energy of the charge, which is directly related to period ( $E=\hbar/\text{period}$ ). Equation (16) gives  $e = 1.60213 \cdot 10^{-19}$  As, with an inaccuracy of 30 ppm relative to the PDG value.

The Coulomb energy within the 4D EM component may vary from that associated with  $e^2$ . For instance (1+2+2+32) in (15) would increase the potential energy  $e^2$  by  $2^{0.5}$  as fewer period doublings result in higher energy. According to (16), this would imply an electric charge with a value that deviates from the elementary charge.

## 5. Proton Model Details

The most symmetric form of the complete elementary charge  $e$ -based representation of  $\mu_p$  is expressed as follows:

$$\mu_p = 2^{\frac{65+65+65}{3}} \cdot 2^{\frac{0+0+0+0}{4}} \cdot \mu_0 \quad (18)$$

The significance of the 4D doublings becomes clearer when a more fundamental, truly Planckian magnetic moment,  $\mu_{00}$  is defined as

$$\mu_{00} = 2^{\frac{1+2+4+32}{4}} \cdot \mu_0 \quad (19)$$

where  $\mu_{00}=4.437 \cdot 10^{-49} \text{ Am}^2$ . Equation (19) shows that  $\mu_0$  is derived from  $\mu_{00}$  through  $M=39=1+2+4+32$  doublings, resulting in  $M=0+0+0+0$  for the  $e$ -based calculations in (18). Equation (18) can be rewritten as

$$\mu_p = 2^{\frac{65+65+65}{3}} \cdot 2^{\frac{1+2+4+32}{4}} \cdot \mu_{00} \quad (20)$$

showing the 3D- and 4D-components and their doublings separately. The 4D magnetic moment of the proton loop (20) corresponds to the Coulomb energy of the elementary charge  $e$  in (16). If the total number ( $M$ ) of 4D doublings does not equal 39, the 4D Coulomb energy arises from a charge distinct from the elementary charge, as exemplified by the second loop of  $A^0$ , where  $M=37$  (Table 1).

TEXT DELETED HERE (energy considerations, not so relevant in this context)

## 6. Summary of Key Points

The baryon magnetic moment model presented here is based on two key principles:

1. Period doubling phenomenon in nonlinear dynamical systems and
2. Consistent use of Planck units as the fundamental basis.

The doubling process is exact by nature, and the fundamental magnetic moment is governed by natural constants only, thus ensuring rigidity of the model.

The doubling numbers indicate that each magnetic moment model loop of the baryons is composed of a product of two components – one with three degrees of freedom (the mass component) and the other with four (the EM component). The correlation between baryon strangeness and the number of primary loop doublings suggests an underlying physical basis for strangeness.

## 7. Discussion

This article presents an empirical classical current-loop model for describing baryon magnetic moments. It offers a significantly simpler approach than the quark-based model while delivering accurate values without adjustable parameters.

Physical interpretation of the PD-values suggests that the magnetic moments of baryons include electromagnetic energy, where the charge deviates from the elementary charge. If the mass of a particle is determined by assuming its charge to be  $e$ , then a different value for the mass is obtained if the charge deviates from  $e$ .

Another important aspect relates to the classification of magnetic moments based on the number of doublings. Table 1 shows that the strangeness ( $S$ ) of baryons would fully correspond to PD-class if the strangeness of omega-minus were  $S=-1$ . However, in the Standard Model,  $S=-1$  is not possible for the omega-minus baryon, as its definition requires  $S=-3$ , indicating that it consists of three strange quarks.

The uncertainty in the calculated magnetic moment values stems from the inherent uncertainties in the natural constants ( $\hbar$ ,  $c$ ,  $\epsilon_0$ ,  $G$ ) used to define the Planck units. Among these,  $G$  has the largest relative uncertainty, approximately  $10^{-5}$ . Consequently, the PD values can be regarded as being as accurate as possible within these constraints. The absence of experimental magnetic moment data hinders PD-based analysis of mesons and other baryons.

M. Feigenbaum [1] demonstrated that period doubling is a universal property of nonlinear dynamical systems leading to natural quantization. The PD approach extends beyond baryon magnetic moments, demonstrating broader applicability. Since both Coulomb and gravitational potentials follow a  $1/r$  dependence, their systems should exhibit similar period doubling characteristics. This is supported by reference [2].

Electron mass, magnetic moment, and electric charge derive their measured values through PD from the correspond-



ing Planck units, effectively reducing the number of independent natural constants by three. The 21 cm hydrogen line emerges from the Planck energy via PD, and the fine structure constant can be determined from the PD-derived elementary charge squared, calculated using the Planck charge as the fundamental charge.

On the gravitational side, PD calculations align with the orbital architecture of the Solar System as well as the quantized redshifts of galaxies, as explored in W. G. Tifft's research [4]. These results originate from the Planck units by PD.

The PD model relies exclusively on Planck units and the precise period doubling process. Notably, the Standard Model does not account for intrinsic electron properties or the discretization of gravitational systems, making it fundamentally incompatible with the PD approach

Numerous scientific studies investigate the magnetic properties of elementary particles, primarily using the quark model, relativity theory, and quantum mechanics. However, these frameworks do not incorporate the multidimensional period doubling phenomenon arising from Planck units. To the author's knowledge, no existing research specifically examines multidimensional period doubling in the context of particle magnetic moments.

Given this gap in existing literature, an extensive reference list would not contribute meaningfully to the study of this phenomenon and its implications.

## 8. Conclusions

Baryon magnetic moments can be modelled using classical current loops, incorporating both three-degree-of-freedom and four-degree-of-freedom components. The fundamental loop is expressed in Planck units, with the moments derived through the period doubling process. This process governs all current loops, yielding calculated values that align closely with observational data.

The fundamental period, known as Planck time, is determined by natural constants. If these constants remain universal, similar phenomena should be observable throughout the cosmos. In the Standard Model, each baryon is assigned a quantum number known as strangeness. Table 1 indicates that magnetic moments may provide a physical basis for understanding strangeness.

The PD model and the Standard Model are built on fundamentally different principles, and the Standard Model cannot be extended to gravitational systems. As a result, the

two models are inherently incompatible.

## Abbreviations

PDG      Particle Data Group

## Author Contributions

Ari Lehto is the sole author. The author read and approved the final manuscript.

## Data Availability

The data supporting the outcome of this research work has been reported in this manuscript.

Data has been obtained from the reference [3].

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## Conflicts of Interest

The author declares no conflicts of interest.

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## Research Field

**Ari Lehto:** Period doubling in nonlinear dynamical systems and applications.