Macrothink Institute™

International Journal of Linguistics
ISSN 1948-5425
2026, Vol. 18, No. 4

From Measurement to Discovery: Metonymic Reasoning and the Epistemological Structure of the Observability Gradient in Physics

Yuhong Liu

School of Foreign Languages and Cultures

Nanjing Normal University, Nanjing, China

E-mail: liuyuhong684@163.com

Received: July 14, 2026 Accepted: August 17, 2026 Published: August 26, 2026

doi:10.5296/ijl.v18i4.24003 URL: https://doi.org/10.5296/ijl.v18i4.24003

Abstract

Physics is renowned for the precision of its knowledge, yet its cognitive foundation—metonymy/abductive reasoning—is inherently fallible. This paper introduces the concept of the "observability gradient," which categorizes physical quantities into continuous levels from directly perceptible (L1) to unobservable (L4), revealing the directional patterns of physical reasoning: discovery reasoning moves upward along the gradient (from L1/L2 to L3/L4), while verification reasoning moves downward (from L3/L4 to L1/L2). Building on this framework, it distinguishes between two basic types: measurement metonymy and discovery metonymy. Through three case studies—Millikan's oil-drop experiment, multiple lines of evidence for dark matter, and the evolution of the neutrino—the paper demonstrates that physics employs three epistemological mechanisms—experimental closure, cross-validation, and the co-evolution of theory and instrument—to converge fallible metonymic reasoning into knowledge with practical certainty. The study shows that the certainty of physics arises not from transcending metonymy, but from systematically utilizing and constraining it.

Keywords: Metonymic reasoning, Observability gradient, Measurement, Scientific discovery, Epistemology of physics

1. Introduction

The basic task of physics is to reveal unobservable entities and laws from observable phenomena. From Galileo's pulse to the Higgs boson being inferred from the detector signal, this process of "knowing the unknown" runs through the history of physics. The mercury column height (L1) of thermometer "represents" the air temperature (L2) and the cloud chamber track "represents" the particle momentum — these inferences share the same cognitive structure: connecting one accessible phenomenon to another inaccessible object.

This cognitive structure — using one entity (source domain) to access another (target domain) within the same idealized cognitive mode (ICM) — is precisely what cognitive linguists term metonymy (Lakoff & Johnson, 1980; Kövecses & Radden, 1998). Unlike metaphor, which involves cross-domain mapping, metonymy operates within a single domain and follows an abductive logic: it moves from observable evidence to the best explanatory hypothesis (Panther & Thornburg, 2018). However, abductive conclusions are inherently fallible, multi-source, and context-dependent — the same mercury column height may indicate air temperature, thermometer calibration error, or instrumental bias. This generates a fundamental epistemological tension: physics is renowned for the precision of its knowledge, yet its cognitive foundation is logically defeasible. How, then, does physics transform such fallible metonymic reasoning into knowledge with practical certainty?

The core argument of this paper is that physics is not beyond the fallibility of metonymy, but develops a systematic epistemological restraint mechanism and converges it into knowledge with practical certainty. This process depends on experimental closure, cross-validation and co-evolution of theory and instrument. In order to explain this argument systematically, this paper introduces the conceptual framework of "observability gradient", divides physical quantities from "directly perceptible" to "unobservable" into continuous levels (L1 to L4), and reveals the directional law of physical reasoning: exploratory reasoning goes up along the gradient (from L1/L2 to L3/L4), while testable reasoning goes down (from L3/L4 to L1/L2).

The structure of the paper is as follows: Section 1 provides a critical literature review of metonymy theory, philosophy of science, and cognitive approaches to science, identifying key research gaps. Section 2 establishes a theoretical framework integrating abductive reasoning and observability gradient. Section 3 distinguishes two basic models: measurement metonymy and discovery metonymy. Section 4 reveals how physics converges fallible reasoning into reliable knowledge through three typical cases (Millikan oil drop experiment, multiple evidences of dark matter and neutrino evolution). Section 5 summarizes the theoretical contribution and puts forward the research prospect.

Through this analysis, we hope to show that the certainty of physics stems from the systematic use and restriction of cognitive mechanism. Metonymy is not only a linguistic phenomenon, but also a basic way of scientific thinking. The restriction of metonymy is the core of scientific methodology.

2. Literature Review

To situate the present inquiry within the broader intellectual landscape, this section critically reviews three intersecting scholarly traditions that bear directly on the cognitive foundations of physical reasoning.

The first tradition originates in cognitive linguistics, where metonymy has been established as a fundamental cognitive operation involving domain expansion and reduction within idealized cognitive models (ICMs) (Lakoff, 1987; Lakoff & Johnson, 1980; Kövecses & Radden, 1998; Ruiz de Mendoza, 2000, 2017). Panther and Thornburg (2018) made a pivotal contribution by explicitly linking metonymy to abductive reasoning, demonstrating that everyday metonymic comprehension shares the same hypothetical, fallible structure as Peircean abduction. Langacker (1993) further illuminated the reference-point nature of metonymic construal. Despite these advances, this body of work remains overwhelmingly focused on ordinary language and social cognition. Even when scientific examples are occasionally invoked, cognitive linguists have not systematically applied the metonymy framework to the epistemic core of physics—namely, how metonymic operations underpin both routine measurement practices and revolutionary theoretical discoveries. The critical question of how fallible metonymic reasoning is epistemologically constrained and gradually converges into reliable knowledge in scientific settings remains largely unaddressed.

The second tradition encompasses philosophy of science, which has long grappled with the logic of discovery and the theory-ladenness of observation. Peirce (1931–1958) identified abduction as the starting point of all scientific creativity, and Hanson (1958) famously argued that observation is inherently theory-laden, thereby challenging the logical positivist dichotomy between observational and theoretical terms (Carnap, 1950; Reichenbach, 1938). Kuhn (1962) historicized this issue by demonstrating that paradigm shifts involve radical reconfigurations of how phenomena are interpreted, while Feyerabend (1965, 1970) further problematized the idea of a neutral observational language. More recently, Hacking (1983) emphasized the role of experimental intervention in conferring reality upon theoretical entities. Yet, despite these contributions, the philosophy of science has not developed a fine-grained cognitive framework capable of analyzing the directionality of scientific inference—i.e., how reasoning systematically moves from observable effects to unobservable causes (discovery) and then back from theoretical postulates to observable predictions (verification). Observability has largely been treated as a binary or context-dependent property, rather than as a structured gradient that constrains inferential pathways in a principled manner.

The third tradition — cognitive approaches to science — has explored analogy, model-based reasoning, and conceptual change (Giere, 1999; Nersessian, 2008; Magnani, 2001). While these studies have illuminated the role of mental models and representational practices in scientific creativity, they have not accorded metonymy its due place as a distinct and irreducible mode of scientific inference. Metonymy is often conflated with metaphor or treated as a secondary phenomenon, thereby obscuring its unique epistemic function: namely, the indexical access to unobservable entities via observable surrogates within the same theoretical framework.

In response to these interconnected gaps, the present study offers three original contributions. First, it introduces the observability gradient (L1–L4) as a heuristic device that renders the cognitive directionality of physical reasoning explicit—distinguishing upward (discovery) from downward (verification) inference. Second, it articulates a dual typology of measurement metonymy and discovery metonymy, systematically differentiating routine epistemic practices from revolutionary conceptual leaps. Third, and most importantly, it identifies and theorizes three epistemological convergence mechanisms—experimental closure, cross-validation, and theory-instrument co-evolution—that explain how physics systematically transforms fallible metonymic reasoning into practically certain knowledge. By bridging cognitive linguistics, philosophy of science, and the cognitive history of physics, this study provides a unified metonymic account that fills a significant interdisciplinary lacuna and offers a novel perspective on the nature of scientific progress and the material culture of experimentation.

3. Theoretical Framework: Abductive Reasoning and Observability Gradient

The generation of physical knowledge begins with a cognitive cycle: inferring unobservable entities and mechanisms from observable phenomena; These entities are integrated into theories to guide new observations and experiments. The starting point of this cycle-the leap from phenomenon to theory-is logically a unique reasoning model: abductive reasoning. This section aims to integrate the retrospective logic and the observability gradient, and lay the foundation for the subsequent analysis.

3.1 Abductive Reasoning: The Logic of Scientific Discovery

The American pragmatic philosopher C. S. Peirce systematically expounded abductive reasoning, and defined it as "the process of forming an explanatory hypothesis". The logical form is as follows (Peirce, 1931-1958, CP 5.189):

> Observe the amazing fact C;
>
> If A is true, then C can be explained naturally;
>
> Therefore, it is reasonable to think that A may be true.

Different from the inevitability of deduction and the probability of induction, retroactivity is hypothetical and fallible-its conclusion is the best explanation of being "guessed". Pierce emphasized that retroactivity is the starting point of all scientific discoveries.

Hanson (1958) inherited and developed this idea in his *Pattern of Discovery*, and named the logic of scientific discovery "retroduction", that is, abductive reasoning from phenomena to theory. Taking Kepler's discovery of the orbit of Mars as an example, he demonstrated that the discovery was logical.

The important contribution of Panther and Thornburg (2018) is to reveal that metonymy understanding in daily language also follows the retrospective logic. For example, to understand the sentence "The piano is in a bad mood", the listener should assume that "the piano" refers to "the piano player" to resolve semantic conflicts. This process completely conforms to the three-stage structure of Pierce's abductive reasoning. From this, they argue that metonymy is essentially a model of abductive reasoning.

This insight is of far-reaching significance for understanding physics reasoning. It means that when physicists infer the existence of particles from cloud chamber tracks or dark matter from galaxy rotation curves, their cognitive operations have the same retrospective structure as their daily metonymic understanding. The only difference is that the source domain and target domain of daily metonymy are at the linguistic level, while the source domain of physical metonymy is an observable phenomenon and the target domain is a theoretical entity.

3.2 Observability Gradient: From Binary Distinction to Continuous Hierarchy

If abductive reasoning or metonymy is the cognitive mechanism of understanding theory from phenomenon, how to draw the boundary between "phenomenon" and "theoretical entity"?

Logical positivism has tried to draw a clear line between "observational terms" and "theoretical terms" (Carnap, 1950), but "directly observable" itself is a vague concept. The proposition of "Observation Penetration Theory" proposed in Hanson (1958) shakes this dichotomy, but does not ask whether there are differences in the theoretical load of different observations. This is exactly what the concept of "observability gradient" proposed in this paper wants to accomplish.

According to the density preset by theory and the complexity of instrument medium, we divide physical quantities into four observability levels:

Levels and ranks	Category	Characteristic	Typical case	Epistemological position
L1	High observable quantity	It can be directly perceived by the senses, without instrument intermediary.	Length, angle, time interval	The directness of measurement is the highest and the theoretical presupposition is the least, but it is not "zero theoretical load"
L2	Moderately observable quantity	Simple instrument transformation is needed, but the transformation relationship is highly stable.	Temperature (mercury height), current (pointer deflection)	The instrument itself has become a "frozen metonymy", and the metonymy chain is short and stable.
L3	Low observable quantity	Complex theoretical reasoning and multi-step metonymy chain are needed.	Entropy (calculated by heat and temperature), electric field (sensed by probing charge)	Metonymy chain is long and theoretical load is heavy, which depends on the reliability of the whole theoretical system.
L4	Unmeasurable quantity	Theoretical entity can be inferred only by indirect evidence.	Dark matter, quarks, inside black holes	It is the "far-end target domain" of metonymy access, which relies entirely on abductive reasoning.

The core insight of this gradient is that observability is a matter of degree, not a binary attribute. L1 and L4 form two ends of the gradient, and there is a continuous transition between them. More importantly, this gradient boundary is dynamic: with the development of detection technology, the former L4 may be transformed into L3 (such as neutrinos), and L3 may gain a higher cognitive status (such as the atom from hypothesis to manipulated object).

3.3 Directionality of Gradient and Basic Form of Physical Reasoning

The introduction of observability gradient provides a conceptual tool for understanding the directionality of physical reasoning. There are two opposite reasoning paths in physical cognition:

Ascending reasoning (upward along the gradient): Starting from the high observable quantity (L1/L2), the theoretical entity with low observable or unobservable quantity (L3/L4) is accessed through abductive reasoning. This is the basic form of metonymy. For example, from the continuous distribution of beta decay energy spectrum (L2) to neutrinos (L4).

Descending reasoning (downward along the gradient): Starting from the theoretical entity (L3/L4), the observable effect (L1/L2) is derived for testing the theory or designing the experiment. This is the basic form of measurement metonymy and experimental prediction. For example, deflection of light (L2) is deduced from general relativity (L3/L4).

Ascending and descending reasoning together constitute the cognitive cycle of physics: ascending can generate a hypothesis while descending can test the hypothesis; The test results have become a new observation phenomenon, triggering a new round of upward reasoning. In terms of Ruiz de Mendoza (2000, 2017), this is a cognitive operation of domain expansion (from part to whole) and domain reduction (from whole to part). Observability gradient provides a unified explanation framework for these two operations.

3.4 Enlightenment of This Framework for Subsequent Analysis

The above theoretical framework laid a conceptual foundation for the subsequent analysis:

Firstly, the observability gradient enables us to accurately locate the "starting point" and "end point" of metonymy operation.

Secondly, the inexorable characteristics of abductive reasoning explain why the same observation phenomenon may support multiple metonymic interpretations-this is the source of the "core tension" in Section 4.

Thirdly, the dynamic nature of the observability gradient provides a framework for understanding the co-evolution of theory and instruments.

4. Dual Metonymy of Physical Cognition: Measurement and Discovery

Under the framework of observability gradient, the cognitive practice of physics can be understood as a series of structured metonymy operations, showing two basic ideal types: measurement metonymy and discovery metonymy.

4.1 Idealized Cognitive Model of Physics

Any metonymy operation takes place in a specific knowledge structure, which Lakoff(1987) called "Idealized Cognitive Model" (ICM). Every branch of physics can be regarded as a complex ICM, which is composed of entities distributed at different levels of the observability gradient and their relationships. This leads to a core proposition: the laws of physics are the systematic expression of metonymy. The law describes the stable relationship between a group of variables, so that we can infer the values of some variables (source domain) from the values of others (target domain).

4.2 Measurement Metonymy: Domain Expansion and Domain Reduction

Measurement is the most basic metonymy practice in physics: inferring physical quantity (target domain) from instrument reading (source domain). According to the cognitive direction, it can be divided into two types:

4.2.1 Domain Extended Measurement

Expand from the part (observable quantity) to the whole (physical state), and then deduce the target quantity. The basic form is: observable quantity (L1/L2)→ physical state as a whole (ICM)→ target quantity (L2/L3).

Case 1: Measure voltage with ammeter (known resistance R)

Source domain: current I(L2)

Intermediate domain: overall state of the circuit (ICM: $V = IR$)

Target domain: voltage V(L2)

Case 2: Measuring Gravity Acceleration G with a Simple Pendulum

Source domain: period t, pendulum length L(L1/L2)

Intermediate domain: simple pendulum system state (ICM: $T = 2\pi\sqrt{(L/g)}$)

Target domain: acceleration of gravity g(L3)

4.2.2 Domain Education Measurement

Focus from the whole (known physical state) to the part (specific sub-domain). The basic form is: known quantity (L2/L3)→ physical state as a whole (ICM)→ target observable quantity (L1/L2).

Case 3: Calibrating Thermometers

Source domain: standard temperature T_std (L2)

Intermediate domain: thermodynamic state of liquid (ICM: $h \propto T$)

Target domain: liquid column height h(L1)

Case 4: Calibrating the Spring Scale

Source domain: standard mass m_std (L2)

Intermediate domain: mechanical state of spring system (ICM: $f = kx = mg$)

Target domain: scale position x(L1)

4.2.3 Orientation and Cognitive Perspective

Comparing the above cases, it can be seen that the same physical ICM can support metonymy operations in opposite directions. The choice of measurement direction depends on the cognitive task-the domain of daily measurement is expanded and the domain of instrument calibration is reduced. The direction of metonymy is not the intrinsic property of physical relations, but a function of cognitive perspective (Ruiz de Mendoza, 2017).

4.3 Discovery Metonymy: Metonymy as an Abductive Reasoning

If measurement metonymy is the "daily practice" of physics, then finding metonymy is its "creative core". The process of scientific discovery is essentially abductive reasoning-from observing phenomena (source domain) to theoretical entities or mechanisms (target domain) that can explain these phenomena.

4.3.1 Discover the Basic Forms of Metonymy

The basic form of discovery metonymy can be expressed as:

Observation of phenomena (L1/L2)→ abductive reasoning → theoretical entity/mechanism (L3/L4)

This process accords with Hanson's (1958) description of the logic of scientific discovery. Hansen named the pattern of scientific discovery "retroduction", which was divided into three steps: first, a surprising phenomenon P was observed; Second, if H is assumed to be true, then P can be explained. Third, there is reason to think that H may be true. This is the metonymic reasoning path from observation to theory.

Case 5: the discovery of neutrinos

In 1930, Pauli faced the dilemma of energy "non-conservation" in β decay:

Observation phenomenon (source domain): In β decay, the emitted electron energy is distributed continuously, which seems to violate the conservation of energy (L2).

Abductive reasoning: If there is an invisible particle that takes away some energy, the conservation of energy still holds.

Theoretical entity (target domain): neutrino (unobservable at that time, L4)

Metonymy operation: energy "loss" (L2)→ neutrino (L4)

The extraordinary feature of this metonymy is that it "explains" the observed phenomenon with an unobserved entity. Neutrinos were not directly detected until 1956, during which the physics community "accessed" their existence through abductive reasoning. From the perspective of observability gradient, this is a leap from L2 to L4-the reasoning type with the longest metonymy chain, the heaviest theoretical load and the highest error.

Case 6: The proposal of dark matter

In 1930s, Zwicky observed the cluster of late constellation galaxies:

Observation phenomenon (source domain): The galaxies in the cluster are moving too fast, and the cluster (L2) cannot be bound by the gravitational force generated by the visible mass alone.

Abductive reasoning: If there is some invisible mass that provides extra gravity, the cluster of galaxies can remain stable.

Theoretical Entity (Target Domain): Dark Matter (L4)

Metonymy operation: velocity dispersion anomaly (L2)→ dark matter (L4)

Similar to the neutrino case, the proposal of dark matter is also a leap from L2 to L4. The difference is that dark matter has not been directly detected so far, and its existence still depends entirely on the convergence of multiple metonymic paths-this is the cross-validation mechanism to be discussed in Section 4.2.

4.3.2 Discovery Metonymy in Conventional Science and Scientific Revolution

Kuhn (1962) proposed the concept of "paradigm", which provides an important dimension for understanding discovery metonymy. In Kuhn's view, the development of science is an alternating process of "conventional science" and "scientific revolution". It is found that there are significant differences in the operation modes of metonymy in these two periods.

In the period of conventional science, scientific communities share the same paradigm (that is, the same set of ICM). Metonymy of discovery at this time has the following characteristics:

ICM stability: the relationship between the source domain and the target domain is defined by the established paradigm, and metonymy is carried out within the framework of the paradigm.

The target domain can be expected: discovery is often "filling the gap"-the theoretically predicted entity is found and confirmed.

Case 7: Discovery of Neptune

Observation phenomenon: Uranus orbit anomaly (L2)

Abductive reasoning: According to ICM of Newtonian mechanics, there is an unknown planetary disturbance orbit.

Theoretical Entity: Unknown Planet (L4)

Experimental confirmation: the existence of planets is confirmed by telescope observation (L2→L1).

Metonymy operation: orbital anomaly (L2)→ [Newtonian mechanics ICM] → Neptune (L4)→ observation confirmation (L1).

This metonymy is carried out within Newton's paradigm, and the target domain (Neptune) is an entity allowed by the theoretical framework. Seen from the observability gradient, it has gone through a complete cycle: from L2 to L4, and then L4 is transformed into L1/L2 through observation, which is a typical mode of interaction between theory and observation.

In the period of scientific revolution, the old paradigm encountered "abnormality", i.e. the accumulation of observation phenomena that the existing ICM could not explain, which eventually led to paradigm shift. Metonymy of discovery at this time has the following characteristics:

ICM competition: the same source domain may be connected to the target domain under different paradigms, forming a competition for metonymic interpretation.

Subversion of target domain: the new target domain may challenge the core commitment of the old paradigm.

Case 8: The proposal of Heliocentrism

Observing the source domain: celestial motion phenomena such as planet retrograde (L2)

Metonymy in Ptolemaic Framework: Adjustment of Current-Equal Wheel Model (L3, in the previous ICM)

Metonymy in the framework of Copernicus: Heliocentrism (L4, a new entity)+Earth movement (L4, a new mechanism).

Metonymous competition: the same phenomenon (Mars retrograde) is connected to completely different target domains in two competitive ICMs.

Case 9: The Birth of Quantum Mechanics

Observe the source domain: black body radiation spectrum, photoelectric effect, atomic spectrum and other abnormal phenomena (L2)

Metonymy in the classical framework: trying to explain the phenomenon by adjusting the classical model (L3, ultimately failed)

Metonymy in Quantum Framework: Quantization, Wave Function and Uncertainty Relation (L4, a brand-new theoretical entity)

Metonymy competition: the competition between various revision attempts under the classical framework and thorough conceptual reconstruction under the new framework eventually leads to paradigm shift.

Kuhn pointed out that there is "incommensurability" between the new paradigm and the old paradigm. They give completely different explanations for the same phenomenon. From the perspective of metonymy theory, this is because the same source domain is connected to different target domains in different ICMs. Which metonymy interpretation physicists choose depends on which ICM can provide a more coherent and fruitful interpretation framework.

4.3.3 Discover the Typological Significance of Metonymy

Distinguishing between conventional science and discovery metonymy in revolutionary period has the following contributions to understanding physical epistemology:

First, it reveals the binding relationship between metonymic interpretation and ICM. The same observation phenomenon is connected to completely different target domains in different ICMs, which confirms Hansen's insight of "observation penetration theory" and provides a cognitive linguistic explanation for Kuhn's "incommensurability".

Secondly, it illustrates the dynamic nature of metonymy competition. In the period of conventional science, metonymy interpretation is relatively stable; In the revolutionary period, multiple metonymic interpretations coexist until the new paradigm is established and new stability is formed. The evolution of physics knowledge can be partly understood as the history of metonymy competition and convergence.

Thirdly, it provides a new perspective for understanding the cognitive essence of scientific revolution. Scientific revolution is not only the replacement of theoretical content, but also the fundamental change of metonymy operation mode, i.e. the stable metonymy path in the previous ICM is blocked, and the metonymy path in the new ICM is established.

4.4 The Relationship and Interaction Between the Two Types of Metonymy

Measurement metonymy and discovery metonymy are in continuous interaction: measurement metonymy provides observation basis for discovery metonymy; It is found that the product of metonymy can be transformed into a tool to measure metonymy; Two types of metonymy together constitute the cycle of physical cognition.

5. From Fallible Reasoning to Reliable Knowledge: Three Epistemological Convergence Mechanisms

The foregoing demonstrates that physics cognition essentially depends on error-prone metonymy/abductive reasoning. The core argument of this section is that physics has developed a systematic epistemological restraint mechanism, which gradually converges the wrong metonymic reasoning into knowledge with practical certainty. We will reveal three core mechanisms through three typical cases: experimental closure, cross-validation and theory-instrument co-evolution.

5.1 The Inevitable Source of Metonymy

The inevitability of metonymy comes from three aspects:

Multi-source: the same source domain can activate multiple potential target domains (for example, thermometer readings may point to air temperature, thermometer temperature, calibration error, etc.).

Context dependence: the same source domain is connected to different target domains in different theoretical frameworks (for example, the sun rises and sets in the west, the sun rotates around the earth in the geocentric theory, and the earth rotates in the Heliocentrism).

Error: Metonymy conclusion may be falsified by subsequent observation or theory (such as Mars "canal" and phlogiston theory).

5.2 Digestion Mechanism 1: Experimental Closure

The essence of experimental closure is to gradually "close" the competitive metonymy path through systematic operation, so that a certain path becomes the most obvious and even the only cognitive choice.

Case 10: Millikan measures electron charge.

In Millikan's oil drop experiment, the "oil drop motion" (L1/L2) faces multiple competitive interpretations: electron charge (A), air viscosity coefficient (B), electric field calibration error (C), oil drop evaporation/deformation (D), Brownian motion (E) and observer's subjective error (F). Millikan gradually closed the competition path through a series of operations:

Isolation operation (excluding B): measure the viscosity coefficient at the same time in the same experiment and "absorb" it into the measurement process.

Variable control (excluding D and E): select oil droplets that are not easy to evaporate, and observe larger oil droplets to reduce the influence of Brownian motion.

Consistency test (excluding C): Repeat the experiment in a wide voltage range, and the obtained E value is highly consistent.

Repeatability procedure (excluding F): publish complete data records, and then independently reproduce the results in multiple laboratories.

The final product of the experiment closure is that the specific source-target domain mapping is "solidified" and becomes a stable starting point for subsequent cognitive operations. After Millikan's experiment, "oil droplet movement → electron charge" has become a recognized cognitive reference point in physics.

5.3 Resolution Mechanism 2: Cross-validation

Cross-validation deals with the convergence relationship between multiple metonymic paths. Its essence is that when multiple independent metonymic paths point to the same target domain, the error of a single path is offset each other, and the confirmation degree of overall reasoning is significantly improved.

Case 11: Multiple Evidence of Dark Matter

Dark matter has never been directly observed, and its "existence" depends entirely on the convergence of multiple metonymy paths;

Path A (galaxy rotation curve): abnormal speed of peripheral stars (L2)→ dark matter halo (L4)

Path B (gravitational lens): background galaxy image distortion (L2)→ dark matter enhanced gravitational field (L4)

Path C (cosmic microwave background radiation): CMB temperature fluctuation map (L2)→ a lot of non-baryon dark matter (L4)

Path D (large-scale structure formation): galaxy distribution data (L2)→ dark matter accelerated structure formation (L4)

Path E (bullet cluster): X-ray and gravitational lens image (L2)→ separation of dark matter from ordinary matter (L4)

These five paths are independent of each other in observation means, theoretical framework and potential system errors. If dark matter does not exist, why do five independent metonymic paths, each of which relying on different presuppositions and error sources, all point to the same target domain? This convergence of multiple independences makes the probability of "coincidence" extremely low, which constitutes a strong confirmation of the existence of dark matter.

5.4 Digestion Mechanism 3: Co-evolution of Theory and Instrument

Theory-instrument co-evolution is a deeper diachronic convergence mechanism: the products of metonymy can be "materialized" into new cognitive tools, which in turn become access to deeper unknown source domains, forming a recursive cycle.

Case 12: Neutrino —— From Theoretical Entity to Cognitive Tool

The history of neutrinos perfectly shows this recursive cycle:

The first stage: the existence of pure metonymy (1930): Pauli deduced neutrinos (L4) from the continuous distribution of β decay energy spectrum (L2). At this time, neutrinos are purely metonymic products of "explaining the conservation of energy"

The second stage: Physicochemical Instrument (1956): Kowen and Reines designed the experiment, and used the (anti-) neutrino produced by the reactor to bombard protons, and observed the coincidence signal (L2). At this time, neutrinos are transformed from "only as the target domain" to "also as the source domain" and from "for explanation" to "for intervention" (Hacking, 1983).

The third stage: From the target domain to the new source domain (after 1962): After neutrinos are detected, they immediately become a tool to explore the new unknown, which is used to discover μ neutrinos and detect solar neutrino oscillations. Neutrino, once the target domain of metonymy, is now the source domain of metonymy, which is used to access the deeper unknown.

This recursive cycle can be formalized as: phenomenon (L2)→ retrospection → entity (L4)→ solidification → entity as a tool (source domain, L3/L4)→ new phenomenon (L2)→ retrospection → deeper theory (L4) ... Each circle promotes the cognitive system to a new level.

5.5 The Relationship and Complementarity of the Three Mechanisms

Experimental closure, cross-validation and co-evolution constitute the "epistemological immune system" of physics;

Experimental closure (synchronicity) guarantees the reliability of a single path.

Cross-validation (synchronicity) provides confirmation for the convergence of multiple paths.

Co-evolution (diachronic) provides a mechanism for the accumulation and deepening of cognitive achievements.

The certainty of physics does not come from the transcendence of metonymy, but from the systematic constraint of metonymy.

6. Theoretical Contribution

Based on the conceptual metonymy theory of cognitive linguistics, this paper demonstrates that the cognitive basis of physics is metonymy-connecting observable phenomena (source domain) to unobservable entities (target domain). By introducing "observability gradient", distinguishing measurement metonymy from discovery metonymy, and revealing three convergence mechanisms, this paper systematically explains how error-prone metonymy reasoning can be transformed into reliable knowledge.

6.1 Core Proposition System

ICM essence of physics: all branches of physics are ICM, and physical laws describe the stable relationship among their internal variables. Physical reasoning is essentially metonymic operation in ICM.

Observability gradient: there is a continuous hierarchy of physical quantities from L1 to L4, and the discovery reasoning goes up and the test reasoning goes down along the gradient.

Dual types of metonymy: measuring metonymy (domain expansion/domain reduction) is a daily practice; Discovery metonymy (abductive reasoning) is the core of creativity, which operates in different ways in conventional science and revolutionary period.

The source of non-inevitability: from multi-source, contextual dependence and fallibility.

Three convergence mechanisms: experimental closure, cross-validation and theory-instrument co-evolution, together constitute the epistemological constraint system of physics.

6.2 Contribution to Metonymy Theory in Cognitive Linguistics

Expanding into the field of scientific thinking: it is proved that metonymy is not only a linguistic phenomenon, but also a basic way of scientific thinking.

The introduction of "observability gradient" provides a systematic explanation framework for the directionality (domain expansion/domain reduction) of metonymy.

This paper reveals the binding relationship between metonymy interpretation and ICM, which provides a cognitive linguistic explanation for the "observation penetration theory".

Dealing with the problem of inevitable resolution: through three convergence mechanisms, the socialization, materialization and historization dimensions of metonymic reasoning are revealed.

This paper puts forward the "upgrading" path of metonymy target domain, which expands the research on the dynamic and historical nature of metonymy.

6.3 Contribution to Physical Epistemology

Provide a new perspective for "measurement problem": reveal the essence of measurement as "cognitive operation of theoretical load"

It provides a new argument for the "reality of theoretical entities": the "instrumentalization" process of entities is a strong evidence of its reality.

To provide a cognitive explanation for "the mechanism of scientific progress": scientific progress is embodied in the transition of metonymy operation level.

6.4 Research Limitations and Prospects

There are limitations in case representativeness, social dimension, quantitative analysis and interaction with other cognitive mechanisms in this study, which points out the direction for further research.

7. Conclusion

The cognitive basis of physics is metonymy. Panther and Thornburg (2018) revealed that metonymy is not inevitable, but the source of its vitality. It is precisely because metonymy is fallible and multi-sourced that it can be confirmed in the convergence of multiple pieces of evidence, driving the recursive leap of cognitive levels.The certainty of physics comes from the systematic use and restriction of metonymy. In this sense, the title of this paper "Metonymy on which physics depends" is not only a tribute to the classic works of Lakoff and Johnson (1980), but also an exploratory revelation of the deep structure of physical epistemology.

References

Carnap, R. (1950). *Logical foundations of probability.* University of Chicago Press.

Giere, R. N. (1999). *Science without laws.* University of Chicago Press.

Hacking, I. (1983). *Representing and intervening*. Cambridge University Press. https://doi.org/10.1017/CBO9780511814563

Hanson, N. R. (1958). *Patterns of discovery.* Cambridge University Press.

Kövecses, Z., & Radden, G. (1998). Metonymy: Developing a cognitive linguistic view. *Cognitive Linguistics, 9*(1), 37-78. https://doi.org/10.1515/cogl.1998.9.1.37

Kuhn, T. S. (1962). *The structure of scientific revolutions*. University of Chicago Press.

Lakoff, G. (1987). *Women, fire, and dangerous things.* University of Chicago Press. https://doi.org/10.7208/chicago/9780226471013.001.0001

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by.* University of Chicago Press.

Langacker, R. W. (1993). Reference-point constructions. *Cognitive Linguistics, 4*(1), 1-38. https://doi.org/10.1515/cogl.1993.4.1.1

Nersessian, N. J. (2008). *Creating scientific concepts.* MIT Press. https://doi.org/10.7551/mitpress/7967.001.0001

Panther, K.-U., & Thornburg, L. L. (2018). Metonymy and the dynamics of conceptual operations. In *Cognitive Linguistics: Key Topics* (pp. 77-104). De Gruyter Mouton.

Peirce, C. S. (1931-1958). *Collected papers of Charles Sanders Peirce* (Vols. 1-8). Harvard University Press.

Reichenbach, H. (1938). *Experience and prediction*. University of Chicago Press.

Ruiz de Mendoza Ibáñez, F. J. (2000). The role of mappings and domains in understanding metonymy. In A. Barcelona (Ed.), *Metaphor and metonymy at the crossroads* (pp. 109-132). Mouton de Gruyter. https://doi.org/10.1515/9783110894677.109

Ruiz de Mendoza Ibáñez, F. J. (2011). Metonymy and cognitive operations. In R. Benczes, A. Barcelona, & F. J. Ruiz de Mendoza Ibáñez (Eds.), *Defining metonymy in cognitive linguistics* (pp. 103-124). John Benjamins. https://doi.org/10.1075/hcp.28.06rui

Ruiz de Mendoza Ibáñez, F. J. (2017). Cognitive modeling and irony. In A. Athanasiadou & H. L. Colston (Eds.), *Irony in language use and communication* (pp. 101-124). John Benjamins. https://doi.org/10.1075/ftl.1.09dem