"Scientific Revolutions" (Catania, 3 June 2011)

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These notes roughly follow my online article, "Scientific Revolutions," in the Stanford Encyclopedia of Philosophy. Consult that article for references. The best detailed discussion of Kuhn's views is still Paul Hoyningen-Huene's (1993).

1. Introduction: Interest & Importance of the Topic

Revolutions are big, sudden changes that are dramatic & fascinating.
They signal deep historical change. They make historiography interesting, dynamic.
In politics we probably think first of the French Revolution, then the Russian Bolshevik Revolution, the English Revolution of the 1640s & the Glorious Revolution of 1688, the American Revolution of 1776-79, the possible revolutions in progress today around the Mediterranean.
In science we think of the relativity and quantum mechanics revolutions in physics, the revolution in chemistry led by Lavoisier, Darwin in biology, and the Scientific Revolution from Copernicus to Newton, which supposedly separated modernity from feudalism and the Middle Ages.
Most recently: the plate tectonic revolution in geology (1960s).
Revolutions are watershed events that give a future reference point: "before & after" the revolution.

Some questions:

What is a revolution, more exactly?
How can we explain why & how a revolution occurred?
Are revolutions necessary? Historically contingent? Both necessary and contingent?
Do revolutions all have a pattern or a dynamical mechanism in common?
Does a time-series of revolutions reveal an underlying pattern of historical development?
What does the existence of revolutions tell us about the nature of politics or science?
In particular, what implications does the existence of scientific revolutions have for . . .
scientific realism: Are we approaching the Truth about objective reality?

scientific progress?
the overall pattern of scientific development?
the nature of scientific practice?

Have there really been any genuine scientific revolutions?
What is a scientific revolution according to Thomas Kuhn in *The Structure of Scientific Revolutions*?
Have there been any specifically *Kuhnian* revolutions?

2. What is a revolution?

Historical path: Copernicus, *De Revolutionibus* → political rev → then back into science itself.
Etymology: "revolve" – a return to a previous state: the wheel of fortune, Copernicus.
Modern meaning: just the opposite – a complete rejection of the past; a new direction.
Revolution ≠ mere **revolt** (achievement vs. attempt) or **rebellion** or **coup d'état** or **reformation**.
Revolution is deeper than mere change of government leadership within the same system.
So a successful **revolt** against current leaders (Locke, social contract) is not necessarily a revolution!
Reformers (e.g., Luther) aim to return to original roots; revolutionaries destroy & replace those roots.
Peter Schouls (*Routledge Encyclopedia of Philosophy*): revolutions . . .

a. introduce radically novel changes: extremely creative of new forms or structures
b. are illegal
c. have greater freedom of some kind as a goal (Hegel-Marx influence)
(Is this true? What about religious fundamentalist revolutions?)

What about time scale? Must revolutions be event-like, sudden? We commonly distinguish revolution from evolution!
What about trajectories? Aren't revolutions so chaotic by nature that their outcome is unpredictable?

3. What is a *scientific* revolution?

Little talk of scientific revolution until Herbert Butterfield, *The Origins of Modern Science* (1949) & especially Thomas Kuhn, *The Structure of Scientific Revolutions* (1962, 1970 with "Postscript").
Butterfield, A.R. Hall et al. spoke mainly of revolutions that found modern sciences, not revolutions within a well-founded, mature science. Kuhn greatly extended the application of 'revolution'.
Logical positivism / logical empiricism (Schlick, Neurath, Carnap, Reichenbach, Hempel) & even Popper were non-historical & had no place for revolution.
Karl Popper trivialized it with his slogan, in response to Kuhn: science as "revolution in perpetuity."

I. Bernard Cohen's 4 criteria in *The Scientific Revolution: A Historiographical Essay* (1994):

a. The original scientists must perceive themselves as revolutionaries.
b. Relevant contemporaries must agree with them.
c. Later historians & philosophers must also agree.
d. So must later scientists working in that general field.

This is too strong? Cf. Copernicus, 1543. Mendel 1865. Planck in 1900. *Should* these fail?
Is 'revolution' a forward-looking vs. retrospective term (like 'biological speciation')?
Science is nonlinear: Major changes of direction may begin with "normal science."

Even when scientists are aware that they are engaged in "revolutionary" work, they cannot know in advance where exactly it will lead. Genuine revolutions of all kinds have unpredictable trajectories.

Hegel: "The owl of Minerva takes flight at dusk."

Does "the Scientific Revolution" (roughly, Copernicus to Newton) fail Cohen's test?

a. Current debate about its revolutionary status: e.g., Shapin, *The Scientific Revolution*: "There was no such thing as the scientific revolution, and this book is about it."

b. 160 years is hardly event-like. But relative to a larger time-scale: feudal → modern?

c. It was part of a much wider social movement, not a revolt within a single discipline.

4. Thomas Kuhn's model of Scientific Revolutions

Kuhn 1957: *The Copernican Revolution*: triple meaning for Kuhn (a kind of pun on 'revolution'?):

a. Copernicus' work itself involved revolution: *De Revolutionibus Orbium Coelestium*, 1543.

b. It was a revolution in the scientific sense, and . . .

c. a model for Kuhn's future work: revolution as cognitive / conceptual reorganization (Why was this revolution so delayed? No intrinsically new theory or data. See Howard Margolis, *Paradigms and Barriers: How Habits of Mind Govern Scientific Beliefs.*)

In that book Kuhn required that a revolution have broad impact on the general public worldview, presaging chapter X of *Structure*: "Revolutions as Changes in World View."

The Structure of Scientific Revolutions recognizes 2 kinds of revolutions:

a. revolutions that found a science or even a period. Model: the Scientific Revolution & Lavoisier.

b. revolutions *within* an ongoing, mature science, e.g., quantum theory. This is the shocking kind of revolution to which Kuhn called attention, especially shocking in physics!

Kuhn divides mature science into long periods of **normal science** under a **paradigm**, interrupted by brief periods of **crisis** or **extraordinary science** that sometimes become full revolutions, sometimes not.

(One way of challenging Kuhn' overly sharp normal-revolutionary distinction is to suggest that crises occur more often than he allows but are usually resolved, that there is a continuum of crisis severity. The nonlinear potential of contagion is always there.)

Normal science is convergent. Science in crisis becomes more divergent as constraints loosen.

Kuhn: a scientific revolution is a paradigm change, a paradigm switch, usually pretty rapid.

So revolutions are rather event-like, episodic.

Via the crisis, most or all of the pieces are already available, only conceptual reorganization is needed.

Normal science is guided by **exemplars**, not rules. **Exemplars = paradigms**, in the small sense.

Paradigms in the large sense = exemplars + main principles + standards + metaphysical worldview.

The elements of a paradigm are accepted dogmatically & deeply ingrained, not subject to test.

exemplar = a widely accepted problem formulation + solution that shows the way to further work.

Note the role of **rhetoric** in Kuhn: analogy, metaphor, similarity via the direct modeling of new research puzzles on exemplars via an "acquired similarity relation."

Note also the importance of **heuristic appraisal** = estimates of future fertility & thus relevance to "context of discovery."

Kuhn emphasizes that there is no such thing as "the scientific method" or a **logic of discovery**, nor what philosophers have called **confirmation theory** or **logic of justification**.

Kuhn's form of **the underdetermination problem** amplifies the old problem of induction: Major scientific decisions are underdetermined by data + logic.

This is especially true of revolutions = paradigm switch. Historically contingent, somewhat arbitrary.

Hence rhetorical persuasion plays a major role in reorganizing the solidarity of the expert community.

In normal science this is not usually a problem, since the rhetorical modeling on past exemplary work is so deeply ingrained.

But since every paradigm has elements of arbitrariness, of historical contingency, & since normal science is so focused on detail, it is bound to produce **anomalies** = results that don't fit the paradigm well.

Long-unresolved anomalies can trigger a **crisis** of confidence in the paradigm.

What is the nature of a Kuhnian revolution?

An unexpected new empirical discovery can trigger a crisis (a potential revolution in miniature): e.g., X-rays, specific heats (experimental). A theoretical example would be the classical equipartition theorem leading to "the ultraviolet catastrophe (Ehrenfest).

But in *Structure* Kuhn saw revolutions mainly not as new **content** but new **form** or **structure**:

a. a conceptual reorganization of the objective material (textbooks, teaching, etc.)

b. a cognitive psychological reorganization that alters the worldview

c. an emotional reorganization = major change in commitment w.r.t. promise vs. sterility, good science vs. bad, new vs. old-fashioned

d. social community reorganization: in-group, out-group, control of old journals, new journals: i.e., a new set of network connections, a new complex system with a different dynamic

e. often a reorganization of technical practices, as what counts as "good science" in this field

Quotes from *Structure* (1970, 102, etc.): Einstein's special relativity revolution might serve as

> a prototype for revolutionary reorientation in the sciences. Just because it did not involve the introduction of additional objects or concepts, the transition from Newtonian to Einsteinian mechanics illustrates with particular clarity the scientific revolution as a displacement of the conceptual network through which scientists view the world. [1970, 102]

b. psychological reorganization: "gestalt switch," different perceptions, "religious conversion," political persuasion, scientists "live in different worlds."

How do Kuhnian revolutions compare with the above criteria of Schouls & Cohen?

a. A strong break with tradition or a return to original purity? Both? E.g., Copernicus vs. QT. (Vasso Kindi says both at different levels: there is a return to purity at the metalevel, to save the integrity of the discipline.)

b. Kuhn does stress revolution as overturning, but reorganization more than complete razing.

c. But Kuhnian revolutions do involve a sharp break, rupture: the old & new paradigms are "incommensurable" = no common measure for evaluation.

d. Kuhn required contemporary awareness of **crisis** & recognition (by the winners!) of a successful revolution.

e. During the crisis phase, revolutionaries are seeking freedom from the old paradigm.

5. Some General Criticisms of Kuhn

a. Kuhn's model of science during crisis (& his theory of human cognition) reduce science to the same level as political debate, even "mob psychology" (Lakatos) & thus fails to explain the

historical watershed that the emergence of modern science represents, the success & progress of the sciences vs. other human endeavors.

b. In particular, Kuhn is guilty of subjectivism, irrationalism, irrealism, & relativism. *Structure* is an attack on science as we know it. Kuhn is a cultural "leveler."

c. Tho an internalist himself in his own historical work, Kuhn's model violates the internal-external distinction by making scientific decisions depend heavily on external influences rather than on internal, technical evidence & argument.

d. His notion of paradigm is hopelessly vague & ambiguous.

e. Therefore, so is his distinction of normal & revolutionary science.

f. Kuhn's historical claim is false: the history of science does not divide into normal & revolutionary periods.

g. Insofar as revolutions follow a nonlinear dynamic, the labels 'revolution' & 'revolutionary' are retrospective. Planck 1900 as a problem case.

h. Kuhn employs a sloppy theory of meaning & reference that leads to an untenable holism that requires sharp breaks to escape from the prison of the present, paradigmatic conceptual scheme.

i. In particular, Kuhn's notion of incommensurable breaks . . .
- — is vague & ambiguous; Kuhn vacillates between stronger & weaker claims.
- — incoherent or self-contradictory in eliminating any basis for opposition of paradigms.
- — leads to a pernicious relativism.
- — is, again, historically false.

6. Incommensurability: Kuhn and His Critics
(see, e.g., Shapere in the *Routledge Encyclopedia of Phil.*, Soler, Sankey & Hoyningen-Huene, 2008)

Paul Feyerabend on incommensurability: 2 mutually contradictory theories are incommensurable, because changing any part of a theory holistically changes the meaning of the terms.
Objection: But if incommensurable, then how can they contradict one another?
'Mutually contradictory' is a comparison. 'Incommensurability' denies comparability.

Kuhn's early holism in *Structure*: paradigm change involves breaks at several levels.

Kuhn: Revolutions involve *incommensurable* breaks at each level, resulting in holistic, global incommensurability:

a. linguistic-conceptual; e.g., 'mass' in classical mechanics & relativity are not interdefinable. The languages of classical mechanics & special relativity are not intertanslatable.

b. observational: scientists working in competing paradigms have different basic perceptions. (Does this confuse confuse human perception with scientific observation?)

c. theoretical (substantive scientific claims): the paradigms are logically incompatible

d. normative: values & standards: local: What constitutes good solid state physics of thermal or electrical conduction?

e. axiological: aims or goals of science, global & local

Stephen Toulmin (1972). Like structuralism, Kuhn's account of revolutions cannot account for transitions between paradigms. The overly rigid conception of paradigm is what necessitates the idea of revolutionary breakouts. [Relatedly, Kuhn could also be accused of employing a version of an equilibrium model popular in American social science. Revolutions occur when the anomalies become so serious that equilibrium cannot be restored. Ironically, Kuhn's own

theory is part of the social science that allows debate over fundamentals. So why was he surprised by strong criticism?]

Larry Laudan (1984): Real scientific cases show the breaks are more local, not global, & thus rational discourse across paradigm change is possible.

The later Kuhn retreated to local incommensurability in his unfinished book: local translation failures that don't prevent mutual interpretation. So why is incommensurability any longer interesting?

The later Kuhn also gives up the perceptual metaphors, Gestalt switch, etc., & even eliminates history of science in favor of linguistic analysis.

My point: creative working scientists are very flexible, always working at frontiers of research. They frequently face ruptures & mini-crises of many kinds. Their concepts & techniques are fluid, frequently shifting. Yet they understand each other. Thus Kuhn's claims are exaggerated.

Einstein quote: "The scientist . . . must appear to the systematic epistemologist as an unscrupulous opportunist."

7. How Does Kuhn Explain Scientific Revolutions?

a. Any creative discipline eventually outgrows its old conceptual & practical framework. So any creative discipline undermines its current products, slowly & rapidly.
(Toulmin, my criticism of Kuhn on normal science as too static, Schumpeter on capitalism.)

b. Revolutions are have historically contingent features that normal research is bound to expose eventually.

c. Paradigms are part of a two-tier system: a dogmatic foundation + a surface layer of normal work.

d. Paradigms are holistically compact. A change required anywhere propagates through the system.

e. Thus revolutions can be highly nonlinear. A small cause may have a very large effect, & vice versa.
(Thus Kuhn is forced to make normal science practially immutable, except for incremental, cumulative additions. For normal science is a very fragile state on his account.)

A normal scientific anomaly can eventually acquire social & logical leverage to overturn the system, if there is a more promising proto-paradigm to replace it.
E.g., William Thomson, Lord Kelvin, "Baltimore Lectures" (1884): "two small clouds" marred the horizon of Newtonian physics: the anomalies of blackbody radiation & the result of the Michelson-Morley experiment. The latter was crucial to the relativity revolution & the former to the quantum mechanics revolution.

f. The new framework is exciting but perplexing & crude & leaves much new work to be done.

g. Thus enough creative success + **heuristic appraisal** of its future prospects is also required.

Thus Kuhnian revolutions are necessary because contingent! The paradox is only apparent.

And thus revolutions are necessary for continued progress, contrary to positivist tradition, which envisioned steady, cumulative progress consistent with the present conceptual framework.

E.g., P.W. Bridgman operationism in *The Logic of Modern Physics* (1927).

> We should now make it our business to understand so thoroughly the character of our permanent mental relations to nature that another change in our attitude, such as that due to Einstein, shall be forever impossible. It was perhaps excusable that a revolution in mental attitude should occur once, because after all physics is a young science, and physicists have been very busy, but it would certainly be a reproach if such a revolution should ever prove necessary again. [1927, 2]

Bridgman (a Nobel Laureate in experimental physics!) completely misunderstands how new concepts, language, & proposed mechanisms emerge as **products** of the ongoing research process rather than providing a fixed, antecedent foundation for it. This is the same mistake as traditional conceptions of "the scientific method" vs. pragmatic consequentialism.

Contrary to Bridgman, Kuhn multiplied revolutions: every small specialty has them: hierarchy.

The visibility problem. If contemporary scientists must be aware of crisis & revolution & if there have been so many revolutions, then why did the world have to wait for Kuhn to see them? Because, he said, they are largely invisible. But why?

a. After a revolution, the winners rewrite the history of science to make it look as if the present paradigm is the brilliant but rational sequel to previous work. They adhere to the older view that respectable rational development requires cumulative continuity.

b. The implication: only someone of Kuhn's historical sensitivity could notice this from outside the field.

Even to scientists in other specialties revolutions usually look like cumulative advances.

c. Disciplinary consequence: a new generation of historians & historical philosophers found subtle conceptual breaks everywhere!

8a. Some Philosophical Implications: Scientific Progress

a. Kuhn: normal science is progressive in a cumulative way.

b. Revolutionary science is not cumulative, but it is still progressive in having wider scope, more precision, greater theoretical sophistication, etc. We can easily order paradigms historically.

c. This is progress with respect to previous results, not progress toward some final theory, some final Truth, written in "nature's own language" (Richard Rorty), waiting to be discovered.

d. Rorty et al. on the pragmatic implication: science is just one more human project among others. It's goals vary with human interests & hence its criteria of success.

8b. Some Philosophical Implications: Realism and Truth

Revolutions provide one argument **for local realism and structural realism**: whatever survives a revolution is robust: invariant under change.

But, on the whole, the existence of revolutions, especially in mature science, is a **shock to realism**.

Why in physics, our most mature science?! Is Kuhn's answer basically correct?

In implying that science is not gradually progressing toward a final Truth, revolutions provide the strongest form of **Larry Laudan**'s negative historical induction (Laudan 1981).

They are also the strongest form of **Kyle Stanford**'s (2006) problem of unconceived or underconceived alternatives.

Future revolutions are beyond our present conceptual-linguistic & thus imaginative horizon.

We may even think them impossible, by today's lights. Consider past examples:

a. Euclidean geometry as a priori true, no consistent alternative is conceivable (Kant).

b. Darwin on the evolution of species.

c. Quantum theory rejects universal causation & accepts entanglement.

Dudley Shapere: modern science gets weirder & weirder, weirder than even previous science fiction writers could imagine.

My Kuhnian point: the Kuhnian revolutionary potential of a science is a function of its compactness & hence its maturity, & hence its nonlinearity. Small violations can propagate rapidly thru the network: tipping points, critical points, phase changes, contagion, epidemiological models.

8c. Some Philosophical Implications: Social Constructionism

Kuhn's emphasis on the community of experts triggered new-wave sociology of science.
Structure dramatically sharpened the old underdetermination problem: the gap between our theories & what the data + logic demand is very large with much constructive adjustment & negotiation possible.
Even if metaphysical realism is true (There is one best, objectively true description of reality.), it is not given to us; hence, a great deal of human construction is always involved.
More radical positions:
a. Metaphysical realism is completely beyond us, so should not be taken seriously.
b. Metaphysical realism is incoherent (Rorty). So we are free from that sort of obligation to nature. Science is a humanly constructed tool designed to satisfy human interests, nothing more.

9. Some Non-Kuhnian Conceptions of Revolution and Rupture

Charles Peirce, the founder of American pragmatism, said in an early essay, "each chief step in science has been a lesson in logic," implying that philosophy must learn from science; hence major scientific lessons will also bring methodological-epistemological lessons (Peirce 1877). But Peirce apparently did not see the revolutionary potential of this linkage of substance & method. Most fin-de-siècle scientists saw what we now call the classical world picture as approaching the final truth about the world.

Howard Margolis, *Paradigms and Barriers* (1993), distinguishes 2 models of revolution.
a. the gap view: there is a large logical gap to be jumped between the old & the new science, e.g., possibly the emergence of the modern conception of probability: see c below.
b. the barrier view: there is a cognitive barrier (a deeply entrenched, often unconscious "habit of
mind") that blocks the conceptual breakthrough. When someone does break through or evade
the barrier, it conflicts with old intuitions & causes incommensurability, e.g., Copernicus.
c. a possible 3rd model: opening up a whole new domain, without direct conflict.
(Something similar to Margolis' barrier view would seem to fit even normal science, where the scientists are convinced that they have all the tools necessary to solve the puzzle but cannot. But when one does solve it, recognition is immediate. But no: there need be no conflict or incommensurability in this case, just bounded rationality. And the heuristic expectations in terms of available techniques are already in place, whereas Copernican frontiers & intuitions do not know which information is relevant, & it may be quite peripheral. Today there is the knowledge-pollution problem.)

Paul Thagard, *Conceptual Revolutions* (1993) articulates a broadly Kuhnian model in computational terms via his computer science program, ECHO, especially taxonomic reorganization in terms of tree structures. (1) "Branch jumping" relocates something to another branch of the same tree, e.g., whale to mammal. (2) "Tree switching" more radically replaces the tree by a reorganized one, as when Darwin's biological conception of biological taxonomy replaced Linnnaeus.

Peter Godfrey-Smith, in a review of Jablonska & Lamb, *Evolution in Four Dimensions* (2005), doubts that Kuhnian **revolutions** can occur in the biological sciences after Darwin & perhaps post-1900 Mendelian genetics. (1) Biology is too loosely structured logically. (2) There are no rapid, really decisive overturning events, only a **deluge** of new information & techniques, as in molecular genetics.

[But compare the so-called Scientific Revolution.] E.g., Crick's Central Dogma was not decisively overturned, just slowly eroded. Revolution in biology will thus be a retrospective label, e.g., if the DNA sequence turns out not to be so central given other forms of inherited information transmission.

The French tradition before Kuhn: "rupture," *coupure*, a break with the past, is a prominent theme.

But Kuhn was largely unfamiliar with their work.

Léon Brunschvicg and Gaston Bachelard: As for Peirce, philosophy must learn from current science.

Gaston Bachelard (1934): We can understand scientific reason only via the history of science.

A fruitful program, such as classical mechanics eventually becomes unfruitful, an obstacle to progress.

A scientific revolution becomes necessary & should produce an epistemological revolution.

But *coupures* for Bachelard are not as radical as for Kuhn. He retains progress toward truth & a kind of cumulativity in that an earlier theory remains in the later one as a special case.

Canguilhem was more interested in the biological & health sciences than physics & stressed that these sciences cannot reduce to physics because, unlike physics, they involve a distinction between the normal & the pathological.

He & Bachelard criticized Kuhn's notion of trans-revolution scientific norms & scientific consensus as too weak to explain the kinds of closure we actually find in the history of science.

Michel Foucault, in *The Archeology of Knowledge*, etc., introduces the idea of discursive formations & of breaks between them. These are much larger cultural breaks than Kuhn's scientific revolutions, although sciences can emerge at these points, e.g., the sciences of social control.

Ian Hacking (Canadian) is strongly influenced by Foucault. Hacking writes:

> Foucault used the French world *connaissance* to stand for such items of surface knowledge while *savoir* meant more than science; it was a frame, postulated by Foucault, within which surface hypotheses got their sense. *Savoir* is not knowledge in the sense of a bunch of solid propositions. This "depth" knowledge is more like a postulated set of rules that determine what kinds of sentences are going to count as true or false in some domain. The kinds of things to be said about the brain in 1780 are not the kinds of things to be said a quarter-century later. That is not because we have different beliefs about brains, but because "brain" denotes a new kind of object in the later discourse, and occurs in different sorts of sentences. [2002, 77]

Hacking's "historical ontology" develops a version of this view: modern probability & statistics & all the "real" quantities they involve are human historical constructions, yet not therefore unreal.

So whole ways of speaking & understanding the world, whole languages & their associated techniques & realities, come into existence & displace older ways—again, broader than Kuhnian revolutions.

Like Foucault, Hacking likes the idea of historical a prioris: taken-for-granted platforms that can't be meaningfully disputed or tested (like Kuhnian paradigms during normal science).

> The historical *a priori* points at conditions whose dominion is as inexorable, there and then, as Kant's synthetic *a priori*. Yet they are at the same time conditioned and formed in history, and can be uprooted by later, radical, historical transformations. T. S. Kuhn's paradigms have some of the character of a historical *a priori*. [Hacking 2002, 5].

Hacking also has a kind of incommensurability (more like Feyerabend's than Kuhn's) & a kind of relativism: "Just as statistical reasons had no force for the Greeks, so one imagines a people for whom none of our reasons for belief have force" (2002, 163).

Michael Friedman (2001) also can be read as defending a sort of historical a priori, in the German tradition of neo-Kantianism & Reichenbach. Without fully committing himself (?) to Kuhnian revolutions, he shows how to interpret them in terms of a historically relativized a priori.

Friedman himself defends a 2-tiered view of science: it needs an underlying "a priori" framework.

This is the modern scientific version of Kant's 2-tiered view of cognition: any position that lacks a bottom level of basic defining or processing rules (categories & forms of intuition) is a naïve empiricism!

Kuhn's view in *Structure* is clearly 2-tiered. He is "a Kantian with moveable categories."

10. Comparison with Economic Innovation

See my Stanford Encyclopedia of Philosophy article.

11. Revolution or Evolution?

Are there / have there been any Kuhnian revolutions?

Kuhn's Aristotle epiphany: misleading: too perceptual + huge time-jump.

Is it a matter of scale? E.g., the Copernican Revolution vs. the Plate Tectonic Revolution.

The closer we look at a "revolution," the less revolutionary it becomes—because dozens of smaller steps are now filled in, each of them a "stretch" but not revolutionary.

Toward the end of *Structure*, Kuhn himself compared revolution with Darwinian biological speciation.

A modified view is even stronger in his last work:

> [R]evolutions, which produce new divisions between fields in scientific development, are much like episodes of speciation in biological evolution. The biological parallel to revolutionary change is not mutation, as I thought for many years, but speciation. . . . [Scientific specialties are analogous to reproductively isolated biological populations in being a] community of intercommunicating specialists, a unit whose members share a lexicon that provides the basis for both the conduct and the evaluation of their research and which simultaneously, by barring full communication with those outside the group, maintains their isolation from practitioners of other specialties. [Kuhn 2000c, 98]

a. Darwinian evolution is slow & gradual & continuous, not rapid & discontinuous.
b. Speciation is a retrospective category. So shouldn't revolution also be retrospective?

One reply: treat Kuhnian revolutions as analogous to Niles Eldredge & Stephen Jay Gould 'punctuated equilibrium' conception of evolution. In a later article they note a connection to Kuhn:

> [C]ontemporary science has massively substituted notions of indeterminacy, historical contingency, chaos and punctuation for previous convictions about gradual, progressive, predictable determinism. These transitions have occurred in field after field; Kuhn's celebrated notion of scientific revolutions is, for example, a punctuation theory for the history of scientific ideas. [1993, 227]

Stuart Kauffman (1993) and Brian Goodwin (1994) defend reorganization in the form of self-organization as the primary macro-evolutionary mechanism, with evolutionary adaptation adding only the finishing

touches.
Gould and Richard Lewontin had raised this possibility in their famous paper of 1979, "The Spandrels of
San Marco and the Panglossian Paradigm." Applied to the development of science, this view implies
that revolutions determine the overall shape, while ordinary scientific work applies the adaptive microevolution.

Complexity theorists such as physicists Per Bak (1996) & Albert-László Barabási (2007) propose more
"Hegelian" models of creative structural change, in the sense that they require no agency of "great
men" or "great discoveries," only a networked distribution of relatively dumb processors.
If they are right, this could give a different way of classifying revolutions, depending on their aetiology:
anonymous nonlinear transformations vs. major contributions.

My view: 'revolution' is a useful descriptive term to recognize sciences as dynamical systems, but Kuhn
exaggerates the normal-revolution distinction & the extent of the breaks.
Creative scientists are used to the uncertainties, confusions, & dangers of frontiers.

12. Kuhn's Attempt to Unite Historicism and Naturalism

Roughly, **evolution** is a **naturalistic** process, while **revolutions** are **human historical** processes.
Kuhn attempts to overcome the old opposition between deep **historicism** (which generally stresses the
humanly constructed, contingent, local & what requires human interpretation or *Verstehen*) vs.
thoroughgoing **naturalism** (stressing objectively necessary & universal laws of nature & *Erklären*).
Kuhn's strong anti-whiggism is deeply historicist, as is his view of social construction, rejection of final
truth, & the generation & corruption in historical time of all things scientific.
Yet he imposes a "lawful" pattern on (some of) the mature sciences: normal science + revolution.
Oliver Wendell Holmes, Jr. (1861) once remarked, "Revolutions never follow precedents nor furnish them." Given the unpredictability, the nonlinearity, the seeming uniqueness of revolutions, whether
political or scientific, it is therefore surprising to find Kuhn attempting to provide a General Theory of
Scientific Revolutions.
Compare **Marx's materialist theory of history** as a similar attempt to be both naturalistic & historicist.
(But unlike Marx's, Kuhn's theory is not a conflict theory, nor does it tell a story with either an ending
or a goal.)
Unfortunately, the later Kuhn gradually gives up history, moving from Hegel back to Kant & emphasizing
a priori arguments and linguistic analysis, while taking little notice of rapid developments in the empirical cognitive sciences.