The Socio-Epistemic Networks of General Relativity, 1925-1970

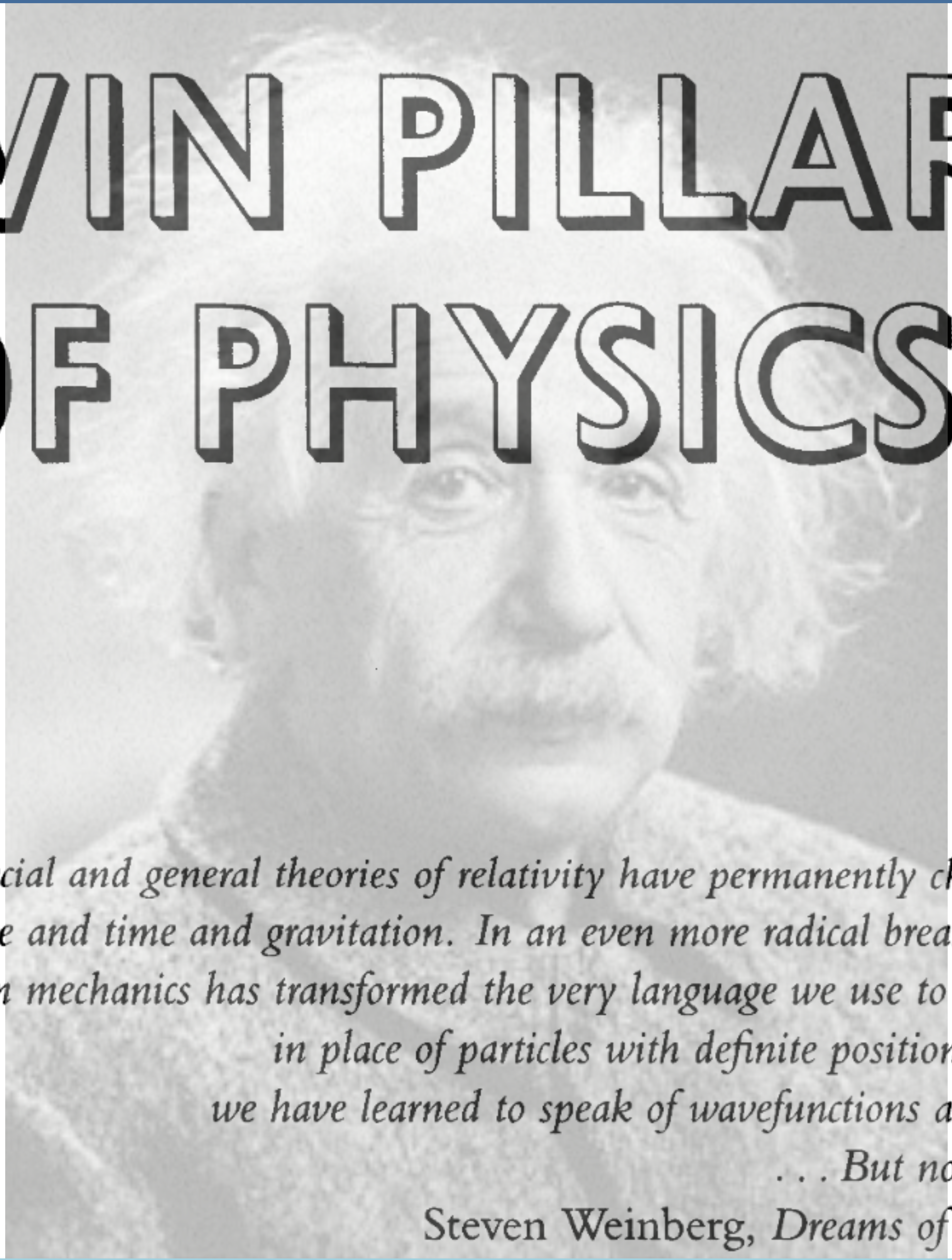
The low-water mark, the renaissance, and the astrophysical turn

Roberto Lalli

MAX PLANCK INSTITUTE
FOR THE HISTORY OF SCIENCE

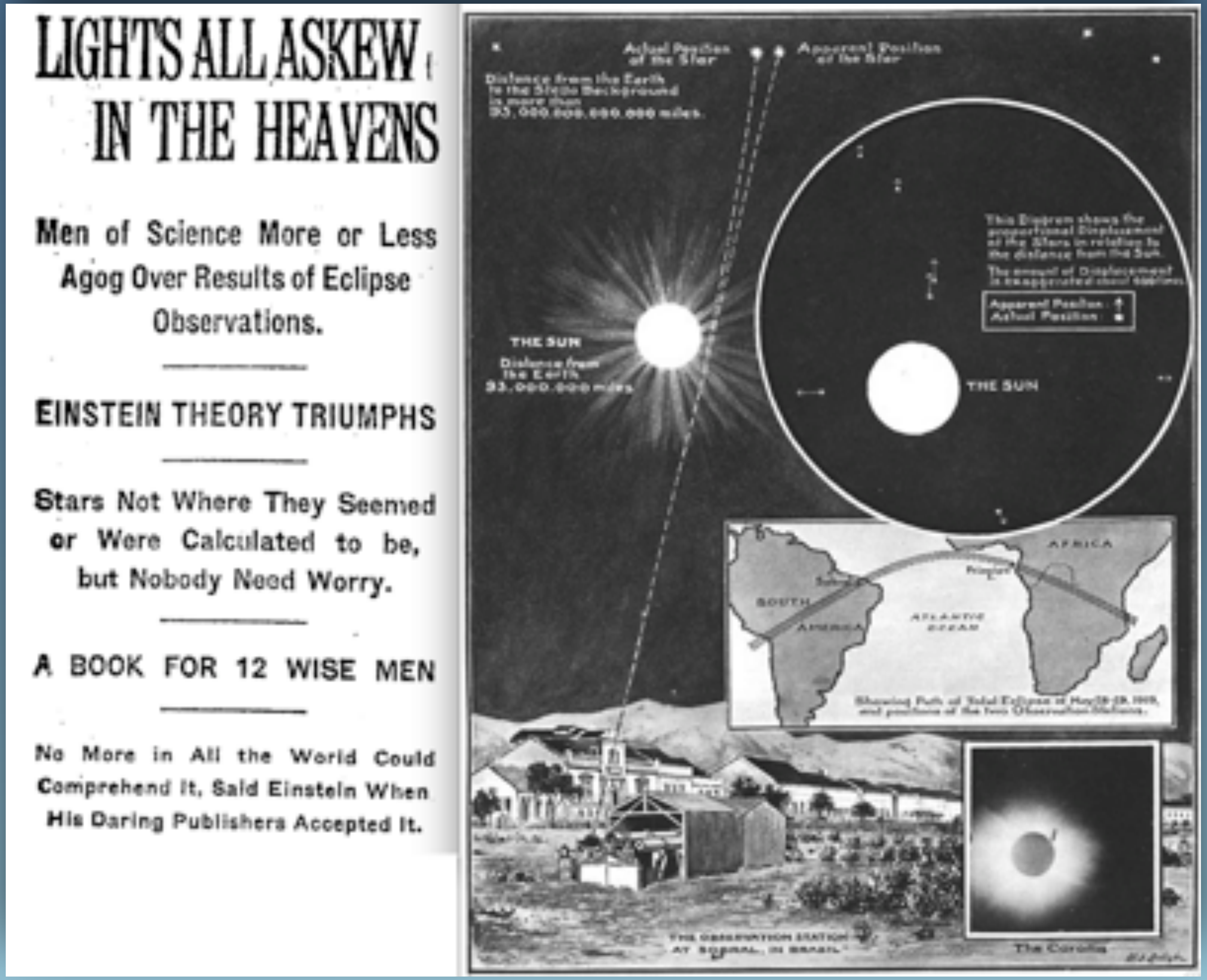
106o Congresso Nazionale SIF
14-18 settembre 2020

TWIN PILLARS OF PHYSICS



Einstein's special and general theories of relativity have permanently changed our view of space and time and gravitation. In an even more radical break with the past, quantum mechanics has transformed the very language we use to describe nature: in place of particles with definite positions and velocities, we have learned to speak of wavefunctions and probabilities. . . . But now we are stuck.

Steven Weinberg, *Dreams of a Final Theory*



LIGHTS ALL ASKEW IN THE HEAVENS

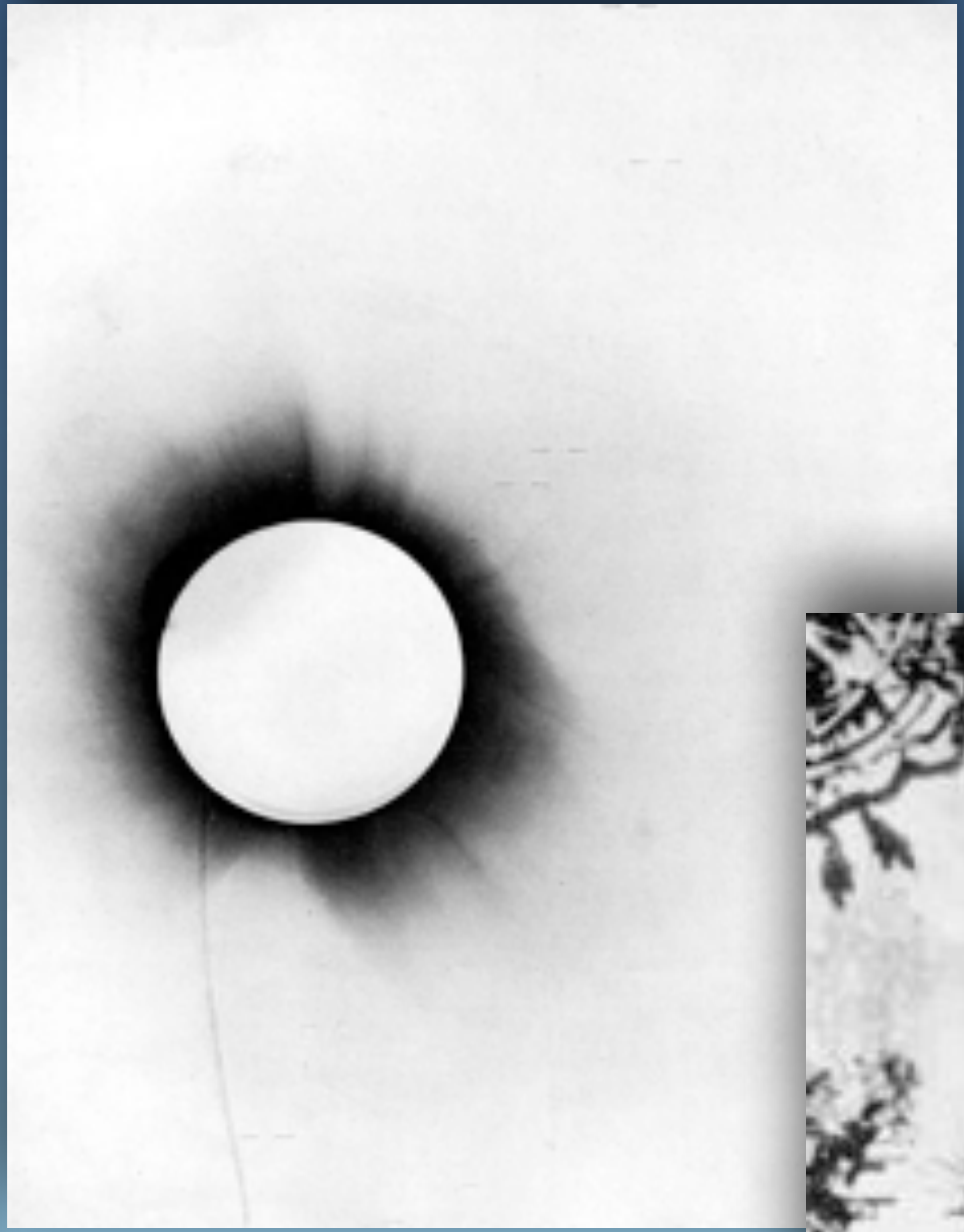
Men of Science More or Less Agog Over Results of Eclipse Observations.

EINSTEIN THEORY TRIUMPHS

Stars Not Where They Seemed or Were Calculated to be, but Nobody Need Worry.

A BOOK FOR 12 WISE MEN

No More in All the World Could Comprehend It, Said Einstein When His Daring Publishers Accepted It.



Einstein and Eddington, 1930

The low water mark general relativity

La relativité générale à l'étiage: 1925—1955

JEAN EISENSTAEDT

Communicated by J. D. NORTH

Sommaire

"A quoi ressemblerait la physique sans la gravitation?"[1]

1. Introduction

Au-delà de la réception proprement dite de la théorie de la relativité générale, qui après novembre 1915 s'étale sur une petite dizaine d'années, au-delà des rares "vérifications expérimentales" de la théorie, au-delà des critiques techniques auxquelles des réponses somme toute convaincantes sont données, au-delà des réactions passionnelles, enthousiastes ou péjoratives, au-delà de la gloire qui à ce titre, saisit EINSTEIN dans les années vingt, la théorie entre dans une période extrêmement curieuse de son histoire: une sorte de traversée du désert.

La description dramatique que nous a laissée WHITEHEAD de la réunion de la Royal Society de Londres en novembre 1919 est bien connue; le portrait de NEWTON au second plan éclipsé par la gloire montante d'EINSTEIN, une image que la théorisation popperienne a plus tard consacrée. On sait l'opinion du co-

[1] EINSTEIN (A.), 1950. – On the generalized theory of gravitation. – Scientific American, 188 (4): 13–17.

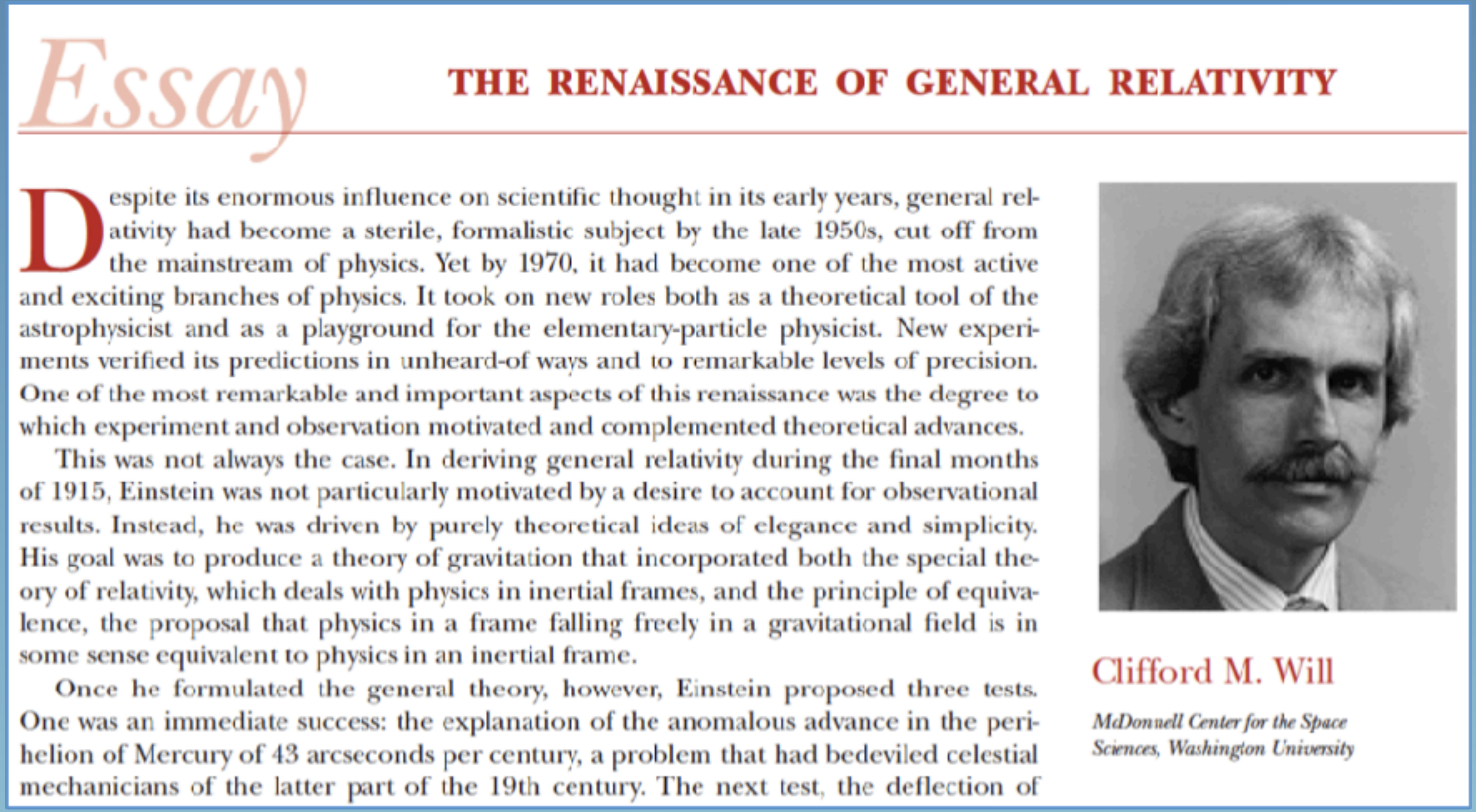
Curious history of general relativity

1907-1915: Genesis

1915-1925: Formative years

1925-1955: Low-water-mark period

1955-1970: Renaissance



Essay

THE RENAISSANCE OF GENERAL RELATIVITY

Despite its enormous influence on scientific thought in its early years, general relativity had become a sterile, formalistic subject by the late 1950s, cut off from the mainstream of physics. Yet by 1970, it had become one of the most active and exciting branches of physics. It took on new roles both as a theoretical tool of the astrophysicist and as a playground for the elementary-particle physicist. New experiments verified its predictions in unheard-of ways and to remarkable levels of precision. One of the most remarkable and important aspects of this renaissance was the degree to which experiment and observation motivated and complemented theoretical advances.

This was not always the case. In deriving general relativity during the final months of 1915, Einstein was not particularly motivated by a desire to account for observational results. Instead, he was driven by purely theoretical ideas of elegance and simplicity. His goal was to produce a theory of gravitation that incorporated both the special theory of relativity, which deals with physics in inertial frames, and the principle of equivalence, the proposal that physics in a frame falling freely in a gravitational field is in some sense equivalent to physics in an inertial frame.

Once he formulated the general theory, however, Einstein proposed three tests. One was an immediate success: the explanation of the anomalous advance in the perihelion of Mercury of 43 arcseconds per century, a problem that had bedeviled celestial mechanicians of the latter part of the 19th century. The next test, the deflection of

Clifford M. Will

McDonnell Center for the Space Sciences, Washington University

Widespread explanations:

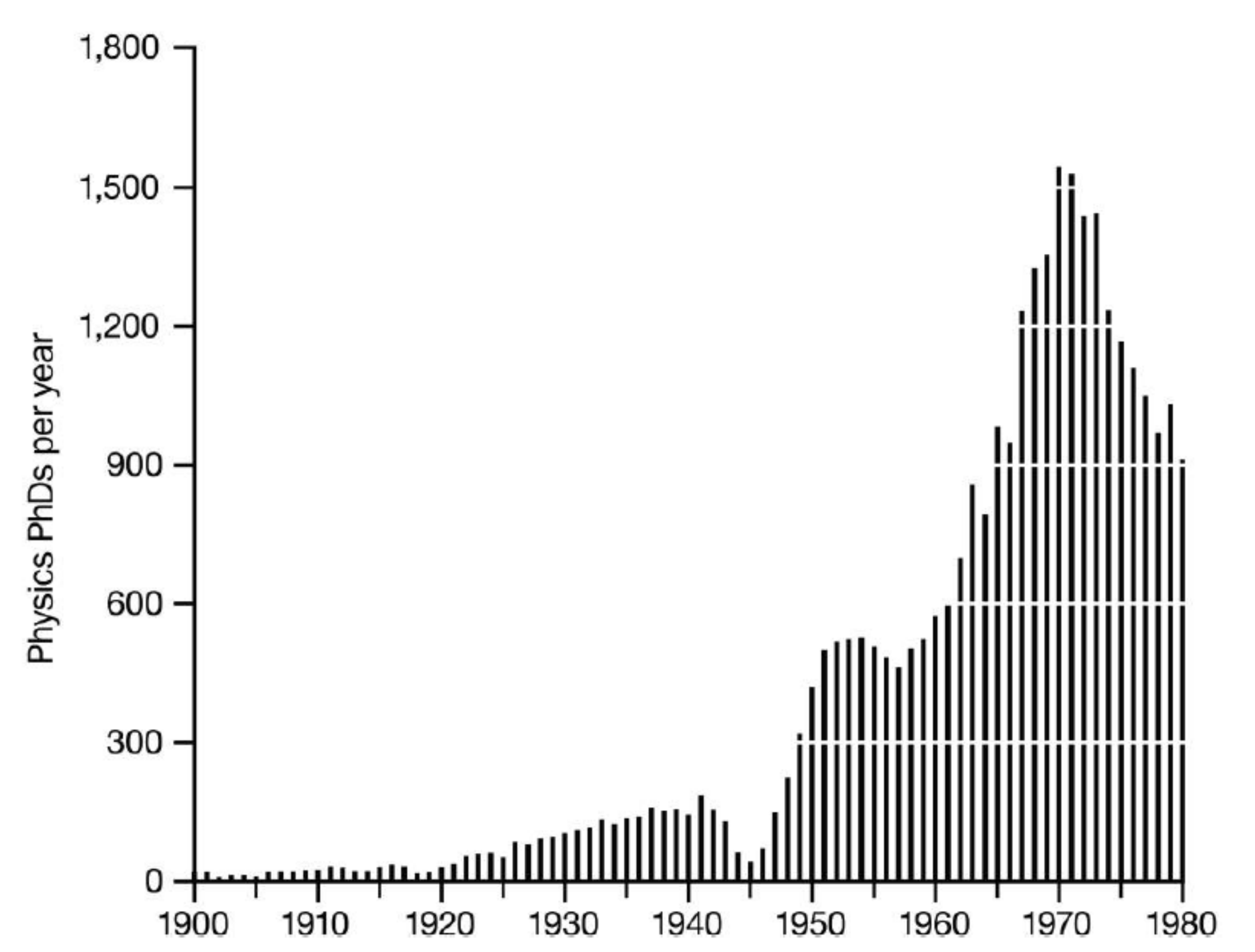
Consequence of astrophysical discoveries

1963: Quasars

1965: Cosmic Background Radiation

1967: Pulsars

Simple by-product of the flow of persons and money into theoretical physics after WWII

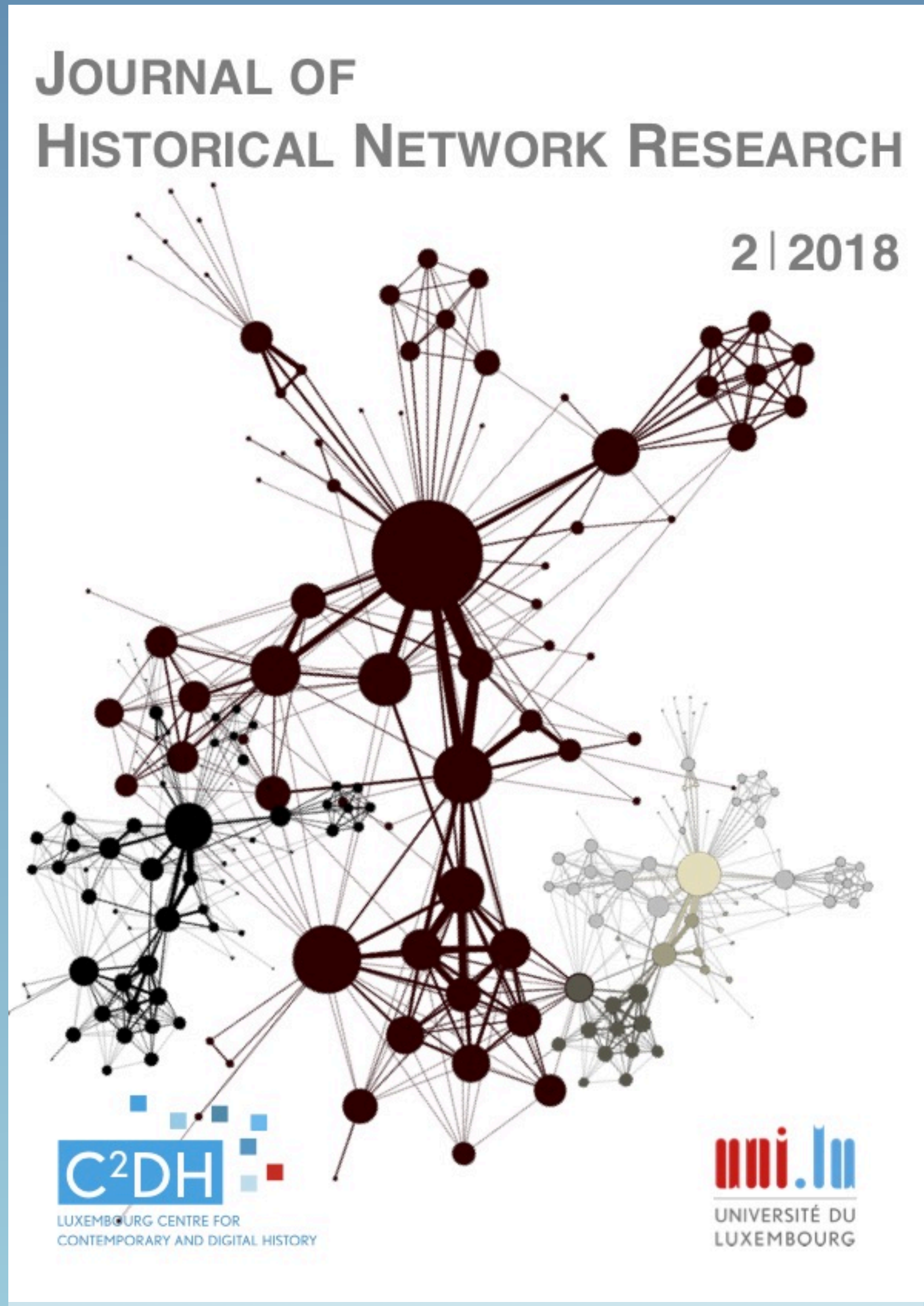


Was the renaissance a simple consequence of the radical transformation of the social landscape of physics following World War II and/or of technological advances?

Or did it entail conceptual modifications in the theory itself and in its relation to other branches of physics?

And how did it unfold?


Historical Network Research
Network analysis in the historical disciplines
About
New: HNR Journal
HNR Workshops & Conferences
Bibliography & Resources
Event Calendar


JOURNAL OF
HISTORICAL NETWORK RESEARCH
2 | 2018
C2DH
LUXEMBOURG CENTRE FOR
CONTEMPORARY AND DIGITAL HISTORY
uni.lu
UNIVERSITÉ DU
LUXEMBOURG

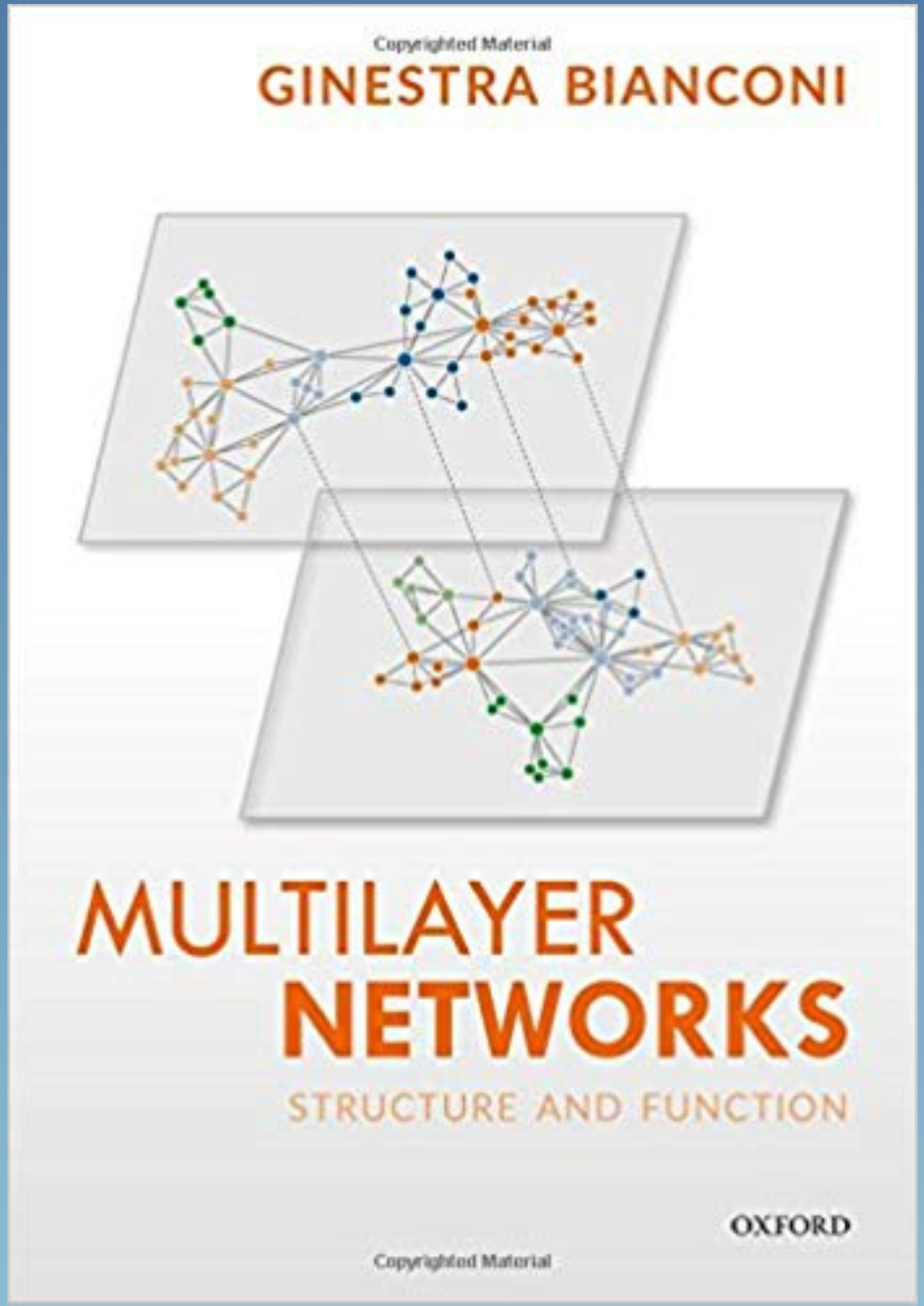
Socio-Epistemic Networks

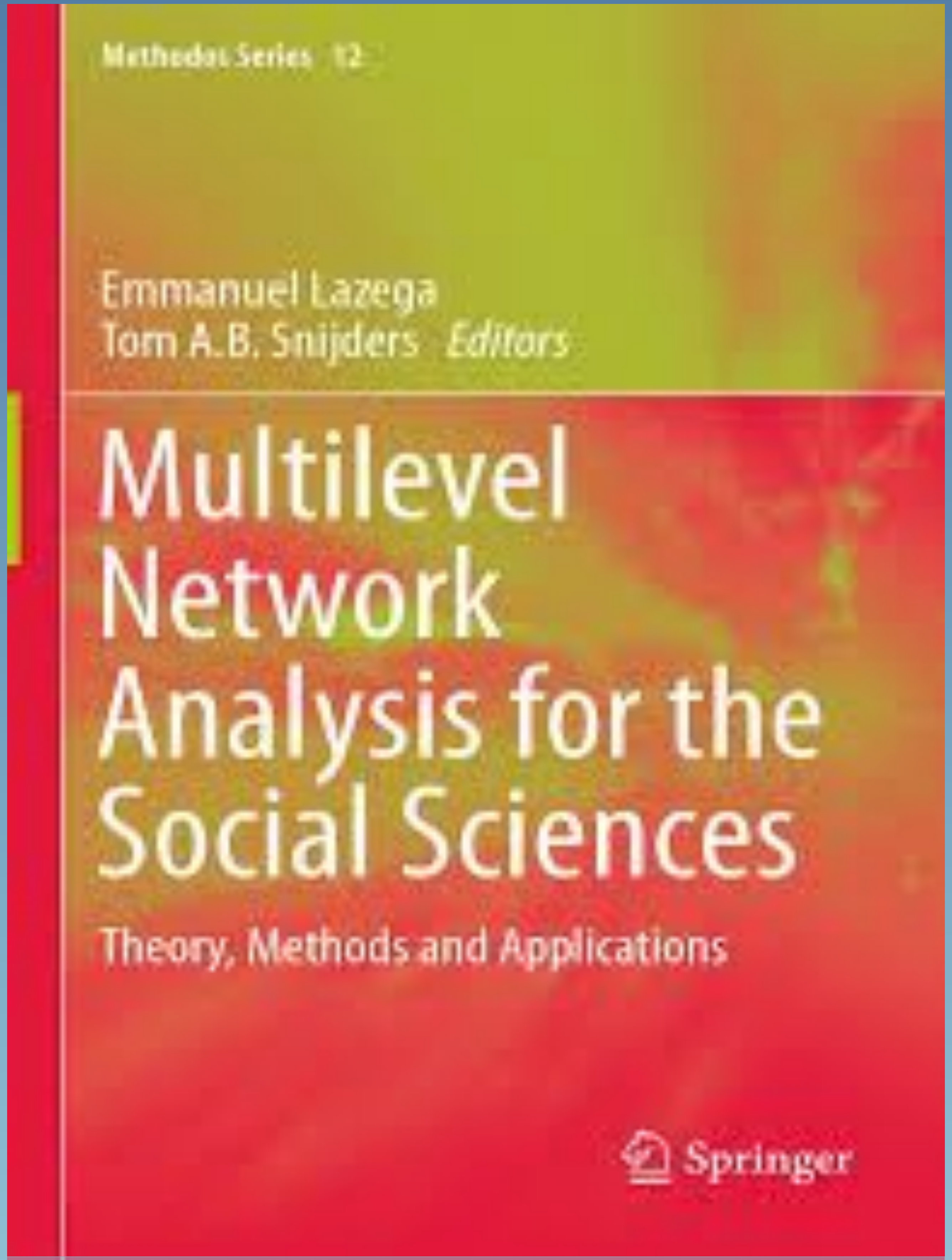
Social

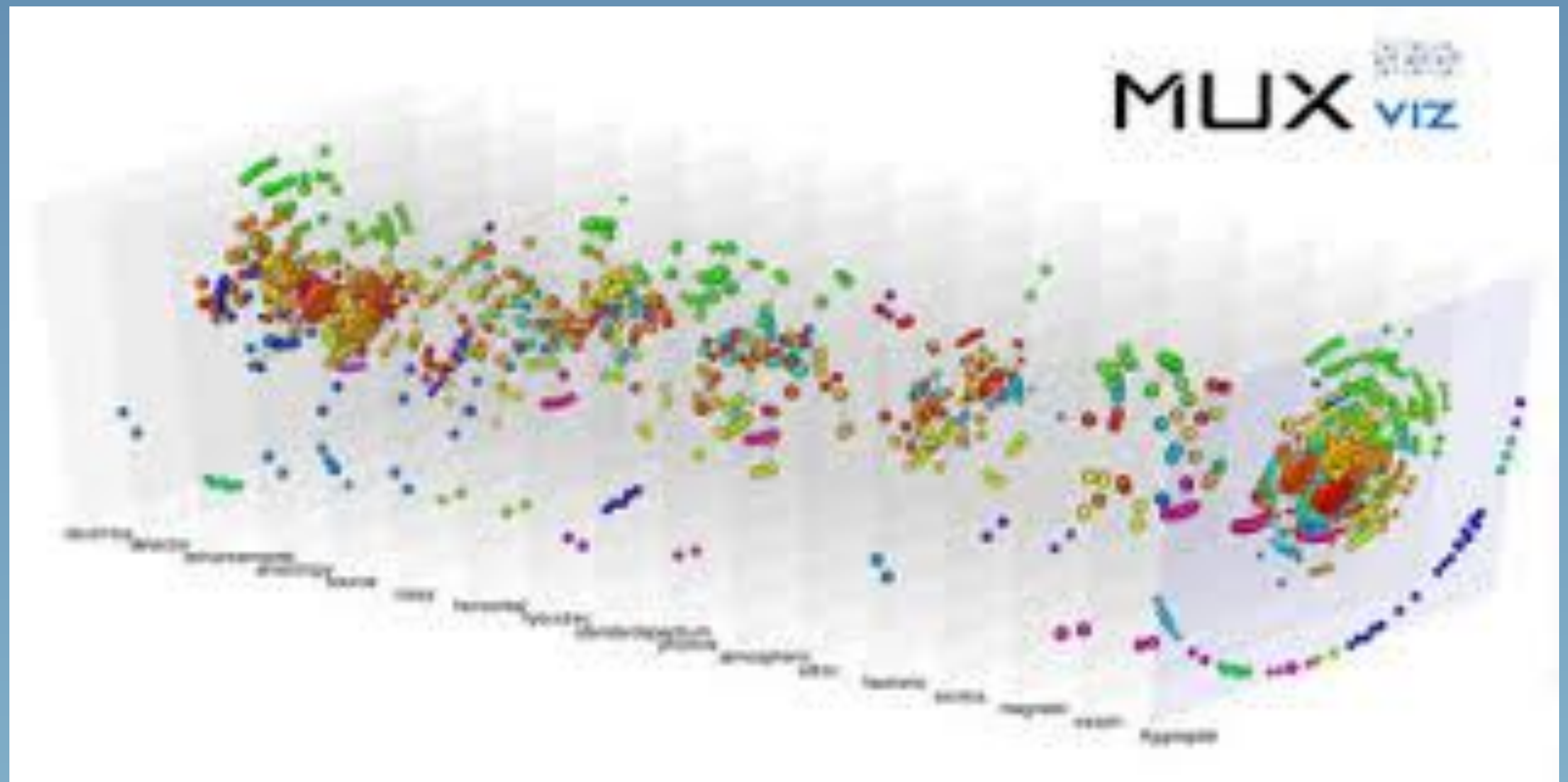
Semiotic

Semantic

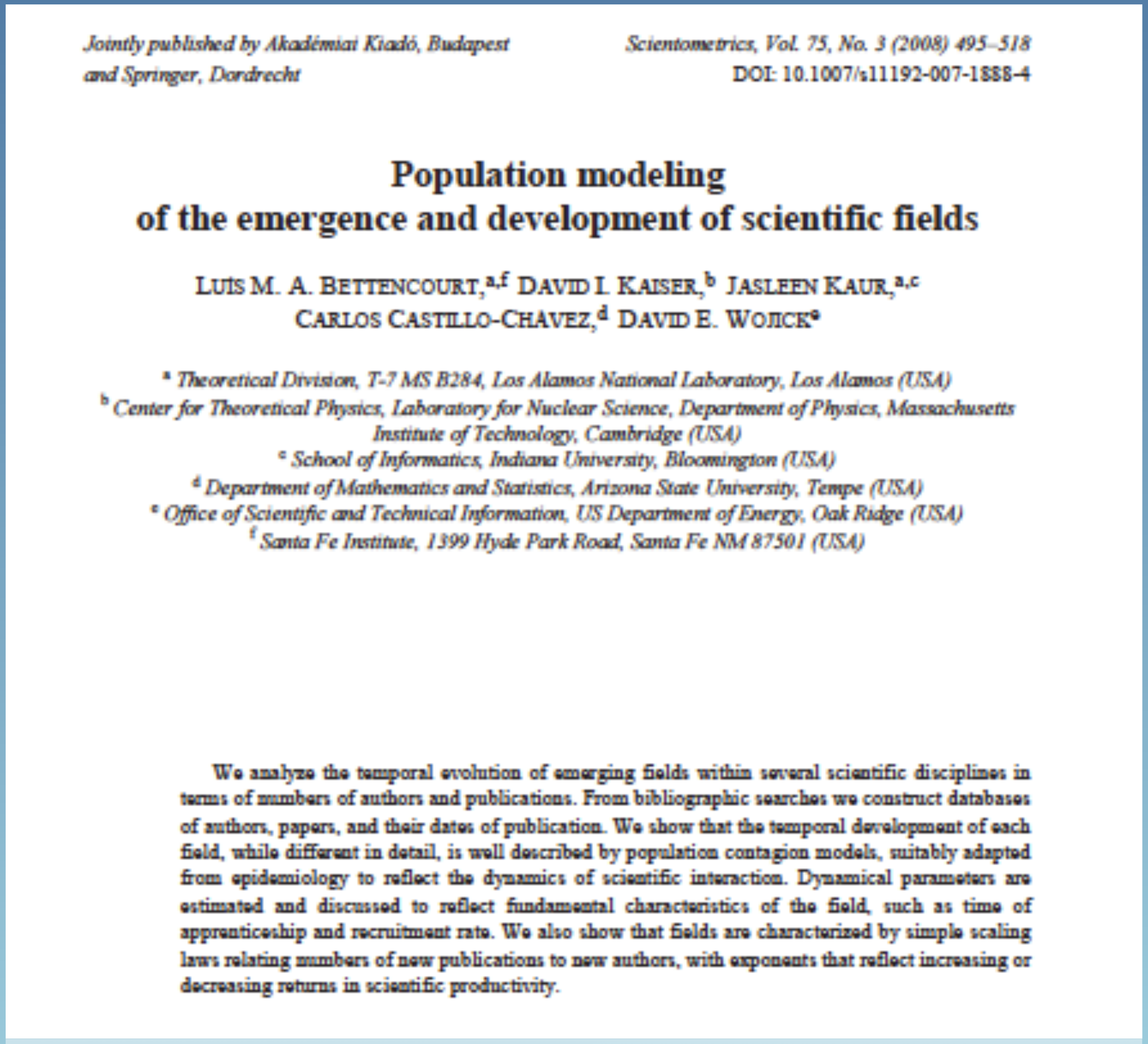
Types	Nodes	Edges	Nodes	Edges
Semantic	Concepts	Causal structures Dependencies	Keywords / Research agendas	Co-occurrence
Semiotic	Material or formal representations of knowledge	Formal relationships	Publications Artifacts Institutions	Citations Organisational structures
Social	Social actors	Social relationships	Persons Institutions Commissions Groups	Collaborations Influence Advice Affiliation Co-participation


Copyrighted Material
GINESTRA BIANCONI
MULTILAYER
NETWORKS
STRUCTURE AND FUNCTION
OXFORD
Copyrighted Material


Methodos Series 12
Emmanuel Lazega
Tom A.B. Snijders Editors
Multilevel Network Analysis for the Social Sciences
Theory, Methods and Applications
Springer


MUX VIZ

Social layer - Dynamics of collaboration networks



Jointly published by Akadémiai Kiadó, Budapest and Springer, Dordrecht

Scientometrics, Vol. 75, No. 3 (2008) 495–518
DOI: 10.1007/s11192-007-1888-4

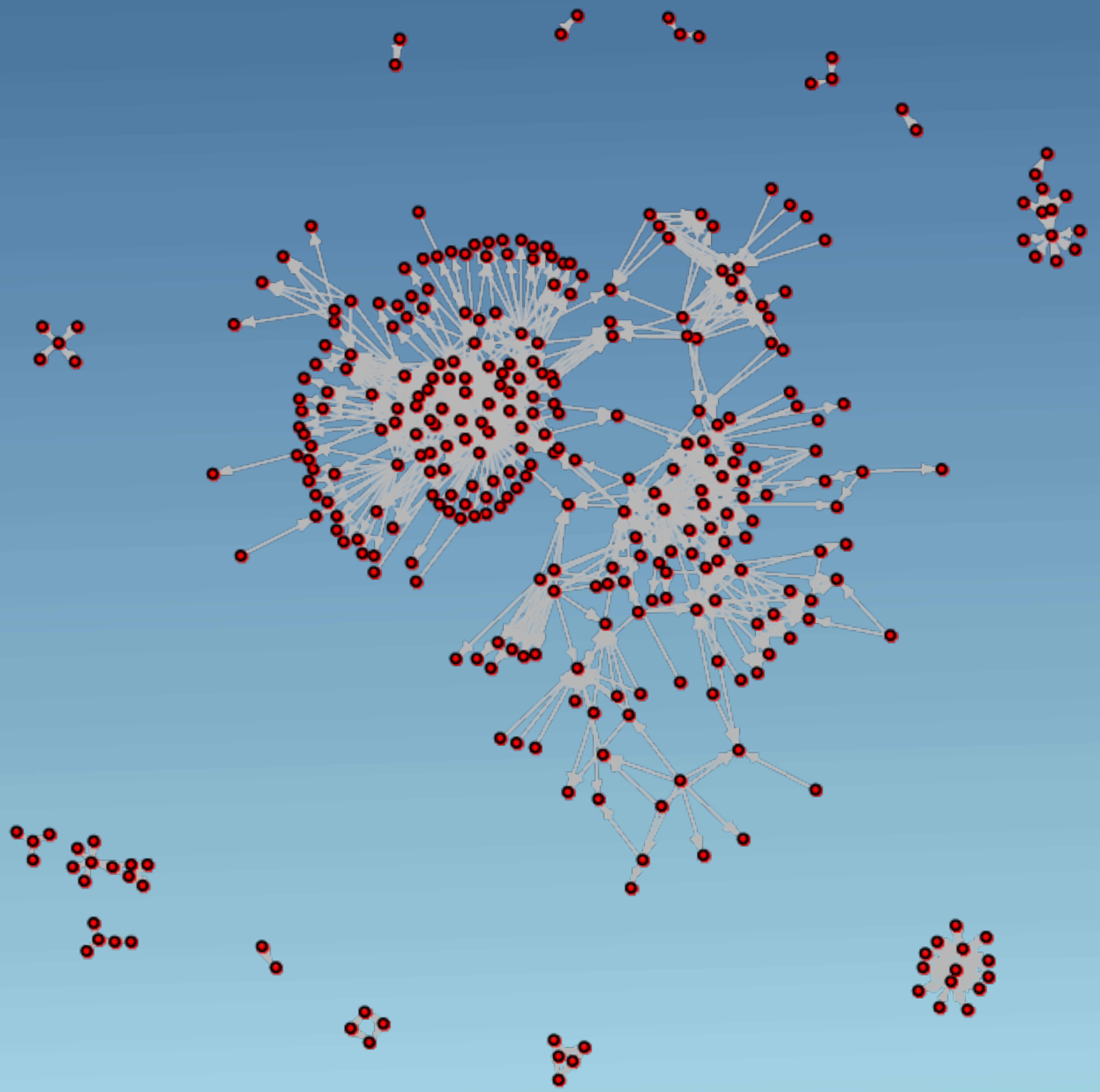
Population modeling of the emergence and development of scientific fields

LUÍS M. A. BETTENCOURT,[a,f] DAVID I. KAISER,[b] JASLEEN KAUR,[a,c] CARLOS CASTILLO-CHÁVEZ,[d] DAVID E. WOJICK[e]

[a] *Theoretical Division, T-7 MS B284, Los Alamos National Laboratory, Los Alamos (USA)*
[b] *Center for Theoretical Physics, Laboratory for Nuclear Science, Department of Physics, Massachusetts Institute of Technology, Cambridge (USA)*
[c] *School of Informatics, Indiana University, Bloomington (USA)*
[d] *Department of Mathematics and Statistics, Arizona State University, Tempe (USA)*
[e] *Office of Scientific and Technical Information, US Department of Energy, Oak Ridge (USA)*
[f] *Santa Fe Institute, 1399 Hyde Park Road, Santa Fe NM 87501 (USA)*

We analyze the temporal evolution of emerging fields within several scientific disciplines in terms of numbers of authors and publications. From bibliographic searches we construct databases of authors, papers, and their dates of publication. We show that the temporal development of each field, while different in detail, is well described by population contagion models, suitably adapted from epidemiology to reflect the dynamics of scientific interaction. Dynamical parameters are estimated and discussed to reflect fundamental characteristics of the field, such as time of apprenticeship and recruitment rate. We also show that fields are characterized by simple scaling laws relating numbers of new publications to new authors, with exponents that reflect increasing or decreasing returns in scientific productivity.

Giant component



Edges, 1925-1970

Persons-institutions (2068)

- Affiliation

Persons-persons links (1063)

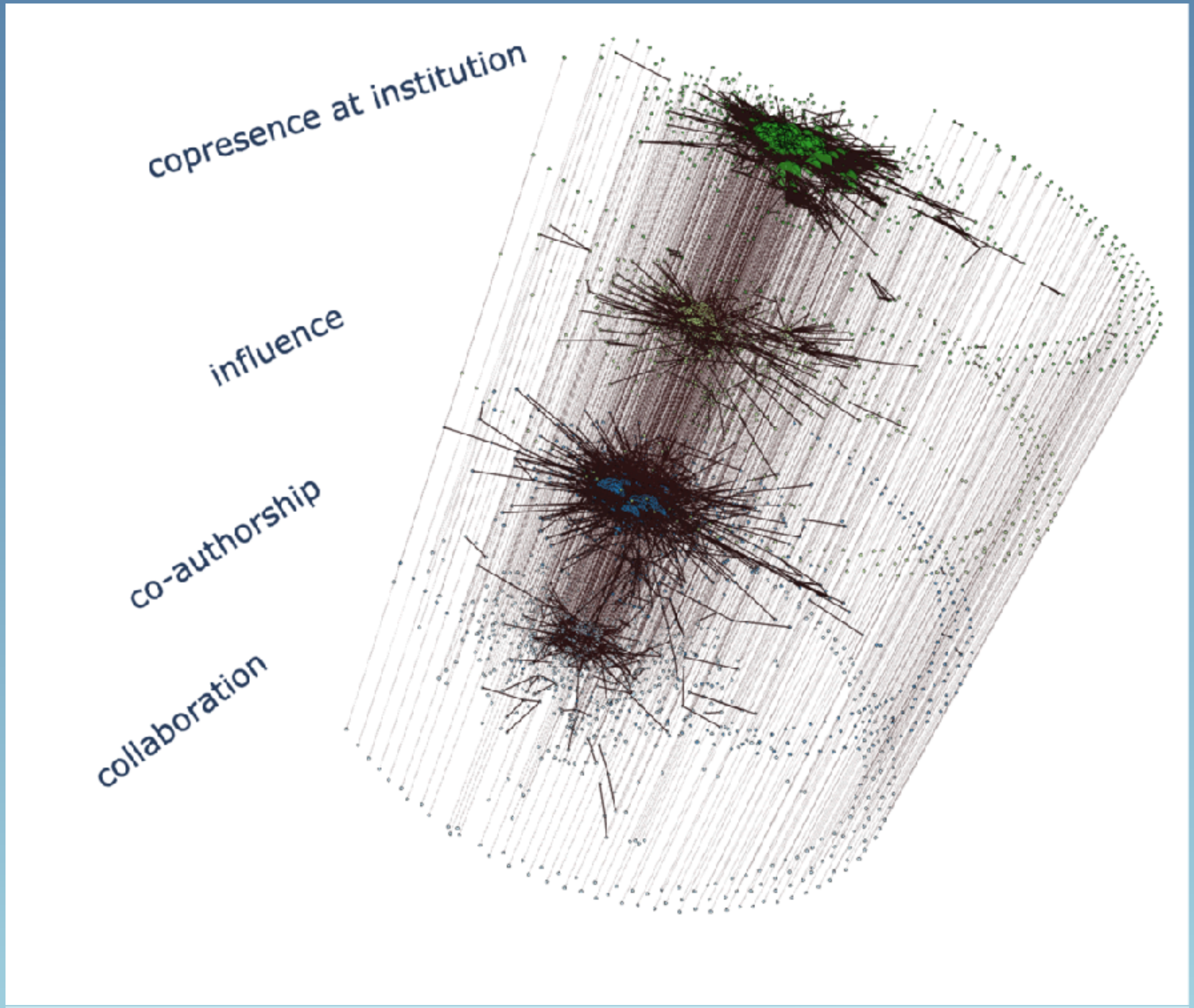
- PhD student / PhD supervisor
- Influenced by
- Collaboration with
  - Long co-authorship relation
  - Collaboration documented in biographical accounts
- Co-authorship

Persons-persons bipartite projection

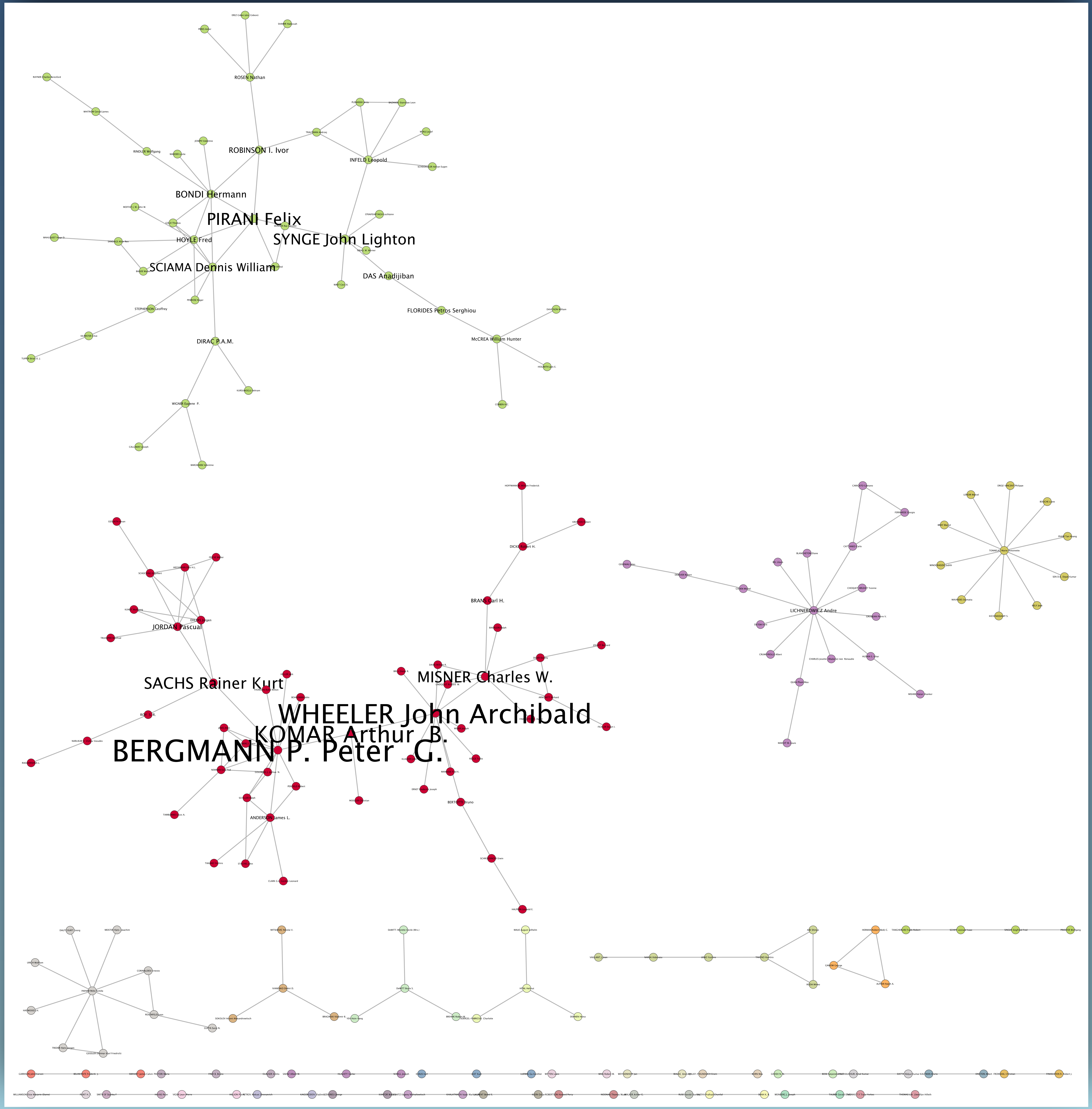
- Work at the same institution at the same time

Institutions-institutions bipartite projection

- Sharing of persons within a certain timespan



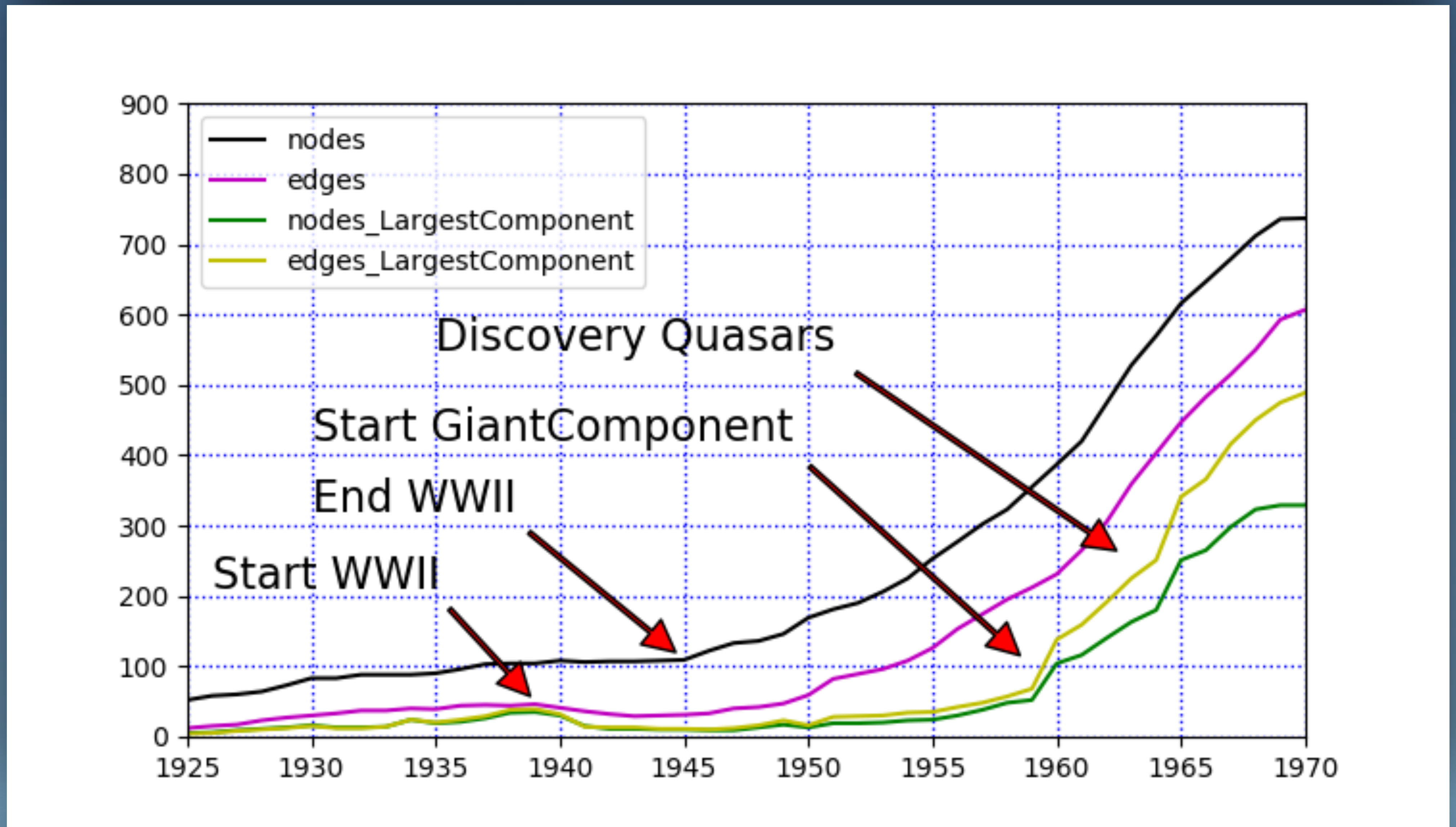
The *Collaboration network* in 1959. Isolated nodes have been excluded. Colors identify different connected components. Size labels proportional to betweenness centrality values. Centrality measure calculation and visualization with *Visone*

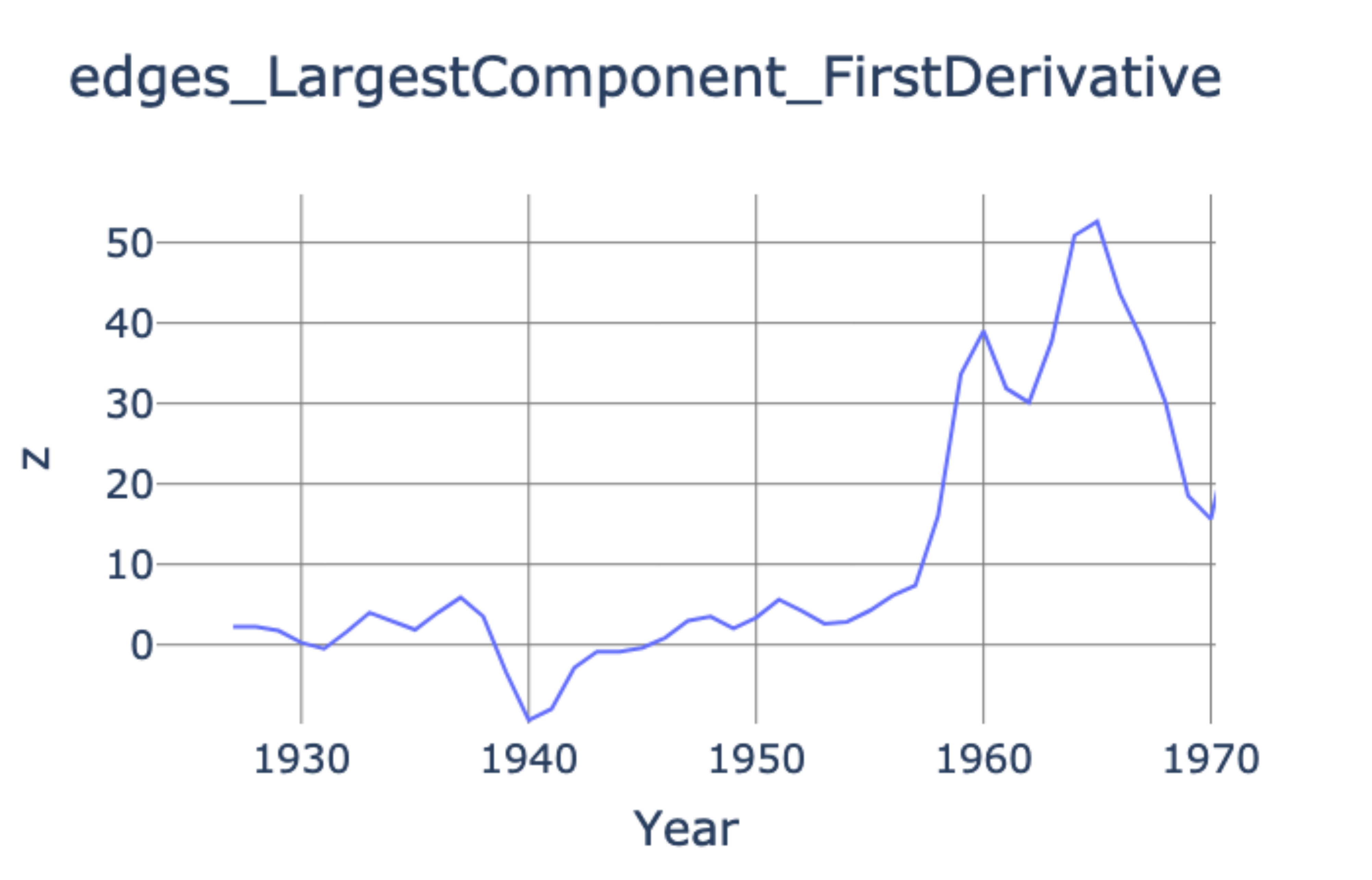


Dynamics of collaboration networks in GR, 1925-1970

Number of scientists working on GR started increasing soon after WWII, but no effect on the largest connected component and the topology of the network.

A sudden, drastic increase in the formation of a giant connected component set in only around 1960 and not immediately after WWII

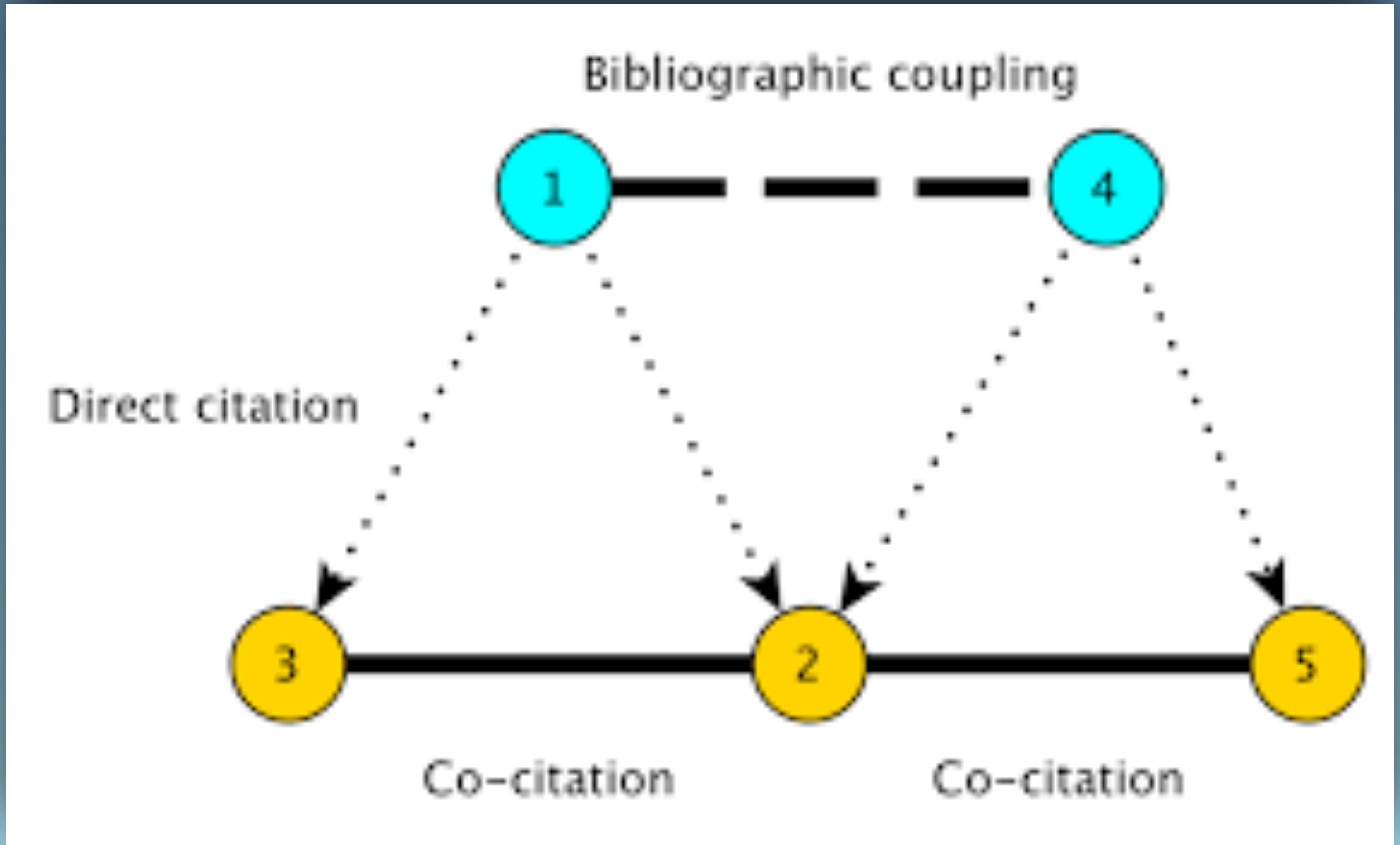


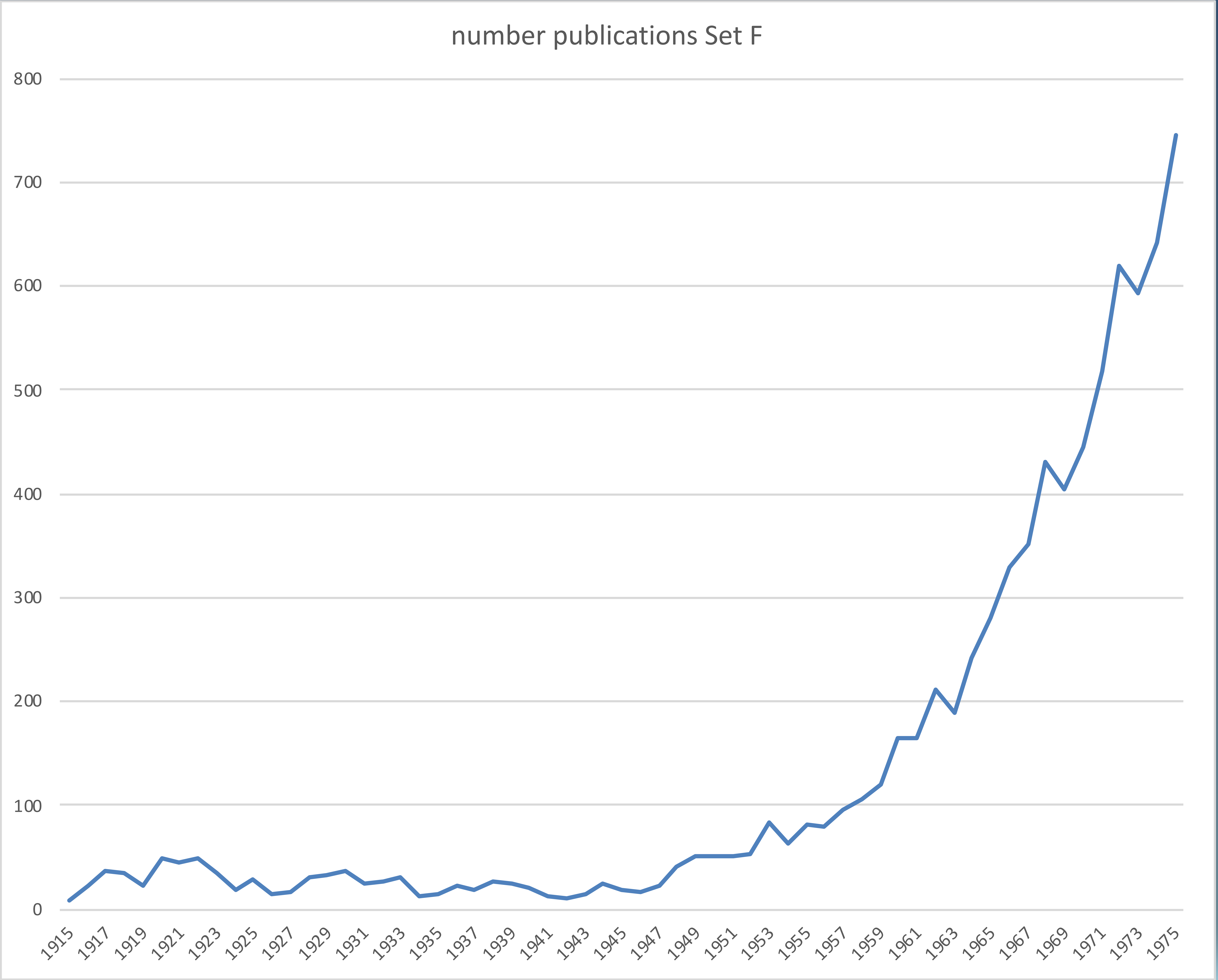


Types	Nodes	Edges	Nodes	Edges
Semantic	Concepts	Causal structures Dependencies	Keywords / Research agendas	Co-occurrence
Semiotic	Material or formal representation s of knowledge	Formal relationships	Publications Artifacts Institutions	Citations Organisational structures
Social	Social actors	Social relationships	Persons Institutions Commissions Groups	Collaborations Influence Advice Affiliation Co-participation

Dynamics of semiotic networks in GR, 1925-1970

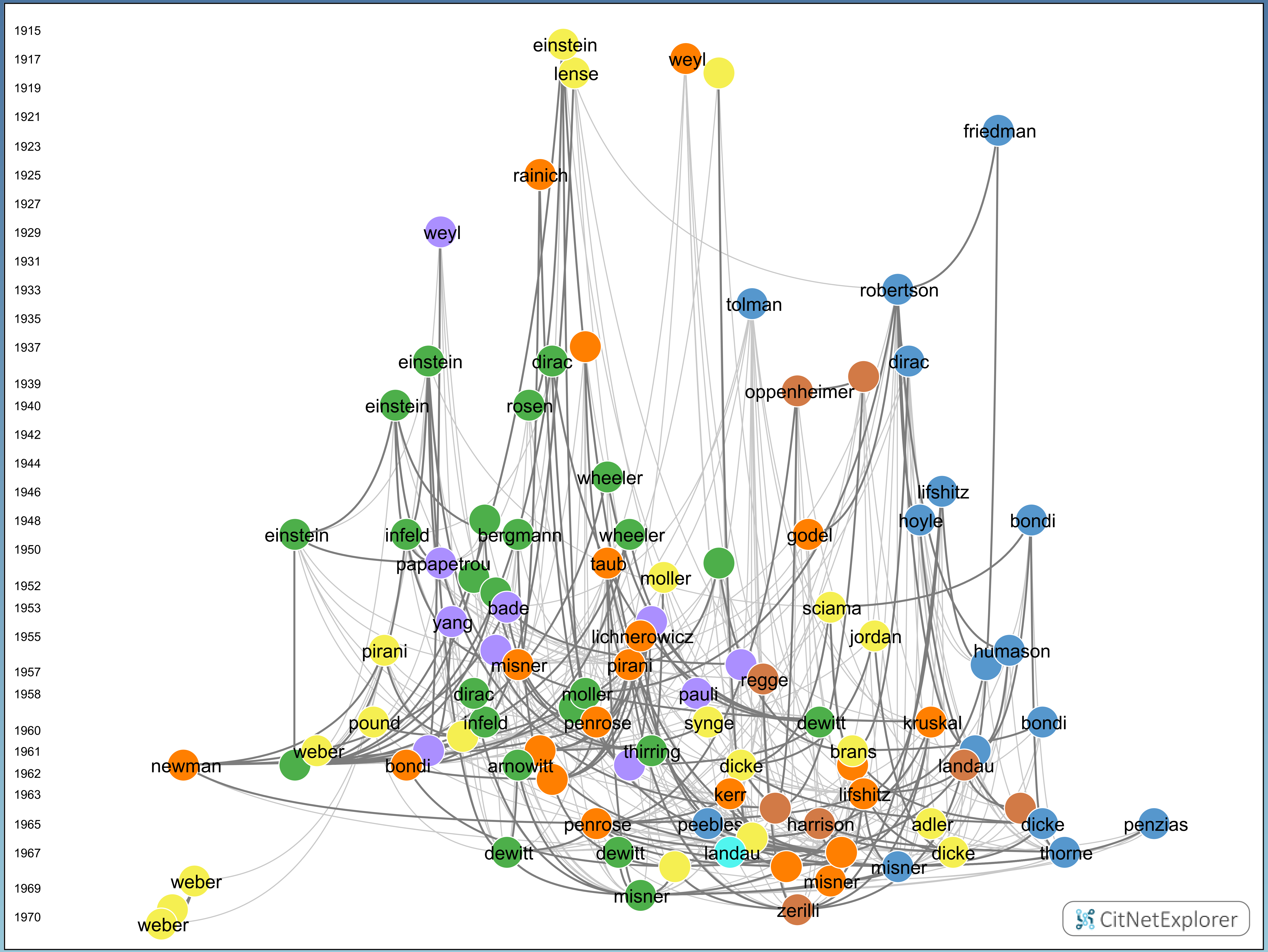
Co-citation network





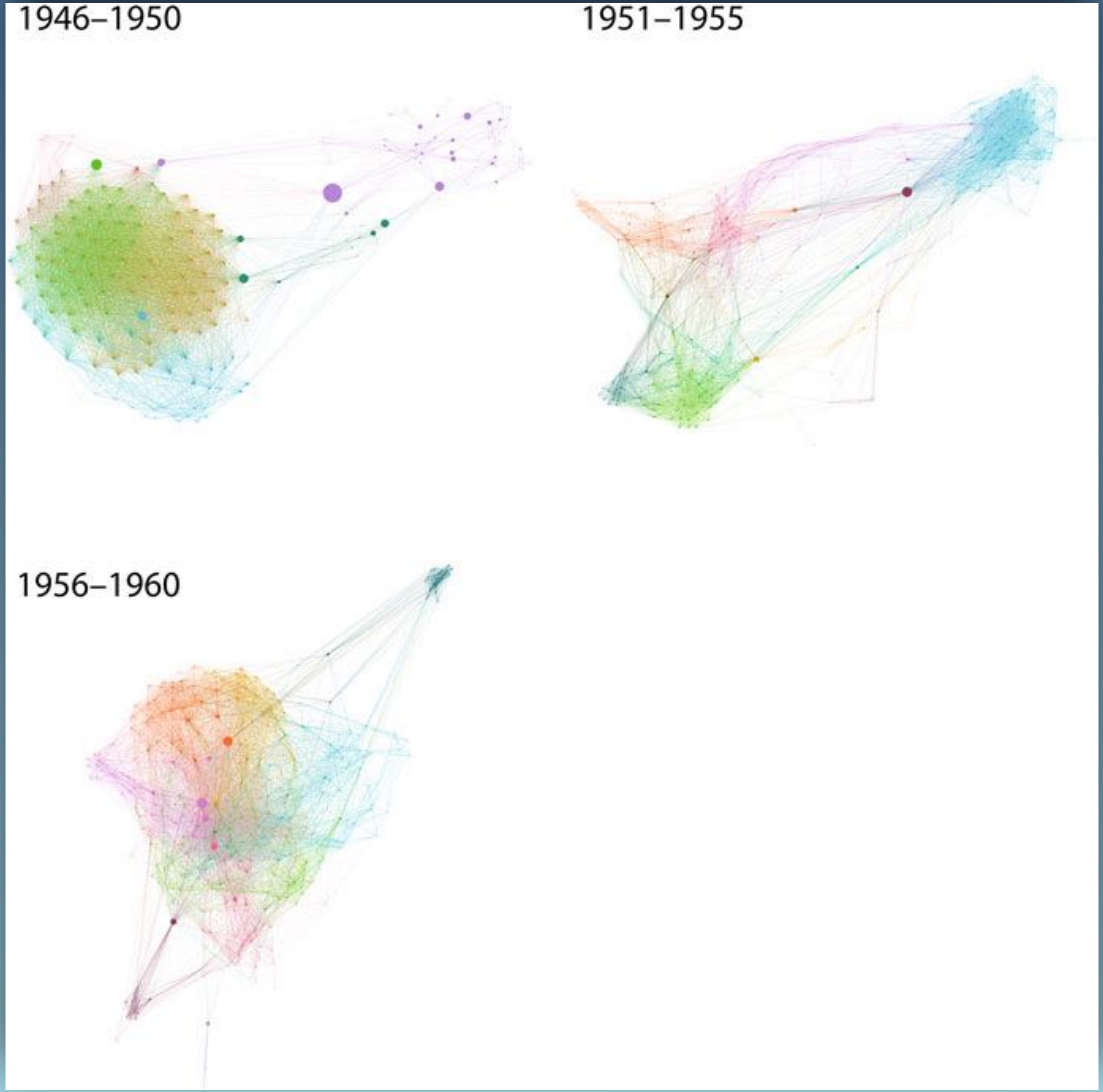
Number of publications per year in the *General Relativity Publication Space* (WoS)

Citation network of the 100 publications with the highest citation scores published between 1915 and 1970. Colors represent different clusters.



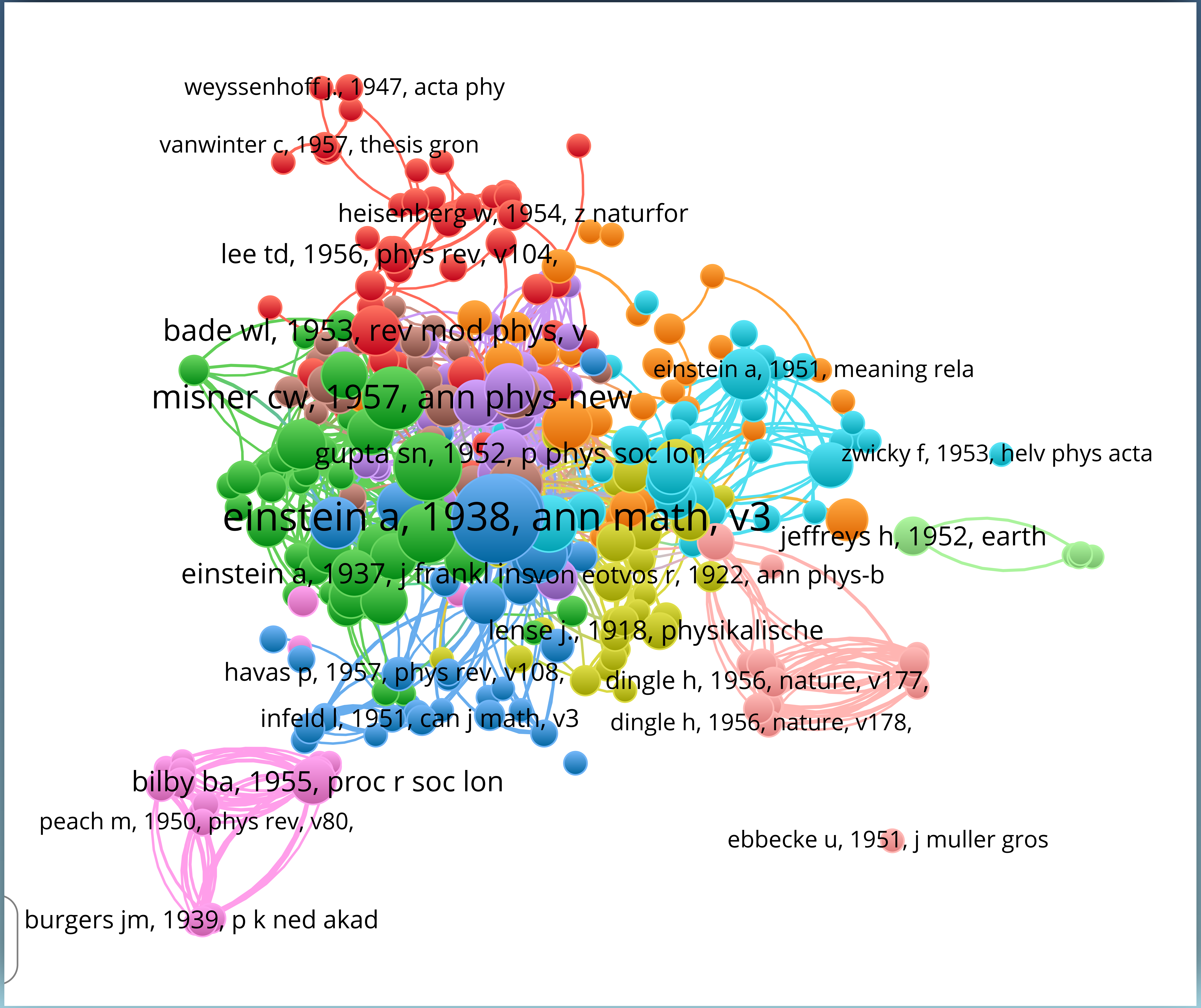
Structure of the co-citation networks in GR, 1946-1960

Structures of the co-citation networks of the general relativity publication space. Colors represent different clusters.



Toward a Semio-semantic analysis
Co-citation network GR, 1956-1960

Cluster	Research area
1 - red	relations between GR and relativistic quantum field theory
2 - green	theory gravitational waves/initial value problem/ conservation laws/ADM formalism/geometrodynamics
3 - blue	equations of motion in GR
4 - yellow	proposal tests in GR/alternative theories for testing
5 - purple	quantization of gravitation
6 - light blue	Non-Big Bang cosmology
7 - orange	Affine UFT
8 - brown	Initial value problem in GR/space-time singularity
9 - pink	crystal dislocation with non-Riemannian geometries
10 - light pink	twin paradox
11- light green	earth gravitational field



Dynamics of Co-citation networks in GR, 1947-1974

Phase I: Low-water-mark

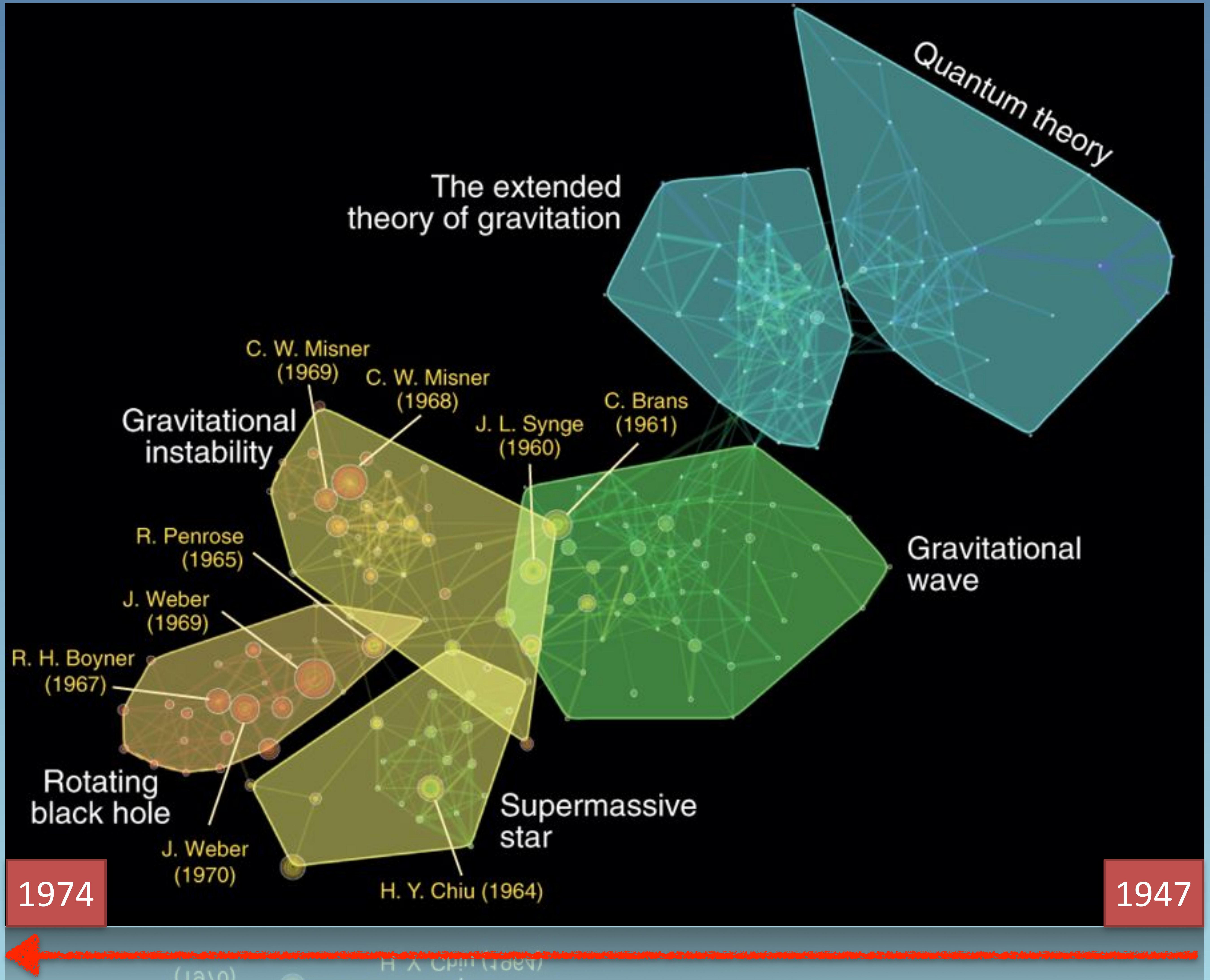
Dispersion in research agendas aimed at overcoming the theory of general relativity

Phase II: Renaissance of GR (mid-1950s-1963)

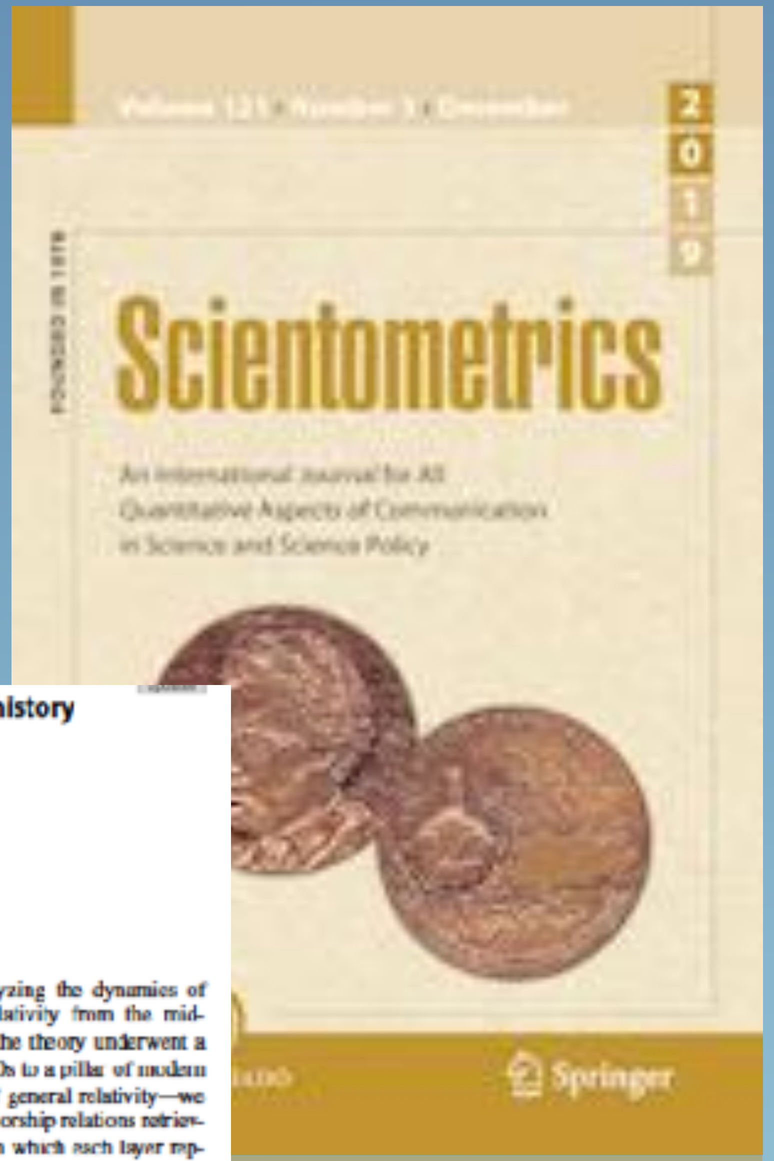
Emergence of a large cluster of papers focusing on GR proper and its physical predictions (esp. GWs). Theoretical reconfiguration related to a social dynamics.

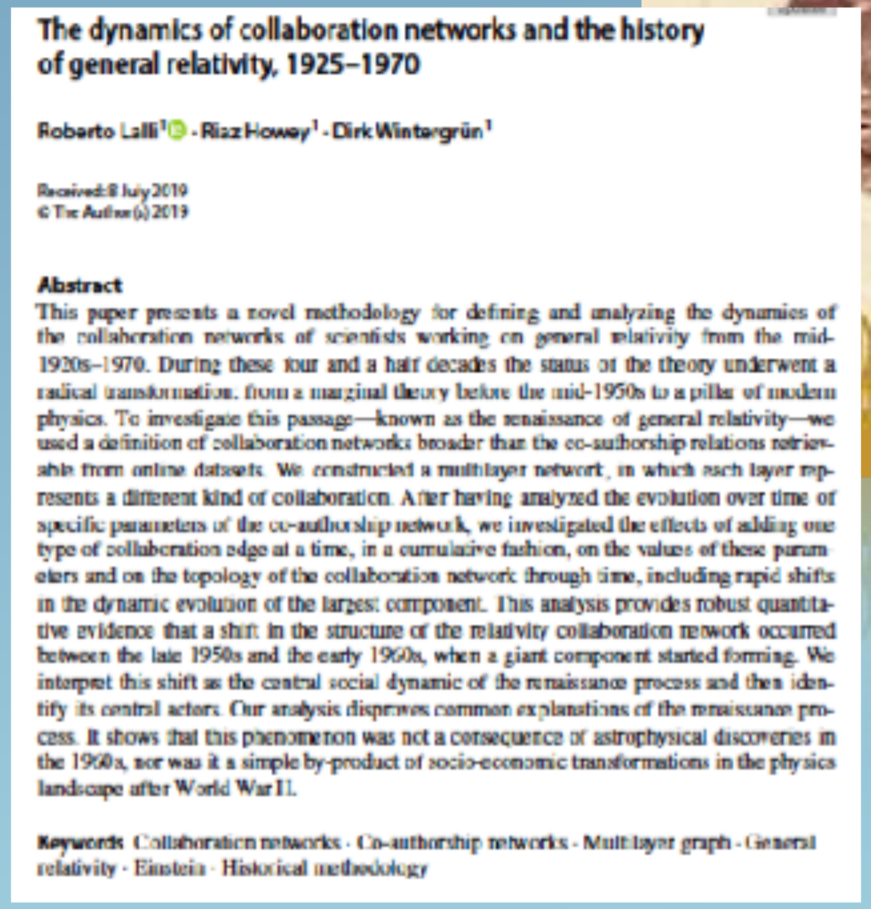
Phase III: Astrophysical turn (1963-1974)

Specialization to research areas strongly connected to recent astrophysical discoveries in the 1960s. Experiment-driven reconfiguration of research agenda toward relativistic astrophysics and physical cosmology.



Thank you for the attention!





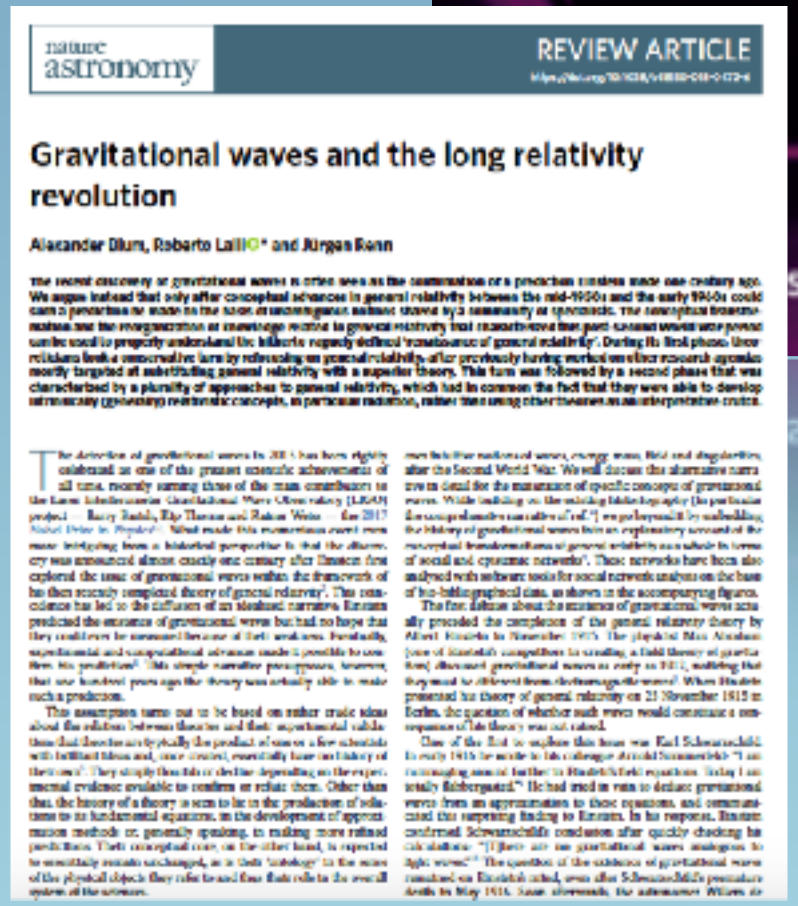
The dynamics of collaboration networks and the history of general relativity, 1925–1970

Roberto Lalli[1] · Riaz Howey[1] · Dirk Wintergrün[1]

Received: 8 July 2019

Abstract
This paper presents a novel methodology for defining and analyzing the dynamics of the collaboration networks of scientists working on general relativity from the mid-1920s–1970. During these four and a half decades the status of the theory underwent a radical transformation: from a marginal theory before the mid-1950s to a pillar of modern physics. To investigate this passage—known as the renaissance of general relativity—we used a definition of collaboration networks broader than the co-authorship relations retrievable from online datasets. We constructed a multilayer network, in which each layer represents a different kind of collaboration. After having analyzed the evolution over time of specific parameters of the co-authorship network, we investigated the effects of adding one type of collaboration edge at a time, in a cumulative fashion, on the values of these parameters and on the topology of the collaboration network through time, including rapid shifts in the dynamic evolution of the largest component. This analysis provides robust quantitative evidence that a shift in the structure of the relativity collaboration network occurred between the late 1950s and the early 1960s, when a giant component started forming. We interpret this shift as the central social dynamic of the renaissance process and then identify its central actors. Our analysis disproves common explanations of the renaissance process. It shows that this phenomenon was not a consequence of astrophysical discoveries in the 1960s, nor was it a simple by-product of socio-economic transformations in the physics landscape after World War II.

Keywords Collaboration networks · Co-authorship networks · Multilayer graph · General relativity · Einstein · Historical methodology



nature astronomy REVIEW ARTICLE

Gravitational waves and the long relativity revolution

Alexander Blum, Roberto Lalli and Jürgen Renn

The Socio-Epistemic Networks of General Relativity, 1925–1970

Roberto Lalli, Riaz Howey, and Dirk Wintergrün

1 Introduction

Network has long been a catchword in history writing. Until recently, however, network concepts and terminologies have been mostly employed on a purely metaphorical level without engagement with the tools of network theory developed in sociology, biology, physics, engineering, computer science, and so on (Freeman 2004).[1] For decades, *network* has been employed to quickly label complex social and, more rarely, conceptual phenomena with little if any explanatory value other than some generalized recognition of the role of social structures in history.[2]

A new body of literature has gone significantly beyond these early attempts to conceptualize and narrate historical processes at the level of network dynamics. Thanks to increasing computing power, newly available big data repositories and dedicated software programs, a research field has recently emerged called Historical Network Research (HNR), which promises to make the most of formal methods of Social Network Analysis (SNA) applied to corpora of historical data (Düring 2017).[3] Within this broad field, new approaches have been developed aimed at employing network concepts and tools in the history of science (e.g., Fangerau 2010; Preiser-Kapeller and Daim 2015; Breure and Heiberger 2019).