Knowledge dynamics

(and its implications for European institutions of science)

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Knowledge for growth

“New” sciences

Unprecedented combination between scientific discovery and technological exploitation in new areas of science:
- computer/ information science
- life science
- materials science (including nanotechnology).

Different from XX century science and technology:

- particle physics and nuclear technology

- fluidodynamics/ control theory/ cybernetics and aeronautics

- biology, biochemistry and clinical science

Epistemic origin

The configuration of new sciences does not result primarily from external influences (e.g. patterns of funding of research, pressure from industry, societal problems).

Rather, it is the result of the unfolding of internal epistemic dynamics in science.
Main factors:

1. Reductionism applied to complex systems
2. Science-driven engineering
3. New forms of complementarity and coordination

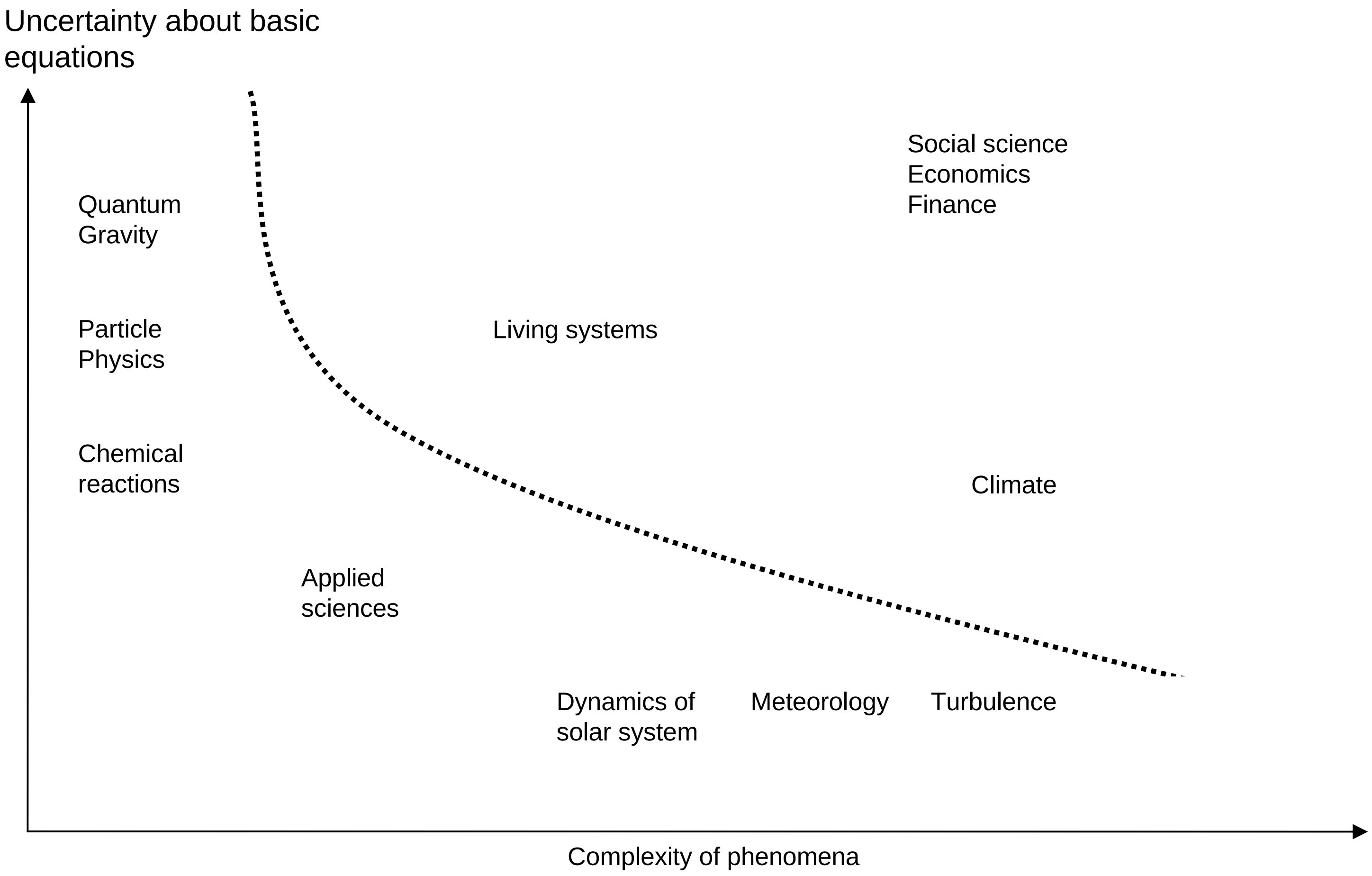
Reductionism applied to complex systems

Emerging sciences have systematically applied the enormously successful model of modern physics (i.e. identifying causal factors of phenomena and modeling them) to objects of increasingly large complexity

Phenomena located at *higher* levels of organization of matter are explained by means of causal factors that are located at *lower* level of organization, e.g.:

- molecular oncology
- optical behavior of nanostructured materials

A schematic representation of the degree of uncertainty that exists in the underlying mathematical equations describing various phenomena relative to the intrinsic complexity of the phenomena



Source: Barrow (1998) after Ruelle

Reductionism applied to complex systems/2

Multi-disciplinarity is not created by a theoretical convergence between disciplines, nor by a supposed Mode 2 knowledge production model.

Rather, and surprisingly, it is the result of admitting that when reductionism is applied to complex systems, **at each layer of the system new knowledge must be added.**

Disciplines can be seen as repositories of knowledge **specialised by layer of matter**.

Disciplines maintain their status, but at the same time engage into dialogue with disciplines at different layers.

Science-driven engineering

In old technoscience technology followed clearly identified trajectories defined by performance levels, e.g.:

- size of airplanes (ASM, available seat mile)
- integration of circuits (Moore’s law: number of logical units per square millimeter)
- cost of kilowatt

Science was called for when technological knowledge and design expertise failed to identify solutions (chain-linked model: Kline and Rosenberg).

Functions of artefacts were defined independently from science (with a few exceptions, e.g. laser).

Science-driven engineering

New technoscience is based on science-driven engineering

Functions of artefacts are not known at all, even not conceived at all, before scientific discovery.
Rather, functions are themselves the object of discovery.

For the first time in the history of science and technology, there is no a long time interval between:
- theoretical prediction
- observation
- manipulation.

E.g. scanning tunneling microscope (1981), polymerase chain reaction (1985) , atomic force microscope (1986)

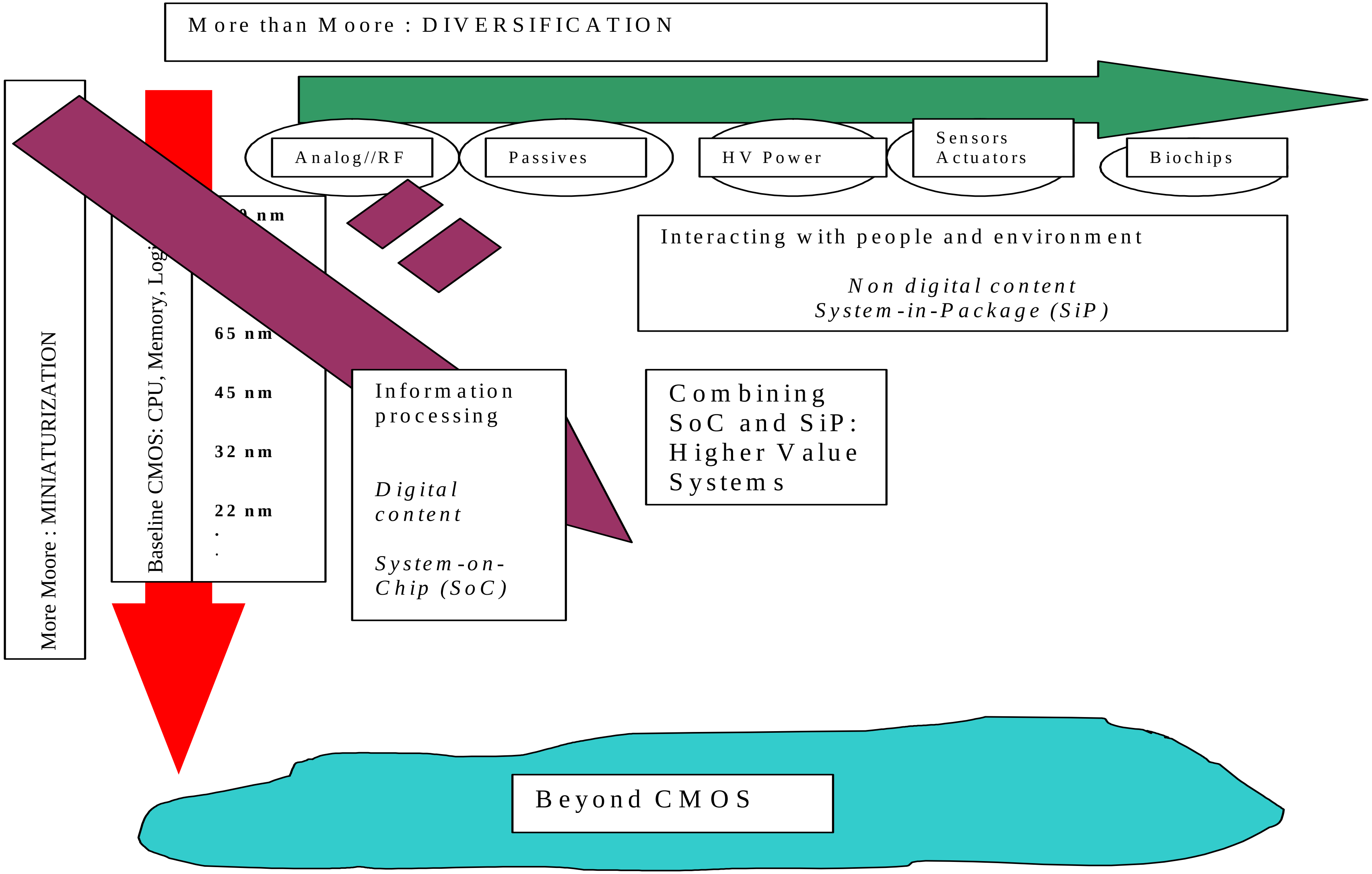


Figura 1
Evoluzione della tecnologia dei semiconduttori nei prossimi 15 anni

Fonte: International Technology Roadmap for Semiconductors, *Final Draft*, 2007.

New forms of complementarity

A. Infrastructure complementarity

XX century big science (particle physics, astrophysics, space) was based on large infrastructures

- high energy levels
- enormous complexity of observation and measurement equipment
- huge cost of construction and operation
- large intergovernmental cooperation
- centralized location
- bureaucratic management

A. Infrastructure complementarity/ 2

New emerging sciences are on the contrary based on equipment :

- intermediate energy levels (solid state matter, condensed state matter, living matter)
- moderate cost
- low barriers to entry for laboratories
- funding by national/ regional governments
- decentralized location and clustering.

Need to design and implement new forms of mobilisation of resources and interactions.

European institutions less prepared.

Table 2
Total expenditure of the French government for large scientific equipment. Year 2000. Personnel expenditure included.

Scientific field	Equipment	Total expenditure (million FF)	%
Meteorology and space	ETW, EUMETSAT, MSG, METOP, International space station	1272	27,6
Particle physics	Electron accelerator, CERN*, Large Hadron Collider (LHC)	894	19,4
Planetology	CASSINI, CLUSTER 2, Mars Exploration, Mars Express, ROSETTA	332	7,2
Earth observation	ENVISAT, ERS 1-2, EURECA, POLDER, PROTEUS-JASON, SCARAB, TOPEX-POSEIDON	300	6,5
Space astrophysics	HIPPARCOS, INTEGRAL, ISO, Reduced cost mission, SIGMA, SOHO, XMM	280	6,1
Neutrons	ILL**, LLB, SILOE	274	6,0
Synchrotron	ESRF***, LURE, SOLEIL	272	5,9
Oceanology	Flotte, WOCE	211	4,6
Life sciences	EMBL****, Life science in space	201	4,4
Astronomy	CFHT, ESO*****, IRAM, VLTI	182	4,0
Nuclear	Ganil, Saturne	159	3,5
Fusion	JET, TORE SUPRA	155	3,4
Gravitational physics	VIRGO******	60	1,3
Geology	GéoFrance 3D, GPF, ODP	12	0,3
Total		4604	100,0

B. Cognitive complementarity

New emerging sciences are based on the cognitive complementarity between different disciplines.

However, there is no such thing as “multi-disciplinarity” in the sense of fusion, or elimination of disciplinary barriers.

Rather, new forms of cognitive complementarity are created:

- molecular biology- biochemistry laboratory- clinical research- epidemiological research
- ocean physics- fluidodynamics- oceanology- ecology
- matter physics- inorganic chemistry- chemical engineering- characterization theory

C. Institutional complementarity

From an institutional point of view, it is interesting to observe that different levels of observation can be historically ascribed to different institutions:

- Molecular level	molecular biology laboratory
- Genomics/Proteomics	bioinformatics laboratory
- Cell level	cell biology laboratory
- Tissue	istology department
- Organ	pathology department
- Patient	hospital
- Population	public health agency
- Collective behaviour	patient association

C. Institutional complementarity/2

Sciences dealing with large scale systems (e.g. epidemiology, food safety) create complementarities with **non-scientific institutions** (e.g. quality agencies, certification labs)

Complementarity with **civic society** (patient association, voluntary organizations)

C. Institutional complementarity /3

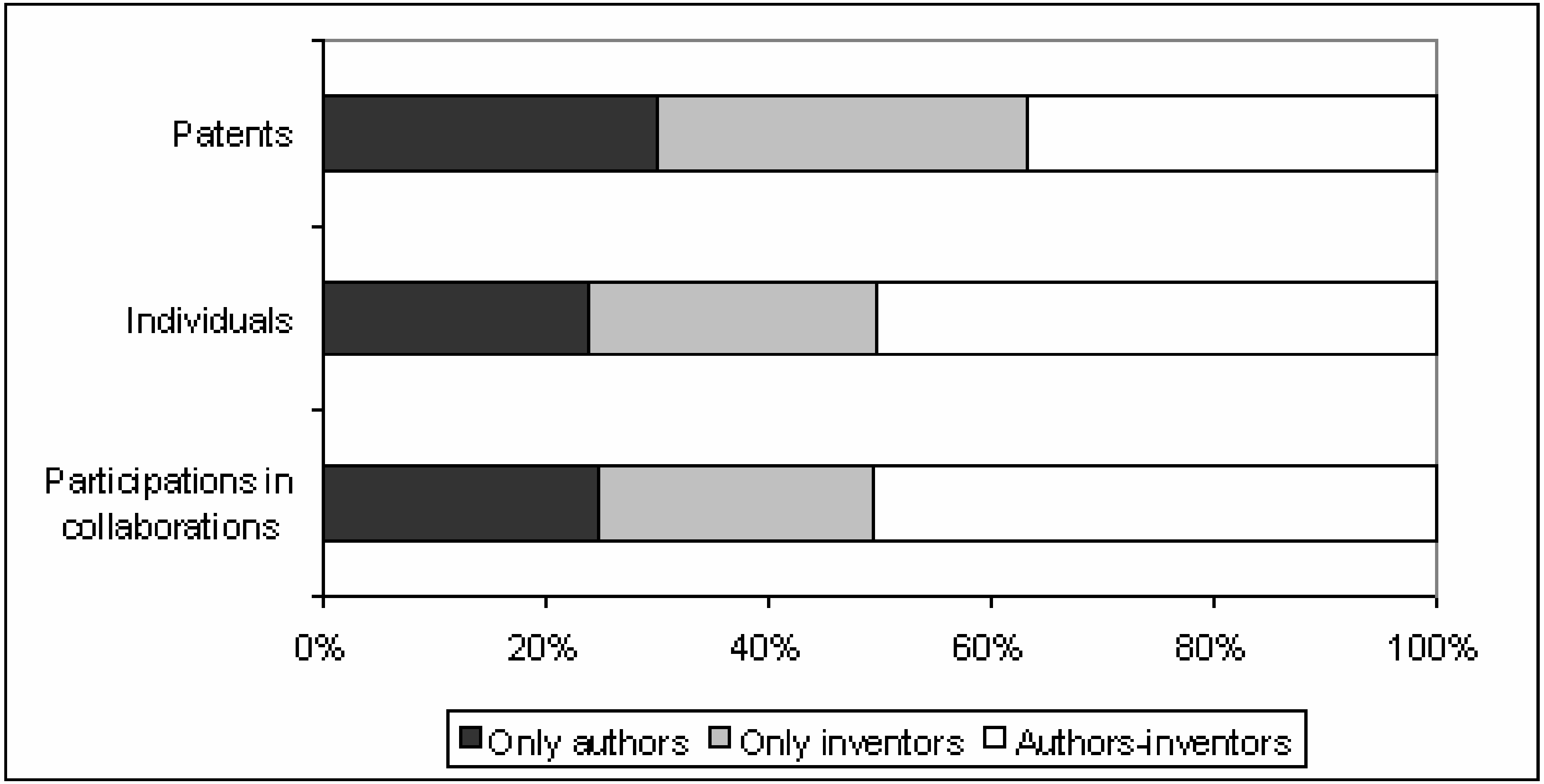
New forms of collaboration between academia and industry are not only the result of external pressures:

- lack of funding of universities
- protection of intellectual property rights on publicly funded research (Bayh Dole Act)
- professionalization of technology management (AUTM)

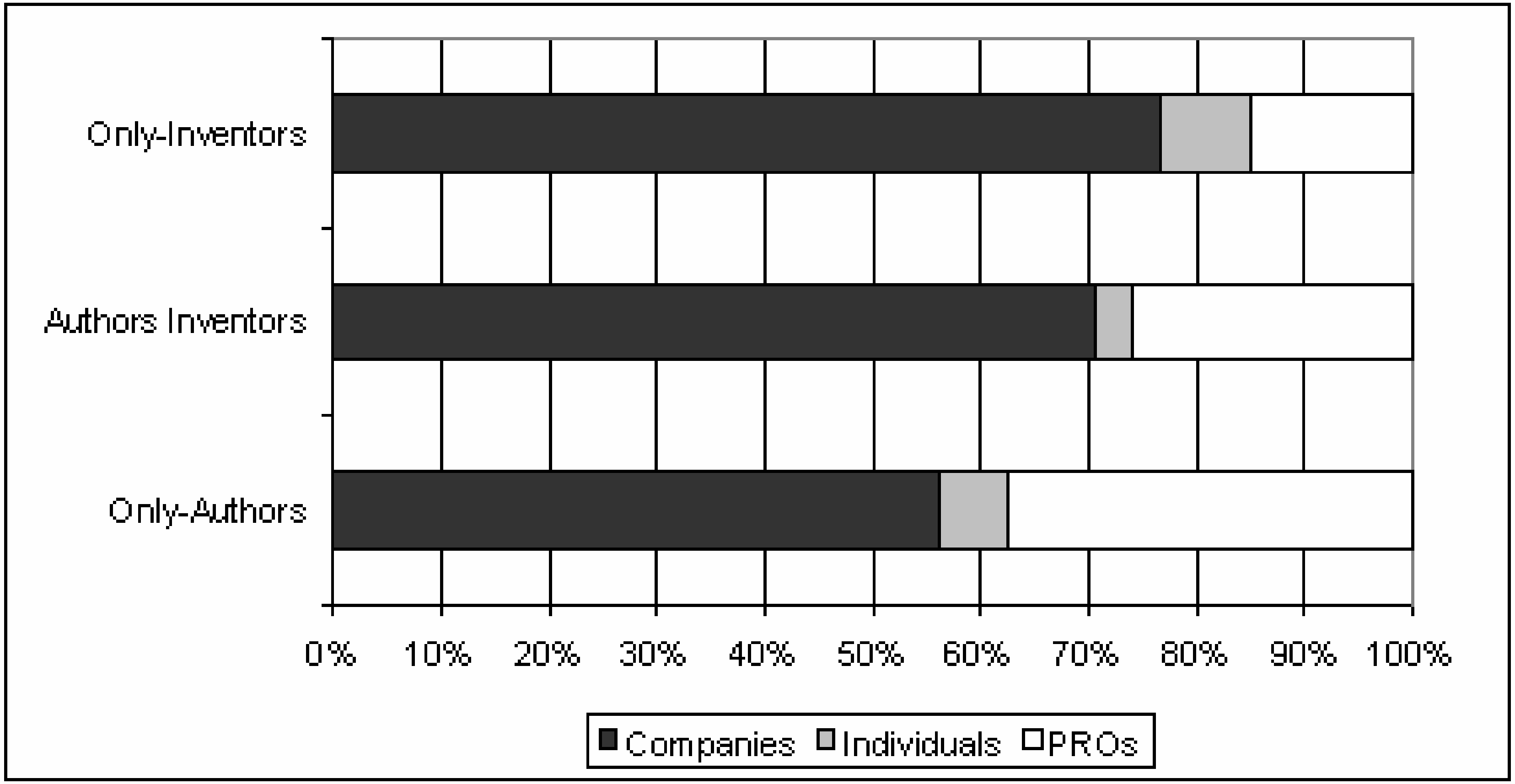
New technoscience require ex ante coordination and joint search between scientists and technologists, or author-inventors.

European institutions weaker.

S&T complementarities at the inventor level



Distribution of patents by assignee type in relation to community



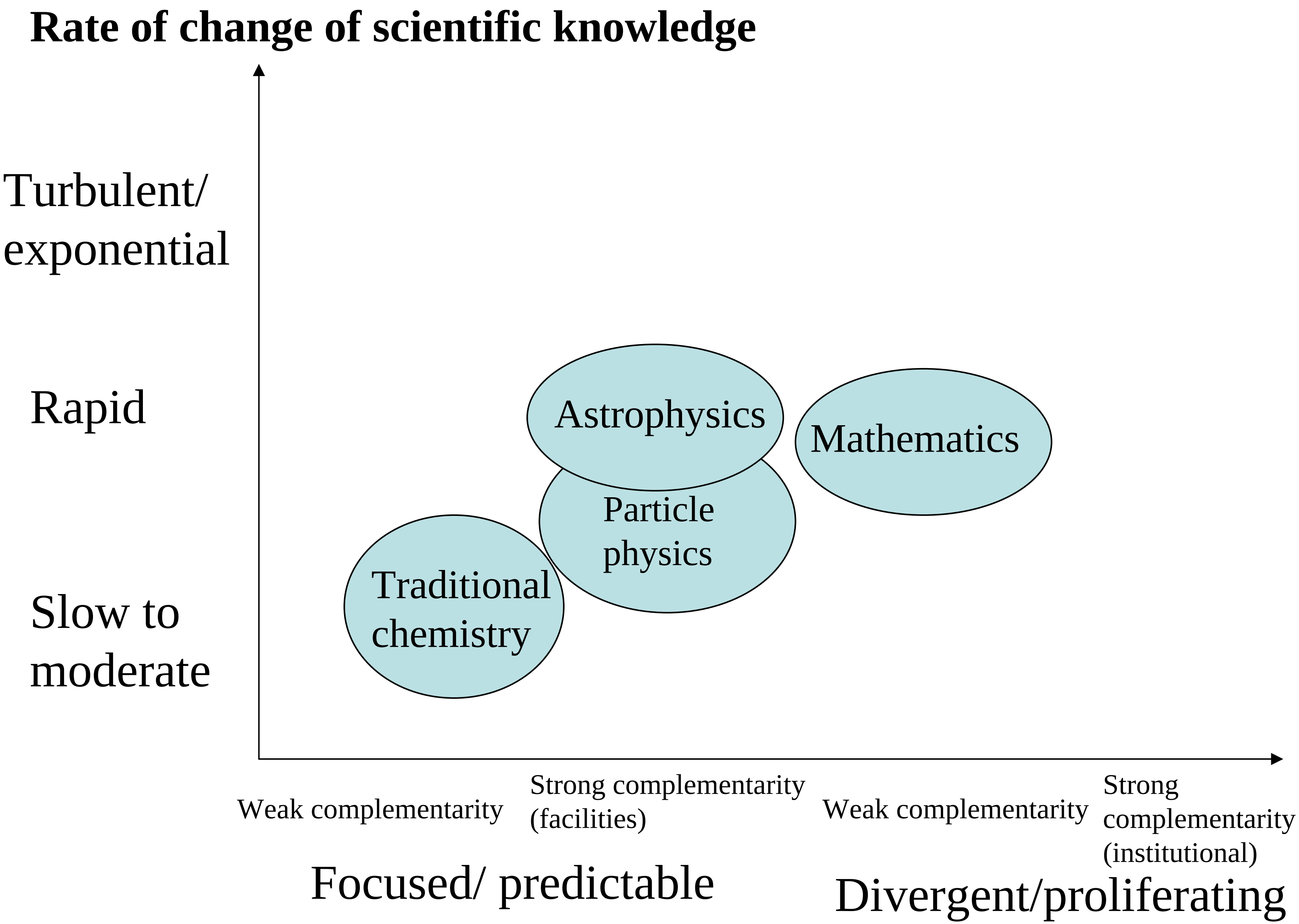
Structure of affiliations and institutional complementarities in publications of top 1,000 scientists in Computer science and High energy physics

	Computer science	High energy physics
Number of publications with full affiliations	6,386	34, 340
Number of different affiliations identified	1,857	6,439
% of papers with at least one industrial affiliation	21.3 %	13.1 %
% of papers with only academic affiliations	67.5 %	49.8 %
% of papers with at least one industrial affiliation and at least one academic affiliation	17.8 %	7.5 %
Total number of occurrences of affiliations in publications from the **top 100 affiliations**	8,304	68,863
Of which:		
- total number of occurrences of universities	7,136 (85.93%)	51,356 (74.58%)
-total number of occurrences of other research institutions	296 (3.56%)	17,507 (25.42%)
- total number of occurrences of companies	872 (10.50%)	0 (0.00%)

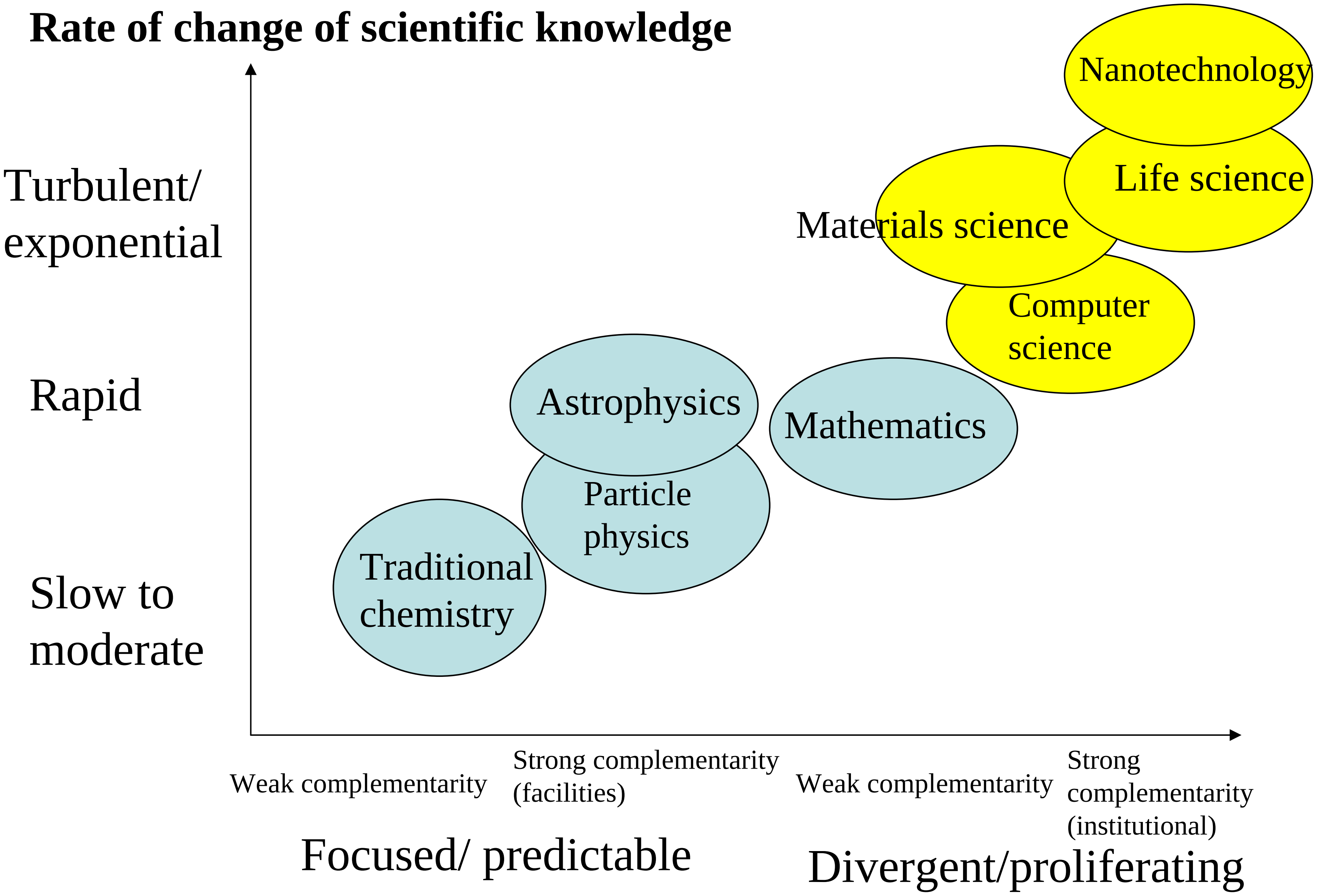
Top ten ideas in computer science

1. Turing machine (Goldstine and von Neumann; Turing)
2. Programming languages; formal description of syntax and semantics; LISP (Mc Carthy)
3. Memory hierarchy; cache memory
4. User interface; Graphic User Interface (GUI); concept of window (Xerox Palo Alto Research Center; Apple)
5. Internet (UCLA/DARPA); packet switched multinetworks; http and html protocols; WWW (Berners-Lee)
6. Computational complexity; computational intractability; pseudocausality
7. Relational database
8. Fourier Fast Transform (FFT) (Cooley and Tuckey)
9. Efficient algorythms; data structure (Knuth and Tarjan)
10. Artificial intelligence

Source: our elaboration from expert opinion



Dynamics of change of scientific knowledge and type of complementarity



Dynamics of change of scientific knowledge and type of complementarity

Implications for institutional change in science

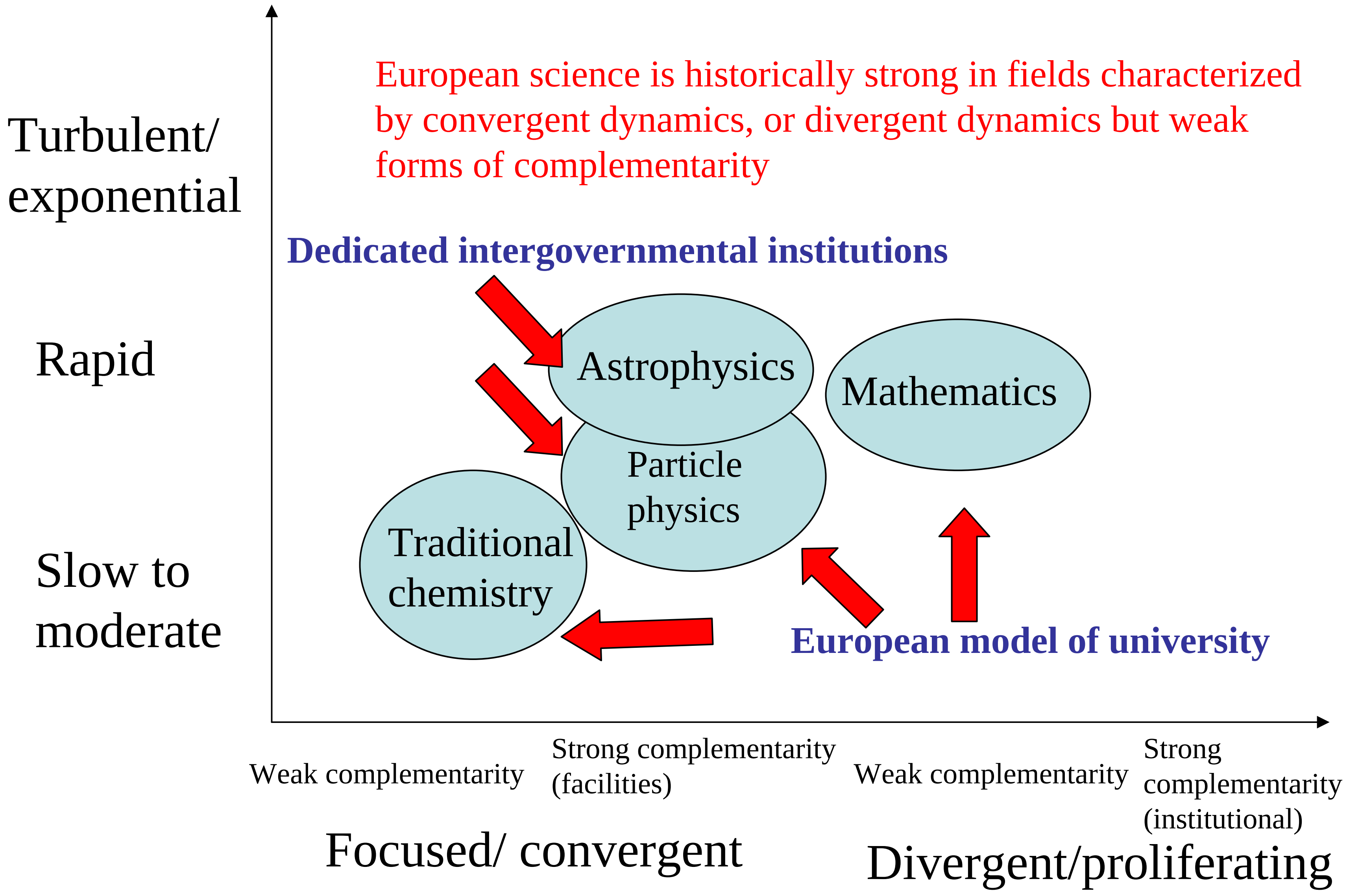
European science has developed **separate institutions** at national, intergovernmental and European level, for dealing with search regimes with strong physical infrastructure complementarities

(e.g. high energy physics, astronomy, space research, oceanography, nuclear technology).

It is much more difficult to provide rapidly emerging fields the required complementarities in terms of human capital within the common institutional framework.

There are few rapid growth mechanisms in European science.

Rate of change of scientific knowledge



Turbulent/ exponential

Rapid

Slow to moderate

European science is historically strong in fields characterized by convergent dynamics, or divergent dynamics but weak forms of complementarity

Dedicated intergovernmental institutions

Astrophysics

Mathematics

Particle physics

Traditional chemistry

European model of university

Weak complementarity

Strong complementarity (facilities)

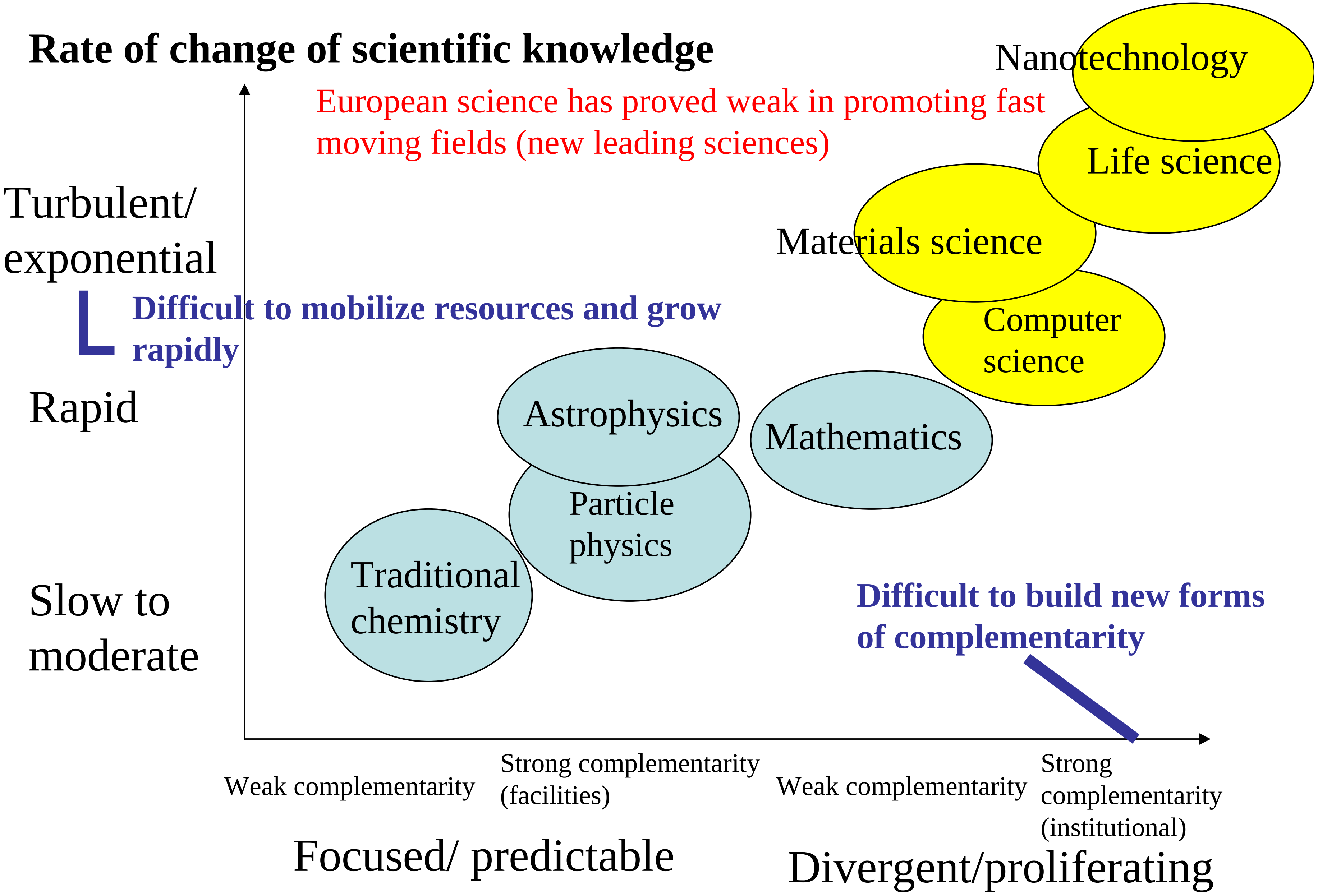
Weak complementarity

Strong complementarity (institutional)

Focused/ convergent

Divergent/proliferating

Dynamics of change of scientific knowledge and type of complementarity



Rate of change of scientific knowledge

European science has proved weak in promoting fast moving fields (new leading sciences)

Turbulent/ exponential

Difficult to mobilize resources and grow rapidly

Rapid

Slow to moderate

Nanotechnology

Life science

Materials science

Computer science

Astrophysics

Mathematics

Particle physics

Traditional chemistry

Difficult to build new forms of complementarity

Weak complementarity

Strong complementarity (facilities)

Weak complementarity

Strong complementarity (institutional)

Focused/ predictable

Divergent/proliferating

Dynamics of change of scientific knowledge and type of complementarity

Problematic implications

Technology follows the same intrinsic tendency to explore so far adopted by science. Autonomy of technology is not only profit-driven, but science- or discovery-driven.

New functions generated internally by scientific discovery are difficult to scrutinize for society.

Increase in awareness and knowledge of citizens require empowerment and delegation of decisions.

Need for science-based societal involvement and ethical dialogue.