Thermodynamics, Evolution, Telescopes.

Olivier Lai,
Laboratoire Lagrange
Observatoire de la Cote D'Azur

GEMINI OBSERVATORY

SUBARU TELESCOPE

Motivation

- Long standing personal interest in Emergence Theory.
  - Robert Laughlin: "A different Universe" (2006)
- Professional (& vested) interest in observatory management, instrumentation & planning thereof.
- "Thermodynamique de l'évolution", F. Roddier 2012.
  - Recent progress in statistical mechanics formalism of thermodynamics in open systems (Dewar, 2003)
    - "To my mind there must be, at the bottom of it all, not an equation, but an utterly simple idea. And to me that idea, when we finally discover it, will be so compelling, so inevitable, that we will say to one another, "Oh, how beautiful. How could it have been otherwise?"

-John Archibald Wheeler

Outline

- This is not a formal science talk, rather a reflection on science, how and why we do it. Questioning current paradigm, necessarily using many shortcuts through analogies, metaphors, tropes… & Personal opinions !
  - Brief outline of thermodynamics of open systems: Entropy, dissipative structures, self-organized criticality
  - Micro/macro evolution, r versus K process.
  - Evolution of observatories. How to stand out in today's landscape.
  - What can we learn from open systems?
    - Towards a more passionate and compassionate Science.

Thermodynamics

- 1st Law: Energy is always conserved. $d\sum E/dt = 0$
- 2nd Law: Entropy always increases: $S \geq 0$
  - Entropy is amount of energy available for work dissipated into heat.
- 2nd law valid is responsible for "the arrow of time". Irreversible processes as entropy increases. From order to heat, from information to noise.
  - System converges towards static equilibrium.
- But we witness (and are witnesses of) local negative entropy (matter self-organizing) all the time.
- Is thermodynamics flawed? No!
  - 2nd law only valid in closed system.

3rd Law of Thermodynamics

- A.k.a. Law of Maximum Entropy Production (MEP)
  - 3rd Law demonstrated by R. Dewar✳ in (broad) terms of statistical mechanics, based on Jaynes information theory.
  - In open systems, it is the rate of production of entropy of entire system that is maximized:
    - ($\sum S \geq 0$, $dS/dt = max$)
- Open systems organize themselves to turn Gibb's Free Energy into heat at maximum rate.

✳Dewar RC. 2003. Information theoretic explanation of maximum entropy production, the fluctuation theorem and self-organized criticality in non-equilibrium stationary states. Journal of Physics A (Mathematical and General) 36, 631-641

Thermodynamics of open systems

- Open systems are defined as ones where there is a flux of matter and/or energy.
  - Open systems receive energy and dissipate it.
- Systems converge towards dynamic equilibrium.
- Given that static equilibrium is peak of phase state probability distribution, dynamic equilibrium necessarily unstable.
  - Being off-equilibrium means the ability to do work → dissipate free energy into heat → Entropy increases.

What is entropy?

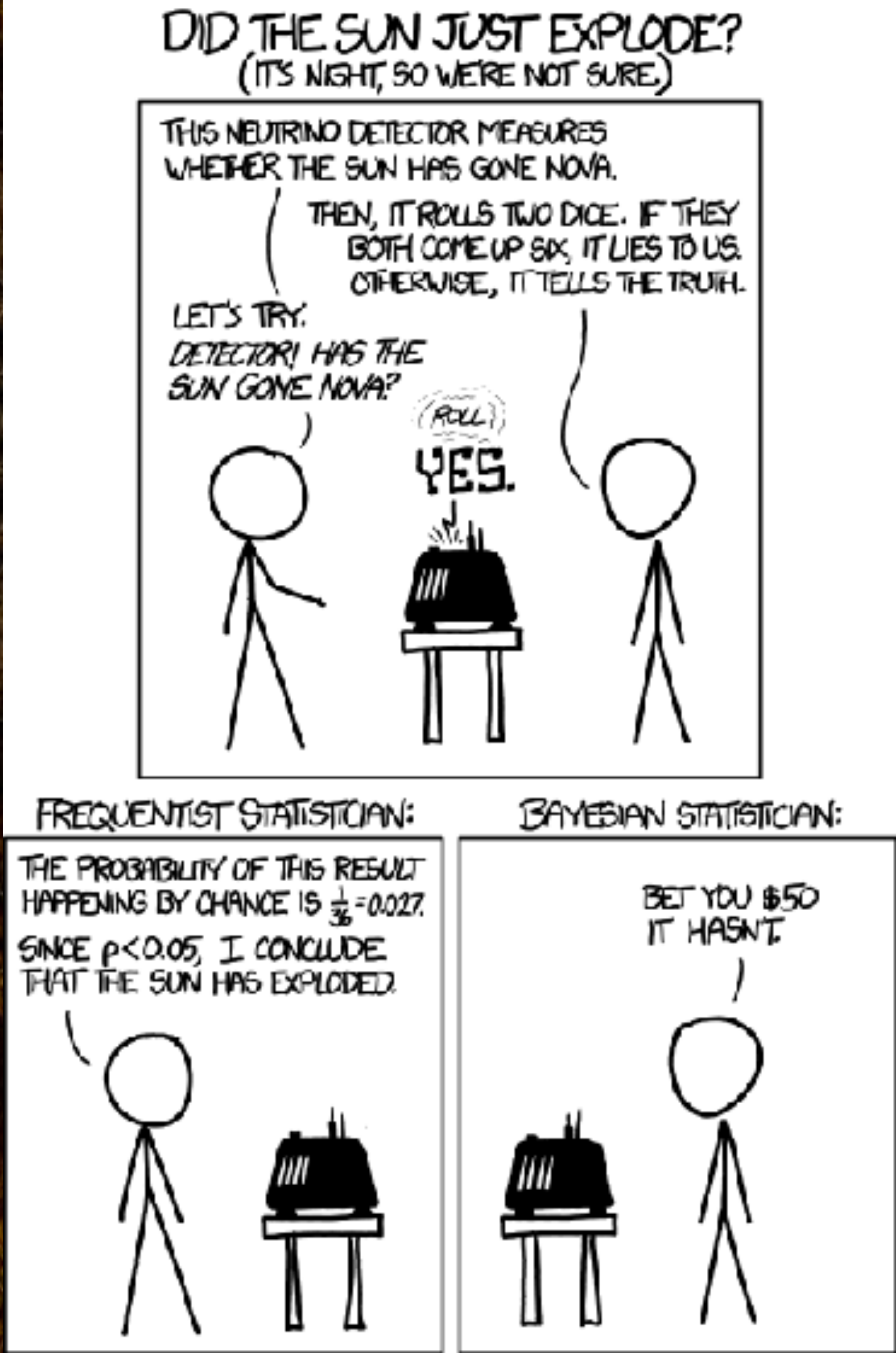
- Not always an easy concept to understand, many different definitions (information entropy, Carnot, etc.)
    - Classically, entropy is the amount of energy capable of doing work (Gibb's Free Energy) converted into unusable energy (heat in equilibrium with surroundings).
    - But information and entropy are also (inversely) related.
        - Information entropy (defined by Shannon) related to knowledge (or probability of a given state) of microscopic system
        - Entropy is a measure of unpredictability of information content.

information & entropy

- According to Jayne's formalism, thermodynamic entropy is interpreted as being proportional to the amount of information entropy needed to define the detailed microscopic state of the system.
    - e.g. adding heat to a system increases its thermodynamic entropy because it increases the number of possible microscopic states compatible with measurable values of macroscopic variables, making any complete state description longer.
    - If all particles in a gas at rest and only one at high velocity: very low entropy, high information content.
    - If all particles have the same velocity, low entropy, mass movement.
    - If particles thermalized, particle's speed (random) distribution

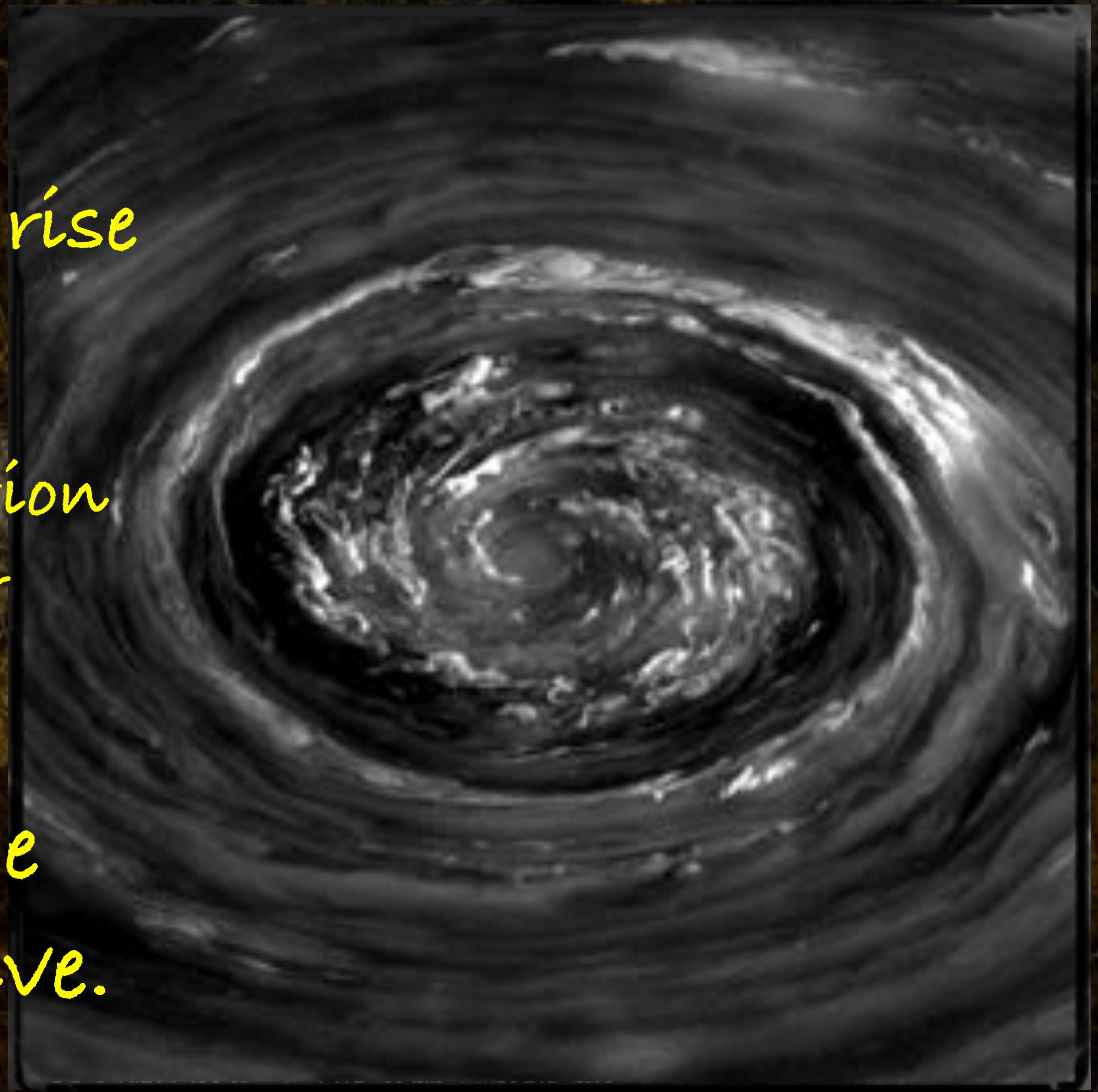
information & entropy

- Jayne's information entropy is decidedly Bayesian, as opposed to frequentist.
  - Because we are part of Universe, our knowledge of it is limited (even without Gödel!)
- Entropy related to probability of a state in system's phase space seen from a macroscopic level.
- The more information contained in a phase state, the lower its probability, the lower its entropy.



Maximum Entropy Production

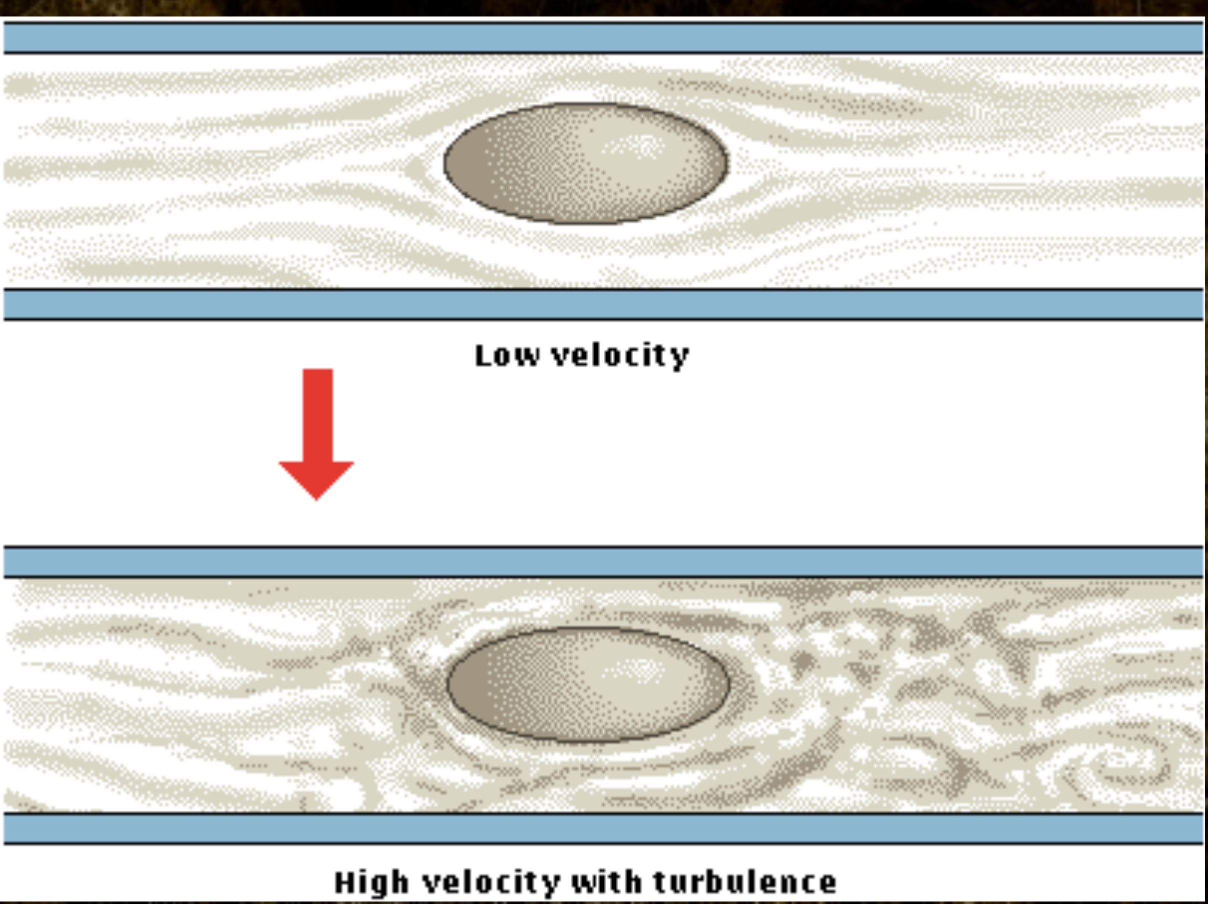
- 3rd Law states that Nature will try to most efficiently homogenize energy distribution.
  - Paradoxically, this may imply the rise of well organized structures:
    - They will internalize some information about environment e.g. velocity shear (locally decreasing entropy).

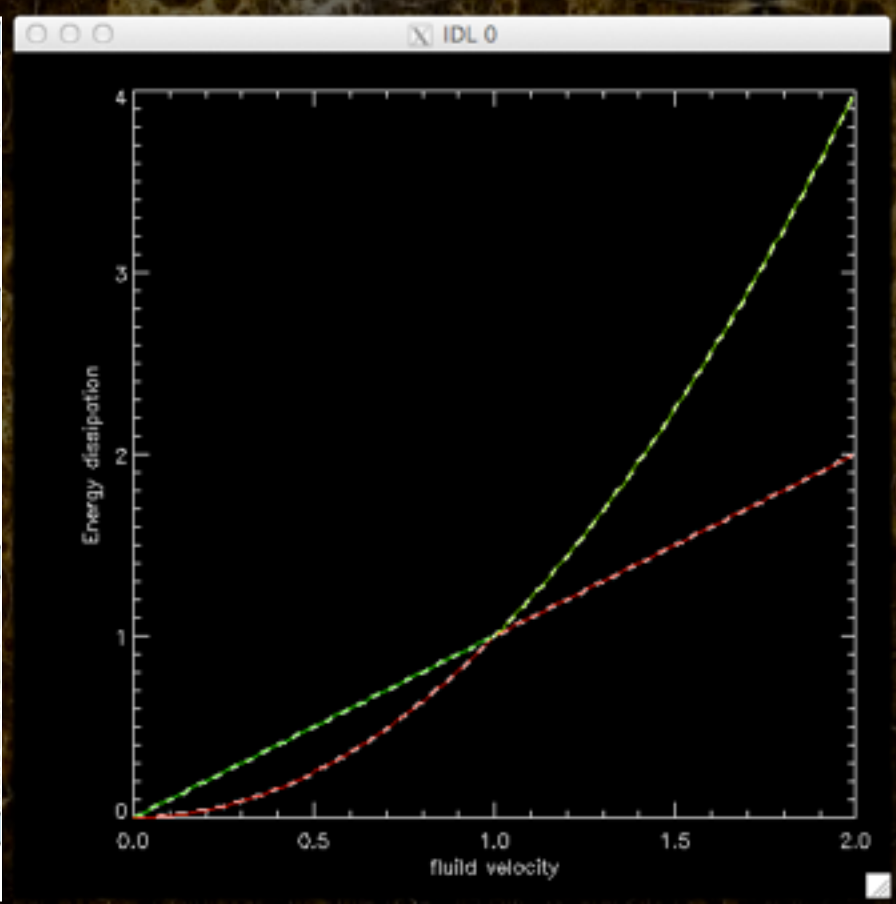


- Emergence of structure to increase entropy may seem counterintuitive.
  - Structure can import information (from environment) to decrease (export) its entropy, as long as entropy maximally produced & free energy dissipated most efficient way.

Simple example

- Fluid flowing in a pipe (open system)
- If velocity is small, flow laminar, kinetic energy dissipated by friction (proportional to v)
- As velocity increases, energy dissipated by turbulence (proportional to v^2), when $v^2 > v$.





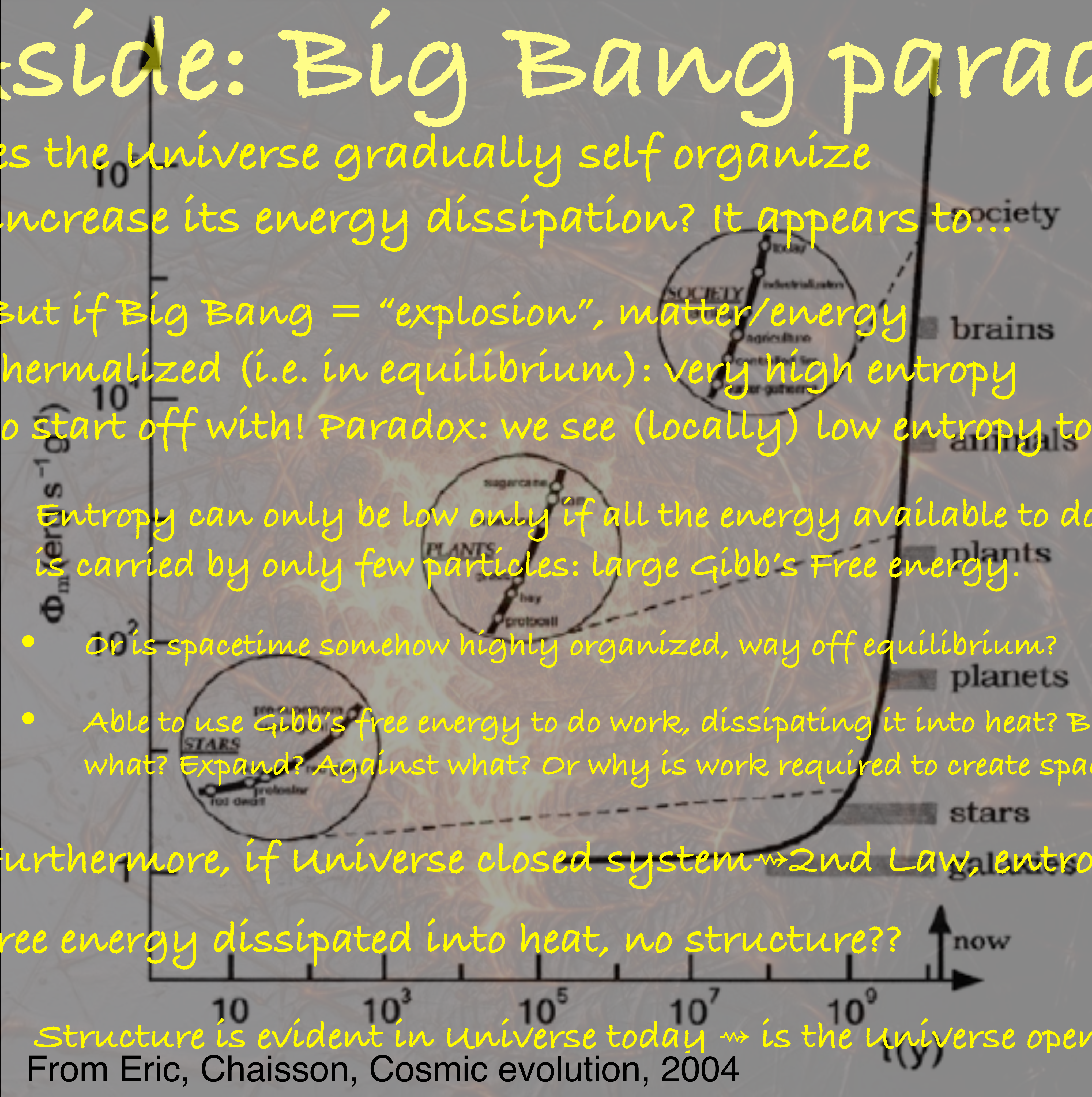
Turbulence & other non-linear processes

- Laminar flow has high information content, but turbulence has even higher information due to emergence of large scale structures (laminar to turbulence = negative entropy difference)
  - Only when turbulence more efficient at dissipating energy.
- It is scale independent (power law). Energy (eddies) at all (small and large) scales. Development of large scale structures implies particles/organisms act coherently at a distance:
  - Information about the environment stored into structure to dissipate energy more efficiently.

ANOTHER EXAMPLE : HURRICANE

Aside: Big Bang paradox

- Does the universe gradually self organize to increase its energy dissipation? It appears to…
  - But if Big Bang = "explosion", matter/energy thermalized (i.e. in equilibrium): very high entropy to start off with! Paradox: we see (locally) low entropy today.
    - Entropy can only be low only if all the energy available to do work is carried by only few particles: large Gibb's Free energy.
      - Or is spacetime somehow highly organized, way off equilibrium?
      - Able to use Gibb's free energy to do work, dissipating it into heat? But to do what? Expand? Against what? Or why is work required to create space?
  - Furthermore, if Universe closed system ⇝ 2nd Law, entropy ↗, free energy dissipated into heat, no structure??
    - Structure is evident in Universe today ⇝ is the Universe open???



From Eric, Chaisson, Cosmic evolution, 2004

A Universal Law?

- Why is structure appearing in the Universe, instead of just diluting/cooling down and increasing entropy?
  - Does this mean that the Universe open?
    - Roddier claims so: Using Dark energy acceleration to infer that matter/energy must escape our cosmic horizon ($= c\, t_0$)
      - (in fact, whether inflation or not).
    - Therefore Universe is open, MEP applies and
  - Dissipative structures emerge.
- Provides entropic ontology (if not mechanism) for inflation.
      - (Although entropy gravity dominated system is tricky, cf. Lee Smolin: "Cosmology as a problem in critical phenomena", arXiv).

Dissipative structures

- Returning to dissipating energy and structure…
- Ilya Prigogine, 1977 chemistry Nobel prize:
- Structures that naturally appear to dissipate energy more efficiently.
  - Only exist as long as system remains open (they die when the flux of matter or energy is turned off). Import information from environment ⇝ Any local decrease in entropy must be balanced in overall entropy increase.
- Extension of classical (Newtonian) mechanics with inclusion of <u>feedback</u> force. Allows for non-linearity.

Dissipative structures

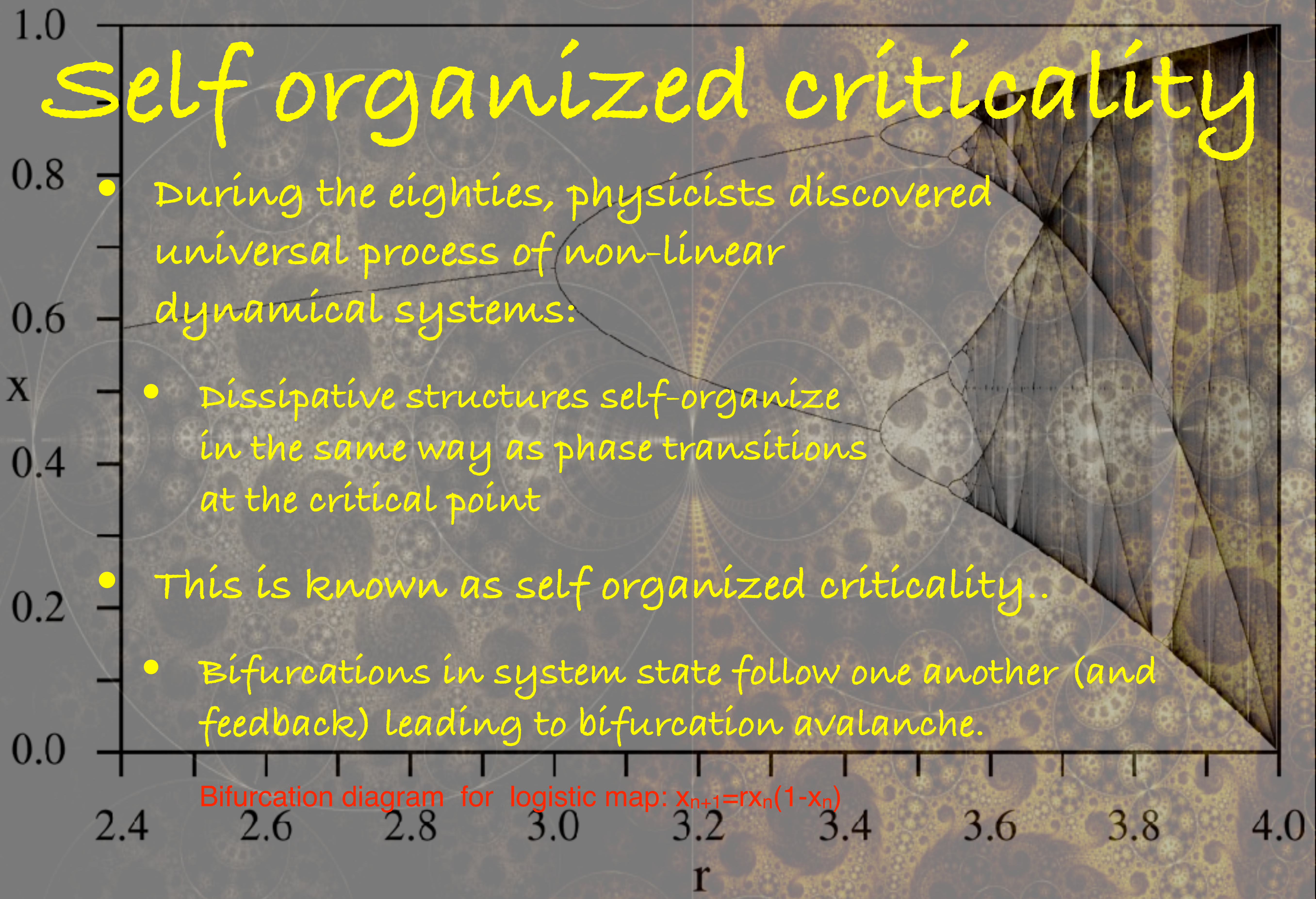
- E.g. Navier-Stokes equation can be solved analytically if viscosity is neglected.
  - But viscosity is the energy dissipating, heat generating (i.e. Entropy increasing) term.
    - It is also the non-linear term in the equations: Responsible for appearance of vortices, turbulence.
  - Vortices spontaneously replicate themselves, drawing energy from fluid shear.
    - Self-replication of dissipative structure is effective way of increasing energy dissipation. Possible as long as there is energy available.
      - Vortices are self replicating physical structures with cascade (or avalanche) of scale and energy dissipation. Exact detail depend on initial conditions and thus appear random.

Non linear dynamics

- Well studied and result from self-organized criticality at or near a phase transition or critical point.
  - Non-linear dynamical systems offer mathematical models of self-organized criticality in strange attractors.
    - Synchronization can emerge in chaotic systems if some conditions are satisfied:
      - Weak coupling, very nearly identical oscillators, certain types of feedback.
      - $\Longrightarrow$ Interacting dissipative structures form a further dissipative structure
    - Fluctuation theorem (analogous to Simulated annealing) process allows to optimize MEP and refine structure.
  - Emergence theory helps to explain coherent behavior of large aggregates.

Self organized criticality

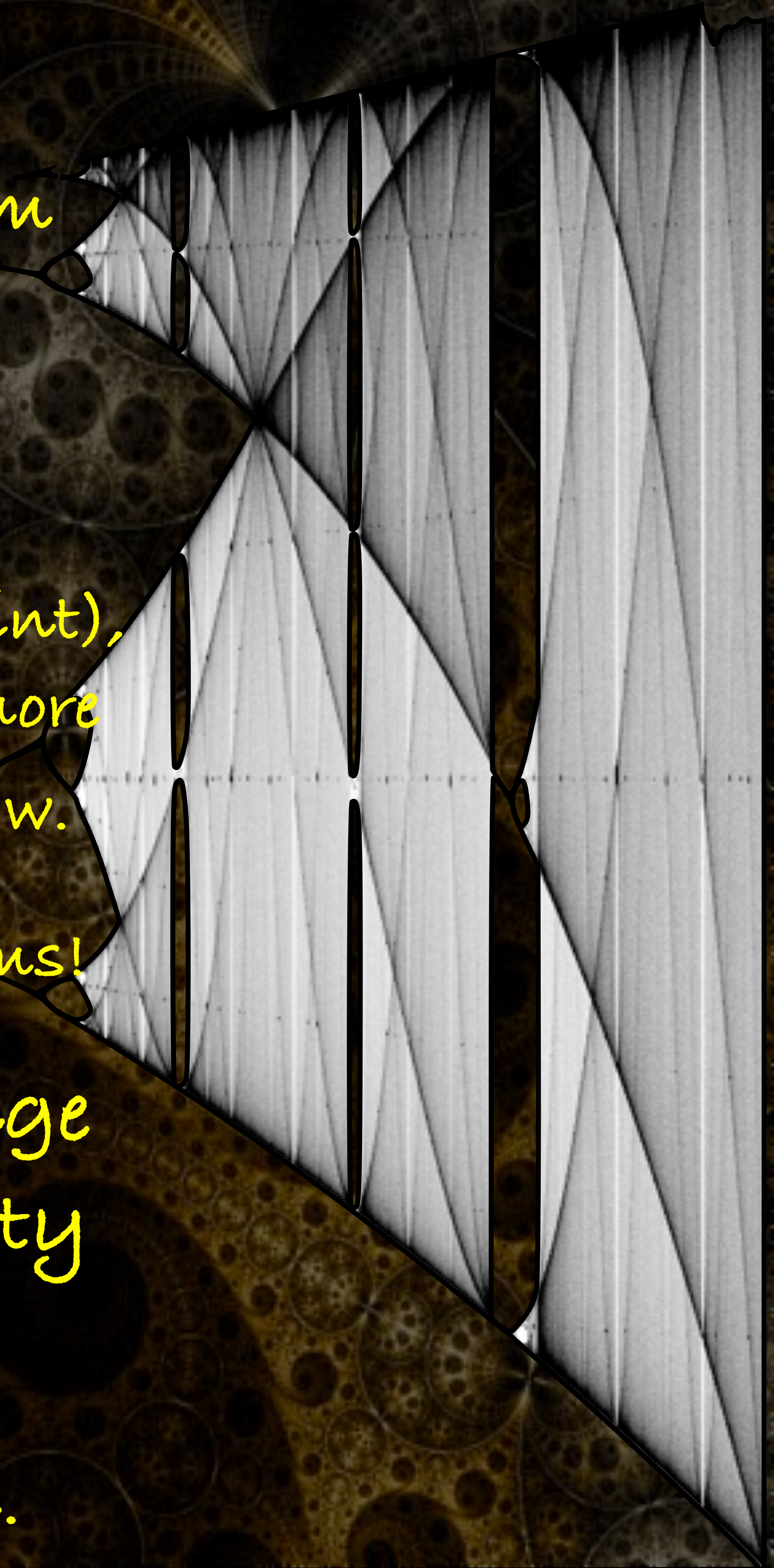
- During the eighties, physicists discovered universal process of non-linear dynamical systems:
    - Dissipative structures self-organize in the same way as phase transitions at the critical point
- This is known as self organized criticality..
    - Bifurcations in system state follow one another (and feedback) leading to bifurcation avalanche.

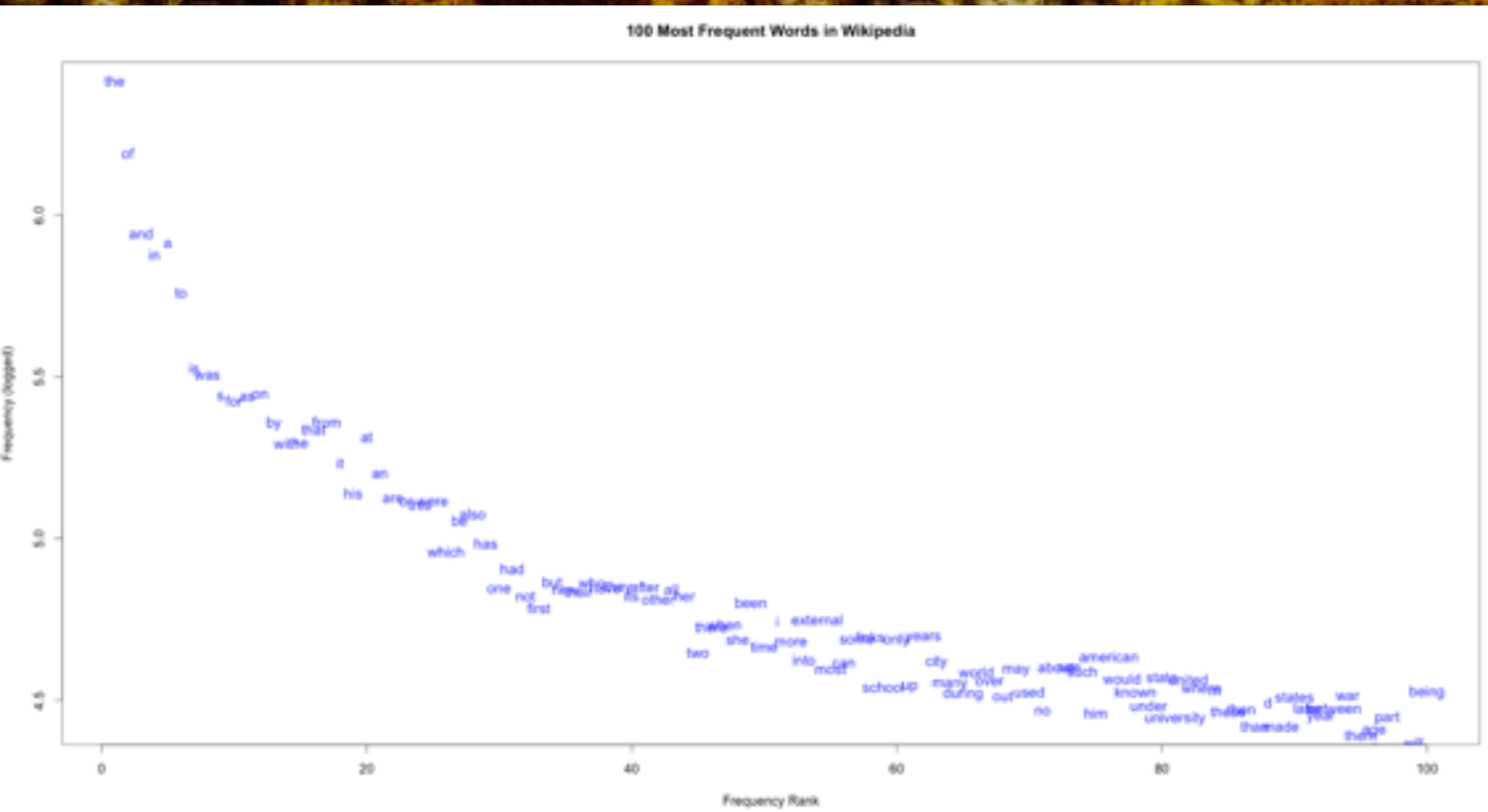


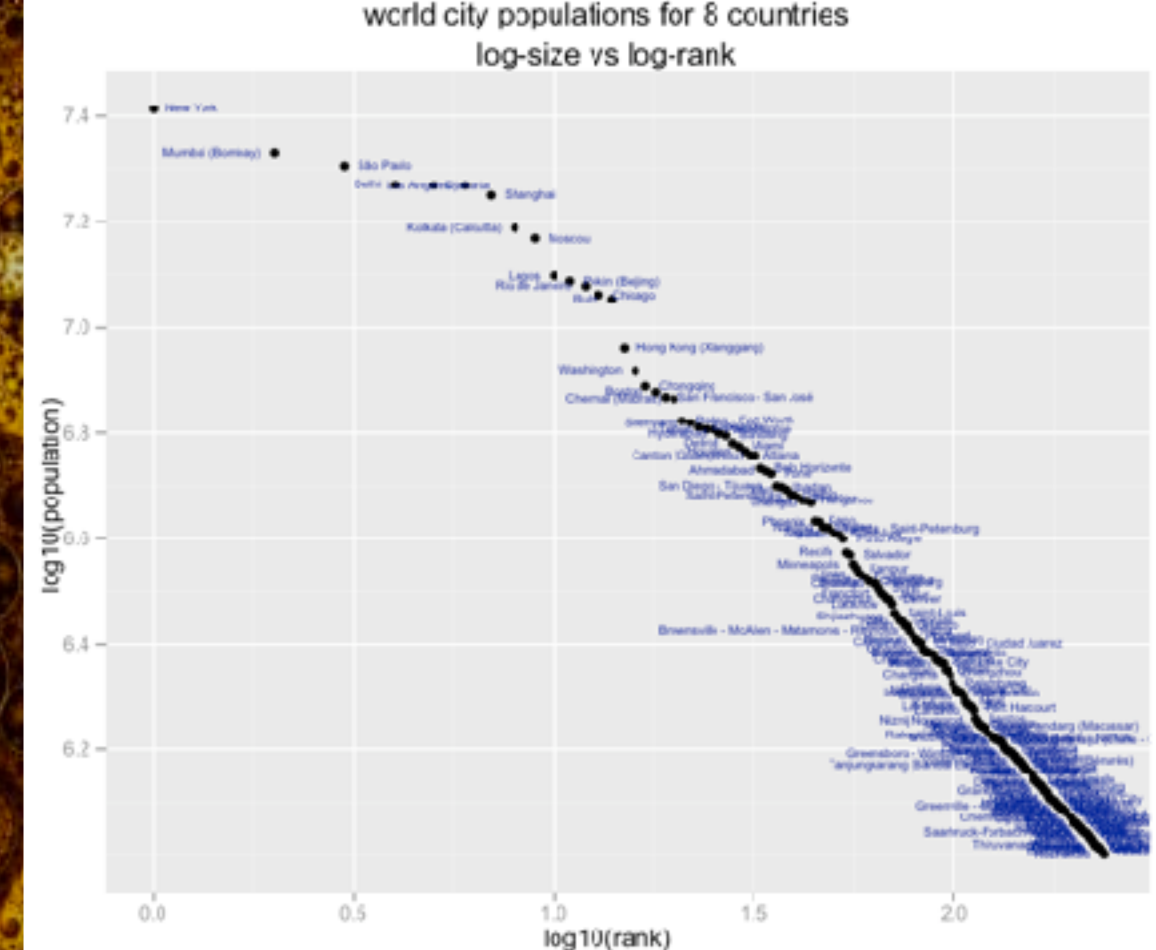
Bifurcation diagram for logistic map: $x_{n+1}=rx_n(1-x_n)$

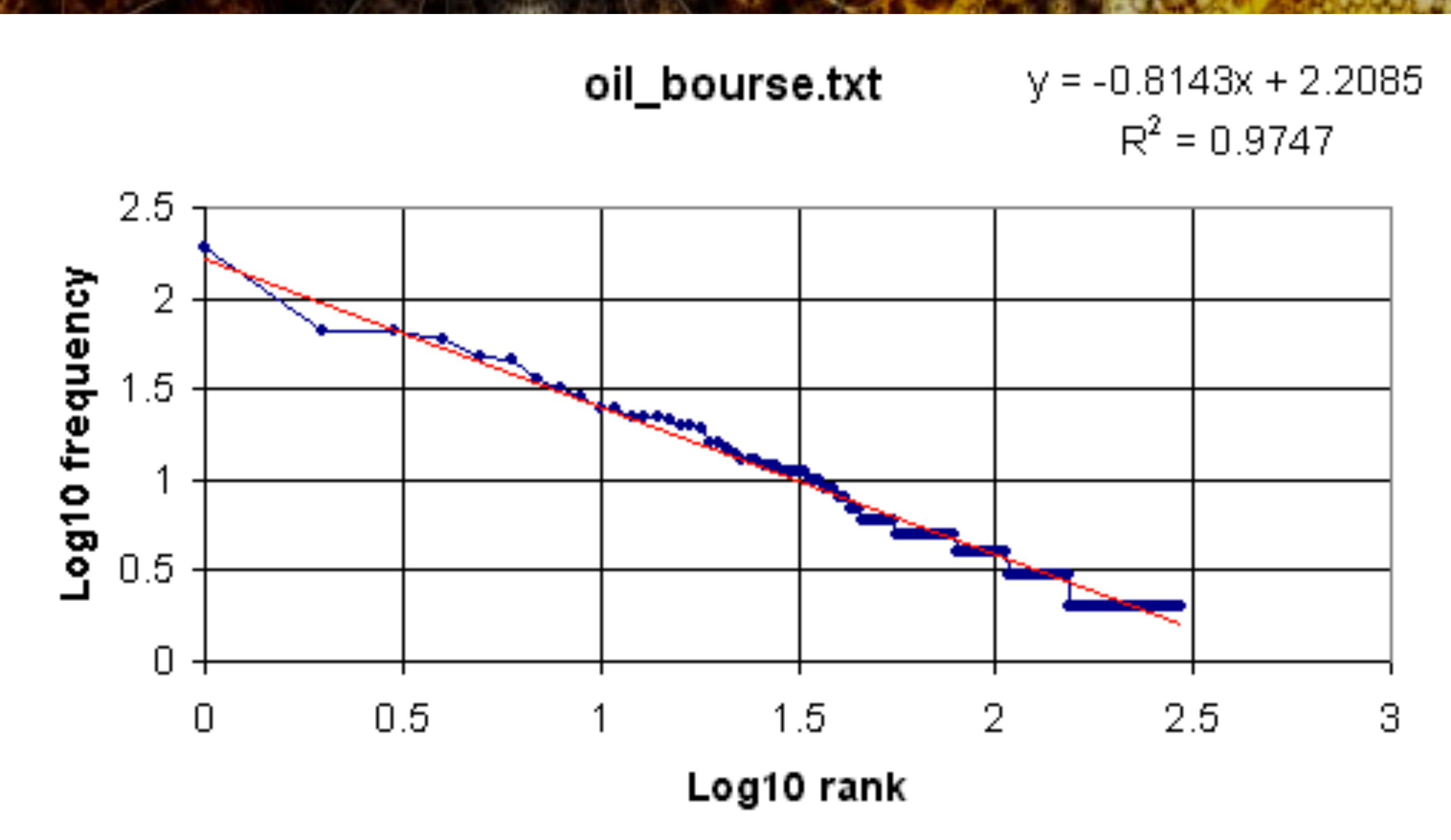
Self organized criticality

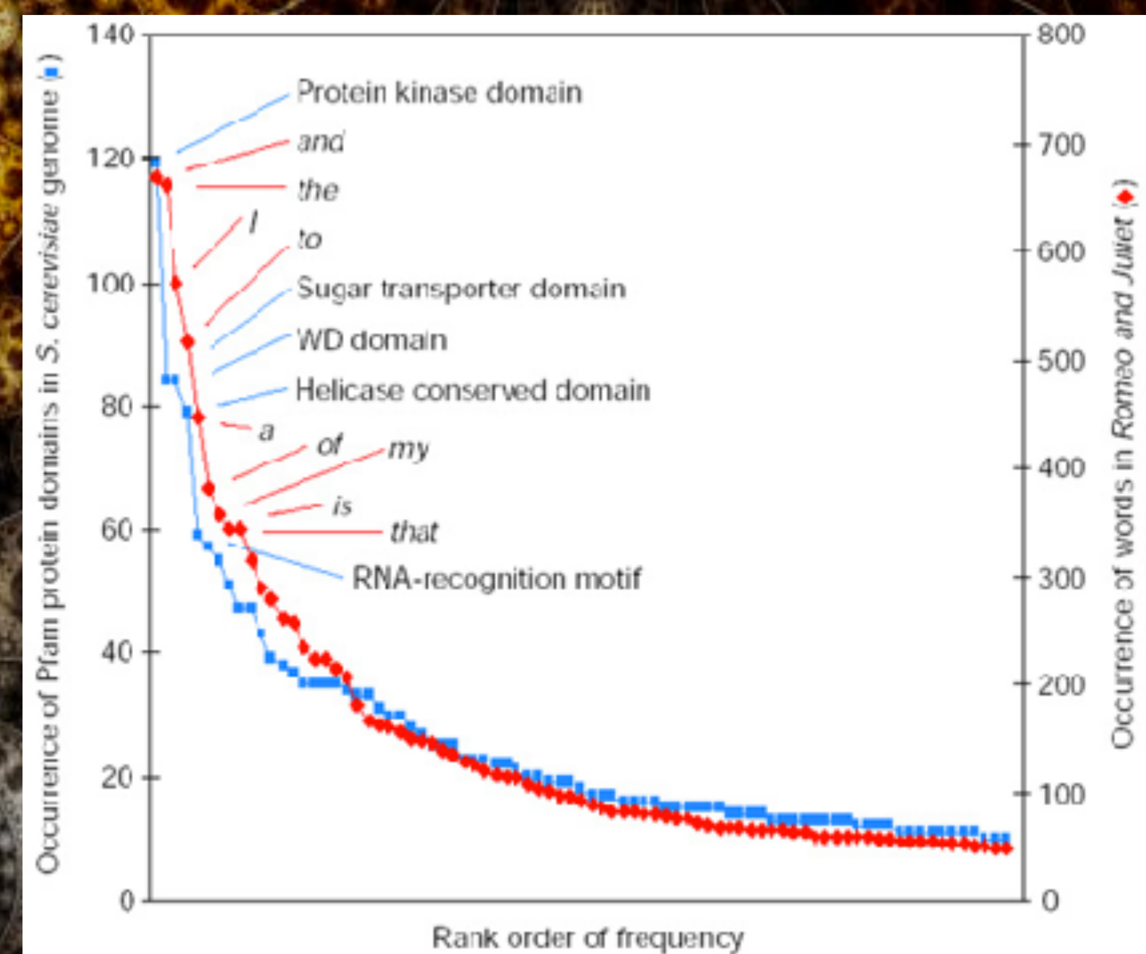
- Bifurcation avalanches:
  - Similar to a simulated annealing algorithm
  - Inverse law (1/f) between bifurcation rank and frequency is known as Zipf's Law.
    - True in sandpile: critical slope (like critical point), slope varies around. Small avalanches occur more often, large ones more infrequently⇝Zipf's law.
    - Also true for earthquakes & many other systems!
- Oscillations around critical point (strange attractor) named self organized criticality by Per Bak.
  - Who also showed that it applied to evolution.




100 Most Frequent Words in Wikipedia
Frequency Rank
the
of
and
in
a
to


world city populations for 8 countries
log-size vs log-rank
log10(population)
log10(rank)


oil_bourse.txt
y = -0.8143x + 2.2085
R2 = 0.9747
Log10 frequency
Log10 rank


Protein kinase domain
and
the
I
to
Sugar transporter domain
WD domain
Helicase conserved domain
a
of
my
is
that
RNA-recognition motif
Occurrence of Pfam protein domains in S. cerevisiae genome
Occurrence of words in Romeo and Juliet
Rank order of frequency

Deterministic Chaos

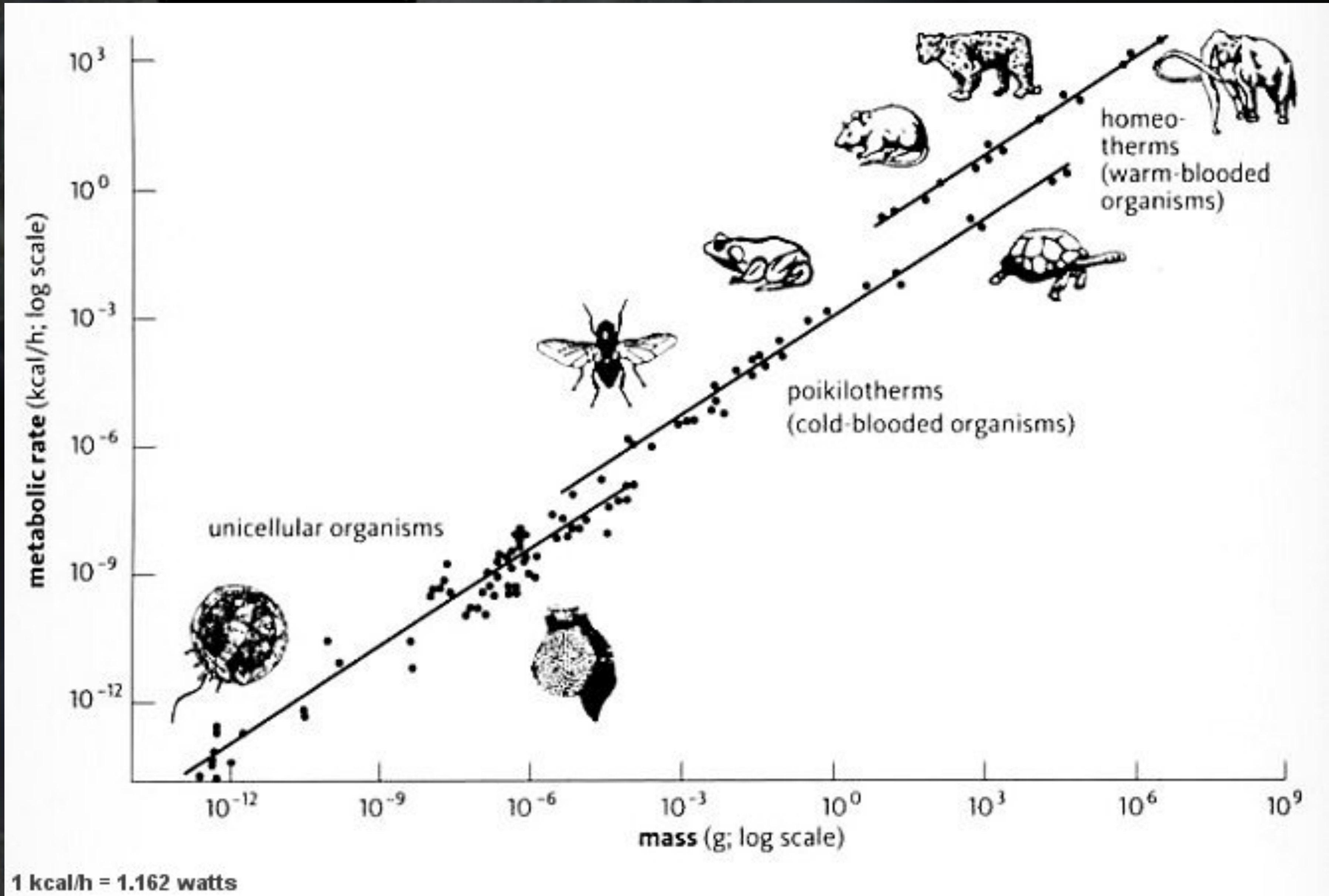
- Bifurcations around critical Point: strange attractor. Similar to domain splitting in phase transition.
  - Highly sensitive to initial conditions: literally impossible to solve or predict, even with most powerful simulation tools.
  - Unpredictability is intrinsic and due to feedback.
    - Yet they share some very specific characteristics which allow us to describe them: Statistical information, pattern, behavior.
- Deterministic chaos produces systems that are:
  - Quasi-periodic, ergodic, fill phase space fractally and
  - whose energy varies as some power law (usually a fraction) of the size of the structures. Non integer fractal dimension.

e.g. Crystal growth

- Crystals grow in open systems (draw chemical energy from environment), decreasing (exporting) their entropy.
  - Importing information (Structure): Bifurcation avalanche leads to fractals spatial structure (power law of spatial scale), maximizing area/Volume.
    - Self organization of matter around critical point (freezing) driven by maximum entropy production.
    - Process exists over many orders magnitude. Emergent macroscopic property: typical of strange attractors, deterministic chaos.
- Why do trees have branches?
  why are ferns biological fractals?

Kleiber's Law

- Most life forms have a metabolic rate (energy dissipation into heat to remain alive) which is proportional to mass$^{3/4}$
- Kleiber's laws therefore implies that life is likely shaped by Maximum Entropy Production and fluctuation theorem, because it is constantly optimizing its energy dissipation via its metabolic rates at a critical point.

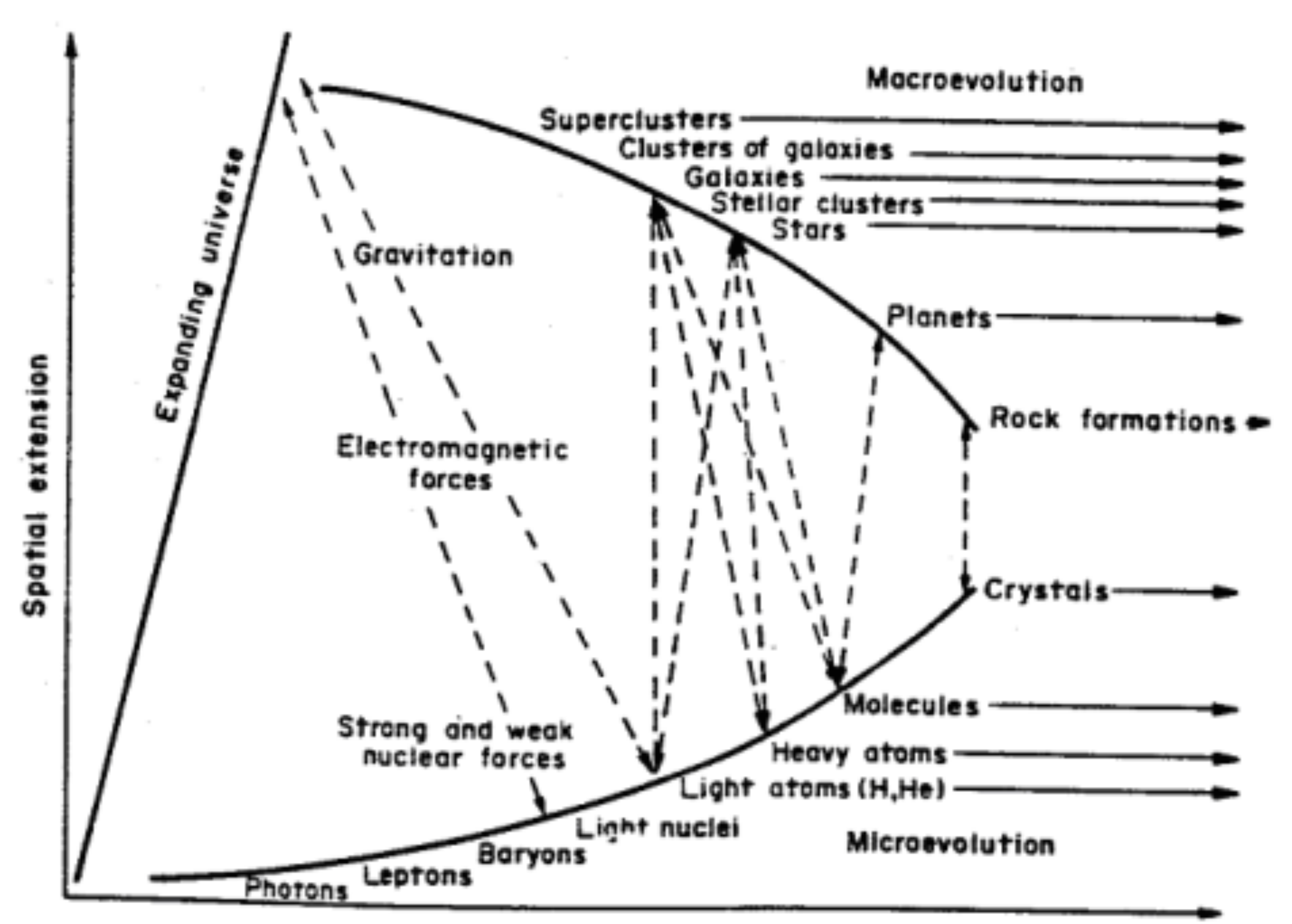


Back to Self-organized criticality & entropy

- A system that self organizes is unpredictable:
  - Indeed, if evolution known, no new information created, knowledge of system remains unchanged.
- Decrease in entropy implies knowledge about (or in) the system increases (or that it has internalized some information about its environment).
  - Emergence of unexpected structure is agreement with Shannon information entropy.
- Structure can exist at macro- or microscopic levels.

Micro-evolution vs. Macro-evolution

- In seeking to maximize entropy production, systems will stabilize at optimum free energy dissipation, whether this requires large scale structure or microscopic growth or adaptation.
  - Systems that dissipate energy efficiently affect their environment more, making free energy less available until structure can't sustain themselves.
  - Simulated annealing optimisation.



From Erich Jantsch, The self-organizing Universe, 1980

r and K selection

- Although micro and macroevolution exist in physical and chemical systems, best illustration from biology.
- Studied by MacArthur & Wilson (1967)
- K selection when resources are plentiful;
  - Gigantism is preferred.
    - Offspring are passed on much information.
    - energy (resource) intensive, so offspring are few and each offspring's survival is crucial.
    - Failure is discouraged.

K selection

- K selection when resources plentiful:
  - Stasis/symbiosis. Organisms grow to compete for resources,
    - Tallest giraffe has access to highest trees, biggest lion to most meat. They are naturally selected.
  - thereby depleting their resources even faster.
- Need to run faster and faster simply to keep existing: known as the "Red Queen Effect", from Lewis Carroll's "Through the Looking Glass":

  Now, here, you see, it takes all the running you can do, to keep in the same place.

Red Queen effect

- Evolutionary hypothesis which proposes that organisms must constantly adapt, evolve, and proliferate, simply to survive facing ever-evolving opposing organisms in an ever-changing environment.
    - And the more they evolve, the more they feedback and change their environment (which can in turn adapt) on which they depend.
- This explains why species constantly die out.

r selection

- r-selection when resources become scarce…
- Natural selection then prefers/favors:
  - Small organisms,
    - Short lifespans.
      - Many offspring,
        - Potential for many genetic mutations,
          - explore every possible ecological niche.
- Evolution becomes unstable.
  - Sensitivity to initial conditions (high feedback, highly non-linear), unpredictable.

r selection

- Evolution becomes unpredictable: information entropy.
  - Idea of failure is built-in to evolution: Many offspring means many will die.
    - Strategic failure. Survival of most adapted to environment is like importing information which gives the appearance of learning from mistakes: feedback ⇝ non-linearity. Impossible to predict outcome. Emergence of new structures or behaviors (ideas?)
  - Many small, nimble, highly adaptable organisms are naturally selected.
  - Natural selection ⇝ species most well adapted to resources will start growing, until they use up their energy source.
    - Zipf's Law of bifurcation avalanches (mass extinctions few and far between, species extinction are common)

K and r selection

- r-selection
  - Grass,
  - Rodents,
  - Insects
- K selection
  - Giraffe,
  - Trees,
  - Lions,
  - Dinosaurs

Figure 2.8. Relationship between size and generation time. [From John Tyler Bonner, *Size and Cycle: An Essay on the Structure of Biology* (© 1965 Princeton University Press). Fig. I, p. 17. Reprinted by permission of Princeton University Press.]

Punctuated equilibrium

Natural catastrophe, meteorite, volcanism.

environment changes too quickly for species to adapt.

Mass extinction
Zip's Law

New species fill out ecological niches left vacant by extinct species.
fierce competition for resources,
unstable environment,
large population fluctuations

Environment gradually stabilizes,
species most adapted to environment thrive
at expense of others

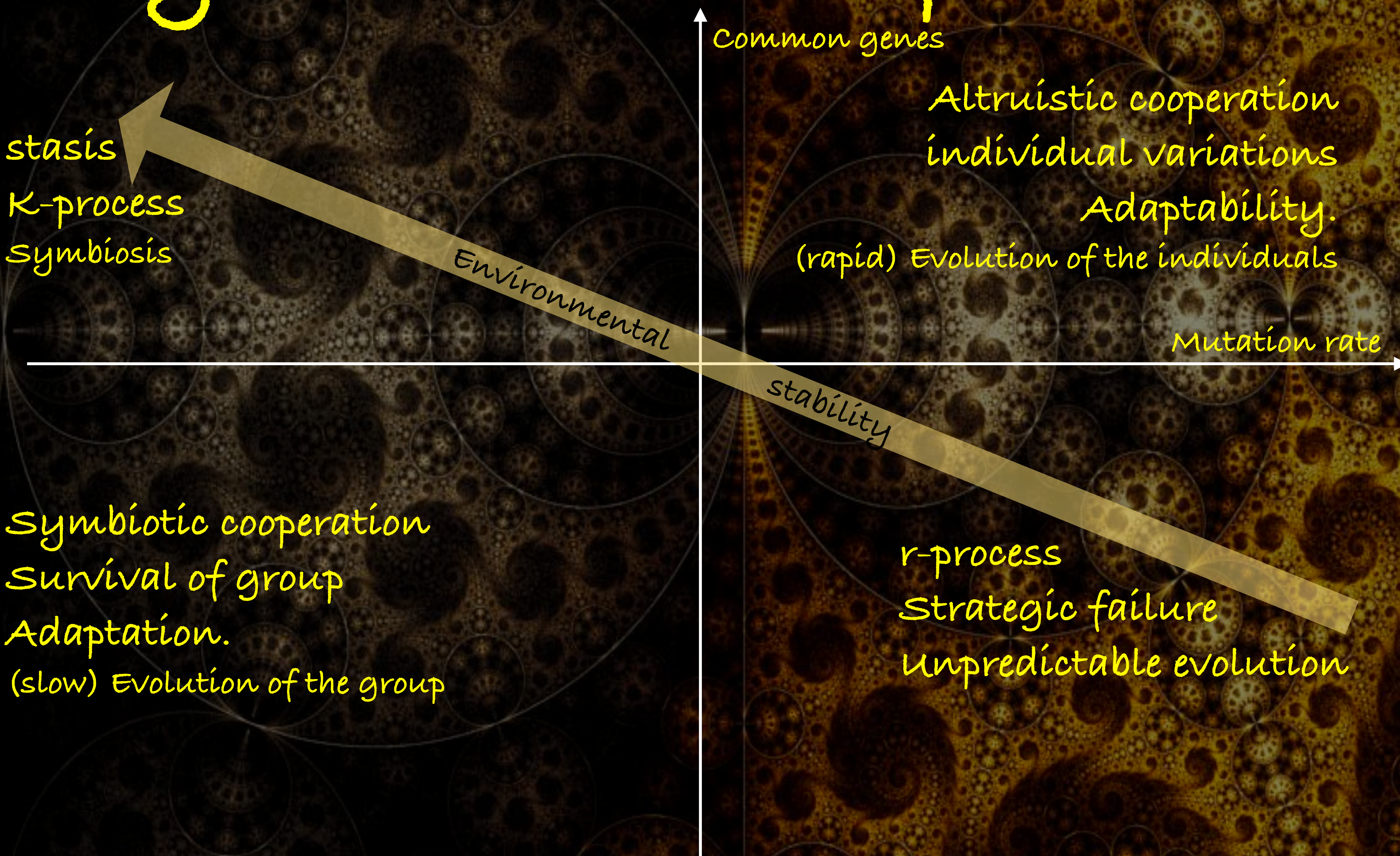
System stabilizes. Resources plentiful: Stasis
species evolve slowly when not under pressure

Growth to increase access to resources against smaller, weaker species or members of species

Longer life spans, specialize further (importing information from environment, but also reducing ability to adapt).

Red queen effect:
feedback on environment:
running out of resources.

Cooperation, altruism, symbiosis, competition

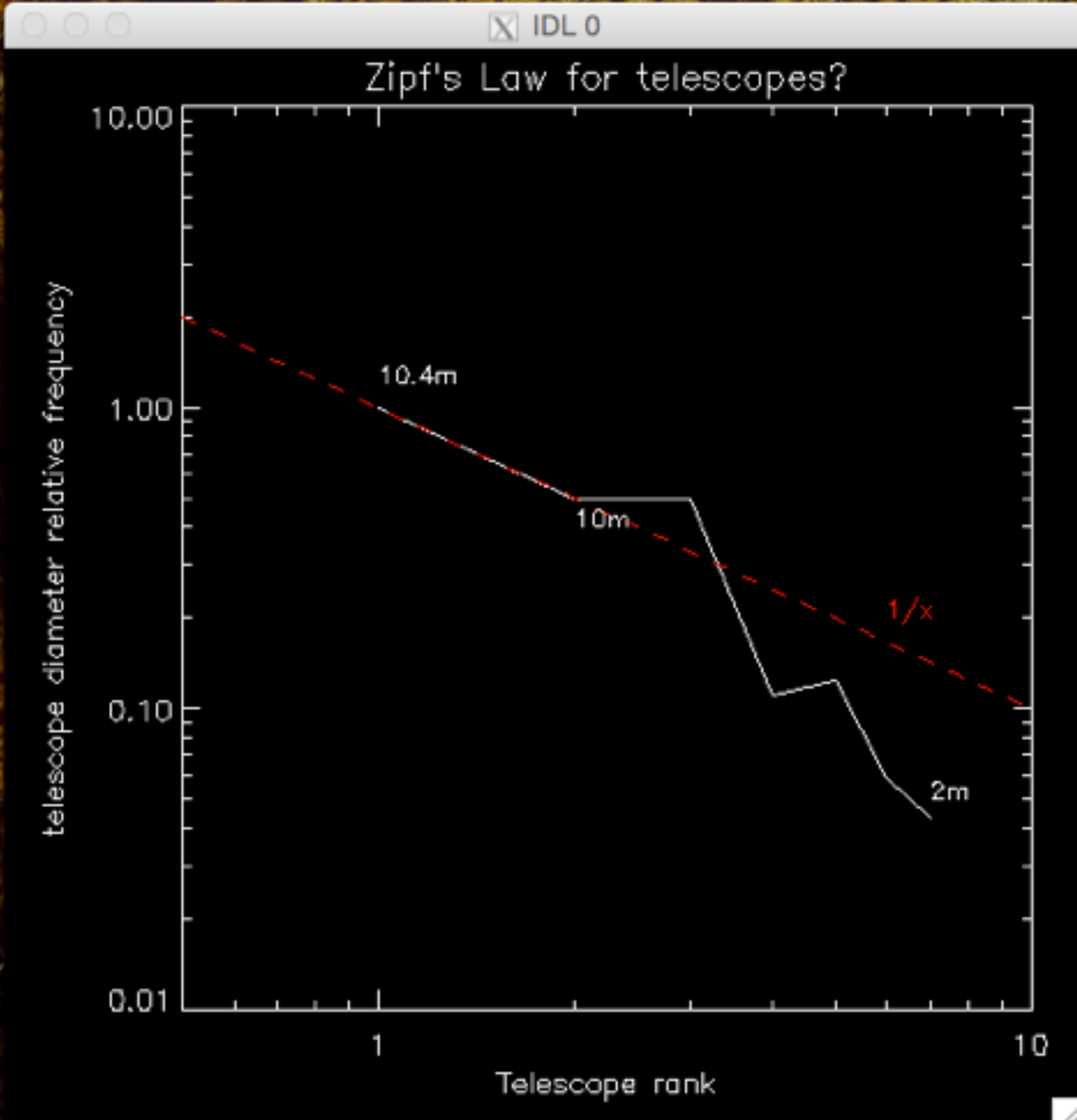


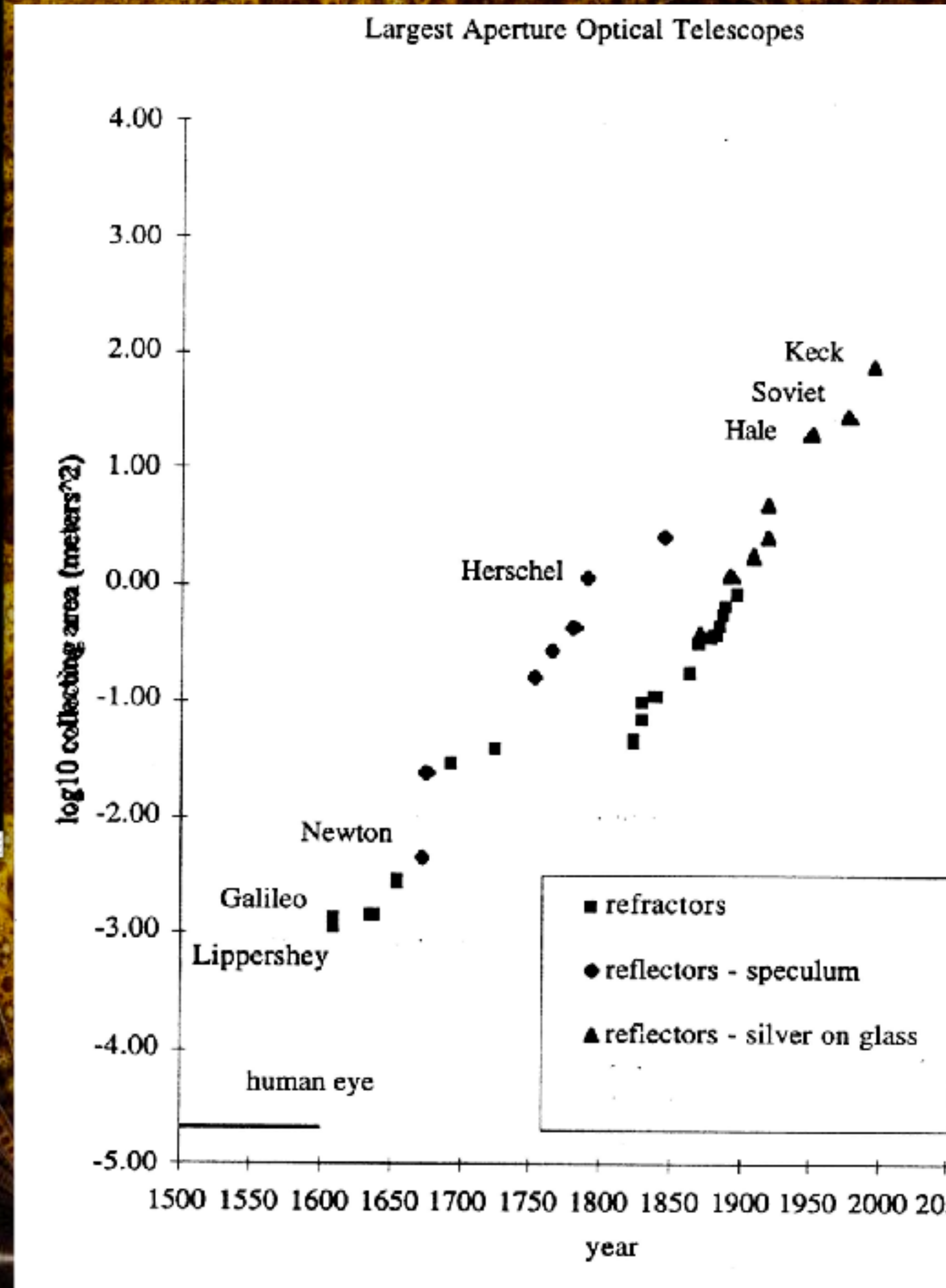
Observatory Management

- What does any of this have to do with observatory management, you may (rightfully) ask.
  - Well, I contend that we can look at the recent history of astronomy and extract some clear patterns reminiscent of open systems barring a few assumptions:
    - Our resource, our food, our Gibb's free energy is money.
    - We are an open system, resources flow in and out.
- We are trying to maximize (internalize) information which requires us to increase external entropy.

Observatory Management

- To maximize entropy production, astronomical community has self-organized at critical point.
  - In the 20th Century, Astronomy's critical point around which strange attractor developed was technology.
    - Think about the occurrence of new technology (e.g. detectors, AO): Punctuated equilibrium (Zip's Law) for technological revolutions?
      - At each generation, all very similar but slightly different, (simulated annealing). Exploring every possible ecological niche, gaining slight advantage here or there: r-selection when new technology became available, until one naturally selected and then grow into K-process (bigger!)
  - But feedback and stasis (growth) imply that the technology will grow to a point where it may be limited by resources (financial and mechanical) in the 21st Century.
  - Is the Red Queen Effect at play in Astronomy?


IDL 0
Zipf's Law for telescopes?
10.00
1.00
0.10
0.01
telescope diameter relative frequency
10.4m
10m
1/x
2m
1
10
Telescope rank


Largest Aperture Optical Telescopes
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
log10 collecting area (meters^2)
Keck
Soviet
Hale
Herschel
Newton
Galileo
Lippershey
human eye
refractors
reflectors - speculum
reflectors - silver on glass
1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000 2050
year

K-selection in Astronomy

- Due to stable funding, K selection process: Telescopes in stasis (of ideas). Physical Growth.
  - But because of feedback process, the environment is changing more and more rapidly.
  - Can we adapt fast enough? Does scaling up ideas make sense in such an environment?
- Red Queen Effect in Astronomy?
  - Bibliometrics:
    - "The increasing velocity of the paper number is higher than the speed of light, but there is nothing to worry about for there is no violation of any physical law, because these papers carry no information"
      - attributed to Chandrashekhar (Editor of ApJ)

Strange attractor

- Need ever increasing financial resources: progenitor of next bifurcation?
  - Telescopes budgets stretch the limits of what countries science budgets can sustain.
  - Telescopes' development cycle longer than current recession-recovery cycles. Cannot adapt.
  - Makes planning ahead difficult (sensitivity to i.c.)
- Giant telescopes: few offspring, risk-averse, use proven technologies, simply scale them.

ELT futures

- My goal is not to criticize Big Science, esp. ELTs,
  - After all, you'll have understood by now that their fate is unpredictable, sensitive to environmental conditions.
- But in this age of darkness (both matter and energy), lacking even the foundation for theories underlying these enigmas, how can we keep developing ideas & concepts to enable discoveries (supported by instrumental research),
  - when the largest fraction of available funding will go to engineering issues related to scaling up existing technologies that don't directly address the dark enigmas?
- How can we enable fast, <u>sloppy</u> & cheap prototypes?

The trouble with Physics

- Lee Smolin made very similar point (for different reasons) in book: "The trouble with Physics".
  - Applied to theoretical physics/string theory,
- He defines incremental & revolutionary science.
  - The former makes bigger instruments, reduces error bars, comforts existing theories,
  - While the latter requires risk taking, proposes bold new ideas, new hypotheses.
- Much needed in theoretical physics!

Economic model

- How do we maintain vibrant "revolutionary" research activities in a risk-averse landscape?
  - Part of the problem is that we have transposed and adopted our economic model, based on growth, to the scientific endeavor, from the belief that competition fosters creativity, new ideas and new solutions.
    - But creative ideas have mostly flourished on how to play the system and gain access to more resources, not new knowledge.
  - Campbell Law of Social Sciences:
    "The more any quantitative social indicator is used for social decision-making, the more subject it will be subject to corruption pressures and the more apt it will be to distort and corrupt the social processes it is intended to monitor."

Pitfalls of unrestrained growth

- Rising number of frauds and retractions
  - Competition favors winning, being first to find result, as opposed to pursuing new knowledge.
    - Also, conquering competition (SSC, Tevatron ⇨ LHC)
- Results lose their significance, replaced by sound bite.
    - Too many press releases devalue knowledge (yet necessary to remain competitive and gain access to funding).
- Growth favors a system where we produce more experts than there are resources for. Scientific careers bottleneck, rise of social (mental health) problems in academia.
    - We can already see the effects of starvation, leading to consolidation, streamlining, efficiency, productivity.

Linear economy

- What is the alternative to a growth based economy?
- Linear economy means we produce only what we need to live (curiosity?). We work individually and exchange openly with others (Think globally, act locally)
  - In other words, the economy is not based on what can be done but what ought to be done. If something detrimental happens based on our actions, we can scale back without consequence, as opposed to hoping that further technology will save us from its own past blunders (red Queen).
  - Giant projects based on what we can achieve, justification often tagged on after the fact. In linear economy, projects based on what we think is valuable or useful.

Is a new paradigm neeeded?

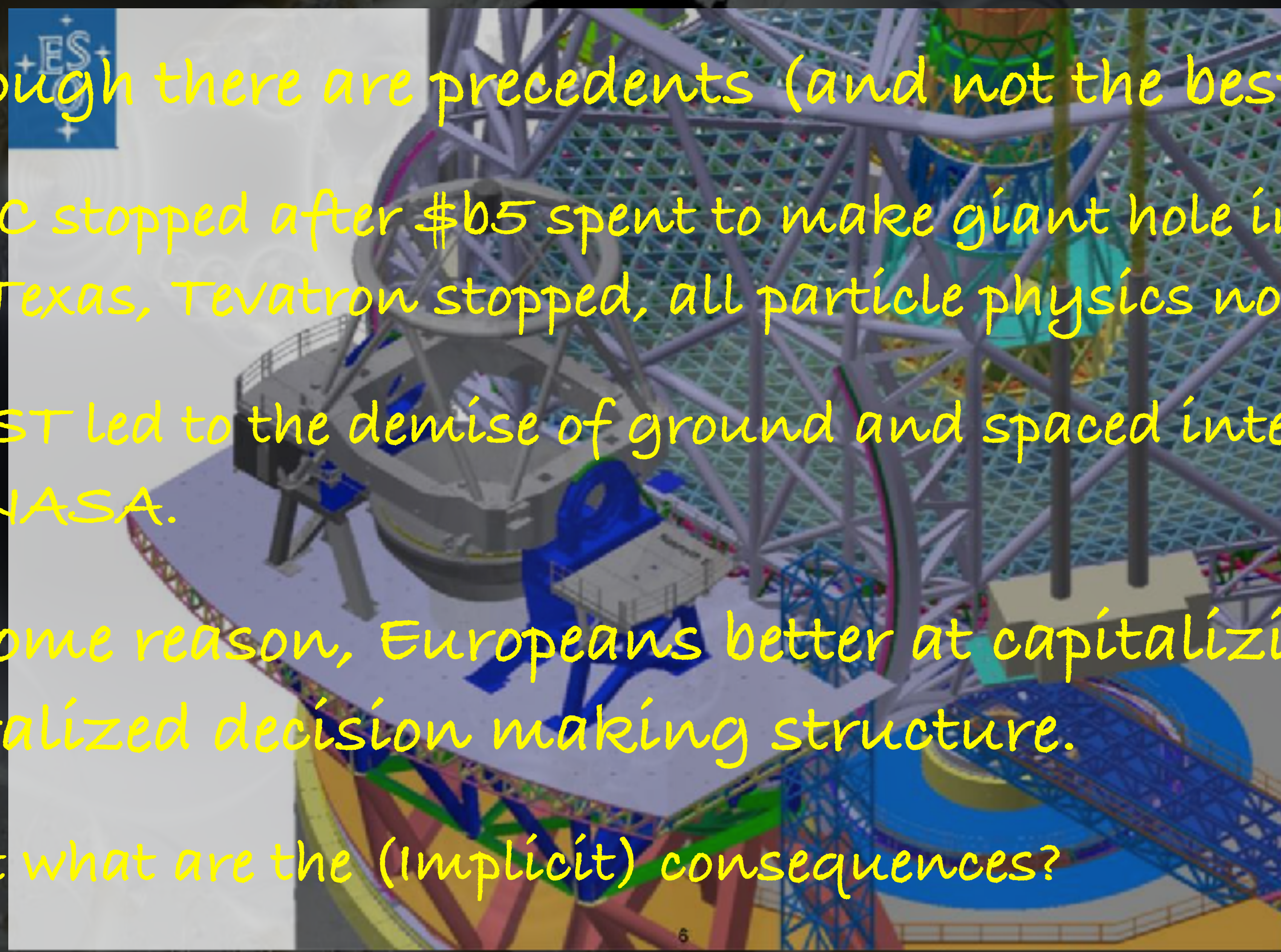
- K selection is like Centralized system with top-down decision making. Risk averse.
    - We see this in the "too big to fail" approach (JWST?).
- What does the r-selection process mean in the context of scientific endeavor?
    - Many small experiments, the outcome of which is unknown, thus with high risk of null results and "strategic failure".
        - But exploring every ecological niche.
    - Role of mistakes and learning from them.
    - No centralized decision making, high feedback.

r-selection and distributed systems

- The Starfish and the Spider, Brafman & Beckstrom.
  - Decentralized systems are highly adaptable.
  - When under attack, a decentralized system becomes even more decentralized,
    - High adaptability, can deal with strategic failure.
      - New solutions can emerge.
  - While a centralized system will become more entrenched.
    - Enforcing old solutions, just stronger.
  - Reminiscent of K versus r-selection at work.

Coexistence?

- Can the K and r processes co-exist?
  - Nothing says ELTs have to be developed at the expense of everything else. That is a choice that is made.
- Although there are precedents (and not the best kind):
  - SSC stopped after $b5 spent to make giant hole in the ground in Texas, Tevatron stopped, all particle physics now at LHC.
  - JWST led to the demise of ground and spaced interferometry at NASA.
- For some reason, Europeans better at capitalizing on centralized decision making structure.
  - But what are the (implicit) consequences?



r-selection in Astronomy

- Thinking in terms of sustainability, it appears we should invest in the r-selection process for our work.
  - After all, rodents existed at the time of dinosaurs...
    - But they exploded when dominant species died out and resources were freed up. Is this a general process?
  - Diversifying to not have all eggs in one basket.
  - And we are in the business of generating new knowledge, new information. Diversity is good!
- How can this be implemented?
  - Access the same pool of resources, judged by same standards (e.g. bibliometrics), managed the same way (productivity/creativity?)

Cooperation/collaboration

(size/cost of project/ telescopes

ELT stasis
exclusive of other projects
(LHC model)
Failure is catastrophic (SSC)

Altruistic cooperation
use small telescopes to develop technologies as needed (some which may be used on ELTs allowing it to adapt and evolve).

ELT

Ideological

Number of projects funded
(diversity of ideas)

stability

Symbiotic cooperation
Smaller telescopes used to feed sources for ELTs to observe. ELTs may fund own support telescopes.

no ELT

Competition for resources, r-process, punctuated equilibrium.
High feedback, unknown outcome, dependent on initial condition

Small is beautiful

- If growth based economic model in a finite resource environment is not adequate, how to implement linear economy? Paraphrasing E.F. Schumacher:
  - Astronomy as if people mattered :-)
    - Schumacher's idea of decentralization is more complex than simply breaking up a large unit into smaller units.
    - Rather, proposed the idea of "smallness within bigness";
      - in other words, for a large organization to work it must behave like a related group of small organizations (meme diversity, altruistic cooperation).
    - Argues that so far, purpose of technology has been to produce as much output per labor input as possible.
      - Devices invented for this purpose have not only (unwittingly) made many workers redundant, but high cost of devices discourages self-employment.

More is different

- As a solution, Schumacher proposes an "intermediate technology," one which can be purchased and used by all people, and which can lead to greater productivity while minimizing social dislocation.
- Provides opportunities for "citizen science" and start addressing current societal rift, distrust of science and experts in our society in general,
  - e.g. rise of flat-earthers in the 21st century!
    - Implies that we, as scientists and academics are doing something wrong towards the society that allows us to exist.
  - People feel dissociated from science because too large, too big, too remote, they can't participate. The gap is widening.
    - Science becomes inconsequential to majority of people.

Engaged Science

- In the end, we have to ask ourselves why we carry out science, and what is the goal of our pursuit.
    - I do not believe that the outcome is predetermined. I would not be surprised if we keep being surprised in our understanding of fundamental questions during our lifetimes.
    - I also do not believe that there is a single, predetermined or optimal way to increase our knowledge. We need to choose the one that fulfills both our curiosity and our duty to the society that allows us to exist, giving us a credible mandate.
- "Somewhere, something incredible is waiting to be known." -Carl Sagan
- It is this simple curiosity that drives the kind of science I want to be involved in.

Conclusion

- I have tried to demonstrate why small scale, more human science, makes sense in today's landscape.
  - Based on our current understanding of thermodynamics of open systems, self organized criticality and deterministic chaos and a good deal of personal opinion!
- ELTs are the dominant species but growth in limited resources means we are experiencing the Red Queen Effect.
- We can remain active and creative by investing ourselves in a lightweight, distributed, adaptable collaborative structure and embrace risk!

- More to be different, to paraphrase P.W. Anderson.

- His words regarding condensed matter physics apply to our current technical and management predicament, which are:

- "[…] confronted with the twin difficulties of scale and complexity. The behavior of large and complex aggregates of elementary particles, it turns out, is not to be understood in terms of simple extrapolation of the properties of a few particles. Instead, at each level of complexity entirely new properties appear, and the understanding of the new behaviors requires research which I think is as fundamental in its nature as any other."

P.W. Anderson, "More is Different", Science 177, 1972.

Isaac Asimov Asks, "How Do People Get New Ideas?"

http://www.technologyreview.com/view/531911/isaac-asimov-asks-how-do-people-get-new-ideas/

- First and foremost, there must be ease, relaxation, and a general sense of permissiveness. The world in general disapproves of creativity, and to be creative in public is particularly bad. Even to speculate in public is rather worrisome. The individuals must, therefore, have the feeling that the others won't object.
- The optimum number of the group would probably not be very high. I should guess that no more than five would be wanted.
- For best purposes, there should be a feeling of informality. Joviality, the use of first names, joking, relaxed kidding are, I think, of the essence—not in themselves, but because they encourage a willingness to be involved in the folly of creativeness. For this purpose I think a meeting in someone's home or over a dinner table at some restaurant is perhaps more useful than one in a conference room.
- Probably more inhibiting than anything else is a feeling of responsibility. The great ideas of the ages have come from people who weren't paid to have great ideas, but were paid to be teachers or patent clerks or petty officials, or were not paid at all. The great ideas came as side issues.
- If thoroughly relaxed, free of responsibility, discussing something of interest, and being by nature unconventional, the participants themselves will create devices to stimulate discussion.

Distributed management

- Funnily enough, I'm not the only one advocating for management based on the science of chaos theory:
  - "Leadership and the New Science, Discovering order in a Chaotic World", by Margaret J. Wheatly.
  - Also: http://www.margaretwheatley.com/articles/Wheatley-Chaos-and-Complexity.pdf
    - (Distinguish between order and control, recognizes self organization and need for criticality, etc.)
- I think these management principles are particularly well adapted to scientific research.