Complexity: Physical Perspective

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http://www.abdn.ac.uk/icsmb/people/details/grebogi

Poincare' in 1908

Why is that showers and even storms seem to come by chance, so that many people think it quite natural to pray for rain or fine weather, though they could consider it ridiculous to ask for an eclipse by prayer?

Dichotomy:

- SIMPLE vs. COMPLEX
- Periodicity vs. unpredictability
- Nature can produce complex structures in simple situations and obey simple laws in complex situations

Both come from the same dynamics

Follow the tradition of nonlinear dynamics

Maxwell-Poincare' → Theory of Dynamical Systems → Chaotic Dynamics → Complexity Theory

- No detailed knowledge of the equations
- It fosters and promotes multidisciplinary interactions across both organizational lines and traditional disciplinary boundaries
- Complexity is like "life" - learn from previous experiences and reach out for lessons
- Transversality

What is complexity?

- Concept filled with ambiguity and dependent on the context
- There is not general consensus on a quantitative measure

GENERAL TRAITS:

- **Composed of many parts interrelated in a complicated manner**
- **Possesses both ordered and random behaviours**
- **Exhibits layered hierarchy of structure over wide range of time and/or length scales**

Controlling Complexity

- Complex system is one in which many emergent competing behaviours are possible, but which one is observed at a given time is highly sensitive to minor perturbations.

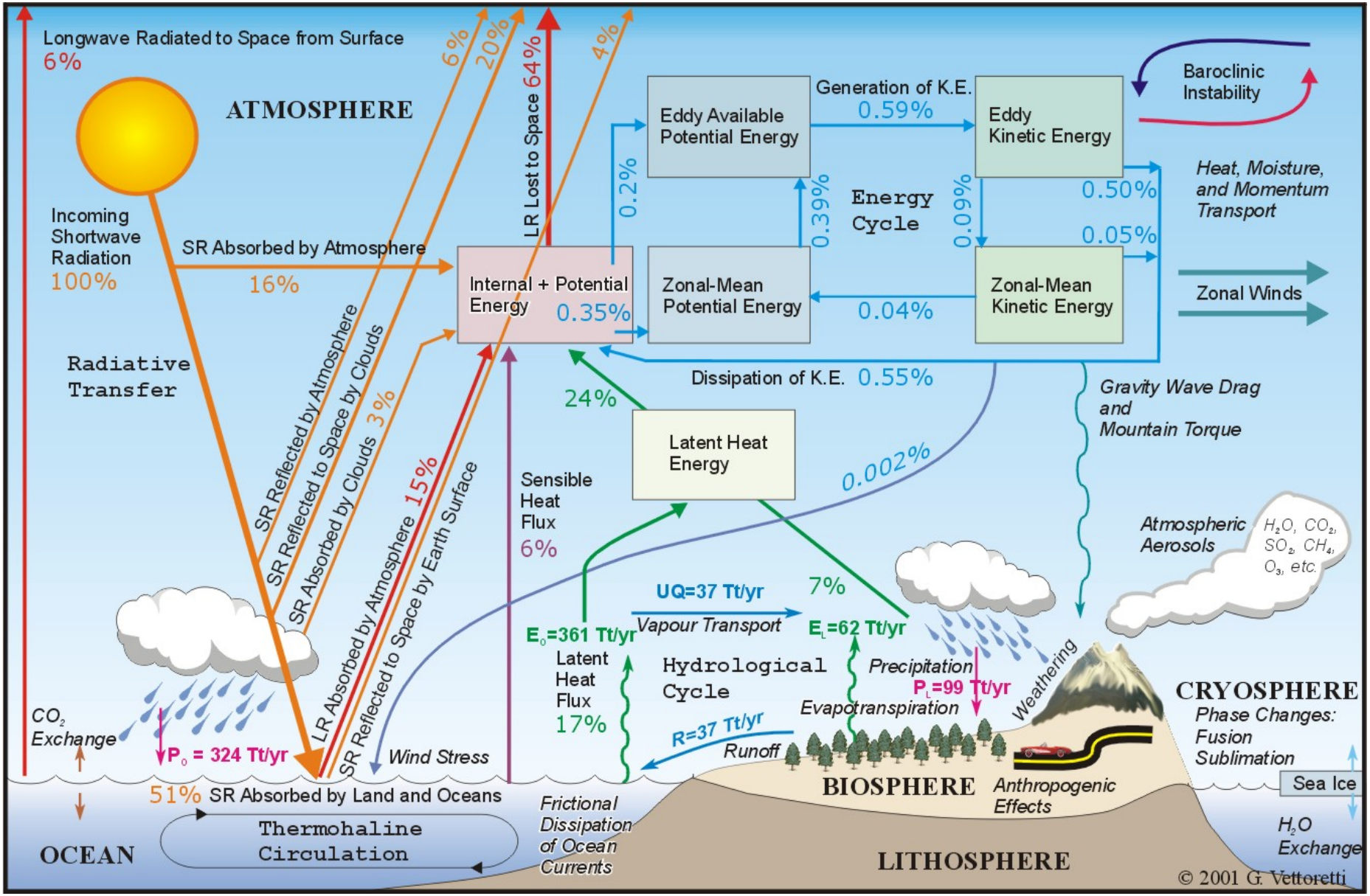
KEY ATTRIBUTES:

- **Accessibility to many states**
- **Sensitivity to initial data and/or parameter perturbations**

allow for the manipulation and control of the complex system's dynamics.

Limits to validity of models and to computer generated trajectories

- Modelling of complex systems is often not amenable to an exact analytical description.
- Model uses simplifying assumptions and approximations.
- Success depends on whether the model is able to make predictions.
- Can the solution of the models approximate the dynamics of the natural or man-made system?
- **Dynamical difficulties may impose severe limits to modelling.**
- **Same difficulties impose severe limits on the validity of numerical solutions of the underlying equations.**


Longwave Radiated to Space from Surface
6%
ATMOSPHERE
Incoming Shortwave Radiation
100%
SR Absorbed by Atmosphere
16%
Radiative Transfer
SR Reflected by Atmosphere
6%
SR Reflected to Space by Clouds
20%
SR Absorbed by Clouds
3%
LR Absorbed by Atmosphere
15%
SR Reflected to Space by Earth Surface
4%
LR Lost to Space
64%
Internal + Potential Energy
0.35%
Eddy Available Potential Energy
Generation of K.E.
0.59%
Eddy Kinetic Energy
Baroclinic Instability
Heat, Moisture, and Momentum Transport
0.2%
0.39%
Energy Cycle
0.09%
0.50%
0.05%
Zonal-Mean Potential Energy
0.04%
Zonal-Mean Kinetic Energy
Zonal Winds
Dissipation of K.E. 0.55%
Gravity Wave Drag and Mountain Torque
24%
Latent Heat Energy
0.002%
Sensible Heat Flux
6%
Atmospheric Aerosols
H_2O, CO_2, SO_2, CH_4, O_3, etc.
UQ=37 Tt/yr
Vapour Transport
7%
E_0=361 Tt/yr
E_L=62 Tt/yr
Latent Heat Flux
17%
Hydrological Cycle
Precipitation
P_L=99 Tt/yr
Evapotranspiration
Weathering
R=37 Tt/yr
Runoff
CO_2 Exchange
P_0 = 324 Tt/yr
Wind Stress
CRYOSPHERE
Phase Changes:
Fusion
Sublimation
Sea Ice
H_2O Exchange
51% SR Absorbed by Land and Oceans
BIOSPHERE
Anthropogenic Effects
Frictional Dissipation of Ocean Currents
Thermohaline Circulation
OCEAN
LITHOSPHERE
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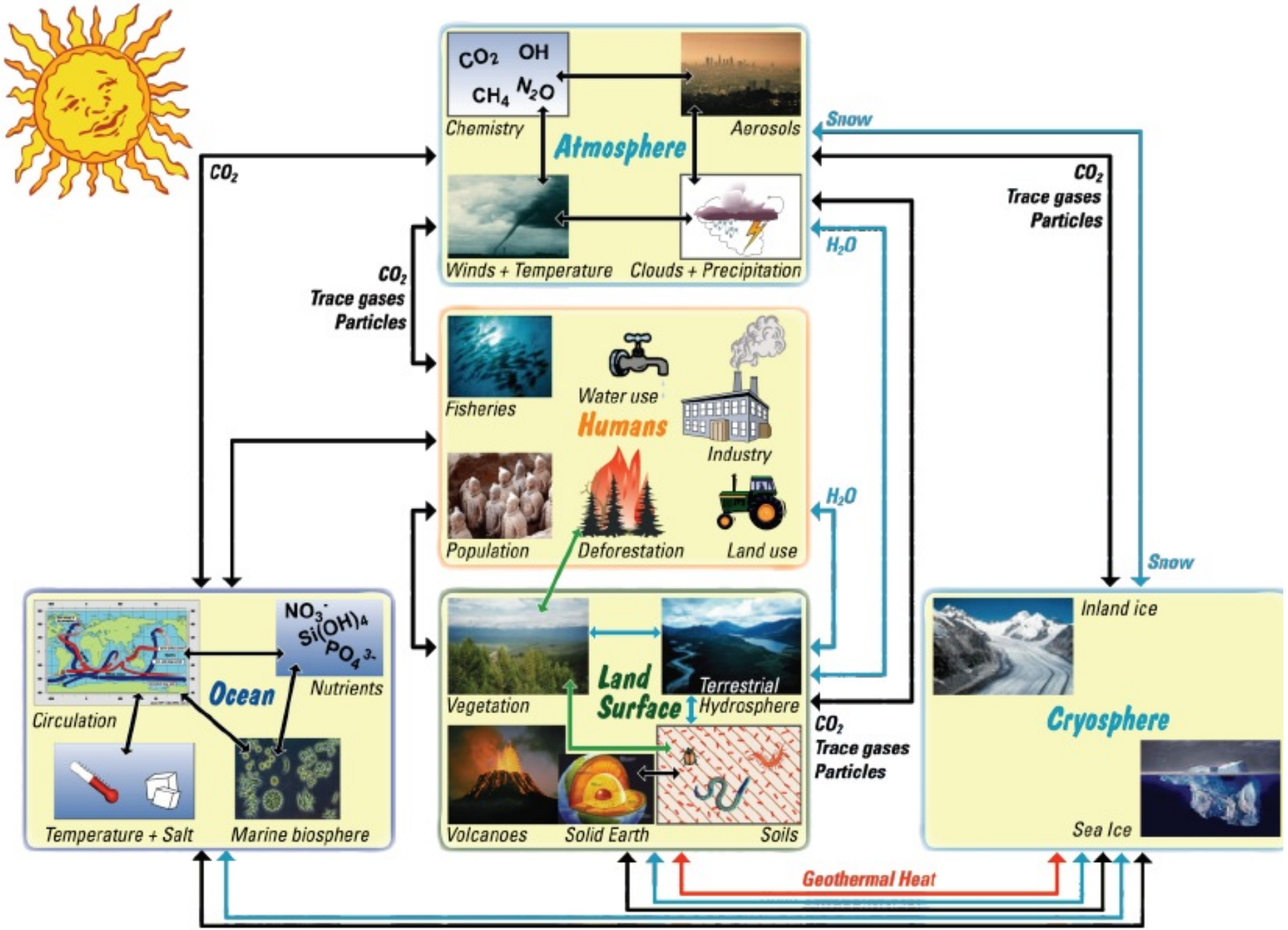

CO_2 OH
CH_4 N_2O
Chemistry
Atmosphere
Aerosols
Winds + Temperature
Clouds + Precipitation
CO_2
Trace gases
Particles
Snow
H_2O
Fisheries
Water use
Humans
Industry
Population
Deforestation
Land use
NO_3^-
$Si(OH)_4$
PO_4^{3-}
Ocean
Nutrients
Circulation
Temperature + Salt
Marine biosphere
Land Surface
Terrestrial
Hydrosphere
Vegetation
Volcanoes
Solid Earth
Soils
Inland ice
Cryosphere
Sea Ice
Geothermal Heat

(99) Descartes, René. *L'homme...*, 1677, p. 72. (10 x 12 cm.)

The Brain – is wider than the Sky –

For – put them side by side –

The one the other will contain

With ease – and You – beside.

Emily Dickinson (1830-1886)

Modelling must be expanded to include nonlinear time series analysis

- Instead of looking at modelling equations, look at the solutions by observing the natural or man-made system through a time series.
- Use **nonlinear time series analysis** for:

  Observation

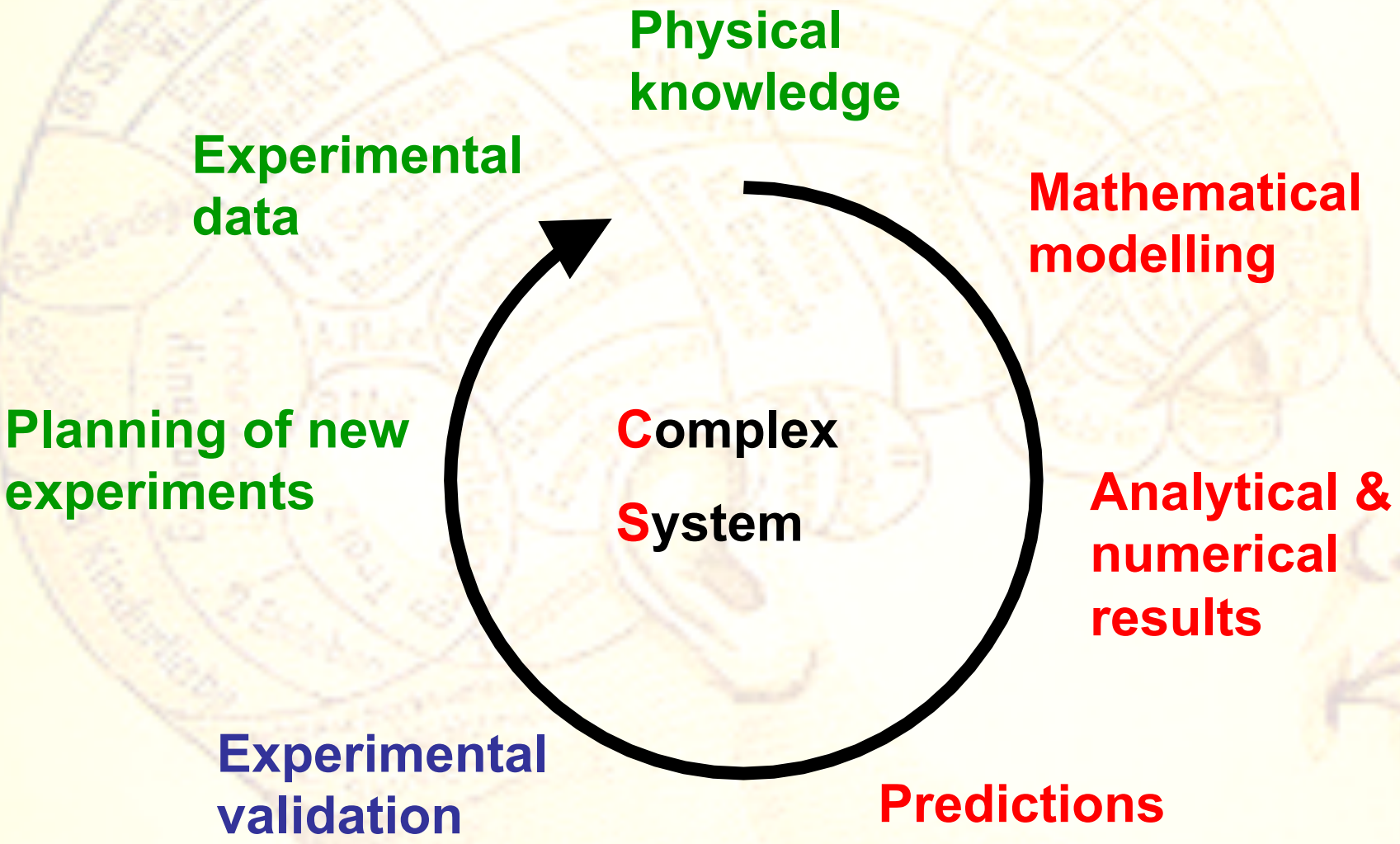
  Understanding

  Prediction

  Control

- Time series trajectory reflects the true behaviour of the dynamics of the real system.

An integrative approach to the research



Conclusion

Never in the annals of science and technology has been a phenomenon as pervasive and universal as that of complexity (and chaos).

IDEA:

- **Supplement the reductionist approach to science with an integrative agenda**
- **Not only to understand complexity but use it to manipulate systems**
- **Complexity presents us with an opportunity to influence its dynamics with small perturbations**

Shakespeare:

There is a tide in the affairs of men which, taking at the flood, leads on to fortune.