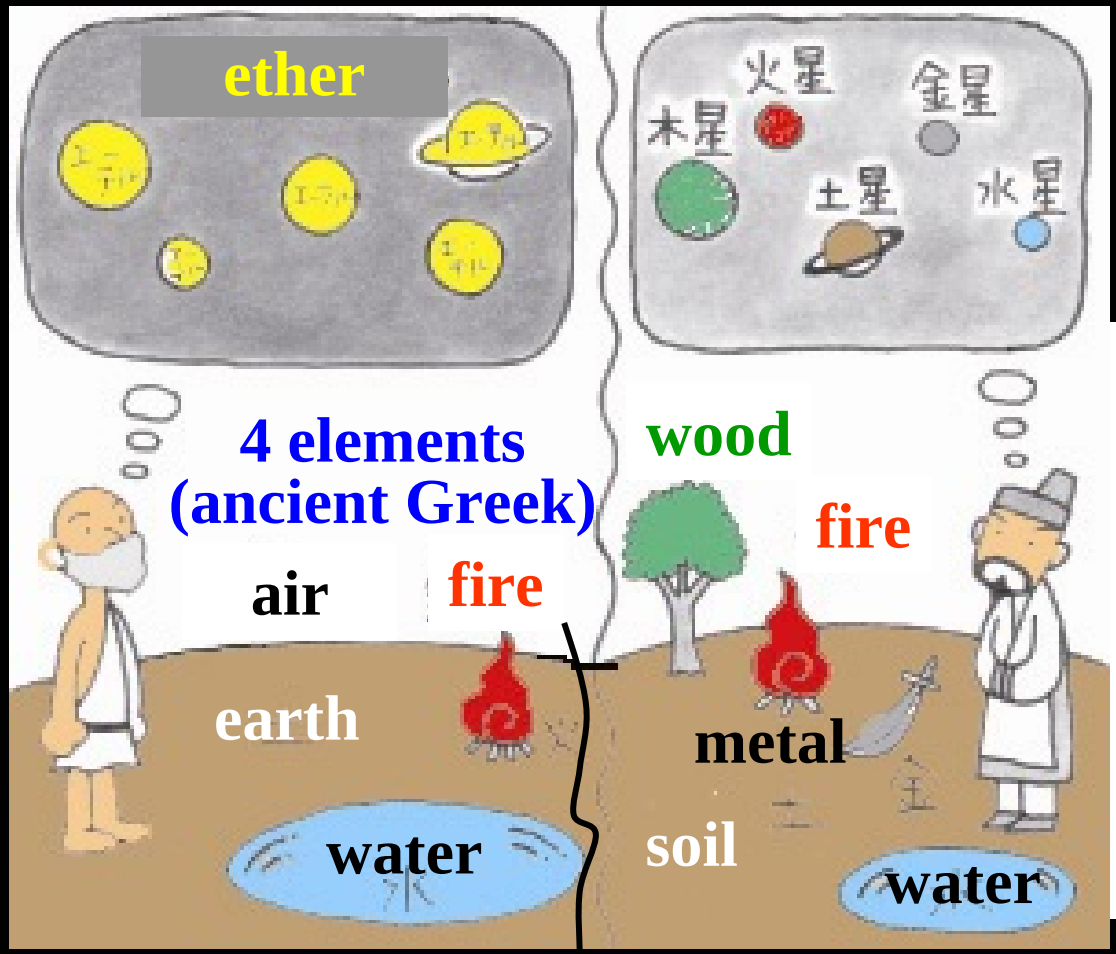
# Dark energy in the Universe




**5 elements (ancient Chinese)**

Wood (Jupiter)
Fire (Mars)
Soil (Saturn)
Metal (Venus)
Water (Mercury)

| | 陽 | 陰 |
|---|---|---|
| 木 | きのえ 甲 | きのと 乙 |
| 火 | ひのえ 丙 | ひのと 丁 |
| 土 | つちのえ 戊 | つちのと 己 |
| 金 | かのえ 庚 | かのと 辛 |
| 水 | みずのえ 壬 | みずのと 癸 |

**Yasushi Suto** *Department of Physics, The University of Tokyo*

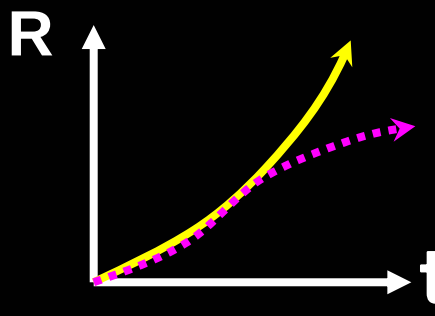
**Decrypting the Universe: Large Surveys for Cosmology**
**ROE-JSPS joint workshop @ Edinburgh, October 24 - 26, 2007**

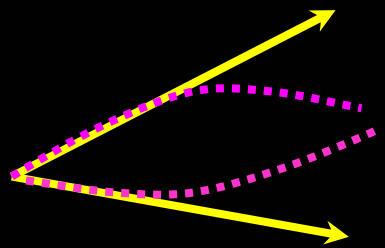
# Why is dark energy observable ?

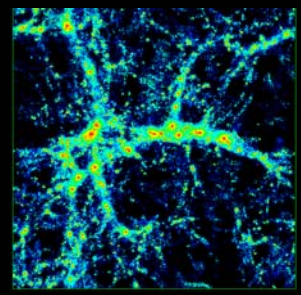
- **Objects are usually identified only through differential observations**
  - Visible matter: contrast between dark and bright regions
  - Dark matter: spatial inhomogeneities dynamically and gravitationally traced by visible stars, galaxies and quasars
- **Dark energy, if exists in a completely homogeneous manner, requires an absolute measurement for detection !?**
  - Time variation (cosmic acceleration, structure growth): differential observation in a time, not spatial, domain

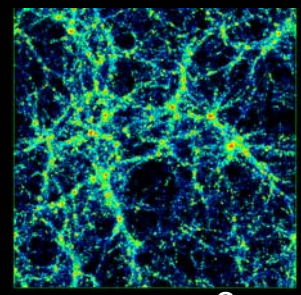
# Signatures of dark energy

- **cosmic acceleration**
- **geometry of the universe**
- **evolution of structure**
- **Probes**
  - Supernova Hubble diagram
  - Cosmic Microwave Background
  - Gravitational lensing
  - Baryon Acoustic Oscillation



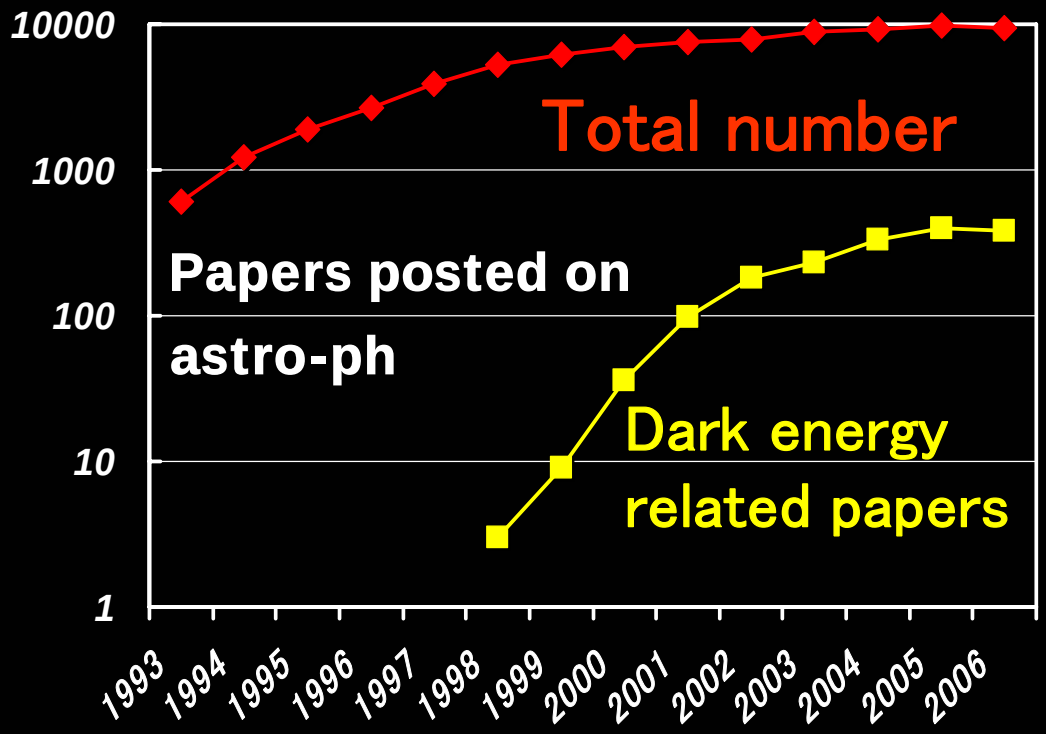







# Why important ?

- **New physics**
  - major but unknown component of the universe ?
  - Breakdown of general relativity at cosmological scales?
- **Astronomy is the key**




- **Steven Weinberg**
  *"Right now, not only for cosmology but for elementary particle theory this is the bone in the throat"*
- **Edward Witten**
  *"Would be number one on my list of things to figure out"*
- **Frank Wilczek**
  *"Maybe the most fundamentally ysterious thing in basic science"*

# Did we make progress at all ?

Egyptian

Chinese

Indian

American





**An improved cosmic picture ?**
**Simply (re)invent different names for the unknowns ?**

# Towards a better understanding of the universe

1. the n-th order parameterized model of the universe
   - $\Omega_\Lambda$, $\Omega_m$, $\Omega_b$, h, $\sigma_8$…
2. improve the precision/accuracy of the numbers
3. understand why
   - (variants of) inflation, superstring, extra-dimension…
4. look for something that cannot be described in the n-th order model
   - w=-1 ⇒ $w=w_0+w_a(1-a)$ ⇒ w(a) ⇒ w(a,r)
   - linear bias ⇒ nonlinear bias ⇒ non-deterministic bias

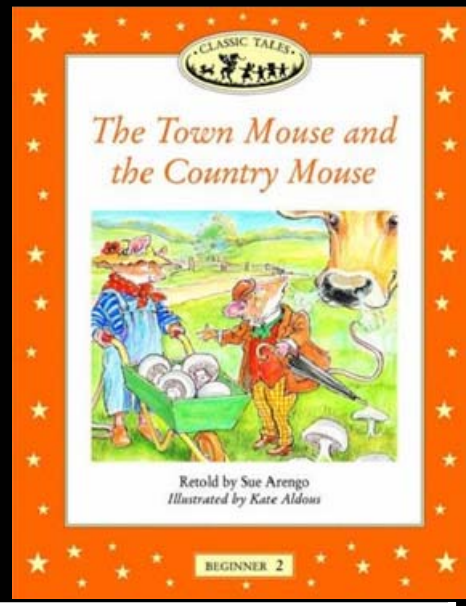
**Repeat the above steps until you become tired (or retire) for higher-order n=1,2,3,4,5…**

# Issues to be iterated in the loop

- **Origin of cosmic acceleration**
  - Physical models for dark energy (Copeland)
  - Modified gravity (Maartens, Yamamoto, Shirata)
- **Optimization of survey strategies** (Parkinson)
- **Nonlinear gravitational evolution and redshift-space distortion**
  - 1 loop PT (Nishimichi), renormalization approach, closure theory (Taruya), resummation method (Matsubara), N-body simulations (Takahashi, Angulo)
- **Galaxy bias** (Cole)
- **More physics**
  - Neutrino mass (Lahav, Saito, Takada)


# Dark energy research: from the country mouse to the town mouse ?

(A la Simon White)




| Town mouse ? | Country mouse ? |
|---|---|
| particle physicists | astronomers |
| >1000 collaborators | < 10 friends |
| huge international projects | many small groups |
| Large Hadron Collider | < 1m telescopes |
| dark energy cosmology | extrasolar planet |

**Nov. 9-10, 2006@Univ. of Tokyo**
**Cosmology with wide-field photometric and spectroscopic galaxy surveys**

# International Research Network for Dark Energy (JSPS, core-to-core program 2007-2009)

**Princeton U. Dept. of Astrophys. Sci.**
**coordinator**
**Edwin Turner**

**Caltech Dept. of Astron.**
**coordinator**
**Richard Ellis**

**Univ. of Tokyo Res. Center for the Early Universe**
**coordinator**
**Yasushi Suto**

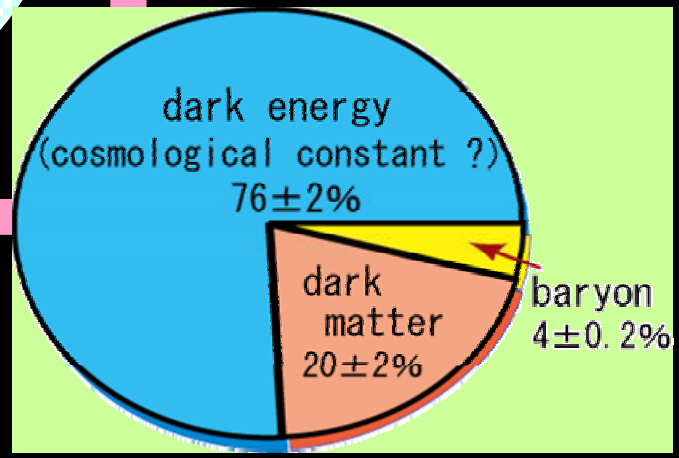
Tohoku Univ.
NAOJ
Hiroshima Univ.
Kyoto Univ.
Nagoya Univ.

CMB
Gravitational lens
Baryon oscillation

Supernova
Weak lens mapping

**Royal Obs. Edinburgh**
**coordinator**
**John Peacock**

Theoretical model
Baryon oscillation
Weak lens mapping




# June 7-8, 2007@Univ. of Tokyo
# Cosmology with wide-field imaging surveys of galaxies

# Next meeting of this series

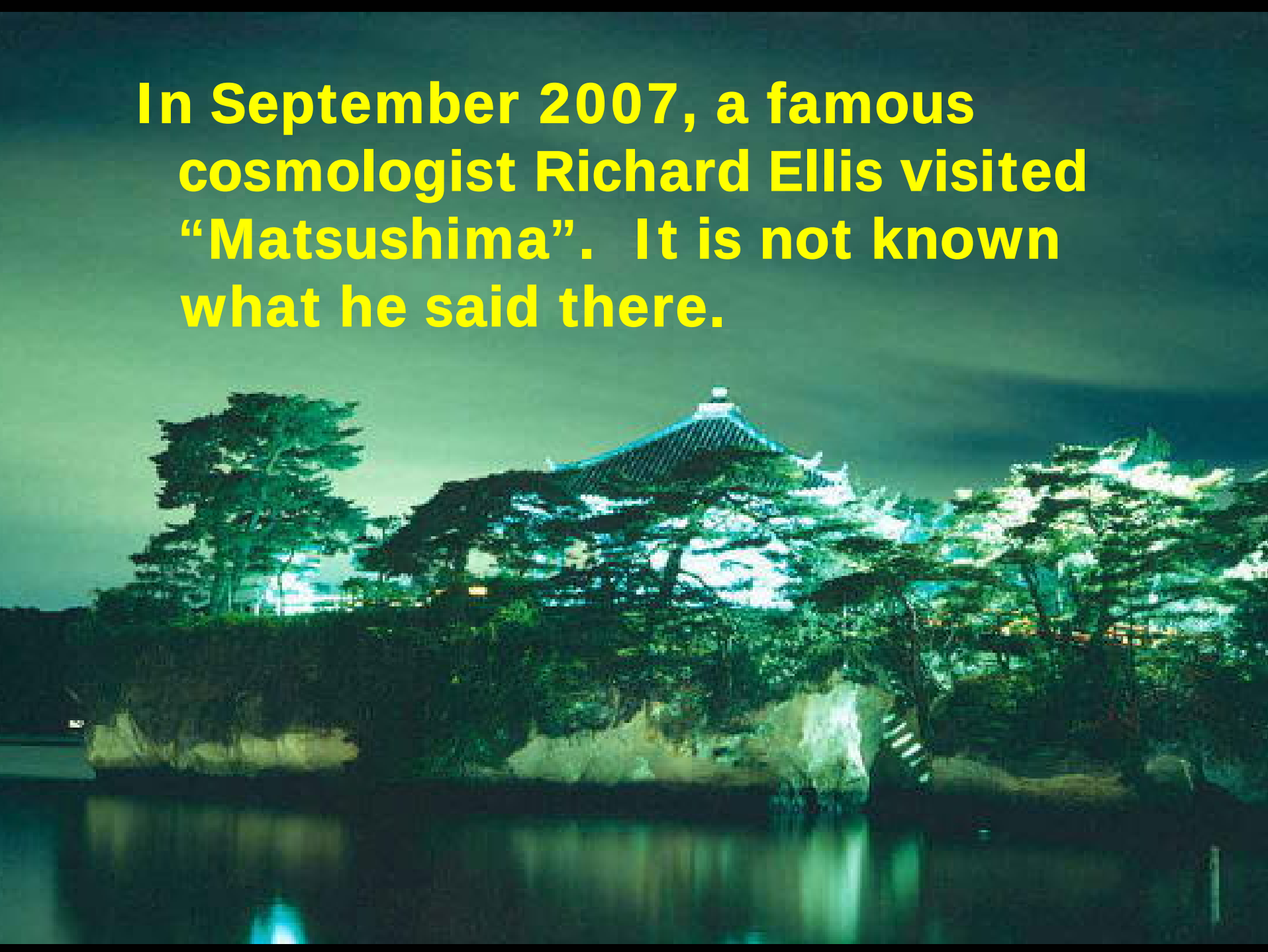
- Tentatively scheduled in Mid/late May, 2008 at Hawaii organized by Subaru and Gemini observatories and DENET (Dark Energy NETwork)

# Matsushima yah
# Ah Matsushima yah
# Matsushima yah

**In 1689 (Principia was published in 1687), a famous Haiku poet Matsuo Basho visited "Matsushima" (now close to Tohoko University).**

**A well-known poem claims to record his reaction, signifying that nothing more could be said.**

In September 2007, a famous cosmologist Richard Ellis visited “Matsushima”. It is not known what he said there.



**In October 2007, more than 20 Japanese astronomers visited ROE. They could merely express their wonderful experience as**

# Edinburgh

# AhAh Edinburgh

# Edinburgh

*Invited S*
D. Sperg
S. Cole
E. Copel
M. Doi
A. Helmi
O. Lahav
R. Maartens
Y. Mellier
S. Miyazaki
A. Murphy
M. Takada
T. Yamada

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avens
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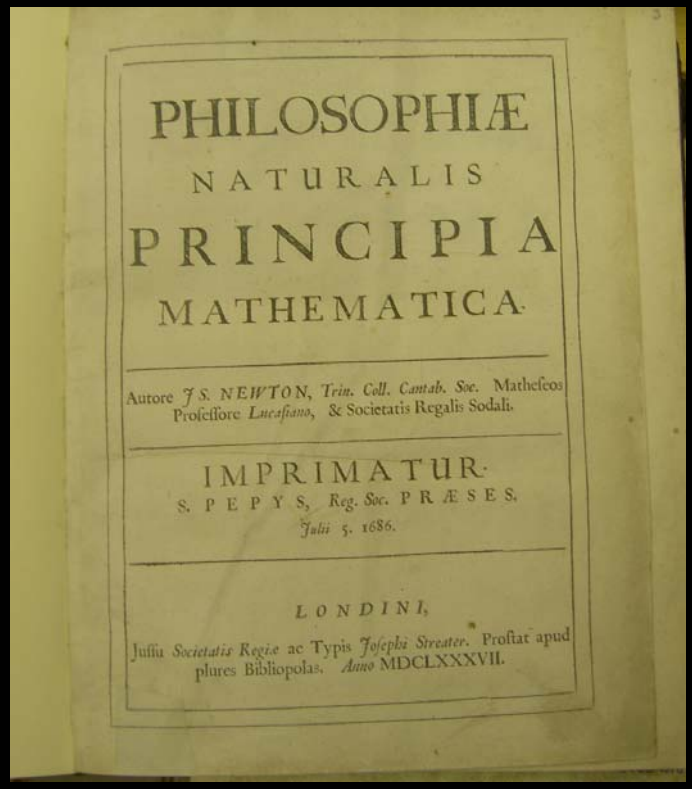
Nicol
P. Norberg (Chair)
P. Simon
F. Simpson
A. Taylor

THE UNIVERSITY OF EDINBURGH

Science & Technology Facilities Council
UK Astronomy Technology Centre

JAPAN SOCIETY FOR THE PROMOTION OF SCIENCE · FOUNDED 1932 ·


**Dark energy**
**Ah Ah Dark energy**
**Dark enegy**



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA

Autore *J S. NEWTON, Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
*Julii* 5. 1686.

*LONDINI*,
Jussu *Societatis Regiæ* ac Typis *Josephi Streater*. Prostat apud plures Bibliopolas. *Anno* MDCLXXXVII.