2014년 2학기

물리학의 현대적 이해

권영준 (물리학과)

Episode 3: 물리학의 언어

- 모델링, 수식, 단위
- the large and the small
- *The unreasonable effectiveness of mathematics in the natural sciences*

자연과학 방법론
(the scientific method)

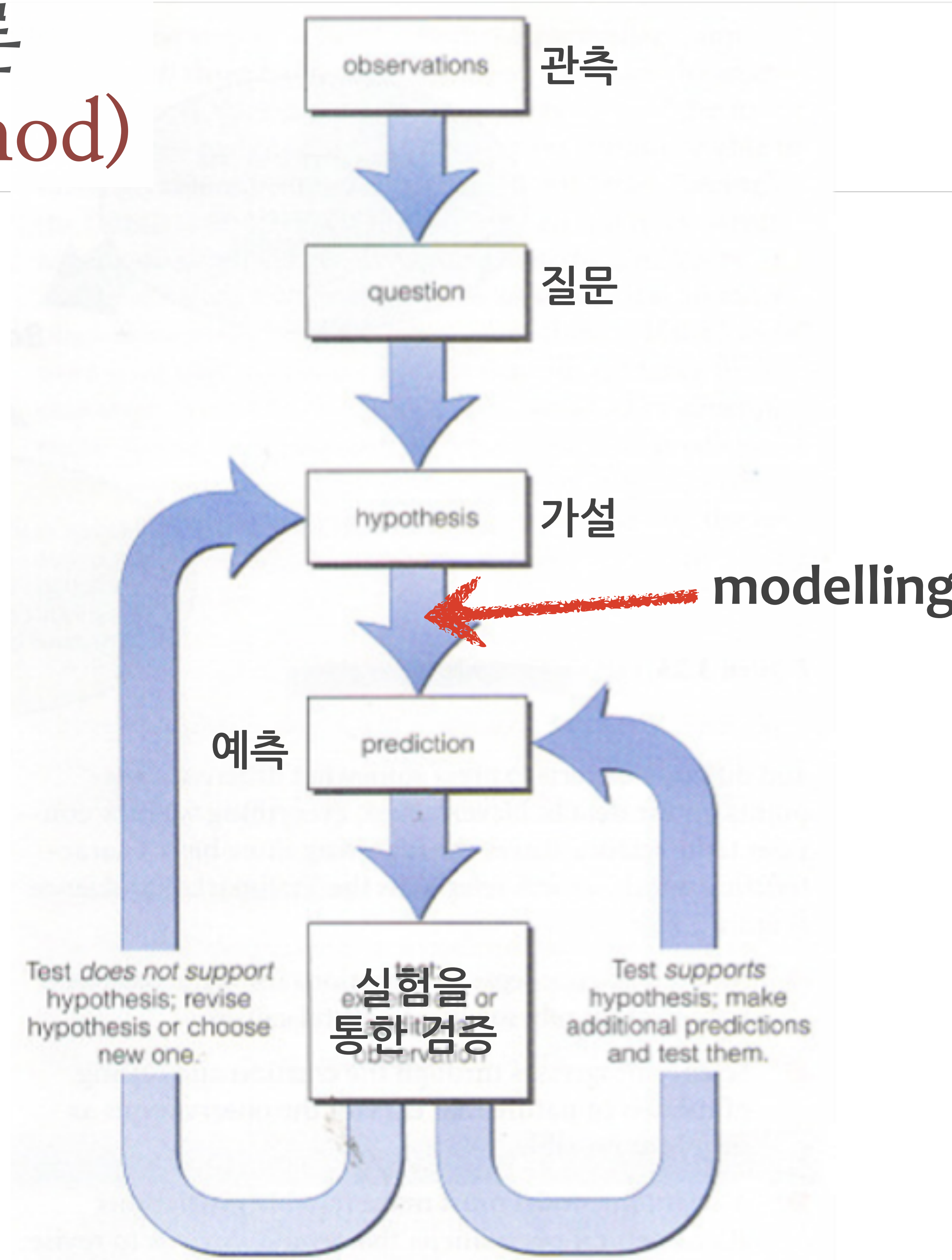
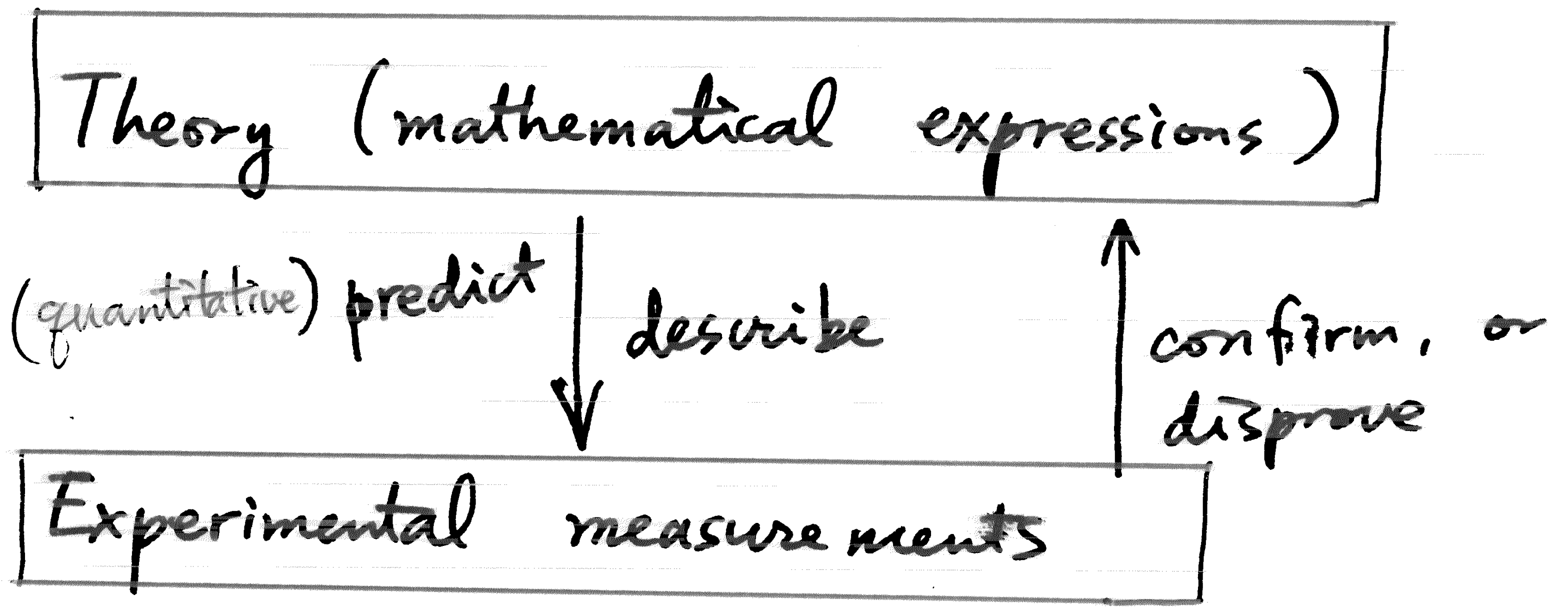


Figure 3.25 This diagram illustrates what we often call the scientific method.

Physics as a numerical science



- 물리학은 실험과 관측을 통해 모델과 가설을 검증하며 이를 바탕으로 이론을 만들어 간다.

- 실험과 이론(모델, 가설 등)을 비교하기 위한 공통 요소는?
  - 수 (數, number)
    - o 이론: 수식으로 표현
    - o 실험: 결과를 숫자로 표현

Memories from my sophomore years

◆ “홈런된 공의 운동량을 추정하시오”

◆ “그것을 풀라는 문제임”

Physics as a numerical science

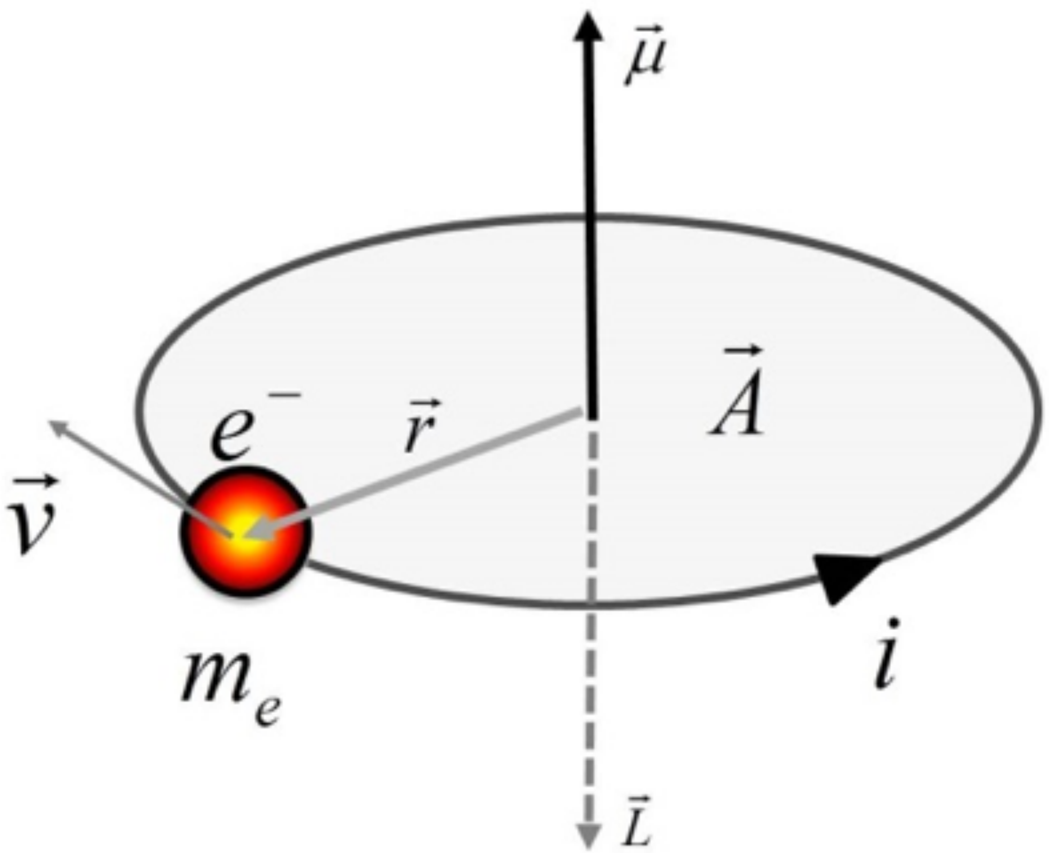
- compare **high-precision** measurements with theoretical calculations
  - 가설(모델)을 검증하여 받아들이거나, 버리거나, 아니면 수정을 가하거나

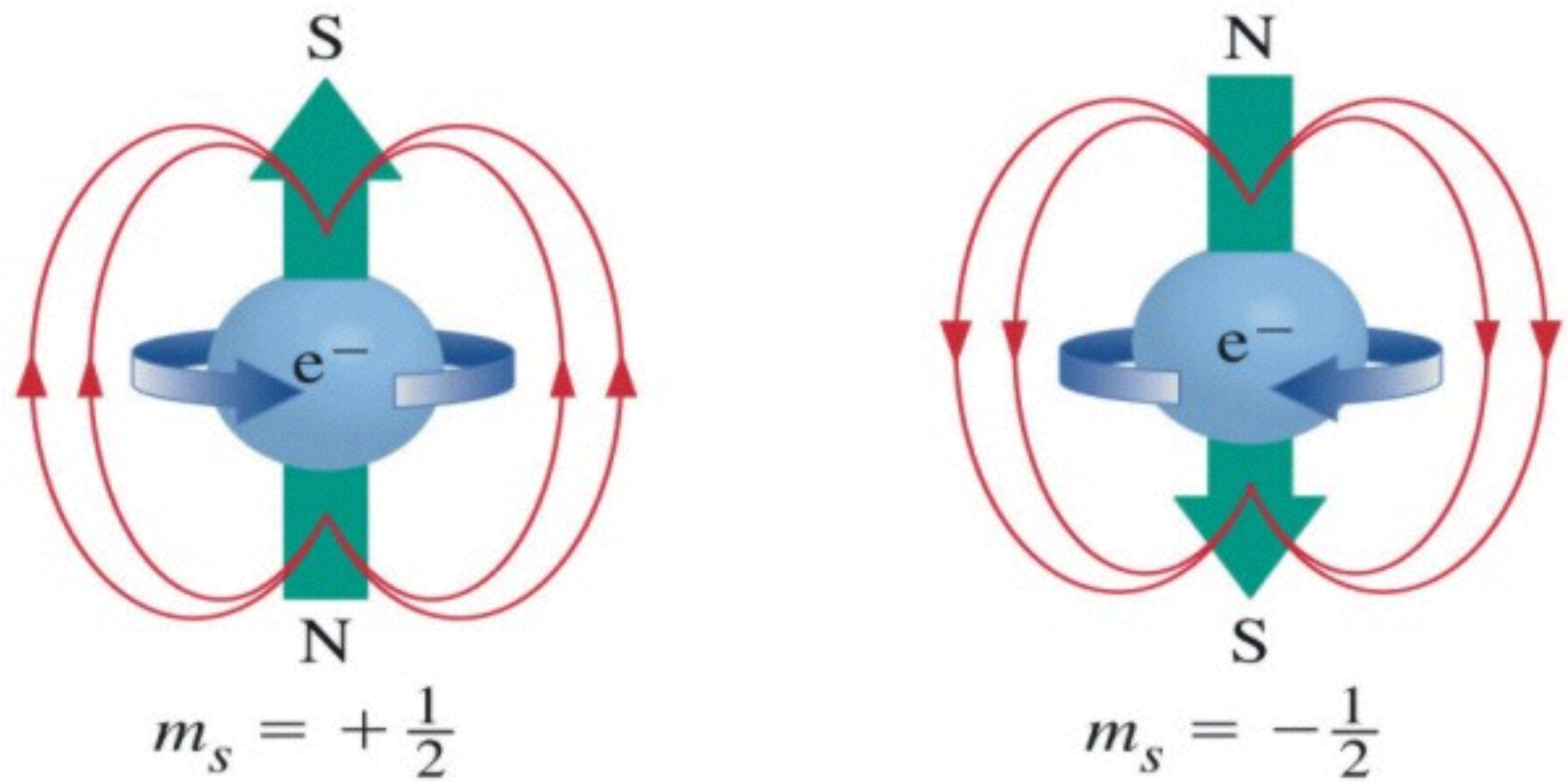
- Why high precision?
  - 실험 결과와 대강 비슷한 결과를 예측하는 가설들이 한 개 이상 있는 경우
  - 대강 비슷한 숫자가 나오는 것은 우연의 일치일 가능성이 크지만 고도의 정밀도로 일치하는 것은 심상치 않은 것 아닐까?
  - 물리학의 역사에서 당시 존재하던 이론(가설)과 실험 결과 사이의 작은 차이를 파고들어 새로운 (훨씬 심오한) 물리법칙을 발견한 사례가 적지않다.

예) 케플러의 타원, 흑체복사 곡선, 수성 궤도, Lamb shift & QED

talking about high-precision?

- 전자의 스핀이 만드는 자석의 크기는?
  - 양자역학(혹은 양자전자기학)에서 g라는 값으로 표시

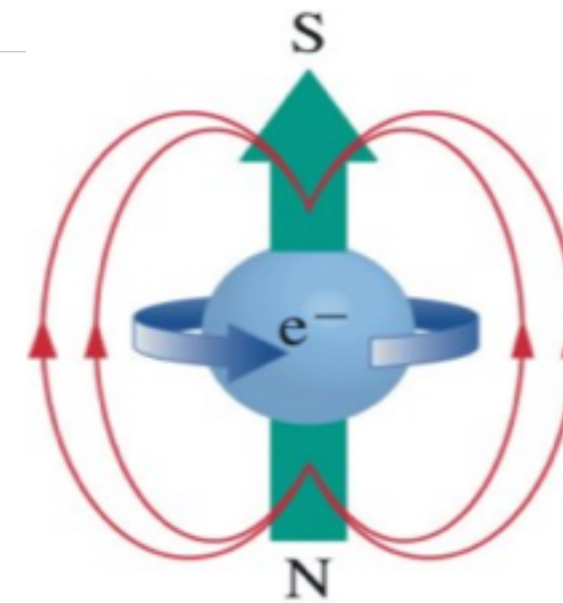




- 전하를 띈 입자(“하전 입자”, 예를 들면 전자, 양성자)가 움직이면 자기장이 생긴다. (전자석의 원리)
- 전자의 궤도운동은 자기장을 만든다 (= 전자석이 된다)
- 전자의 스핀도 자기장을 만든다 (즉, 전자는 가만히 있어도 전자석이 된다)

talking about high−precision?

- 전자의 스핀이 만드는 자석의 크기는?
  - 양자역학(혹은 양자전자기학)에서 g라는 값으로 표시



$$g = 2(1 + a) \approx 2$$

- **P. A. M. Dirac: $g \simeq 2$**
- **J. Schwinger:**

$$a = \frac{g-2}{2} = \frac{\alpha}{2\pi} \approx 0.0011614$$

- **Schwinger 이후 – 엄청난 정밀도로 이론 계산과 실험 측정이 이루어짐**

실험: a = 0.00 115 965 218 07 (3)
이론: a = 0.00 115 965 218 18 (8)

talking about high-precision?

(a lesson)

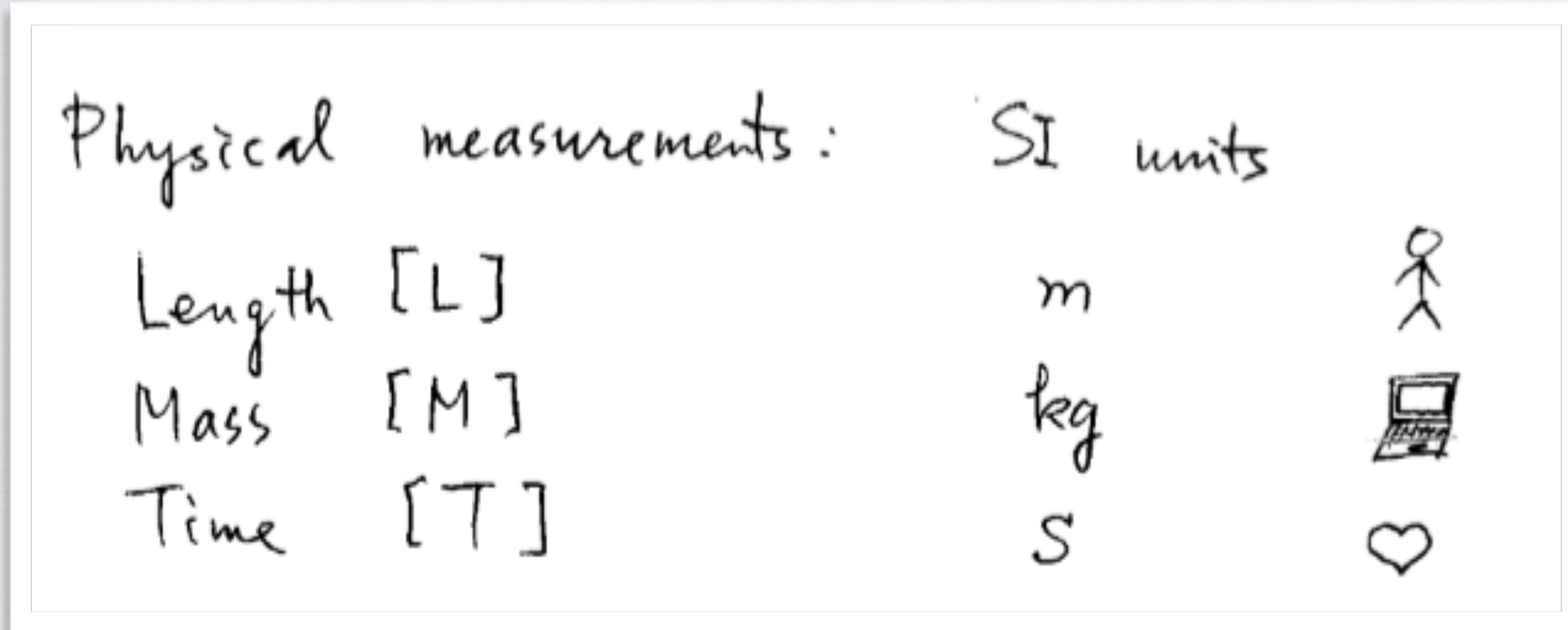
만일 주어진 현상을 대략 정성적으로 설명하는데서 만족했다면 앞서 예시한 바와 같은 측정과 계산의 비교에서의 작은 차이의 발견은 가능하지 않았을 것이다.

The large and the small

How Big is the Universe?

"The universe is THIS big"

Units for measurements



- They are standard units (SI), but human-oriented
- Any "natural" units?

  → for this, we need modern (20th C) physics

  i.e. Relativity & Quantum Theory

SI units (International System of Units)

Base Quantity	unit	symbol
길이	meter	m
질량	kilogram	kg
시간	second	s
전류	ampere	A
온도	kelvin	K
물질의 양	mole	mol
빛의 밝기	candela	cd

SI Prefixes

Multiple	Prefix	Symbol
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f

The Large & the small

[small]

Time : ??

Length : (size of an atom $\sim 10^{-9}$ m.

〃 a nucleus $\sim 10^{-14}$ m

〃 a proton $\sim 10^{-15}$ m)

mass : mass of a proton $\sim 1.7 \times 10^{-27}$ kg

for a time-scale, we do not have a good reference, but consider this.

time for a light to pass the size of a proton $\simeq \frac{10^{-15}}{3\times 10^{8}} \sim 3\times 10^{-24}$ s

The Large & the small

[large]

Time : age of universe ~ 1.4×10^{10} years

Length : size of universe

Hubble length : $\ell_H = c/H_0 \simeq 10^{26}$ m.

Mass : $10^{11} \times 10^{11} \times M_\odot$

($\simeq 2 \times 10^{30}$ kg)

Meaning of H_0, the Hubble constant, H_0?

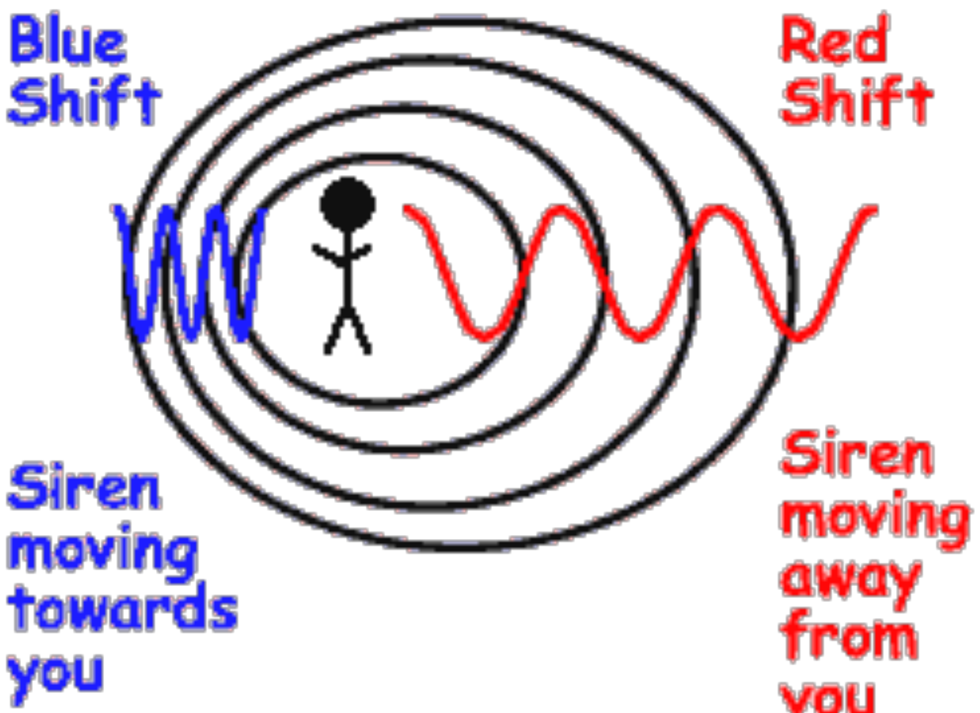
Meaning of H_0, the Hubble length, ℓ_H?

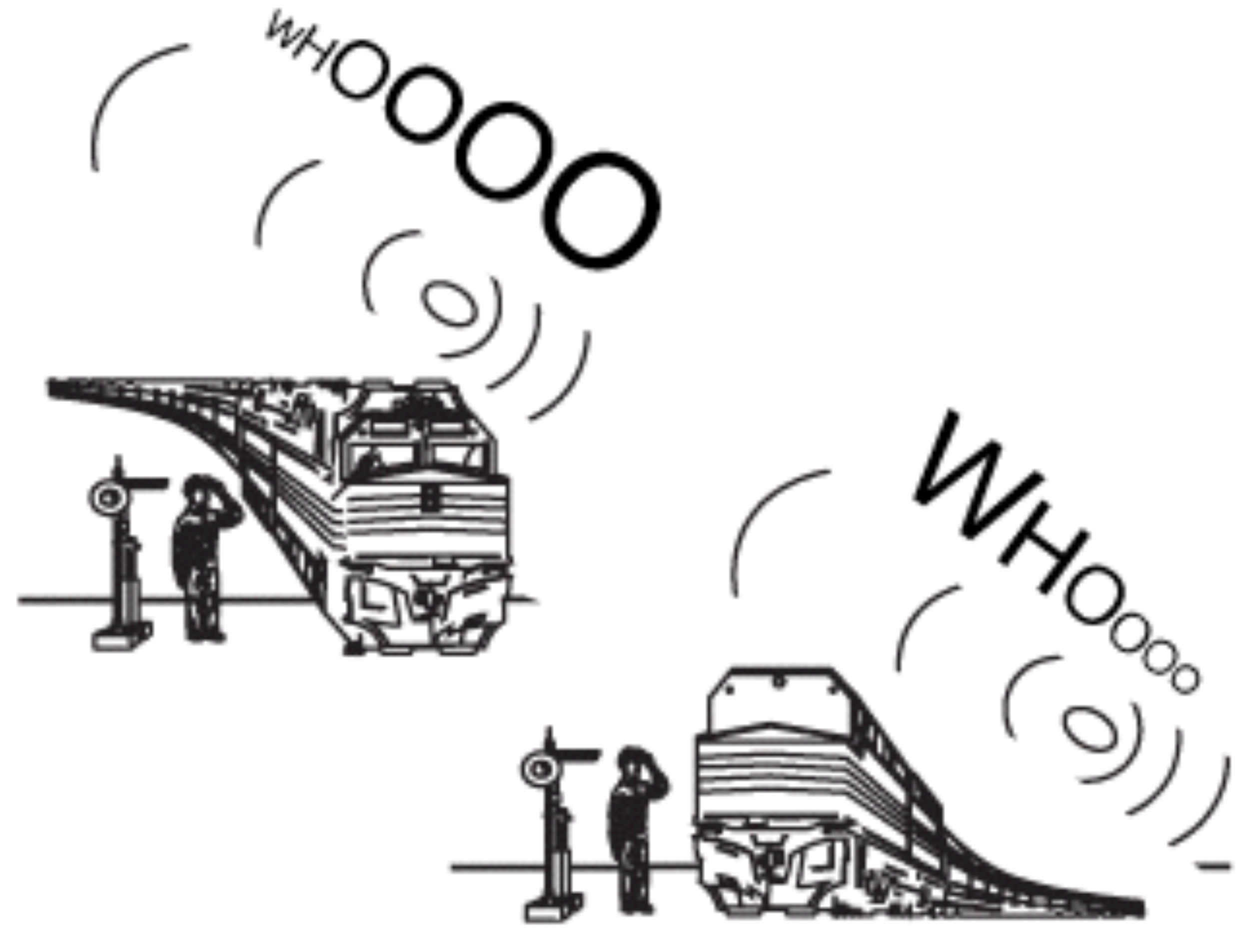
the Hubble's law

허블의 법칙은 먼 우주로부터 오는 빛의 적색 편이(**red shift**)는 거리에 비례한다는 법칙이다. 이 법칙은 약 **10**년간의 관측 끝에 **1929**년 **Edwin Hubble**과 **Milton Humason**이 발표하였다. 허블의 법칙은 우주팽창론의 첫 관측 증거이며, 빅뱅에 대한 증거로 가장 널리 인용된다. **2013**년 **3**월 발표된 유럽 우주국 플랑크 위성(**Planck**) 데이터에 따르면, 허블 상수는 약 **67.80 km/(s · Mpc)**이다.

Hubble 상수(**H_0**)의 의미는 무엇인가**?**

Doppler effect



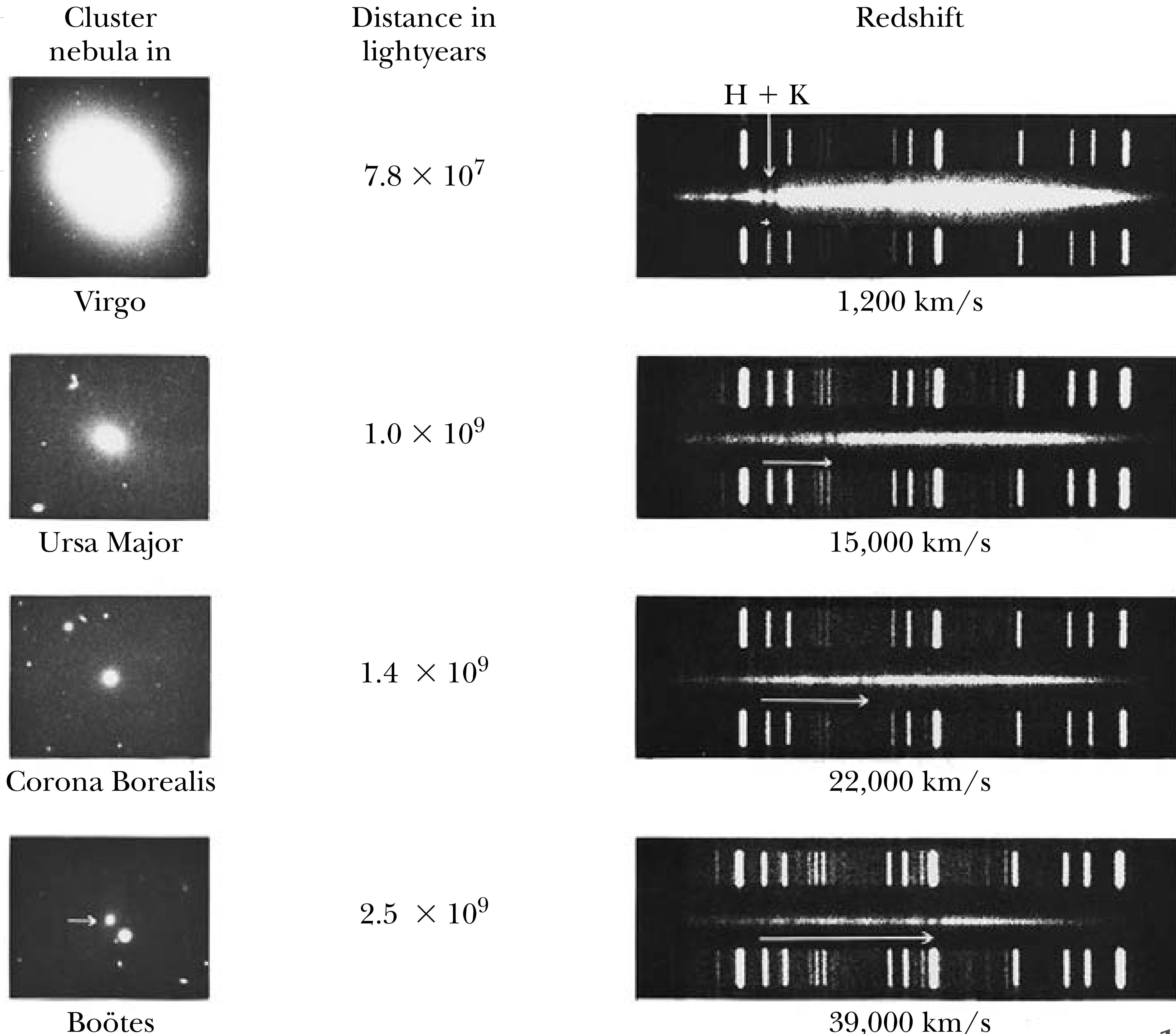


도플러 효과(**Doppler effect**, 도플러 현상, 도플러 편이 현상)는 크리스티안 도플러가 발견한 것으로, 어떤 파동(예를 들어 소리 혹은 빛)의 파동원과 관찰자의 상대 속도에 따라 진동수와 파장이 바뀌는 현상을 가리킨다.

빛의 경우 광원과 관측자의 거리가 가까와지면 진동수가 증가하고(**blue shift**) 거리가 멀어지면 진동수가 감소한다(**red shift**). 진동수의 변화는 상대속도에 비례한다.

$$v = H_0 R$$

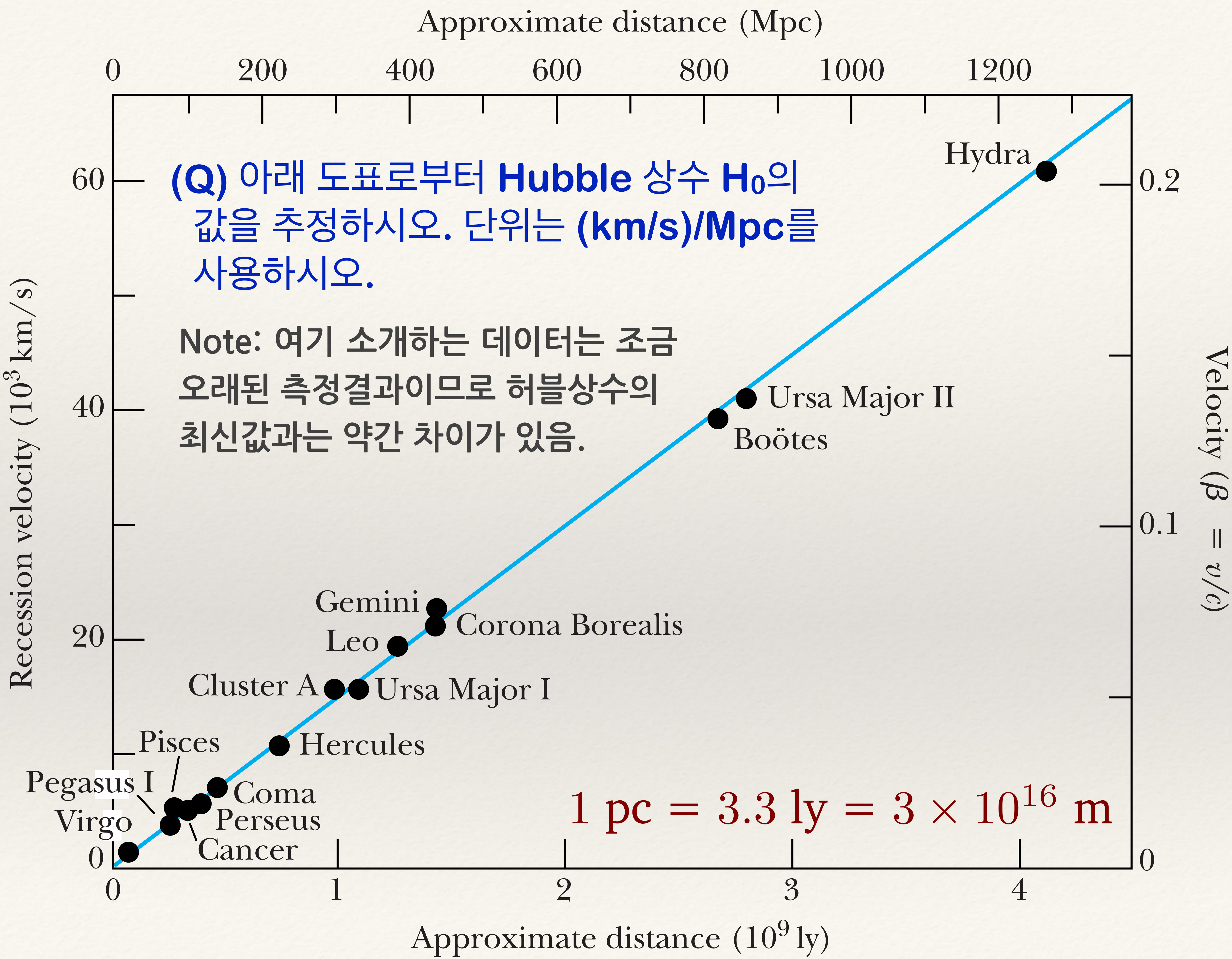
우주의 팽창!



Cluster nebula in
Distance in lightyears
Redshift
H + K
Virgo
7.8×10^7
1,200 km/s
Ursa Major
1.0×10^9
15,000 km/s
Corona Borealis
1.4×10^9
22,000 km/s
Boötes
2.5×10^9
39,000 km/s

(Q) 아래 도표로부터 **Hubble** 상수 **H_0**의 값을 추정하시오. 단위는 **(km/s)/Mpc**를 사용하시오.

Note: 여기 소개하는 데이터는 조금 오래된 측정결과이므로 허블상수의 최신값과는 약간 차이가 있음.



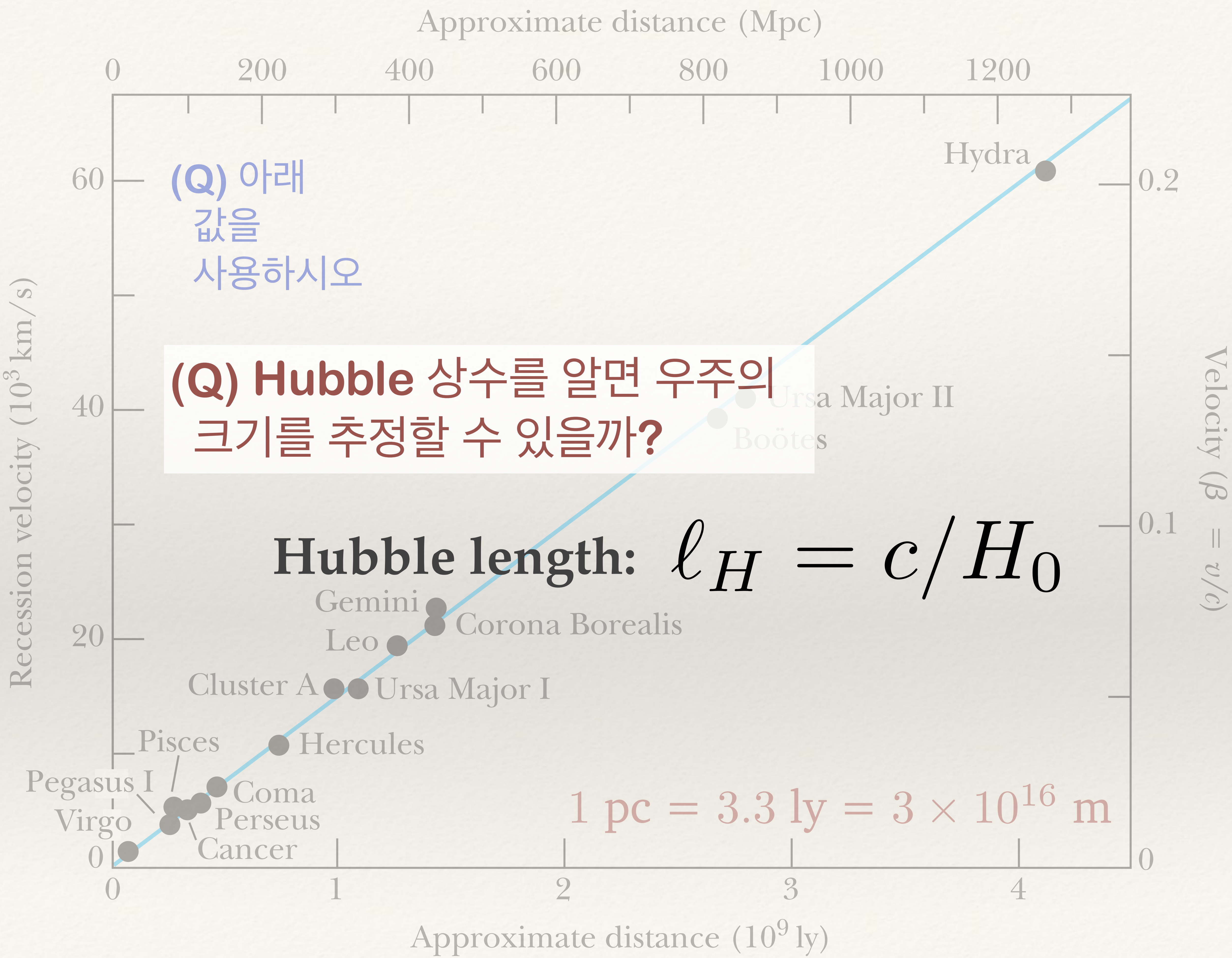
$1\ \text{pc} = 3.3\ \text{ly} = 3 \times 10^{16}\ \text{m}$

(Q) Hubble 상수를 알면 우주의 크기를 추정할 수 있을까?

(Q) 아래 값을 사용하시오

Hubble length: $\ell_H = c/H_0$

$1 \text{ pc} = 3.3 \text{ ly} = 3 \times 10^{16} \text{ m}$



Cosmic Journey Through Our Backyard
where are we now?

Earth: 1.3×10^7 m

Solar sysem: 10^{13} m

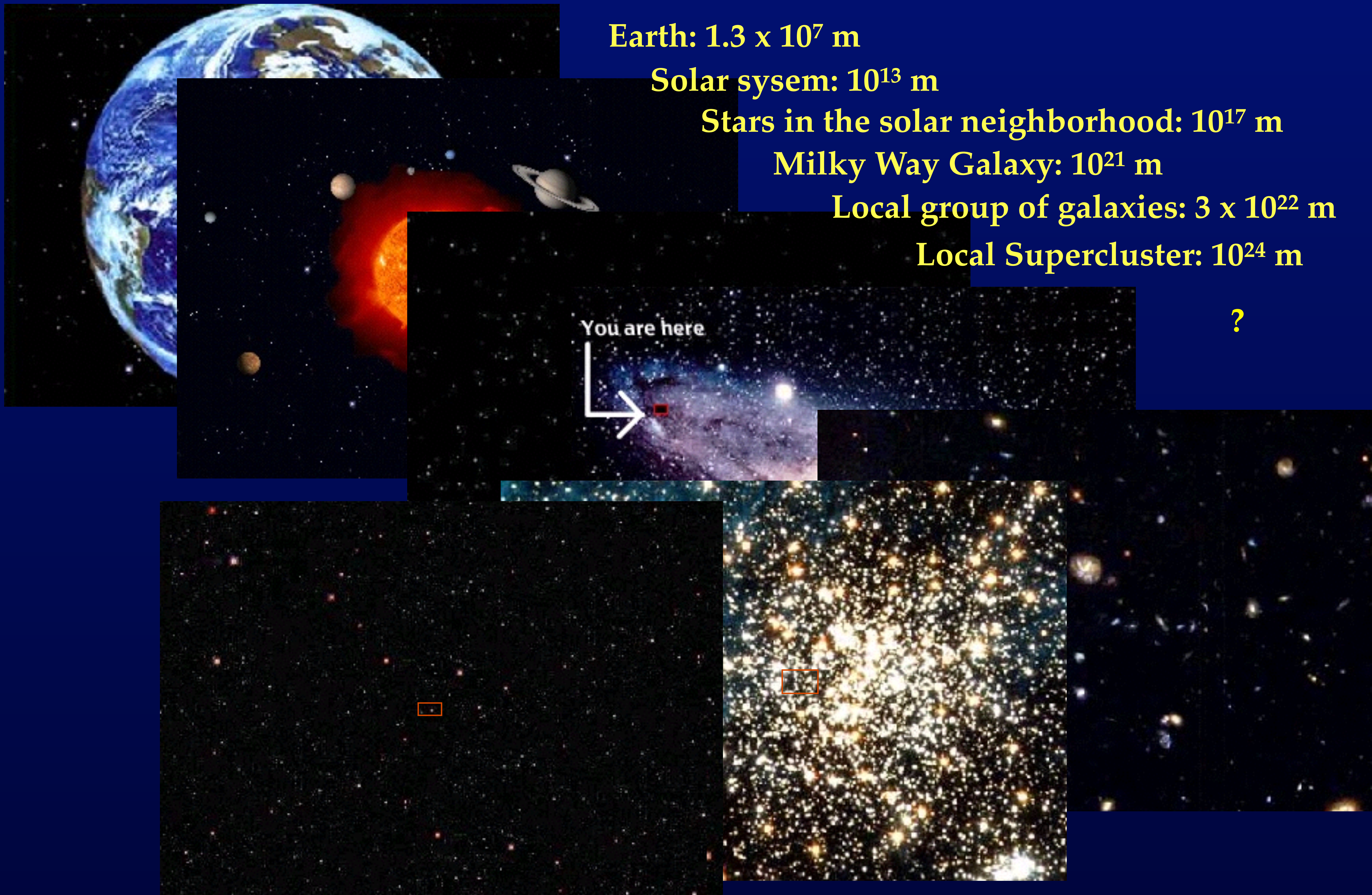
Stars in the solar neighborhood: 10^{17} m

Milky Way Galaxy: 10^{21} m

Local group of galaxies: 3×10^{22} m

Local Supercluster: 10^{24} m

?



The Large & the small

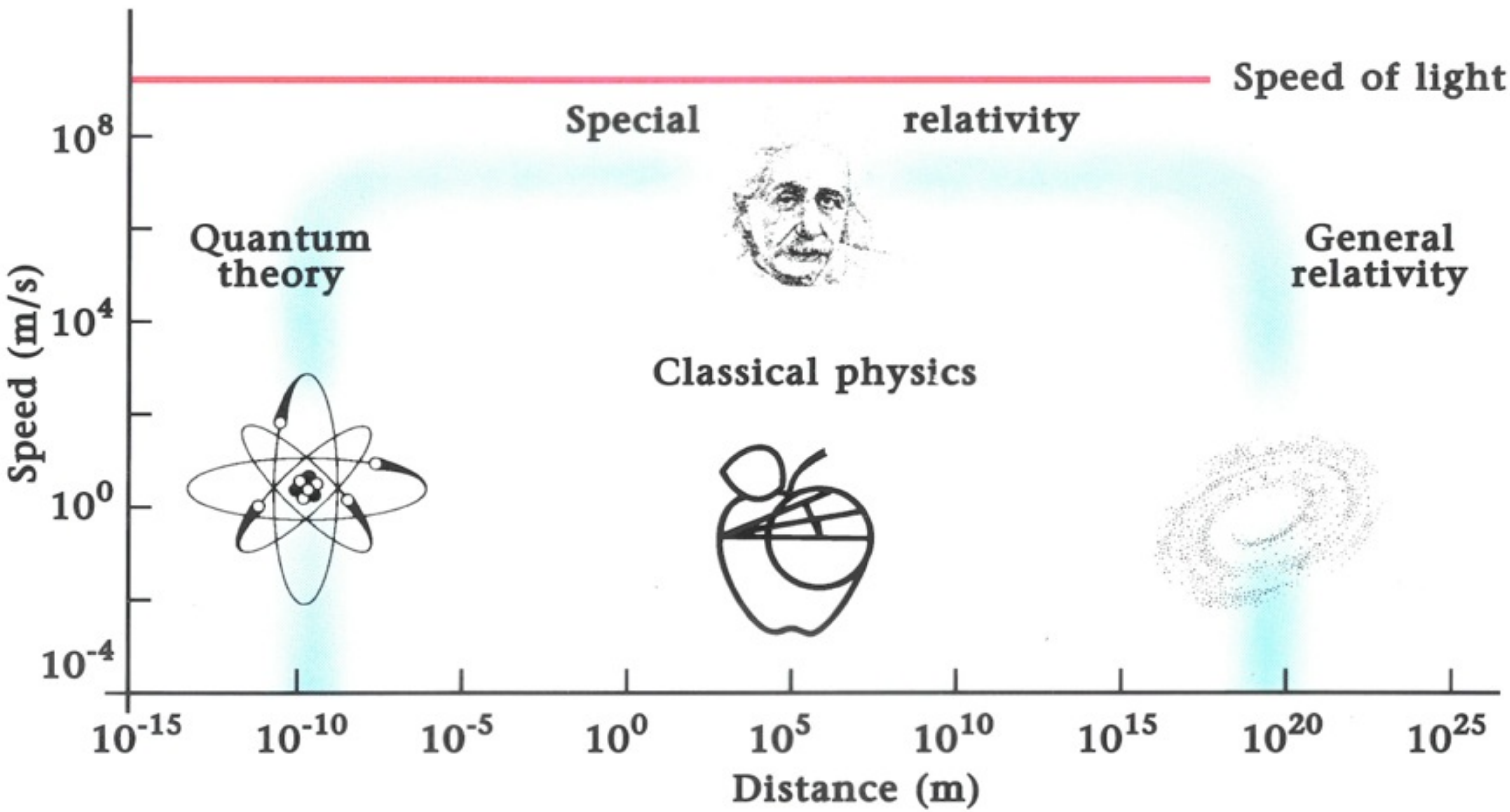
[Homework]
Express your height, mass and age in terms of the Largest and smallest such measurements in the universe!

For example, let's think about the mass.

- $60\ \text{kg} = 60\ \text{kg} * (m_p\ /\ 1.7\text{x}10^{-27}\ \text{kg})$
  $= 3.5 \text{ x } 10^{28}\ m_p$

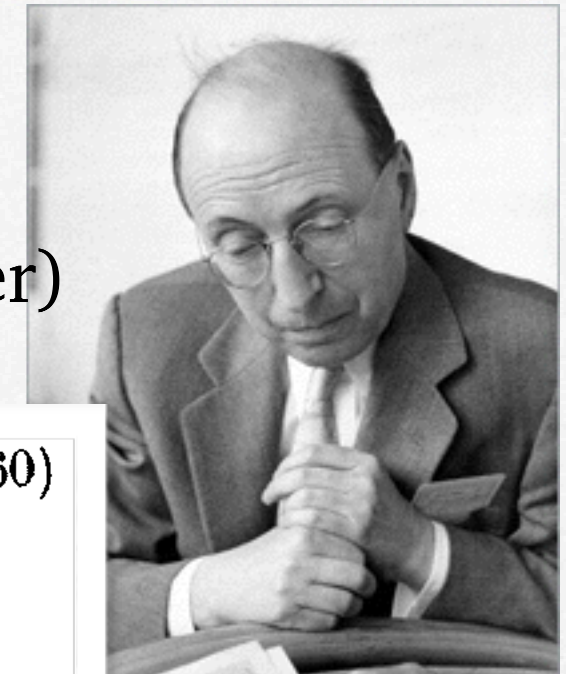
- $60\ \text{kg} = 60\ \text{kg} * (M_{univ.}\ /\ 2\text{x}10^{52}\ \text{kg})$
  $= 3.0 \text{ x } 10^{-51}\ M_{univ.}$

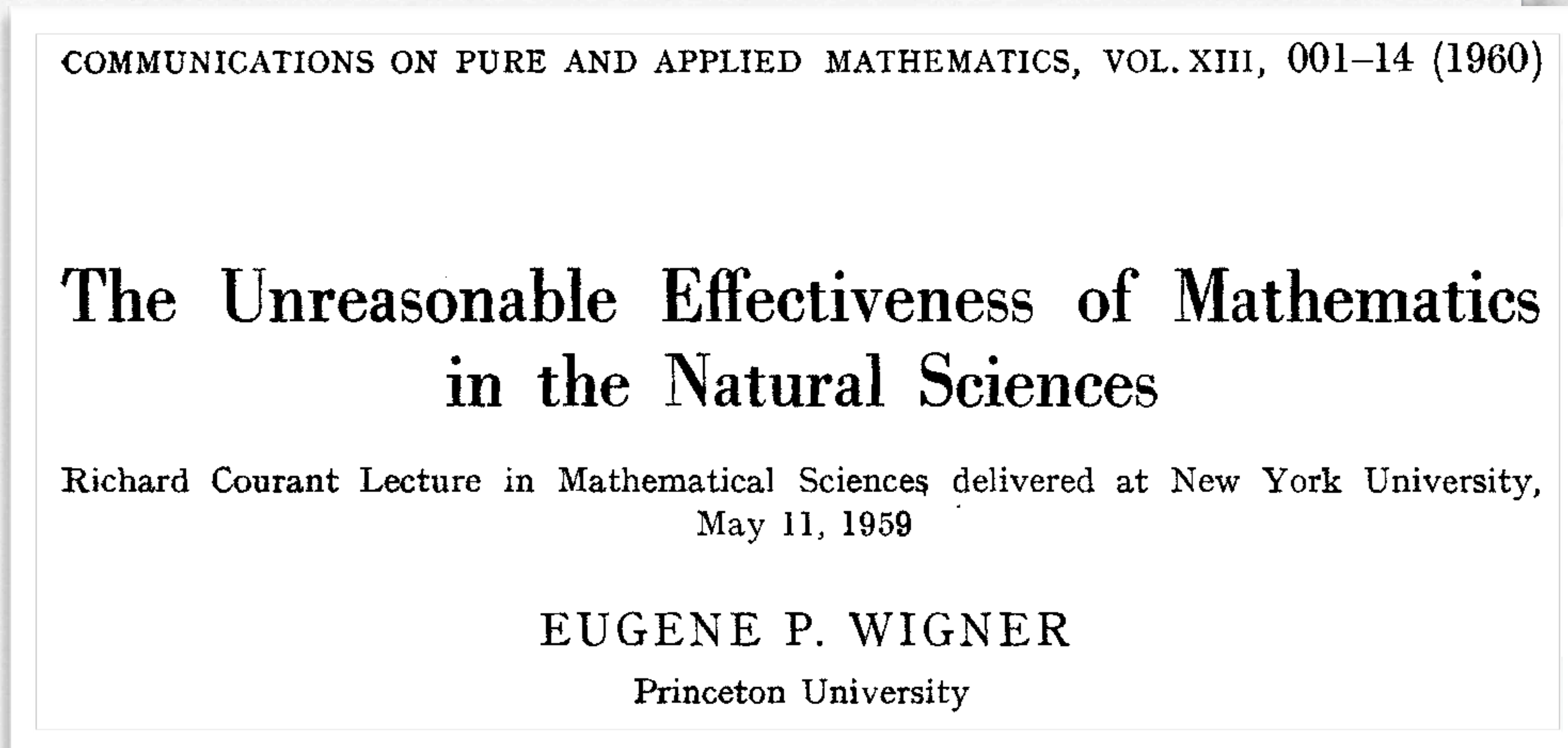
Same physics for all scales?



24. Range of applicability of Newton's laws. (Fig. 4.26)

- 물리법칙을 표현하는 수학의 위대한 아름다움…
  - *'the unreasonable effectiveness of mathematics'* (Eugene Wigner)





COMMUNICATIONS ON PURE AND APPLIED MATHEMATICS, VOL. XIII, 001–14 (1960)

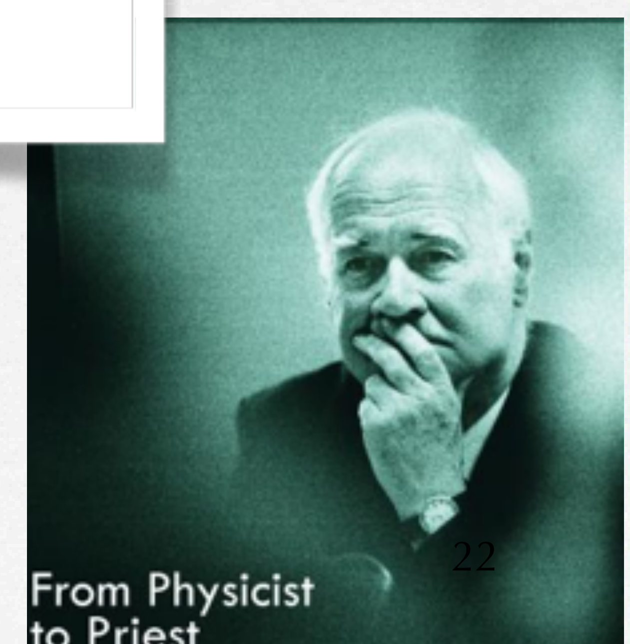
The Unreasonable Effectiveness of Mathematics in the Natural Sciences

Richard Courant Lecture in Mathematical Sciences delivered at New York University, May 11, 1959

EUGENE P. WIGNER

Princeton University

  - *'The universe is both rationally transparent and rationally beautiful'* (John Polkinghorne)



If you stop to think about it, all this is very odd. Mathematics, after all, is just abstract thinking, but it turns out that some of the most beautiful patterns that the mathematicians can think up are not just airy-fairy ideas, but they actually occur, out there, in the structure of the world around us. Dirac's brother-in-law, Eugene Wigner, (himself also a Nobel prize winner) once called it 'the unreasonable effectiveness of mathematics'. He also said it was a gift that we neither deserved nor understood. I do not know about deserving it, but I would certainly like to understand this strange property that makes theoretical physics both possible and greatly rewarding.

The universe is both rationally transparent and rationally beautiful. The first fact makes science possible, the second gives scientists their deepest satisfaction, the sense of wonder at the marvellous order revealed to our enquiry.

(J. Polkinghorne)

There is a story about two friends, who were classmates in high school, talking about their jobs. One of them became a statistician and was working on population trends. He showed a reprint to his former classmate. The reprint started, as usual, with the Gaussian distribution and the statistician explained to his former classmate the meaning of the symbols for the actual population, for the average population, and so on. His classmate was a bit incredulous and was not quite sure whether the statistician was pulling his leg. "How can you know that?" was his query. "And what is this symbol here?" "Oh," said the statistician, "this is π." "What is that?" "The ratio of the circumference of the circle to its diameter." "Well, now you are pushing your joke too far," said the classmate, "surely the population has nothing to do with the circumference of the circle."

Let me end on a more cheerful note. The miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve. We should be grateful for it and hope that it will remain valid in future research and that it will extend, for better or for worse, to our pleasure even though perhaps also to our bafflement, to wide branches of learning.

E. Wigner