

**Pondering on
the unknown world
beyond the pale blue dot**



Yasushi Suto (Department of Physics, The University of Tokyo)

「 D'ou Venons Nous / Que Sommes Nous / Où Allons Nous 」
そのストーリーと新たな博物館の可能性@国立科学博物館 2023年10月9日 13:40-14:10

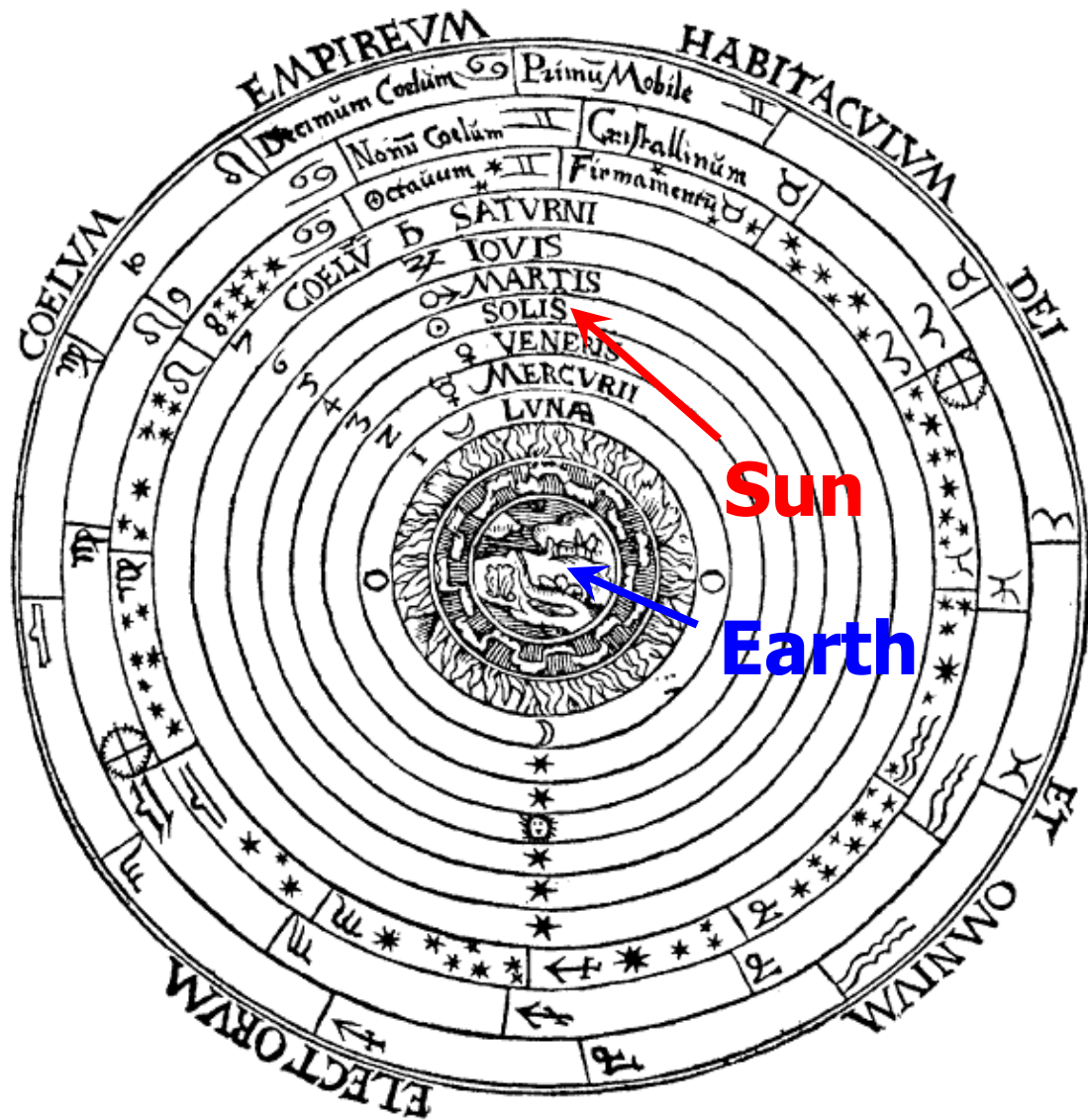
Today's talk

- 1 Universe viewed from Earth,
Earth viewed from universe**
- 2 Co-evolution of the universe, stars,
galaxies, and life**
- 3 Unknown world beyond the horizon of
our visible universe**
- 4 Can we really understand the world
beyond the horizon ?**

1 Universe viewed from Earth

Earth viewed from universe

Earth = the center of the world



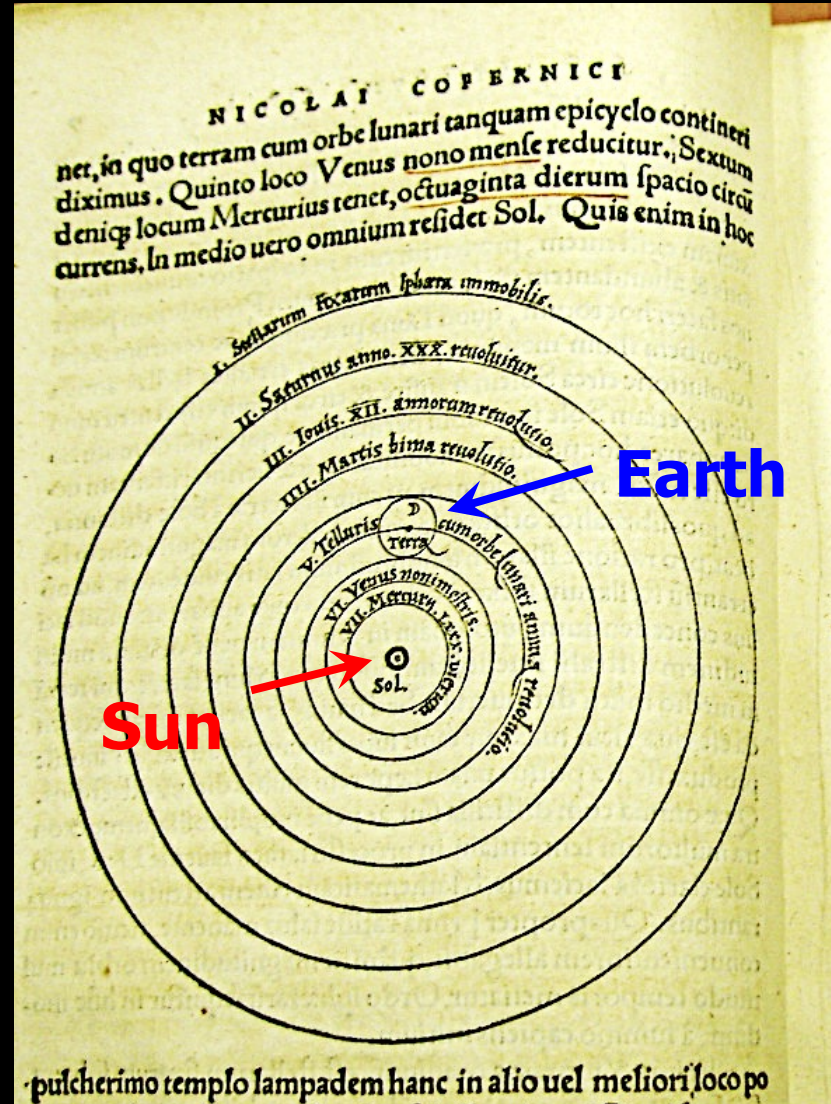
- *The Almagest by Claudius Ptolemy* (~AD 150)
 - one of the most influential books in history
 - a geocentric model of the universe based on the ancient Greek astronomy that has been accepted before Copernicus

Cosmographia (1539) by Petrus Apianus
(from Wikipedia)

Earth is not the center of the world



Nicolaus Copernicus (1473-1543)

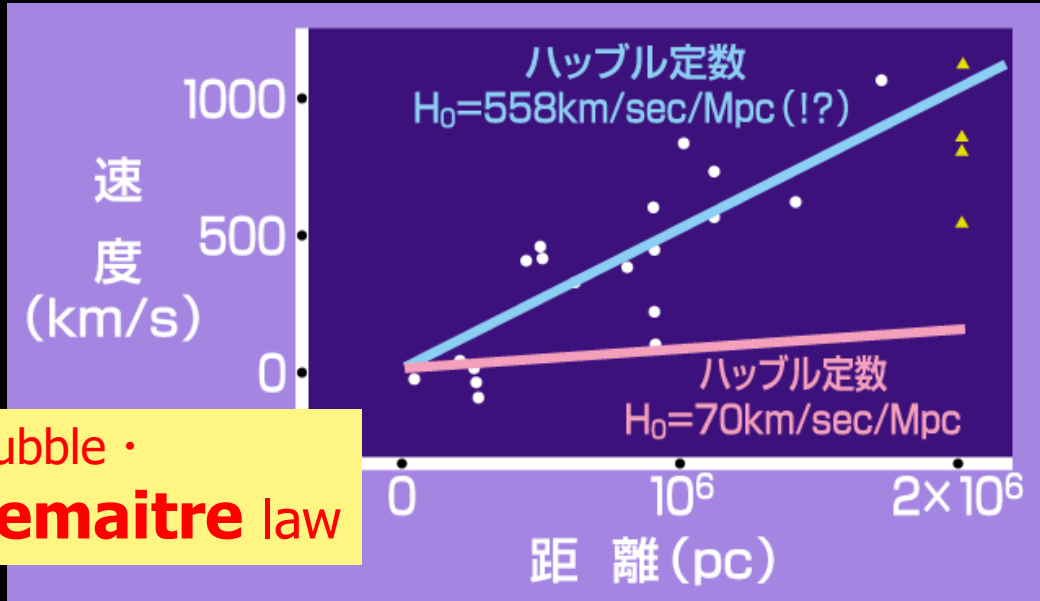


De revolutionibus orbium coelestium (1543)



Torun (Feb 19, 2023)

Cosmological principle (Copernicus principle) = there is no center in the universe



Hubble ·
Lemaitre law

A RELATION BETWEEN DISTANCE AND RADIAL VELOCITY AMONG EXTRA-GALACTIC NEBULAE

By EDWIN HUBBLE **PNAS 15(1929)168**

MOUNT WILSON OBSERVATORY, CARNEGIE INSTITUTION OF WASHINGTON

Communicated January 17, 1929

Determinations of the motion of the sun with respect to the extra-galactic nebulae have involved a K term of several hundred kilometers which appears to be variable. Explanations of this paradox have been sought in a correlation between apparent radial velocities and distances, but so far the results have not been convincing. The present paper is a continuation of the question, based on only those nebular distances believed to be fairly reliable.

UN UNIVERS HOMOGENE DE MASSE CONSTANTE ET DE RAYON CROISSANT,
RENDANT COMPTE
DE LA VITESSE RADIALE DES NÉBULEUSES EXTRA-GALACTIQUES

Note de M. l'Abbé G. LEMAITRE

1. GÉNÉRALITÉS.

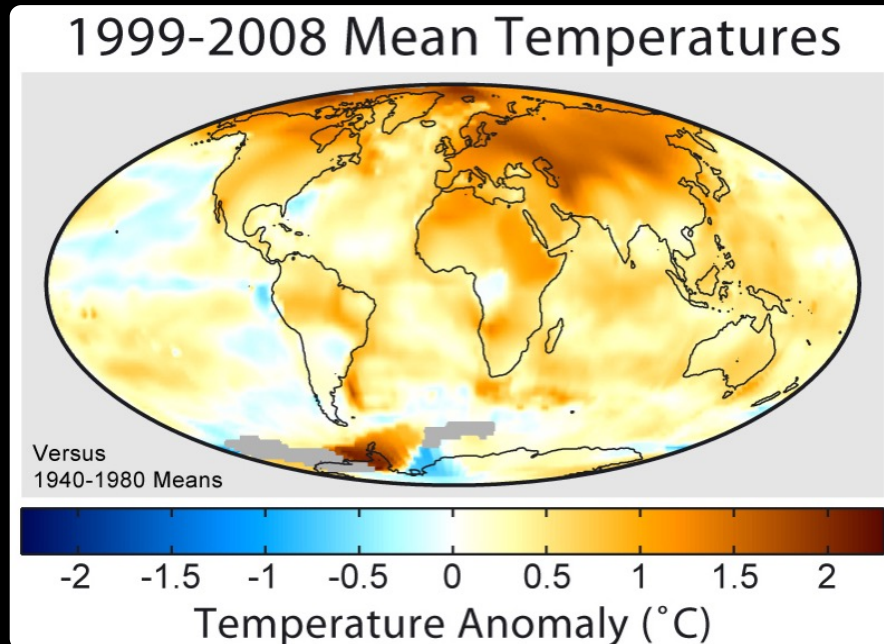
Annales Soc. Sci. Bruxelles A47(1927)49

La théorie de la relativité fait prévoir l'existence d'un univers homogène où non seulement la répartition de la matière est uniforme, mais où toutes les positions de l'espace sont équivalentes, il n'y a pas de centre de gravité. Le rayon R de l'espace est constant, l'espace est elliptique de

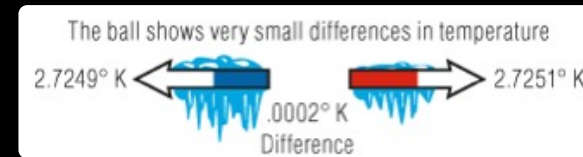
- Hubble was interested in the motion of the Sun relative to the rest frame of distant galaxies (he did not properly understand the implication of the distance-velocity relation that he found in 1929)
- Lemaitre discovered the relation in 1927 from a fully general relativistic viewpoint

Relic light from the primeval fireball (big bang) - CMB (Cosmic Microwave Background) Temperature Map-

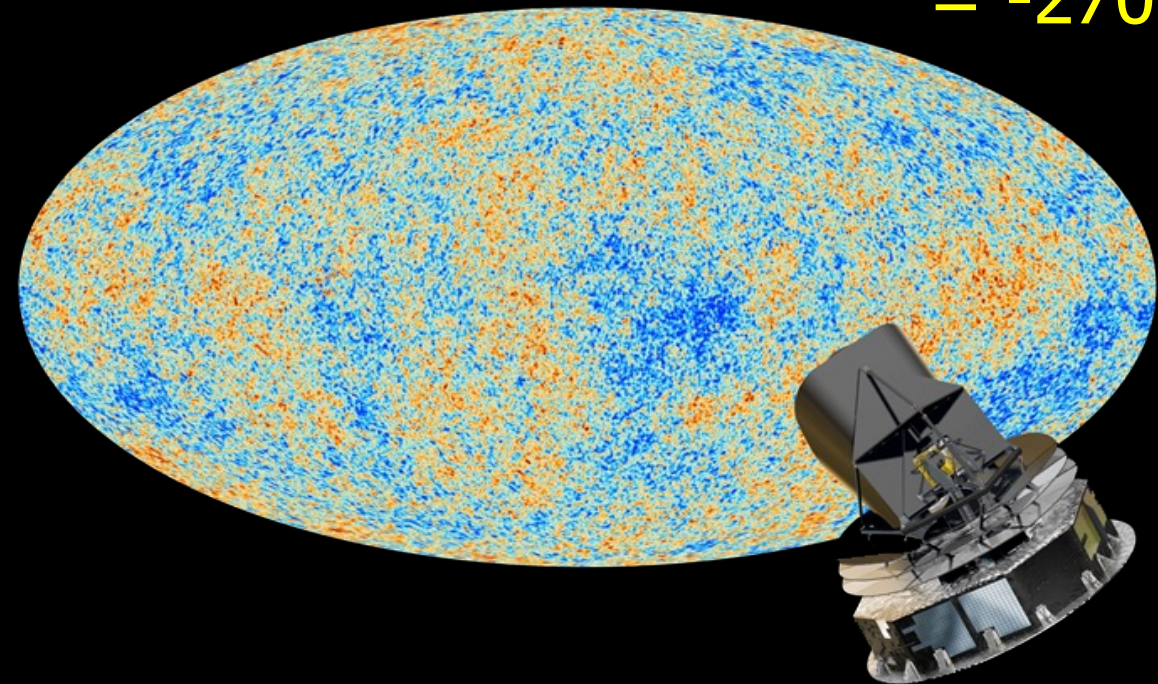
our universe is homogeneous and isotropic to high precision



Robert A. Rohde (from wikipedia)
temperature map of "global" warming
(viewed from outside)



$$T = 2.7 \text{ K} \\ = -270 \text{ °C}$$



ESA and the Planck Collaboration - D. Ducros
CMB map by Planck mission (2013)
(viewed from inside)

Japan viewed from International Space Station



<https://www.flickr.com/people/nasa2explore/>

Earth and Milky Way viewed from ISS

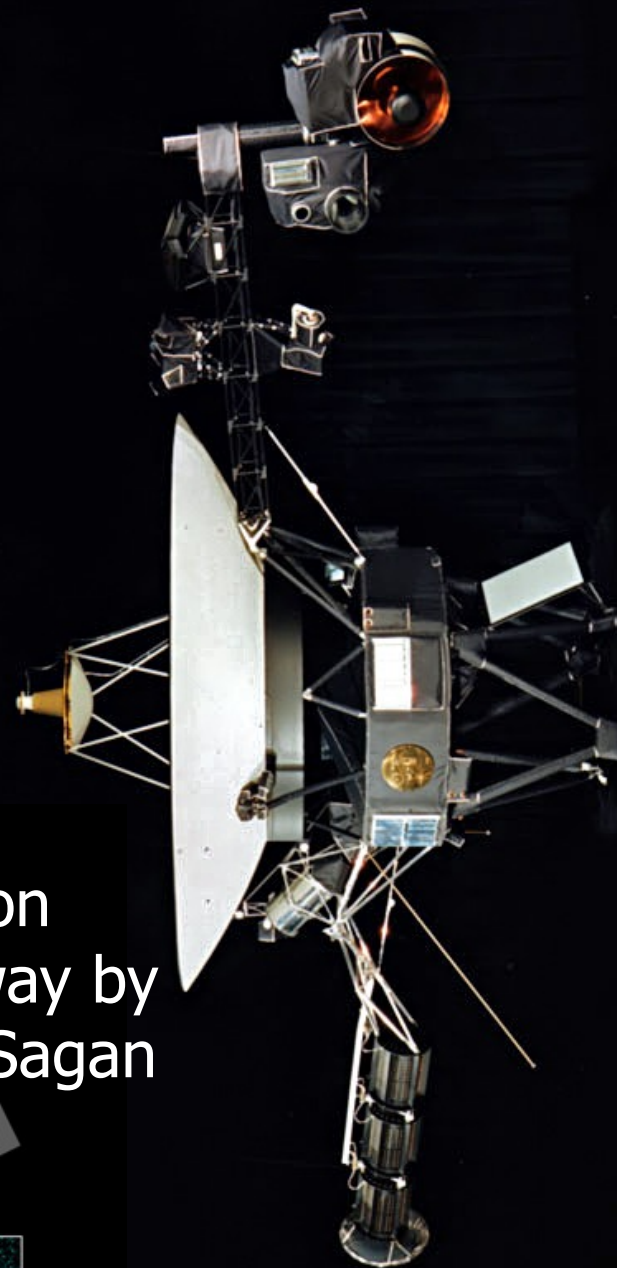


<https://www.flickr.com/people/nasa2explore/>

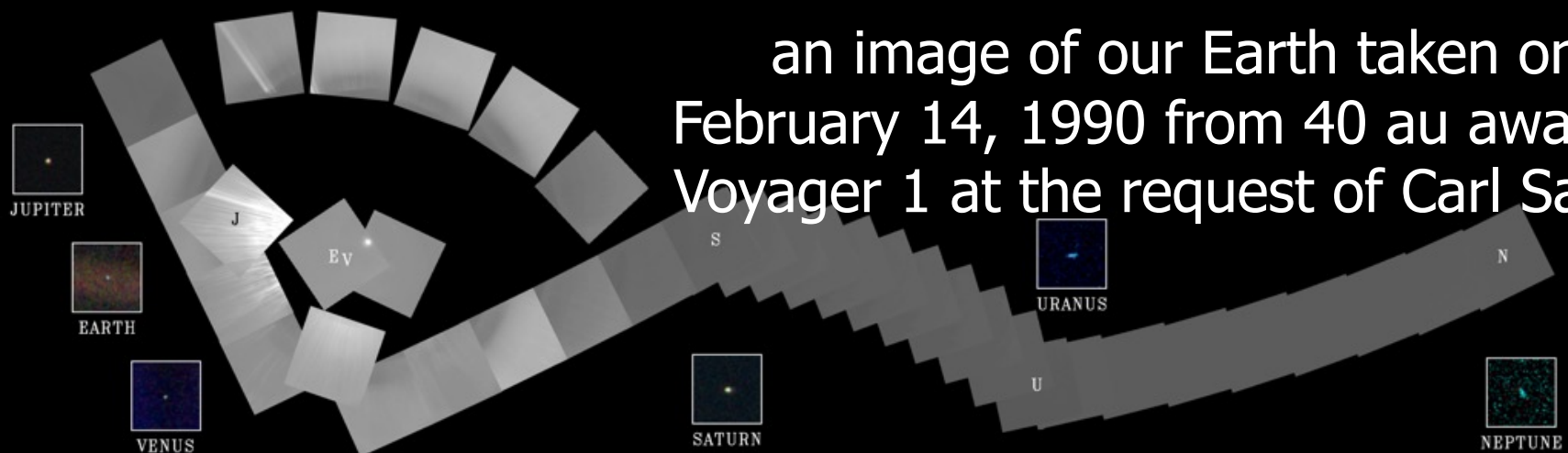
Earth viewed from space

-Pale Blue Dot-

"Look again at that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives."



an image of our Earth taken on February 14, 1990 from 40 au away by Voyager 1 at the request of Carl Sagan



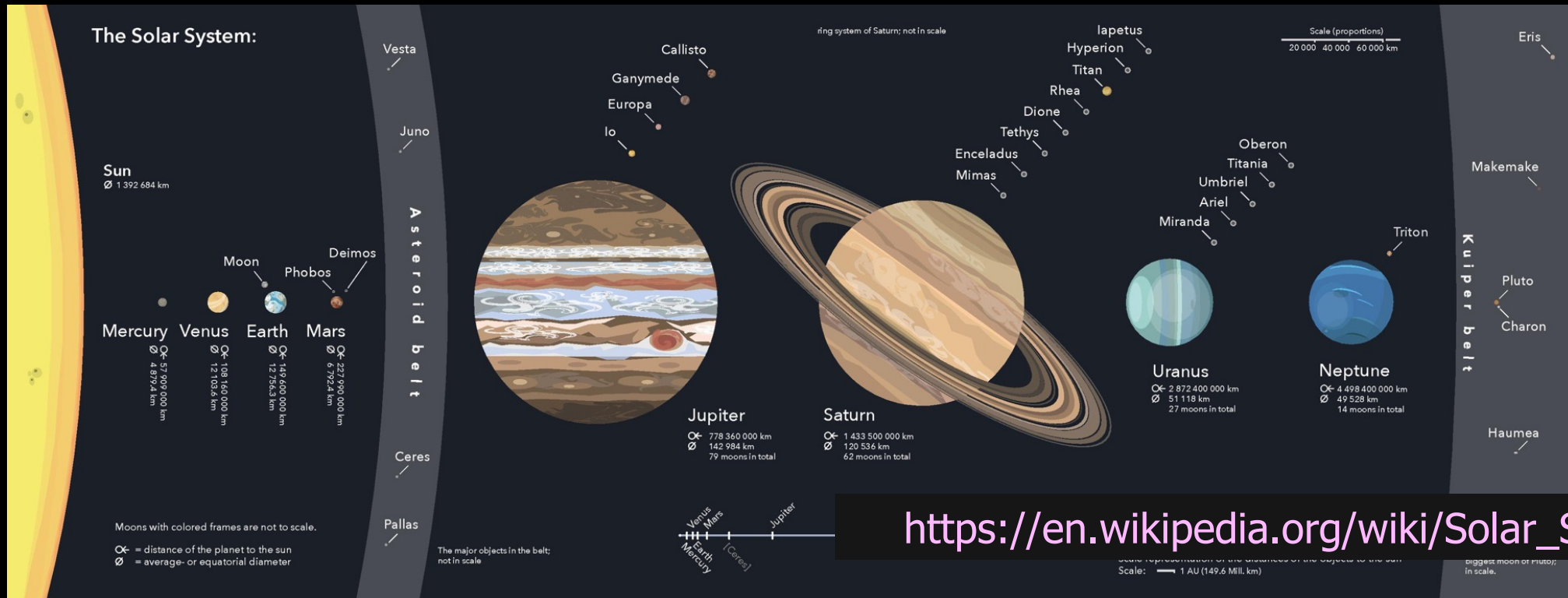


**Earth looked through
Saturn's ring**

- Earth and moon viewed by Cassini mission
 - on July 20, 2013 (JST) : 20,000 Americans waving their hands toward Cassini!



Our Solar system is typical or atypical (unique)?

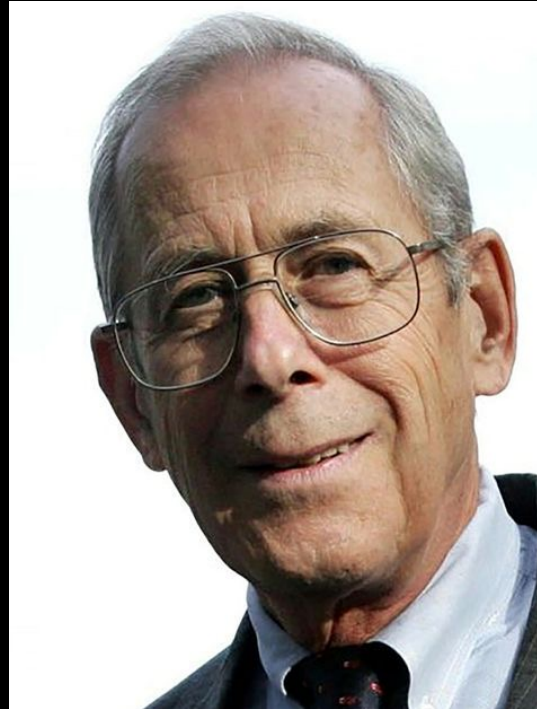


- Since 1995, (exo)-planetary systems have been known to be common
- No other planet hosting life is known (yet) except our own Earth

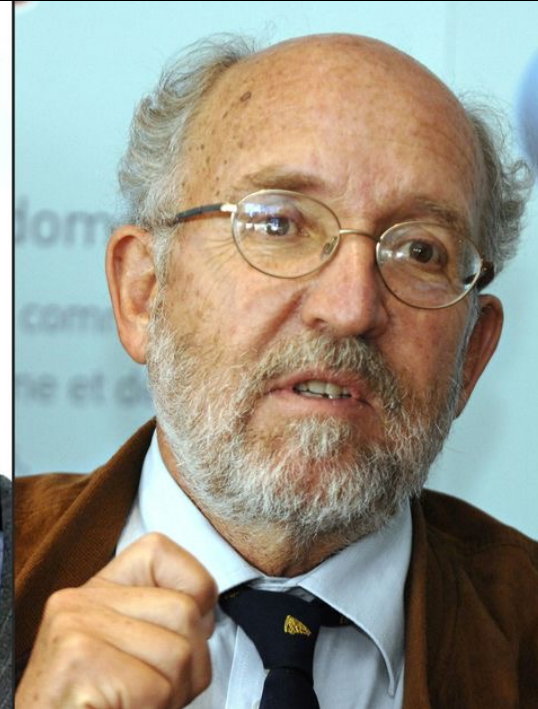
History of progress in astronomy = endless confirmation that we do not occupy any special place in the universe

2019 Nobel Prize in Physics

“for contributions to our understanding of the evolution of the universe and Earth’s place in the cosmos”



James Peebles



Michel Mayor



Didier Queloz

- Nothing in the universe occupies a special place
⇒ **If true, it is very unlikely that our Earth is the only single planet hosting life in the entire universe**

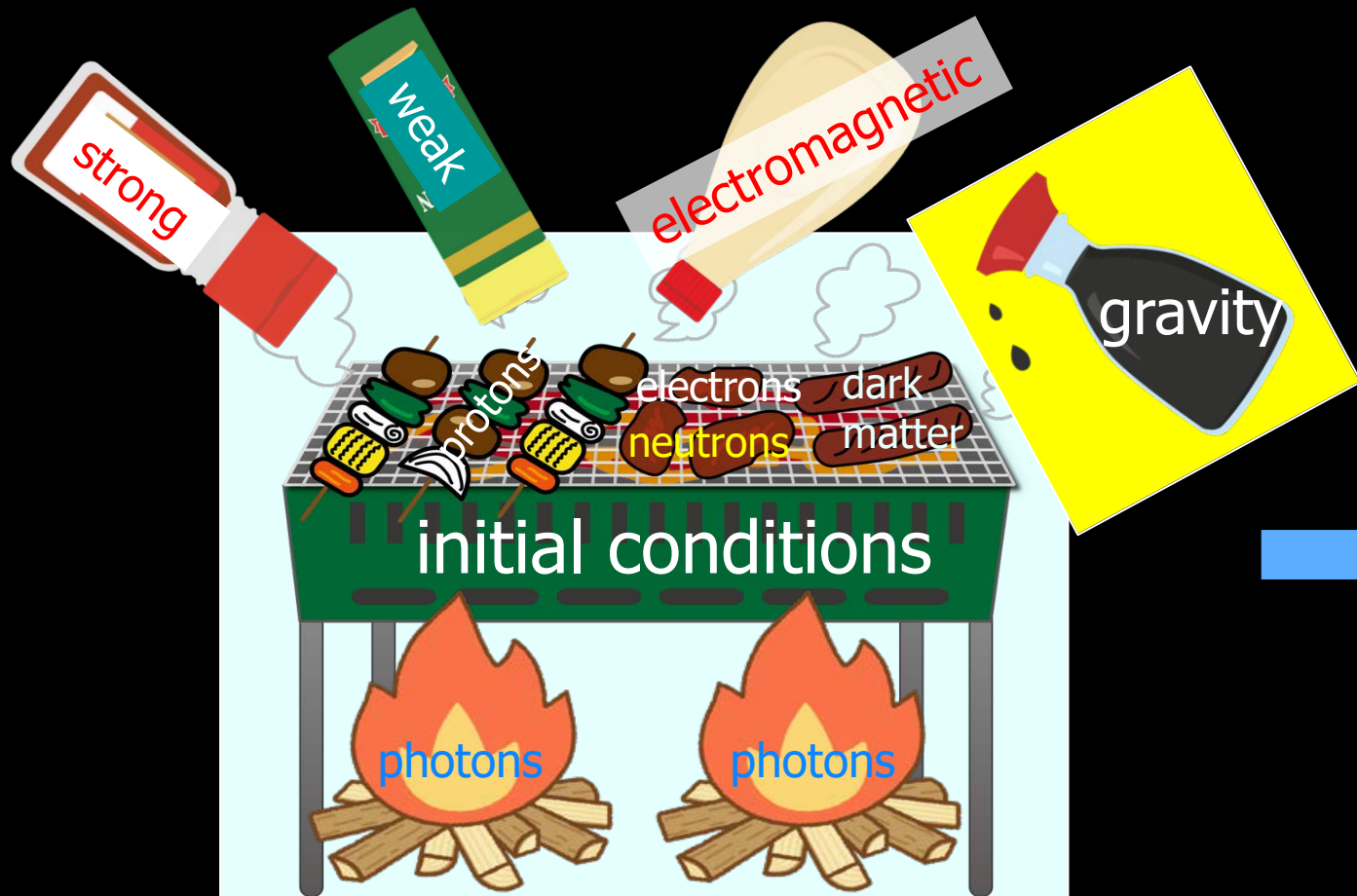
2 Co-evolution of the universe, stars, galaxies, and life

Brief history of the universe over 13.8 G yrs

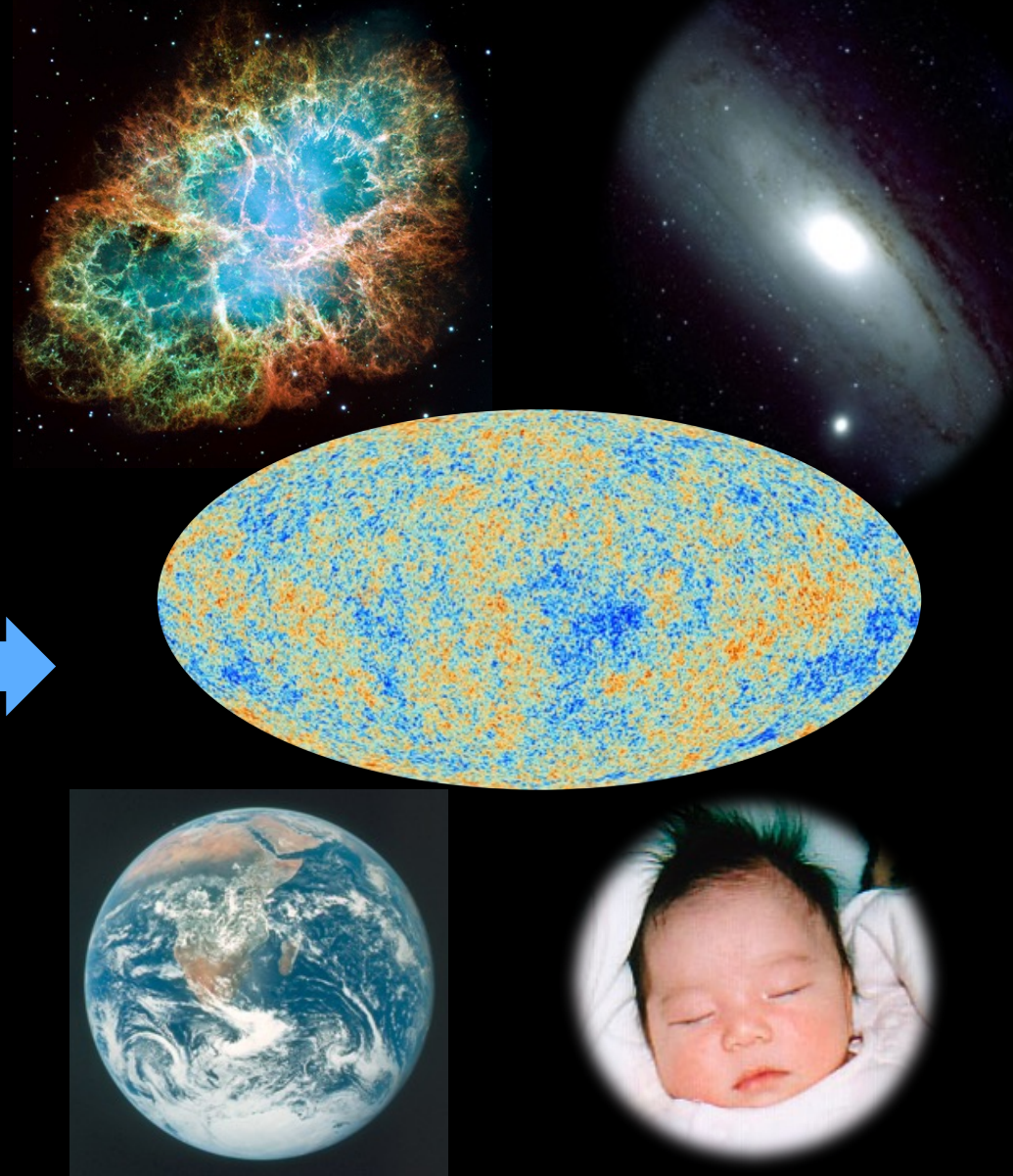
- the first 3 mins: Big-bang nucleosynthesis
 - formation of helium from protons and neutrons
- $t=380,000$ years: Recombination
 - protons and electrons combine and form neutral hydrogen atoms
 - the universe becomes transparent for photons, and the last scattered photons are now observed as CMB
- $t \approx 10^{8-9}$ years : First stars
 - heavy elements are formed in the central regions of stars, emitted to space when those stars die, and become part of new-born stars
 - the above processes are repeated many times (cosmic recycling of elements) , and eventually form life
- Now ($t=13.8$ billion years) : Rich and diverse cosmic structures

Universe evolves according to the laws of physics

Four fundamental interactions



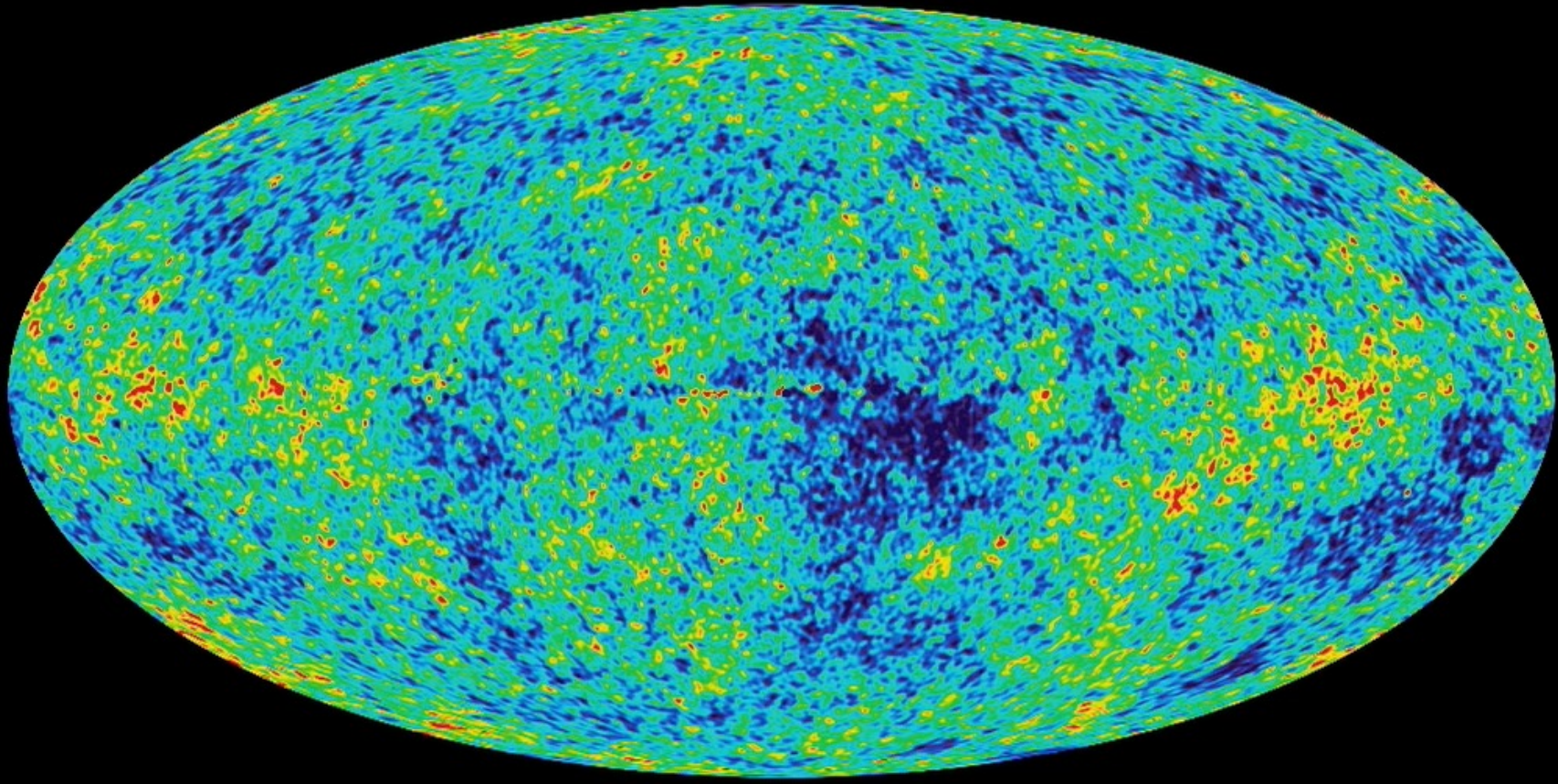
high temperature & high density
(Big Bang)



Four fundamental interactions and formation of elements

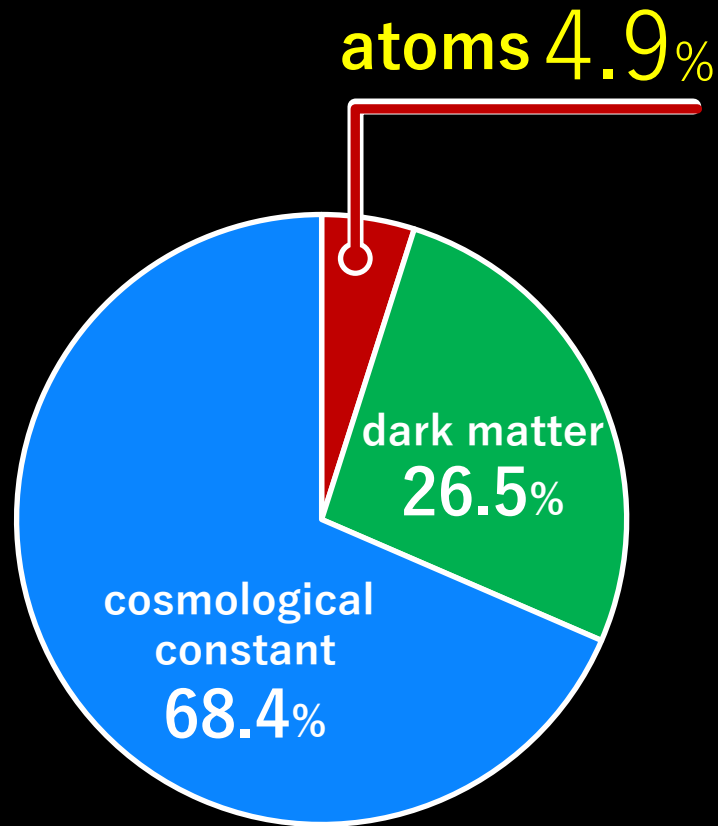
- **Early universe was at very high temperature and density**
 - at high temperature ($T > 10^{11}\text{K}$), protons and neutrons prefer to being free, and do not form elements (nuclei)
 - When T cools below 10^8K , stable helium nuclei (2 protons + 2 neutrons) start to be formed (the first three minutes)
 - some 10^8 years later, heavy elements are synthesized in the central region of stars and emitted to space. Those elements are recycled and form second generation stars, and gradually accumulated in the universe
 - **All the four interactions are involved in cosmic nucleosynthesis**
 - strong force between protons and neutrons
 - electromagnetic force between protons
 - neutron beta-decay via weak force
 - high density in the central region of stars via gravity
- cosmic nucleosynthesis and recycle are a natural outcome of the laws of physics

From CMB to large-scale galaxy distribution evolution of structures over 13.8 billion years



NASA/WMAP Science Team -David Spergel

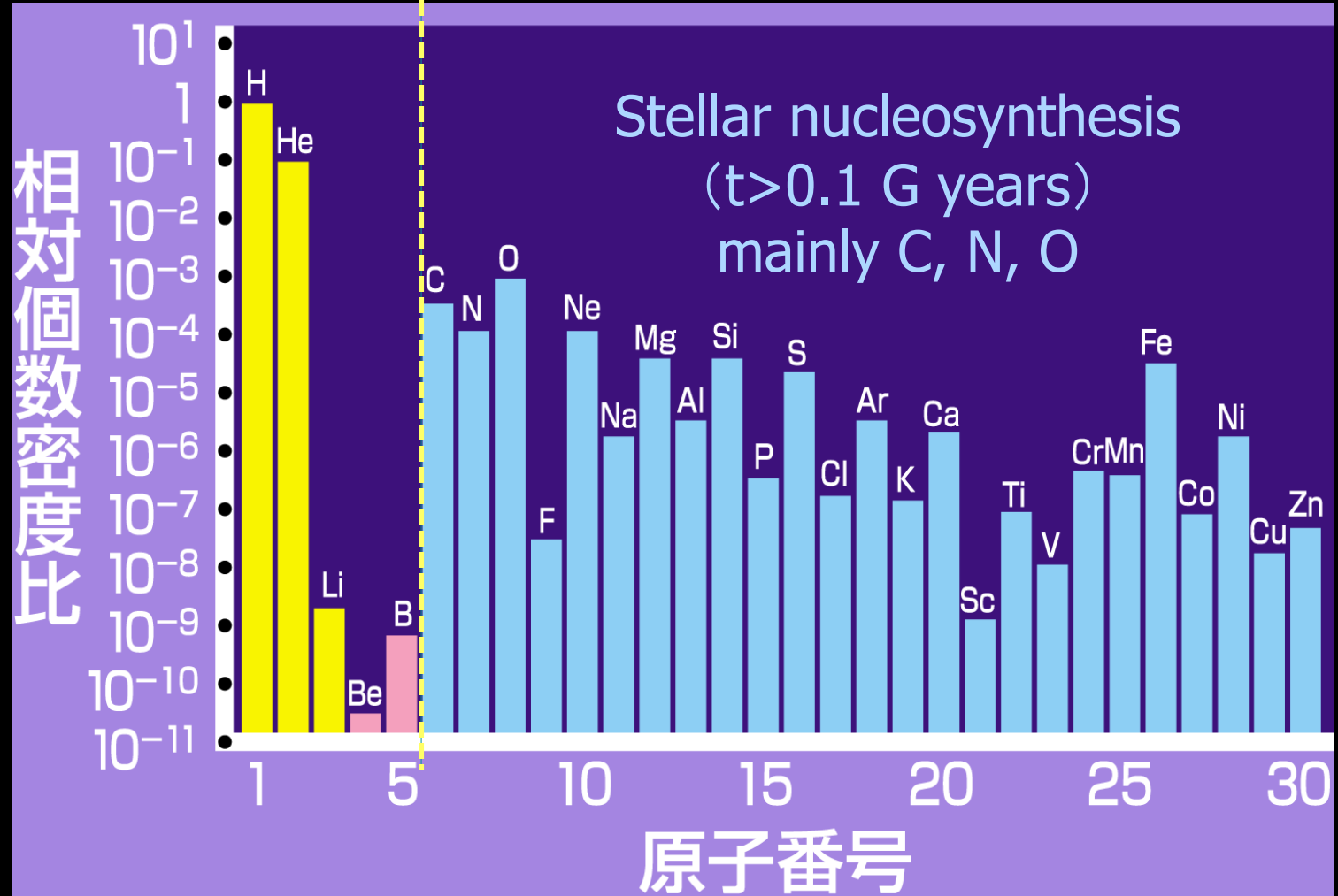
Composition of the universe



Cosmic expansion is dictated by dark matter and cosmological constant, while stars, galaxies, and life form from the remaining 5% of atoms (ordinary matter)

Big-bang nucleosynthesis
(the first three mins)
mainly He

number density of
atoms relative to H



Carl Sagan: "The cosmos is within us. We are made of star-stuff"

Sun	%
H	70.7
He	27.4
O	0.96
C	0.31
Ne	0.17
Fe	0.14
N	0.11
Si	0.07
Mg	0.07
S	0.04

Sea	%
O	85.8
H	10.8
Cl	1.9
Na	1.1
Mg	0.13
S	0.09
Ca	0.04
K	0.04
Br	0.007
C	0.003

Human body	%
O	65
C	18
H	10
N	3
Ca	1.5
P	1.0
S	0.25
K	0.20
Cl	0.15
Na	0.15

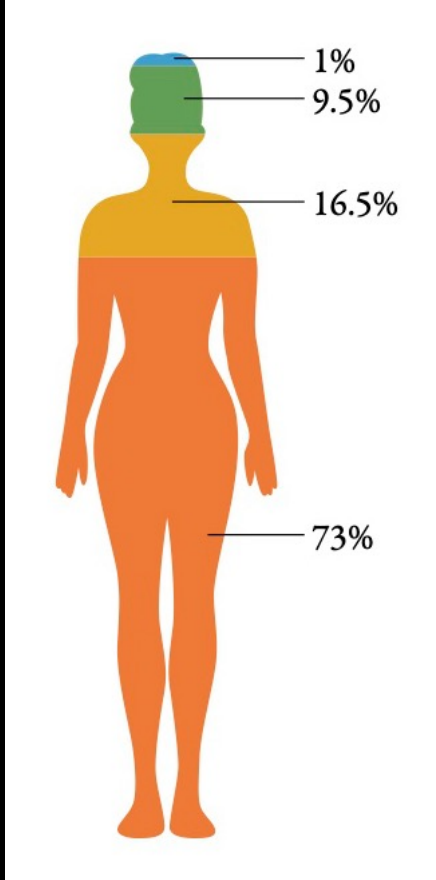
(mass-weighted abundance ratio)

- ~60% of human body is made of water (H₂O)
 - H and O are among the most abundant atoms in the universe
- Biomolecule=organic molecules
 - Carbon with 4 bonds can form various stable molecules
 - C is also one of the most abundant atoms in the universe
- Our body is made of heavy elements that have been formed in centers of stars somewhere in the universe

Universe ⇒ stars ⇒ elements ⇒ human (=children of stars)

H 水素																
Li リチウム	Be ベリリウム															
Na ナトリウム	Mg マグネシウム															
K カリウム	Ca カルシウム	Sc スカンジウム	Ti チタン	V バナジウム	Cr クロム	Mn マンガン	Fe 鉄	Co コバルト								
Rb ルビジウム	Sr ストロンチウム	Y イットリウム	Zr ジルコニウム	Nb ニオブ	Mo モリブデン	Tc テクネチウム	Ru ルテニウム	Rh ロジウム								
Cs セシウム	Ba バリウム	ランタノイド	Hf ハフニウム	Ta タンタル	W タングステン	Re レニウム	Os オスミウム	Ir イリジウム								
Fr フランシウム	Ra ラジウム	アクチノイド														
ランタノイド		La ランタン	Ce セリウム	Pr プラセオジム	Nd ネオジム	Pm プロメチウム	Sm サマリウム	Eu ユウロピウム								
アクチノイド		Ac アクチニウム	Th トリウム	Pa プロトアクチニウム	U ウラン											

- ビッグバン
元素合成
- 低質量星の
質量放出
- 大質量星の
超新星爆発
- 宇宙線
破碎反応
- 中性子連星
合体
- 白色矮星の
超新星爆発



										He ヘリウム
					B ホウ素	C 炭素	N 窒素	O 酸素	F フッ素	Ne ネオン
					Al アルミニウム	Si ケイ素	P リン	S 硫黄	Cl 塩素	Ar アルゴン
Ni ニッケル	Cu 銅	Zn 亜鉛	Ga ガリウム	Ge ゲルマニウム	As ヒ素	Se セレン	Br 臭素	Kr クリプトン		
Pd パラジウム	Ag 銀	Cd カドミウム	In インジウム	Sn スズ	Sb アンチモン	Te テルル	I ヨウ素	Xe キセノン		
Pt 白金	Au 金	Hg 水銀	Tl タリウム	Pb 鉛	Bi ビスマス	Po ポロニウム	At アスタチン	Rn ラドン		
Gd ガドリウム	Tb テルビウム	Dy ジスプロシウム	Ho ホルミウム	Er エルビウム	Tm ツリウム	Yb イットルビウム	Lu ルテチウム			

The nitrogen in our DNA, the calcium in our teeth, the iron in our blood, the carbon in our apple pies were made in the interiors of collapsing stars. We are made of starstuff

– Carl Sagan "Cosmos"

3 Unknown world beyond the horizon of our visible universe

- We didn't know anything -

My horizon of the world more than 50 years ago @Pacific Ocean viewed from Kochi, Japan

- **Is that horizon really the edge of the universe?**
- **Is there any unknown world beyond the horizon?**
- **If so, how different is the world from our visible landscape?**

**Is the blue sky the edge of the universe?
or are there any other worlds beyond it?**



**Are there any other worlds beyond
the starry night sky?**



**Are there any other unknown worlds
beyond the currently visible edge of the universe?**



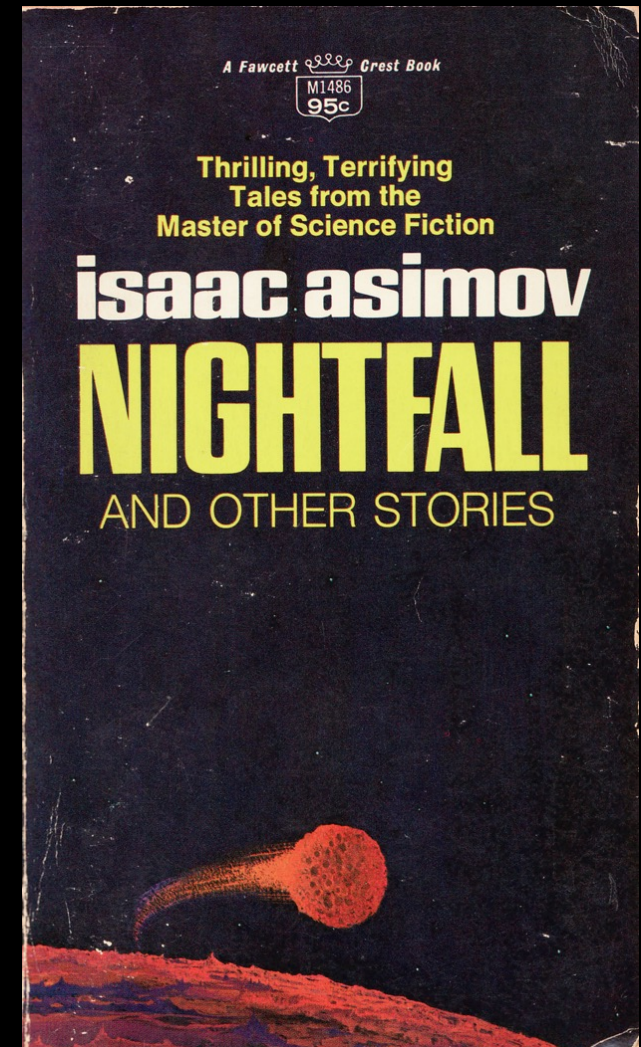
JWST First Deep Field
SMACS 0723

<https://www.nasa.gov/image-feature/goddard/2022/nasa-s-webb-delivers-deepest-infrared-image-of-universe-yet>

A novel by Isaac Asimov: "Nightfall"

- We didn't know anything -

- A planet Lagash has 6 Suns in the sky, and thus no night
- According to the ancient myth, Lagash enters a dark "cave" every 2000 years
 - This is a total eclipse due to an inner planet relative to Lagash, when only one of the six Sun is up in the sky accidentally
 - The story begins at the time just a few hours before the "night" that nobody in Lagash has experienced in the lifetime



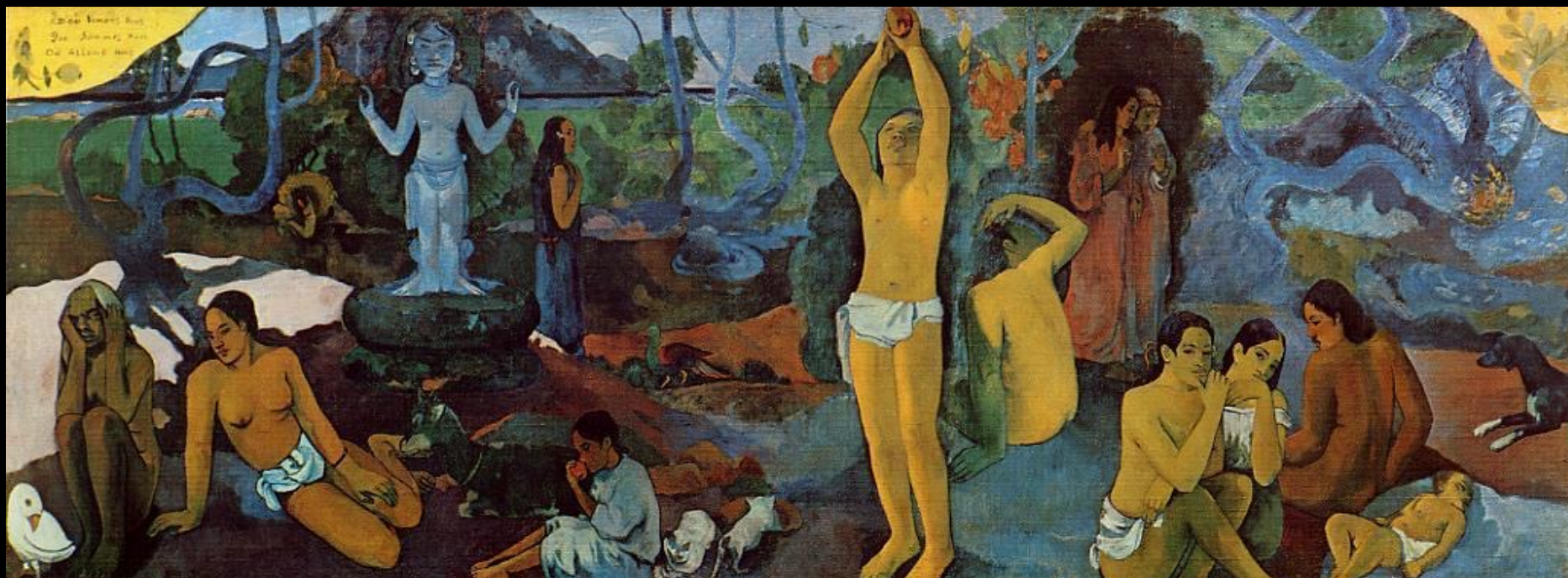
“Light !” he screamed. Aton, somewhere, was crying,
whimpering horribly like a terribly frightened child.

“Stars -- all the Stars -- we didn't know at all.
We didn't know anything.”



(Illustration by Alisa Haba)

4 Can we really understand the world beyond the horizon ?



D'où Venons Nous / Que Sommes Nous / Où Allons Nous

Three most fundamental puzzles remained to be solved in science

■ **origin of cosmos**

- why our universe began?
- our universe is unique?
- other different worlds than ours?

Not clear if there is any answer at all to those great and attracting puzzles

■ **origin of life**

- why life in the Earth began?
- other life in the universe?
- what diversities/universality for the other life?

Even if right scientific answers exist, are we

■ **origin of consciousness (intelligence)**

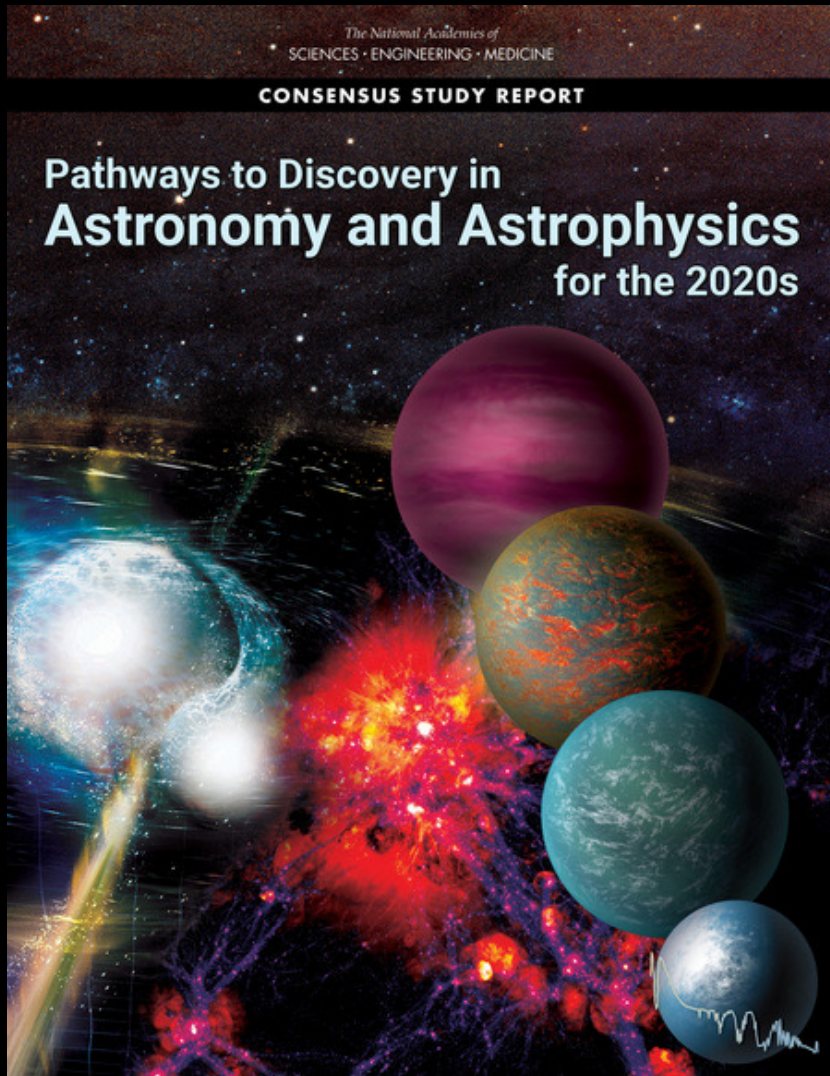
- why life developpes consciousness?
- intelligence is a natural outcome for life?
- other extraterrestrial intelligence?

intelligent enough to discover and understand them?

Life in the *universe* is really *universal*?

- Evolution of the universe is dictated by the laws of physics
 - amazing success of big-bang cosmology
 - all available observed data (abundance of elements, cosmic microwave background, diverse cosmic structures) are fully consistent with the laws of physics
- Cosmic ecosystems
 - formation and evolution of cosmic objects
 - = formation of heavy elements in the central parts of massive stars
 - + their subsequent recycling in the space
 - + formation of next-generation stars
- evolution of the universe = evolution of life ?
 - formation of life is an inevitable outcome in the universe ?
 - not a merely philosophical, but a testable scientific question in the near future !

Astro2020: Pathways to Discovery in Astronomy and Astrophysics for the 2020s



- **Worlds and Suns in Context**
 - Pathways to Habitable Worlds
- **New Messengers and New Physics**
 - New Windows on the Dynamic Universe
- **Cosmic Ecosystems**
 - Unveiling the Drivers of Galaxy Growth

<https://www.nationalacademies.org/our-work/decadal-survey-on-astronomy-and-astrophysics-2020-astro2020>

Highest Priority: an IR/Optical/UV space telescope optimized for observing habitable exoplanets and general astrophysics

- **Recommendation:** After a successful mission and technology maturation program, NASA should embark on a program to realize a mission to **search for biosignatures from a robust number of about ~25 habitable zone planets** and to be a transformative facility for general astrophysics. If mission and technology maturation are successful, as determined by an independent review, implementation should start in the latter part of the decade, **with a target launch in the first half of the 2040's**

Quotes from Carl Sagan

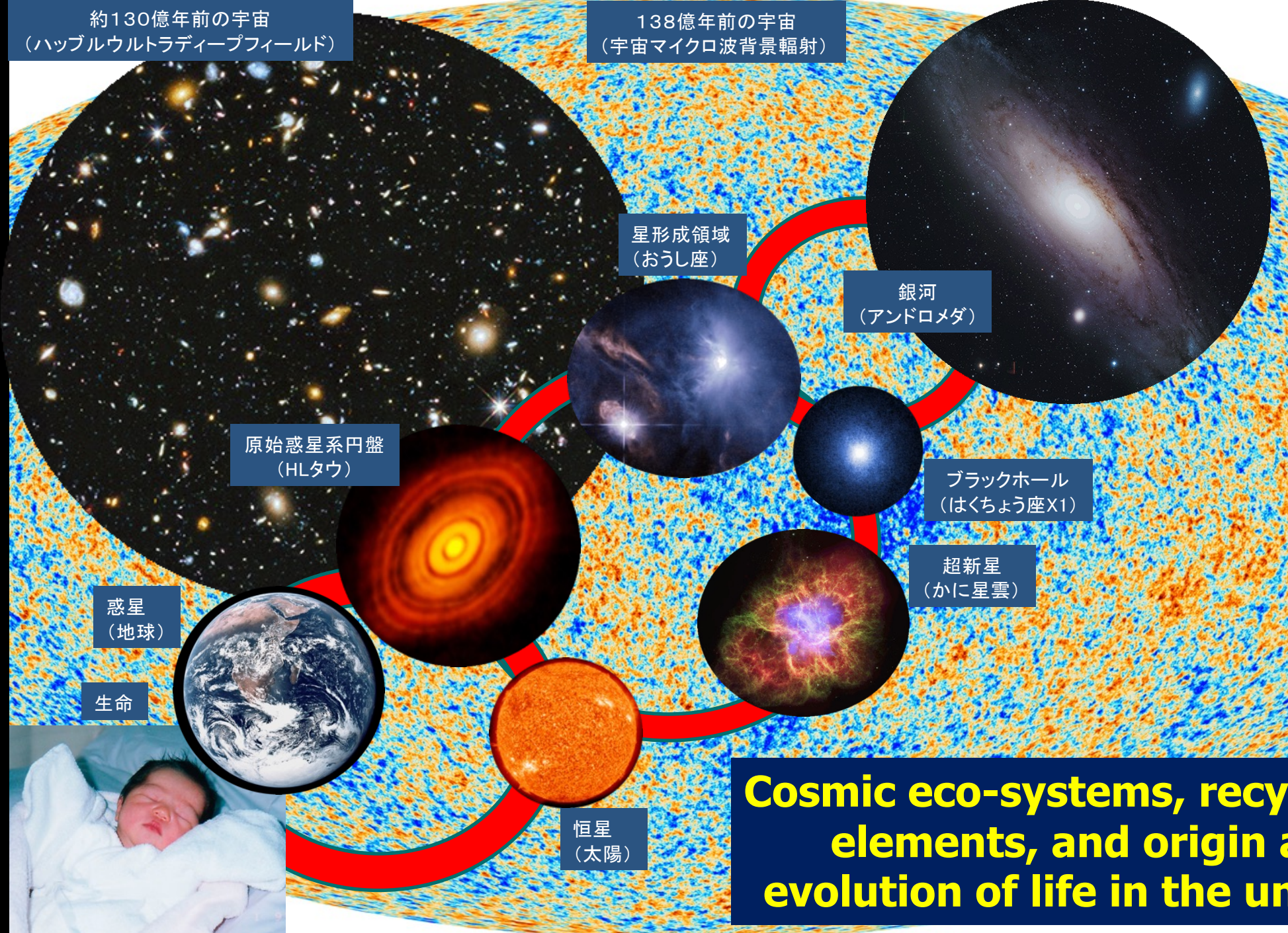
- *Everything not forbidden by the laws of nature is mandatory*
- *The universe is a pretty big place. If it's just us, seems like an awful waste of space*
- *Nobody's guaranteeing success. But can you think of a more important question? Imagine them out there sending us signals, and nobody on Earth is listening. That would be a joke, a travesty.*
- *Somewhere, something incredible is waiting to be known.*

— Carl Sagan, *Contact* (1986)

Evolution of cosmic structures over 13.8 G years

約130億年前の宇宙
(ハッブルウルトラディープフィールド)

138億年前の宇宙
(宇宙マイクロ波背景放射)



**Cosmic eco-systems, recycling of
elements, and origin and
evolution of life in the universe**