Astrophysics, Astroparticles and Cosmology

A journey through matter, space, and time

Réza Ansari

Univ. Paris Scaly & IJCLab CNRS/IN2P3

- From particles to cosmos
- Star dust
- Major questions in physics and cosmology
- Astroparticles at IJCLab

physics | ˈfiziks |

plural noun *[treated as singular]*

the branch of science concerned with the nature and properties of matter and energy. The subject matter of physics, distinguished from that of chemistry and biology, includes mechanics, heat, light and other radiation, sound, electricity, magnetism, and the structure of atoms.

• the physical properties and phenomena of something: *the physics of plasmas*.

ORIGIN

late 15th century (denoting natural science in general, especially the Aristotelian system): plural of obsolete *physic* 'physical (thing)', suggested by Latin ***physica***, Greek ***phusika*** 'natural things' from ***phusis*** 'nature'.

Astroparticle Physics ?

astronomy | əˈstränəmē |

noun

the branch of science which deals with celestial objects, space, and the physical universe as a whole.

In ancient times, observation of the sun, moon, stars, and planets formed the basis of timekeeping and navigation. Astronomy was greatly furthered by the invention of the optical telescope, but modern observations are made in all parts of the spectrum, including X-ray and radio frequencies, using terrestrial and orbiting instruments and space probes.

ORIGIN

Middle English (also denoting astrology): from Old French ***astronomie***, from Latin ***astronomia***, from Greek, from ***astronomos*** (adjective) 'star-arranging'.

astrophysics | ˌastrōˈfiziks |

plural noun *[treated as singular]*

the branch of astronomy concerned with the physical nature of stars and other celestial bodies, and the application of the laws and theories of physics to the interpretation of astronomical observations.

DERIVATIVES

astrophysical | ˌastrōˈfizək(ə)l | adjective

cosmology | käzˈmäləjē |

noun (plural **cosmologies**)

the science of the origin and development of the universe. Modern astronomy is dominated by the Big Bang theory, which brings together observational astronomy and particle physics.

• an account or theory of the origin of the universe.

DERIVATIVES

cosmologist | käzˈmäləjəst | noun

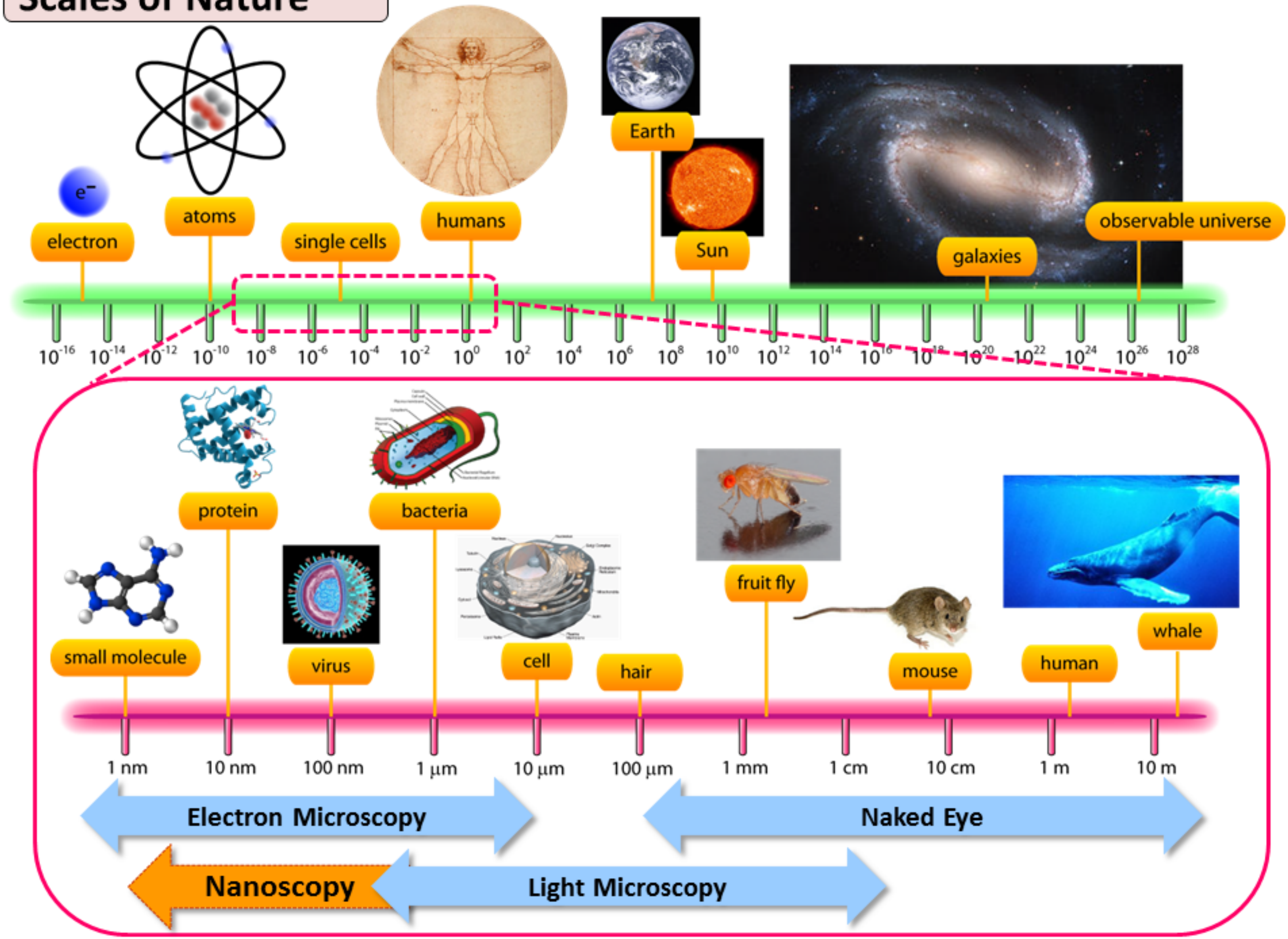
ORIGIN

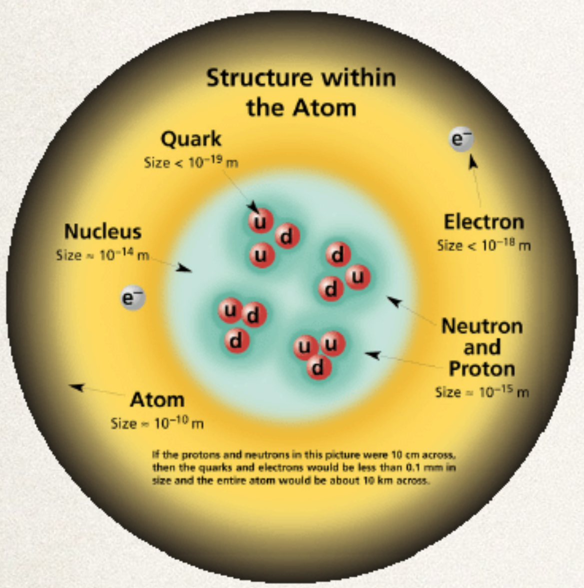
mid 17th century: from French ***cosmologie*** or modern Latin ***cosmologia***, from Greek ***kosmos*** 'order or world' + ***-logia*** 'discourse'.

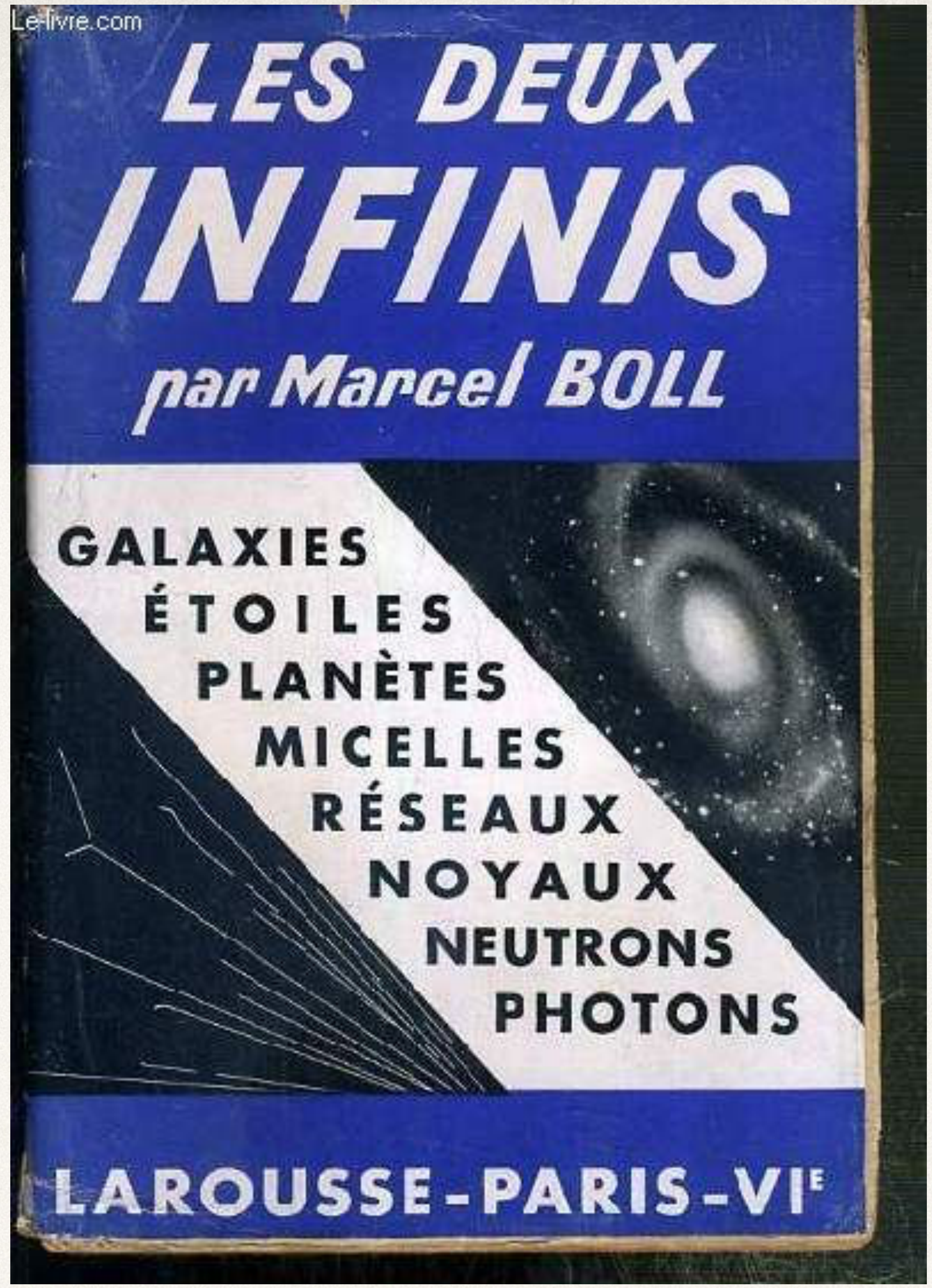
Oxford dictionary of english

Scales of Nature

more than 40 orders of magnitude . . . > 10^{40}



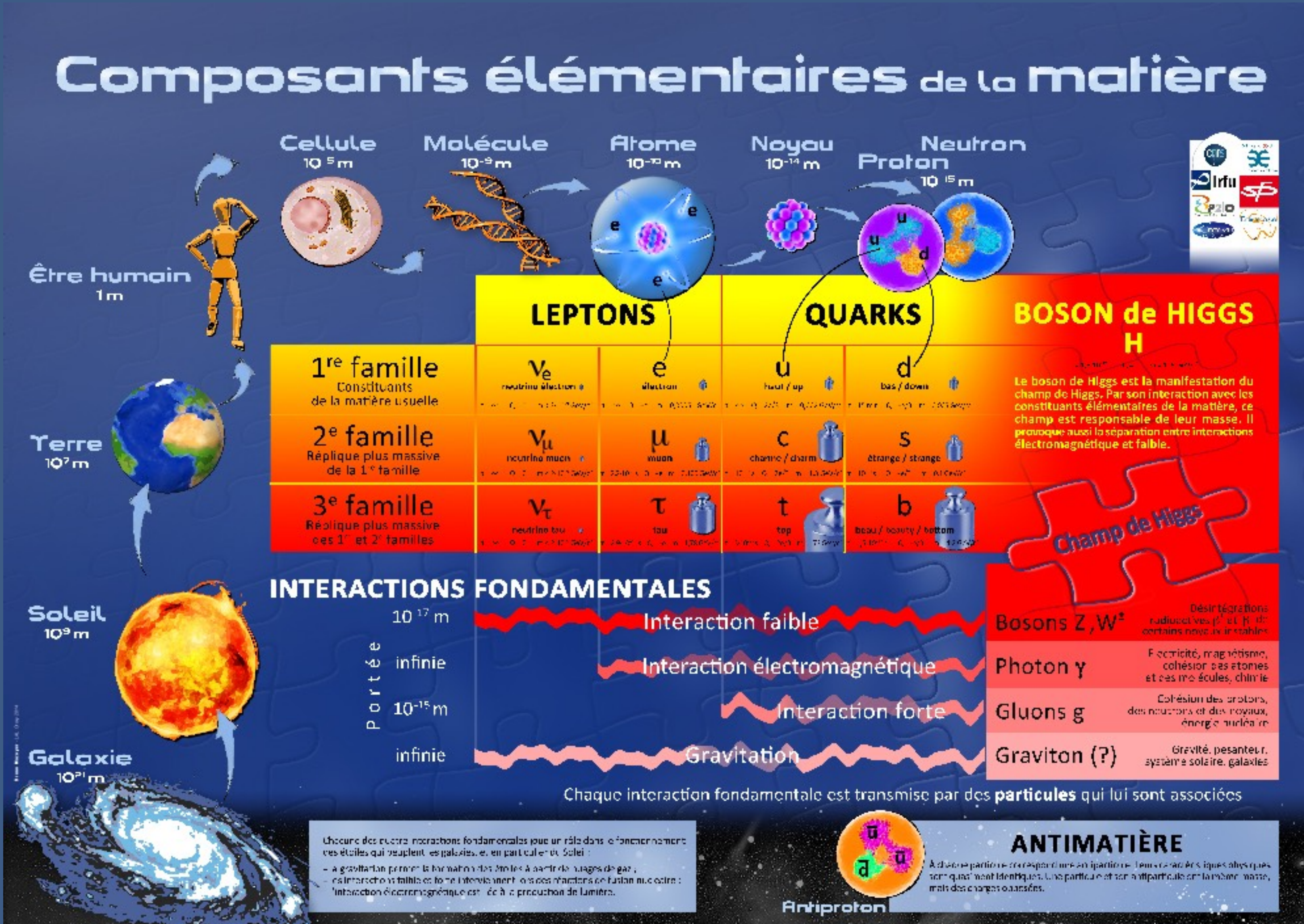




Les Deux Infinis : galaxies, étoiles, planètes, micelles, réseaux, noyaux, neutrons, photons, Larousse, 1938

Small scales : matter structure at subatomic scales

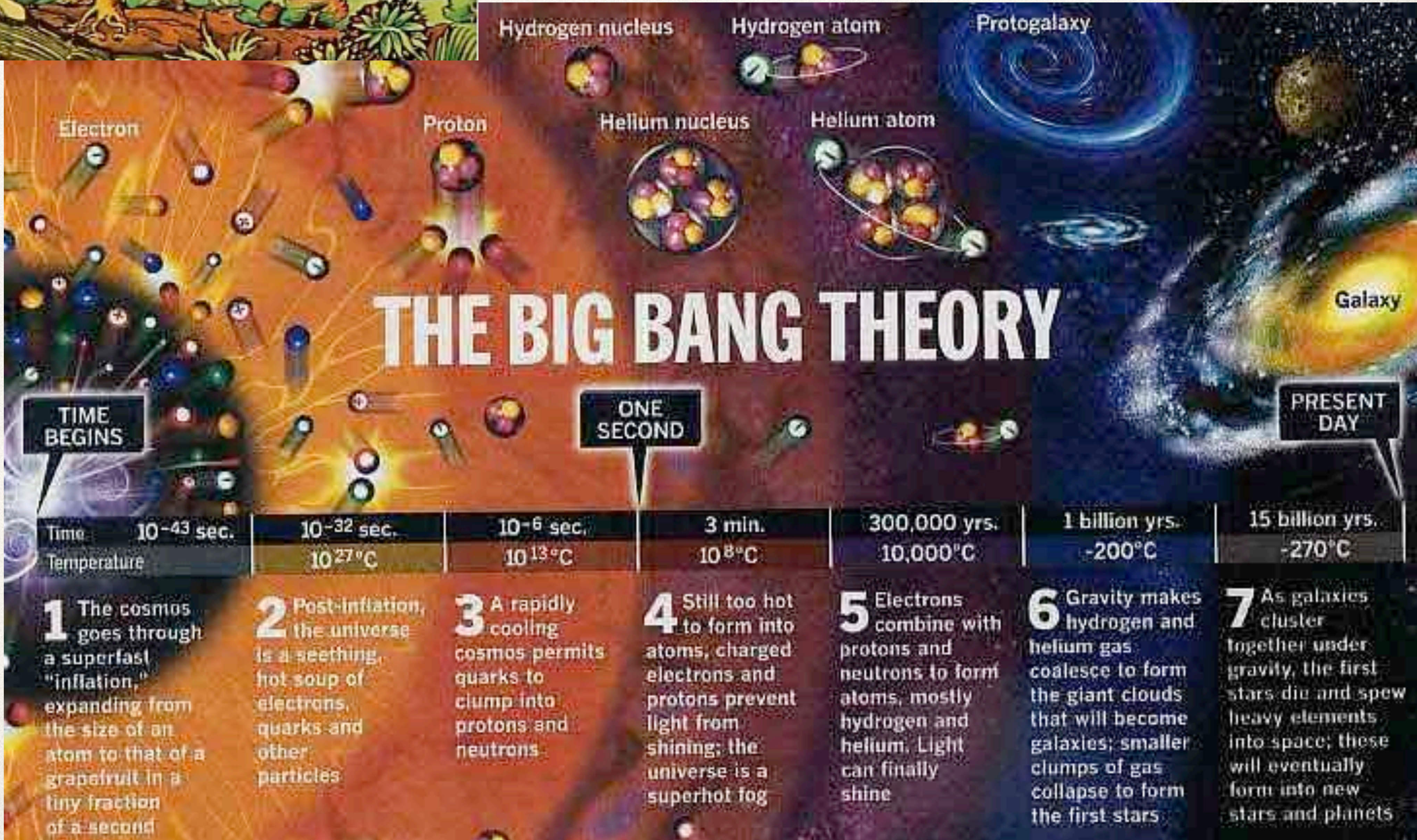
Large scales : stars, galaxies… universe



Composants élémentaires de la matière
Cellule
10⁻⁵ m
Molécule
10⁻⁹ m
Atome
10⁻¹⁰ m
Noyau
10⁻¹⁴ m
Neutron
Proton
10⁻¹⁵ m
Être humain
1 m
Terre
10⁷ m
Soleil
10⁹ m
Galaxie
10²¹ m
LEPTONS
QUARKS
BOSON de HIGGS
H
1re famille
Constituants de la matière usuelle
2e famille
Réplique plus massive de la 1re famille
3e famille
Réplique plus massive des 1re et 2e familles
νe
neutrino électron
e
électron
u
haut / up
d
bas / down
νμ
neutrino muon
μ
muon
c
charme / charm
s
étrange / strange
ντ
neutrino tau
τ
tau
t
top
b
beau / beauty / bottom
Le boson de Higgs est la manifestation du champ de Higgs. Par son interaction avec les constituants élémentaires de la matière, ce champ est responsable de leur masse. Il provoque aussi la séparation entre interactions électromagnétique et faible.
Champ de Higgs
INTERACTIONS FONDAMENTALES
Portée
10⁻¹⁷ m
infinie
10⁻¹⁵ m
infinie
Interaction faible
Interaction électromagnétique
Interaction forte
Gravitation
Bosons Z, W±
Désintégrations radioactives de certains noyaux instables
Photon γ
Électricité, magnétisme, cohésion des atomes et des molécules, chimie
Gluons g
Cohésion des protons, des neutrons et des noyaux, énergie nucléaire
Graviton (?)
Gravité, pesanteur, système solaire, galaxies
Chaque interaction fondamentale est transmise par des particules qui lui sont associées
Antiproton
ANTIMATIÈRE

From ancient cosmography to modern **Physical Cosmology**

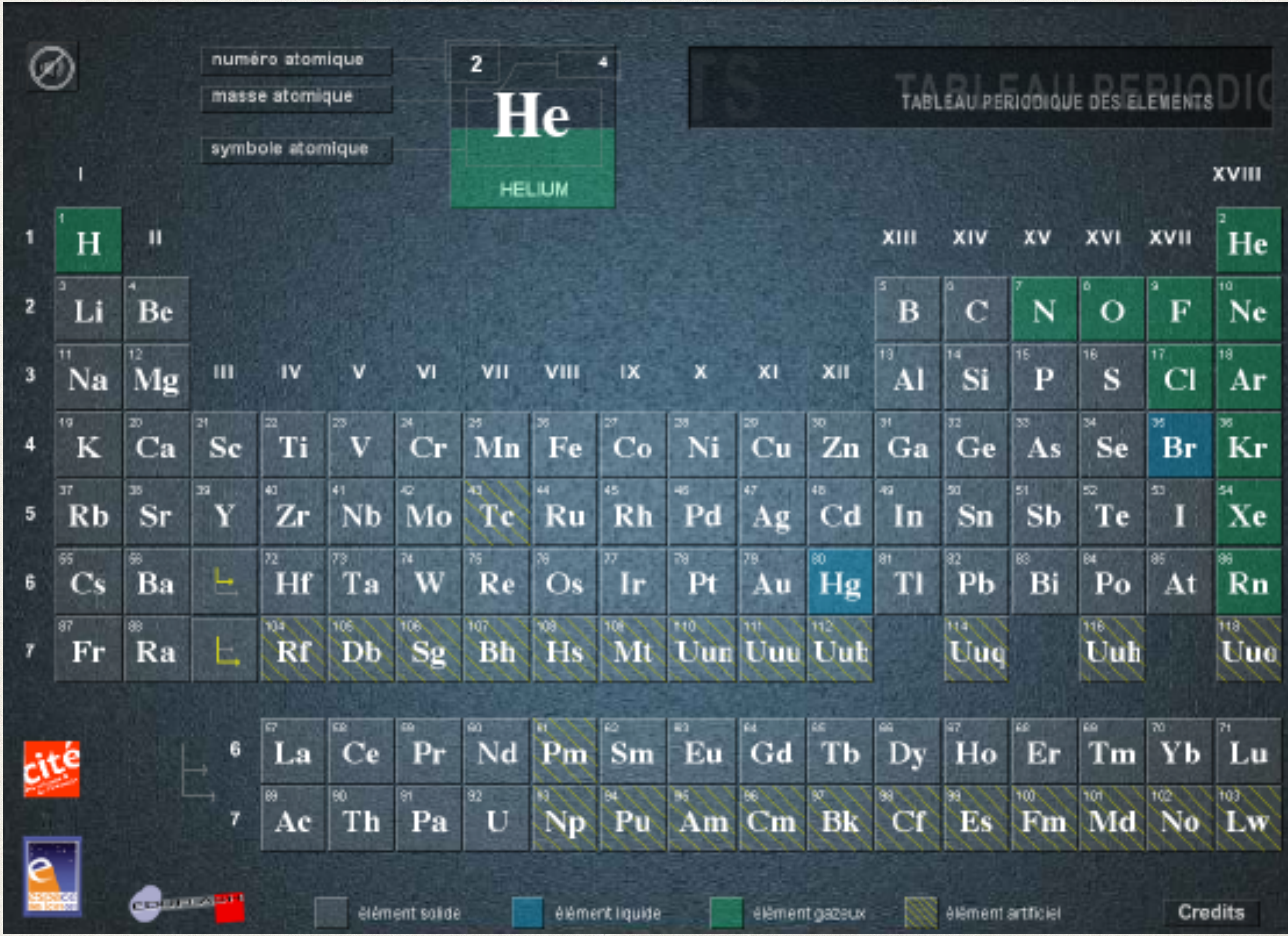
(General relativity & Standard model of particles and interactions)

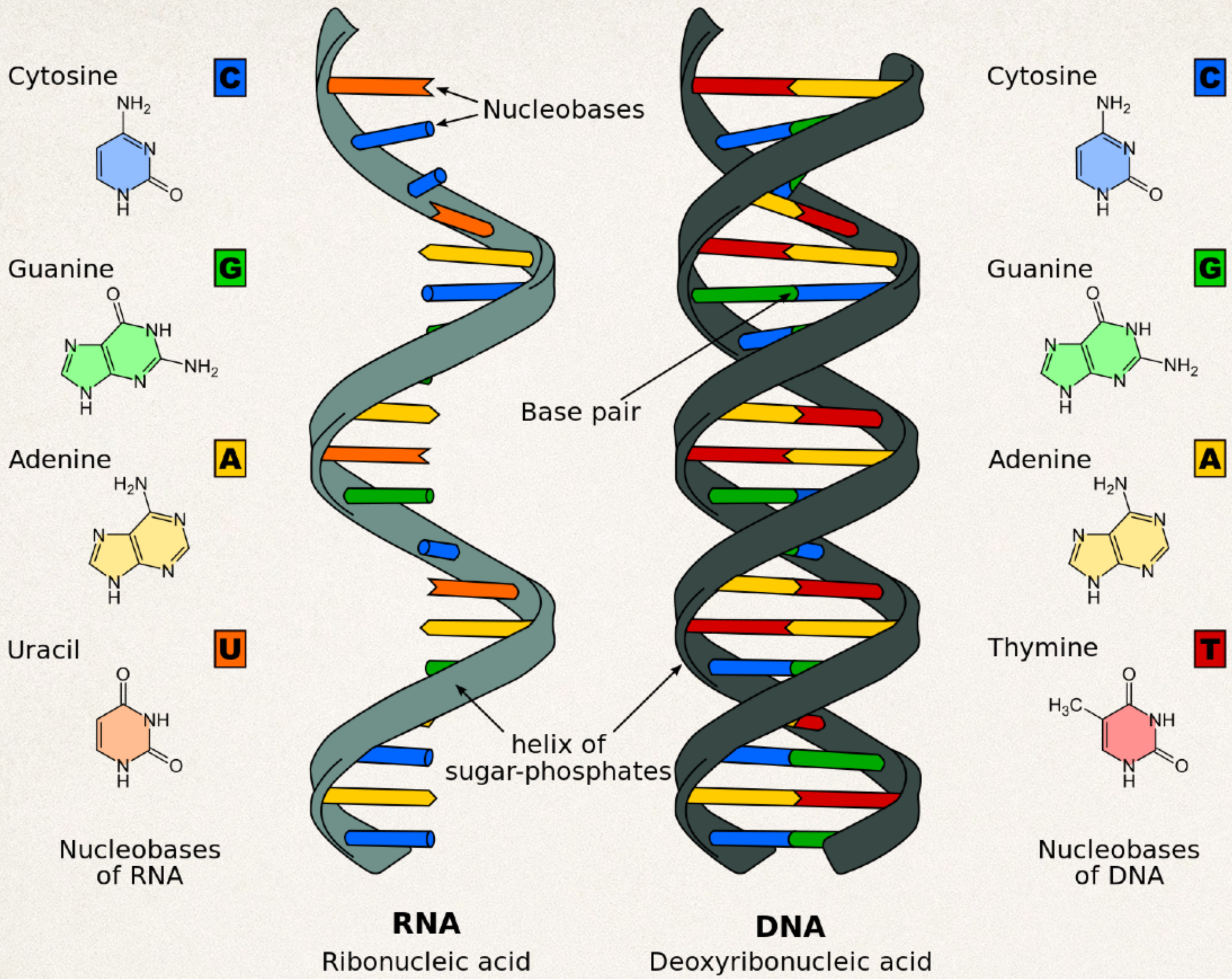


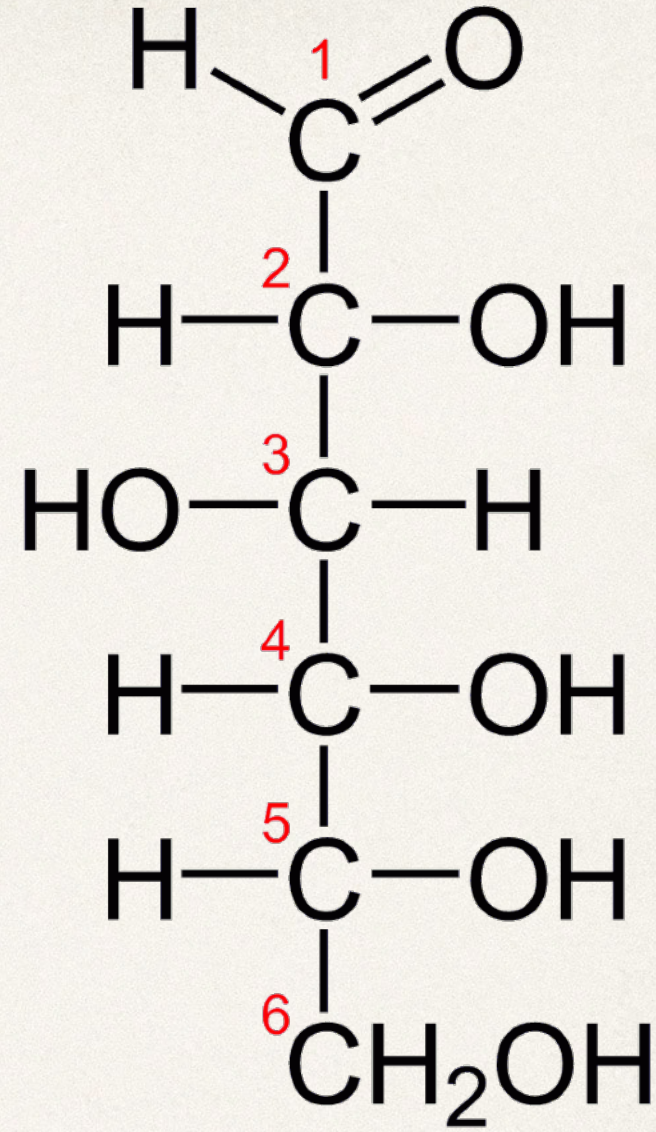
We come from star dust (or ashes) …


We come from star dust (or ashes) …

Periodic table of elements (~ 100 different atoms)







Sugar

Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N) ...

Earth

http://visibleearth.nasa.gov/

Element	Approximate % by weight
Oxygen	46.6
Silicon	27.7
Aluminum	8.1
Iron	5.0
Calcium	3.6
Sodium	2.8
Potassium	2.6
Magnesium	2.1
All others	1.5

Element	Symbol	Atomic Number	Percent in Universe	Percent in Earth	Percent in Human Body
Hydrogen	H	1	91	0.14	9.5
Helium	He	2	9	Trace	Trace
Carbon	C	6	0.02	0.03	18.5
Nitrogen	N	7	0.04	Trace	3.3
Oxygen	O	8	0.06	47	65
Sodium	Na	11	Trace	2.8	0.2
Magnesium	Mg	12	Trace	2.1	0.1
Phosphorus	P	15	Trace	0.07	1
Sulfur	S	16	Trace	0.03	0.3
Chlorine	Cl	17	Trace	0.01	0.2
Potassium	K	19	Trace	2.6	0.4
Calcium	Ca	20	Trace	3.6	1.5
Iron	Fe	26	Trace	5	Trace

Solar composition

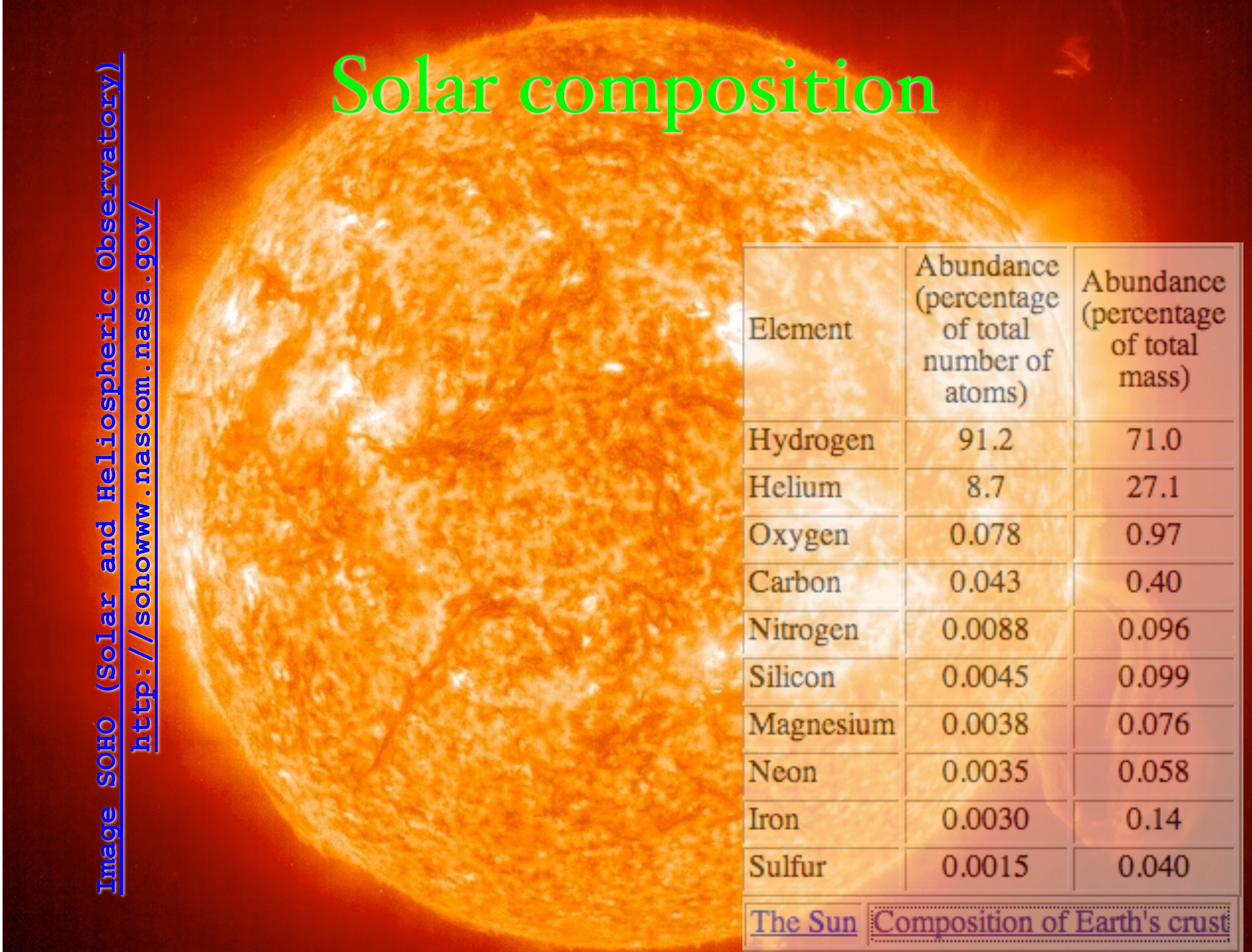


Image SOHO (Solar and Heliospheric Observatory)
http://sohowww.nascom.nasa.gov/

Element	Abundance (percentage of total number of atoms)	Abundance (percentage of total mass)
Hydrogen	91.2	71.0
Helium	8.7	27.1
Oxygen	0.078	0.97
Carbon	0.043	0.40
Nitrogen	0.0088	0.096
Silicon	0.0045	0.099
Magnesium	0.0038	0.076
Neon	0.0035	0.058
Iron	0.0030	0.14
Sulfur	0.0015	0.040

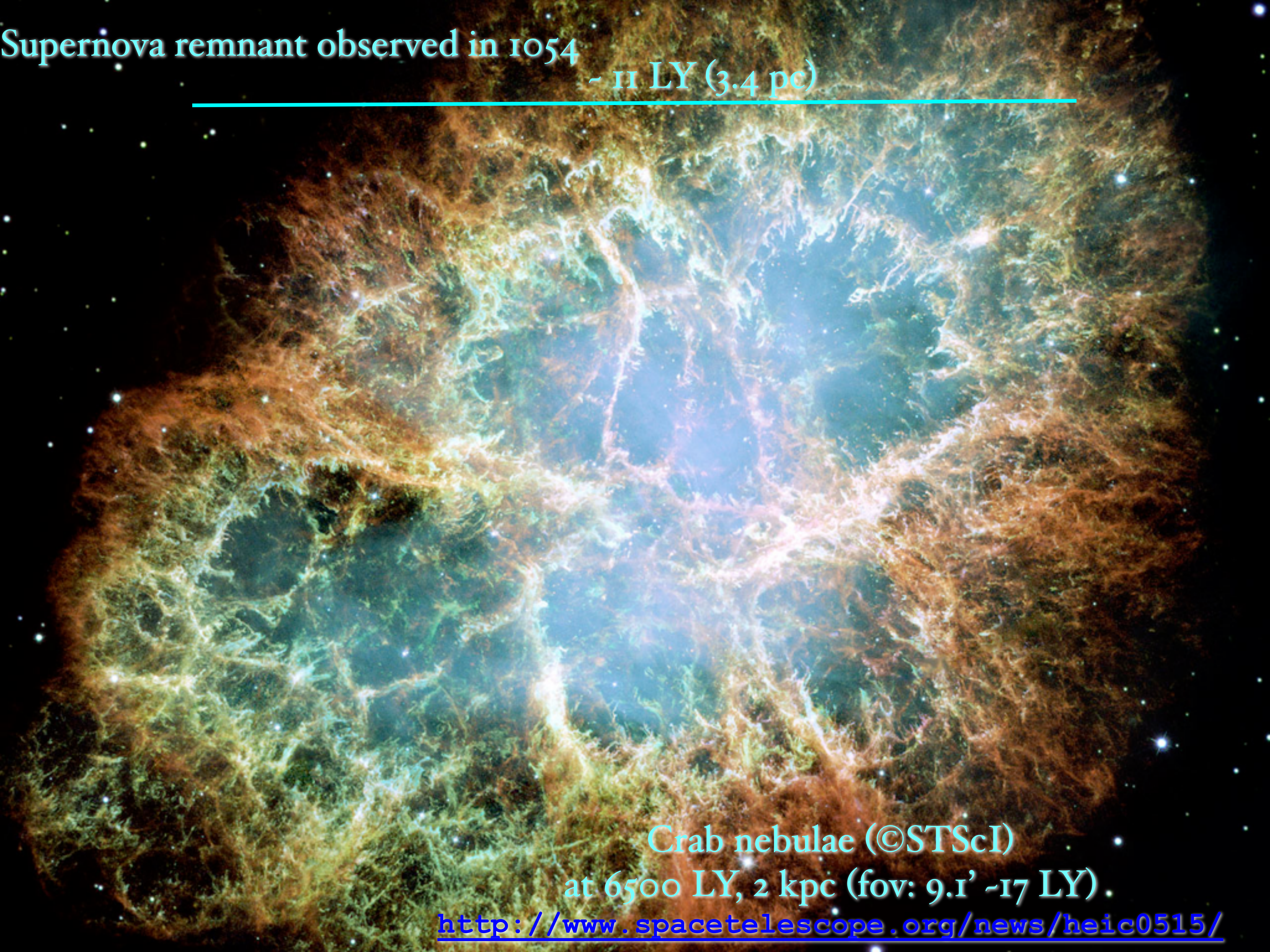
The Sun | Composition of Earth's crust

Photograph: Y. Beletsky

The Planet, the Galaxy and the Laser

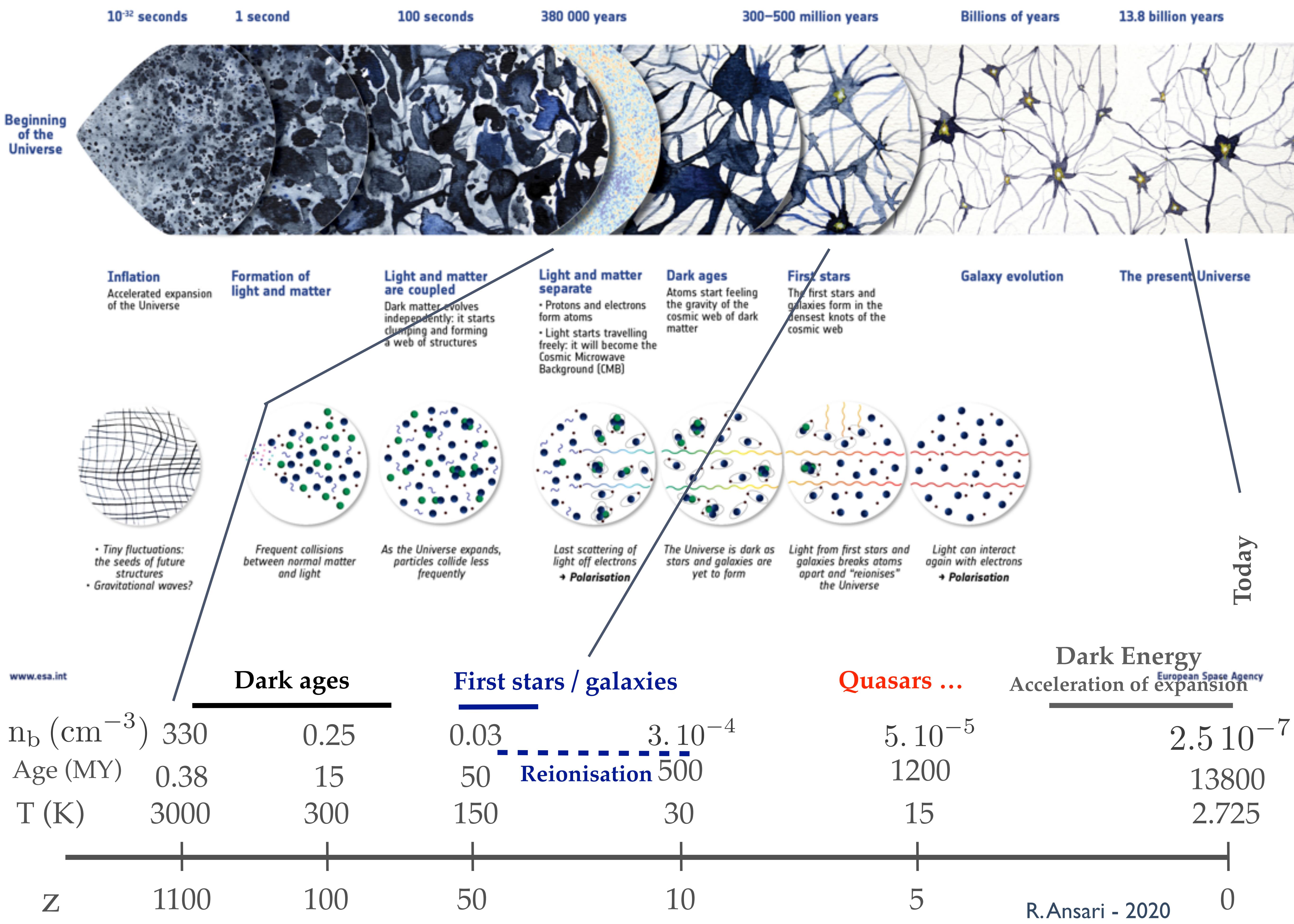
ESO Press Photo 33a/07 (2 August 2007)

- The sun is our star, at about 8 light-minutes
- It produces about 10^26 watt (million x billion nuclear reactors)
- Its energy source is from nuclear fusion, combining 4 hydrogen atoms to make a He atom. Energy is released in this process
- There are a variety of stars, with masses ranging from a fraction of solar mass to about 100 solar masses
- More massive stars produce heavier elements through their lives, more or less up to Iron
- The heaviest elements are produced in cosmic fireballs, such as supernovae



Supernova remnant observed in 1054
~ 11 LY (3.4 pc)
Crab nebulae (©STScI)
at 6500 LY, 2 kpc (fov: 9.1' ~17 LY)
http://www.spacetelescope.org/news/heic0515/

Major questions in physics and cosmology



10^-32 seconds
1 second
100 seconds
380 000 years
300–500 million years
Billions of years
13.8 billion years
Beginning of the Universe
Inflation
Accelerated expansion of the Universe
Formation of light and matter
Light and matter are coupled
Dark matter evolves independently: it starts clumping and forming a web of structures
Light and matter separate
• Protons and electrons form atoms
• Light starts travelling freely: it will become the Cosmic Microwave Background (CMB)
Dark ages
Atoms start feeling the gravity of the cosmic web of dark matter
First stars
The first stars and galaxies form in the densest knots of the cosmic web
Galaxy evolution
The present Universe
• Tiny fluctuations: the seeds of future structures
• Gravitational waves?
Frequent collisions between normal matter and light
As the Universe expands, particles collide less frequently
Last scattering of light off electrons
→ Polarisation
The Universe is dark as stars and galaxies are yet to form
Light from first stars and galaxies breaks atoms apart and "reionises" the Universe
Light can interact again with electrons
→ Polarisation
Today
www.esa.int
European Space Agency
Dark ages
First stars / galaxies
Quasars …
Dark Energy
Acceleration of expansion
Reionisation
n_b (cm^{-3}) 330 0.25 0.03 3.10^{-4} 5.10^{-5} $2.5\,10^{-7}$
Age (MY) 0.38 15 50 500 1200 13800
T (K) 3000 300 150 30 15 2.725
z 1100 100 50 10 5 0
R.Ansari - 2020

Cosmology: main questions and tools

- Energy and matter content of the universe (Dark matter, dark energy)
- Structure formation and evolution
- Primordial cosmology: inflation …
- Primordial nucleosynthesis
- Formation and evolution of galaxies and stars
- Cosmic microwave background: temperature and polarisation C(l) spectrum
- Statistical properties of large scale structures
- Geometrical probes: $d_A(z)$, $d_L(z)$ … : SNIa , Clusters, BAO …

ΛCDM model with 6 parameters

3 parameters to set (though General Relativity) the dynamics of the Universe,
1 parameter to capture the effect of reionisation (end of the dark ages),
2 parameters to describe the characteristics of primordial fluctuations.
Flat spatial geometry assumed.

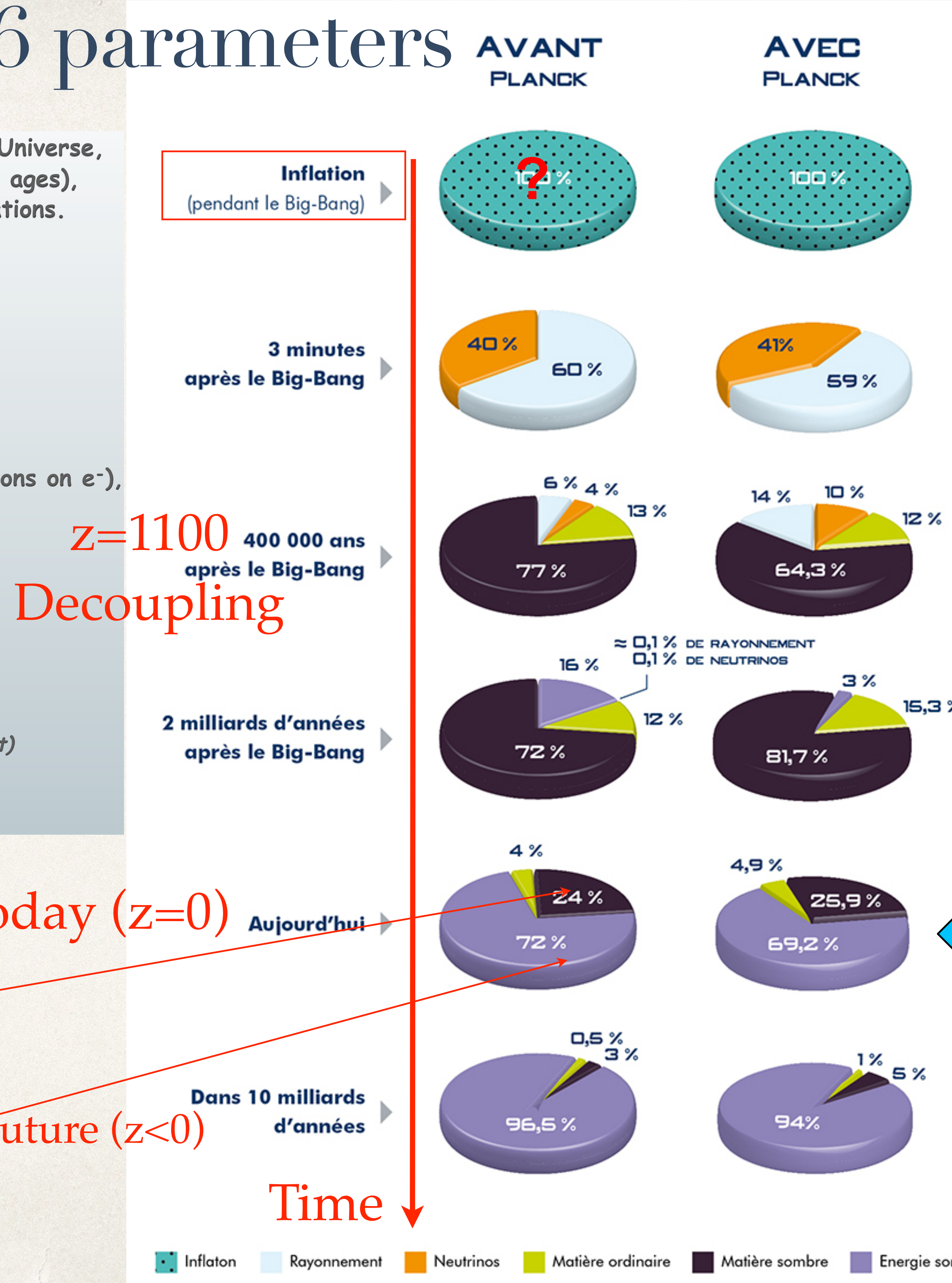
$\Omega_b h^2$ Baryon density today - The amount of ordinary matter
$\Omega_c h^2$ Cold dark matter density today – only weakly interacting
Θ Sound horizon size when optical depth τ reaches unity
(Distance traveled by a sound wave since inflation, when universe became transparent at recombination at t ~380 000 years)

τ Optical depth at reionisation (due to Thomson scattering of photons on e^-), fraction of the CMB photons re-scattered during that process

A_s Amplitude of the curvature power spectrum (Overall contrast of primordial fluctuations)
n_s Scalar power spectrum power law index (n_s-1 measures departure from scale invariance)

Others are *derived* parameters within the model, in particular
- *Ω "Dark Energy" fraction of the critical density (derived only if assumed flat)*
- *H_0 the expansion rate today (in km/s per Mpc of separation)*
- *t_0 the age of the universe (in Gy)*

Planck 2015 , arXiv:
Planck 2018, arXiv:1807.06209



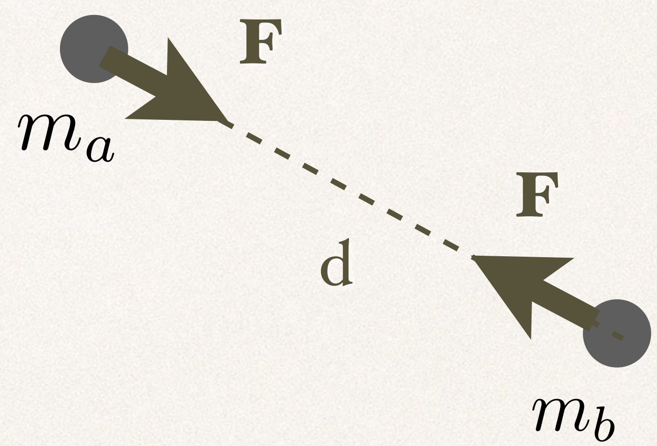
Dark Matter (25%)

Dark Energy / Λ (70%)

Dark Matter : invisible matter revealed by its gravitational effects

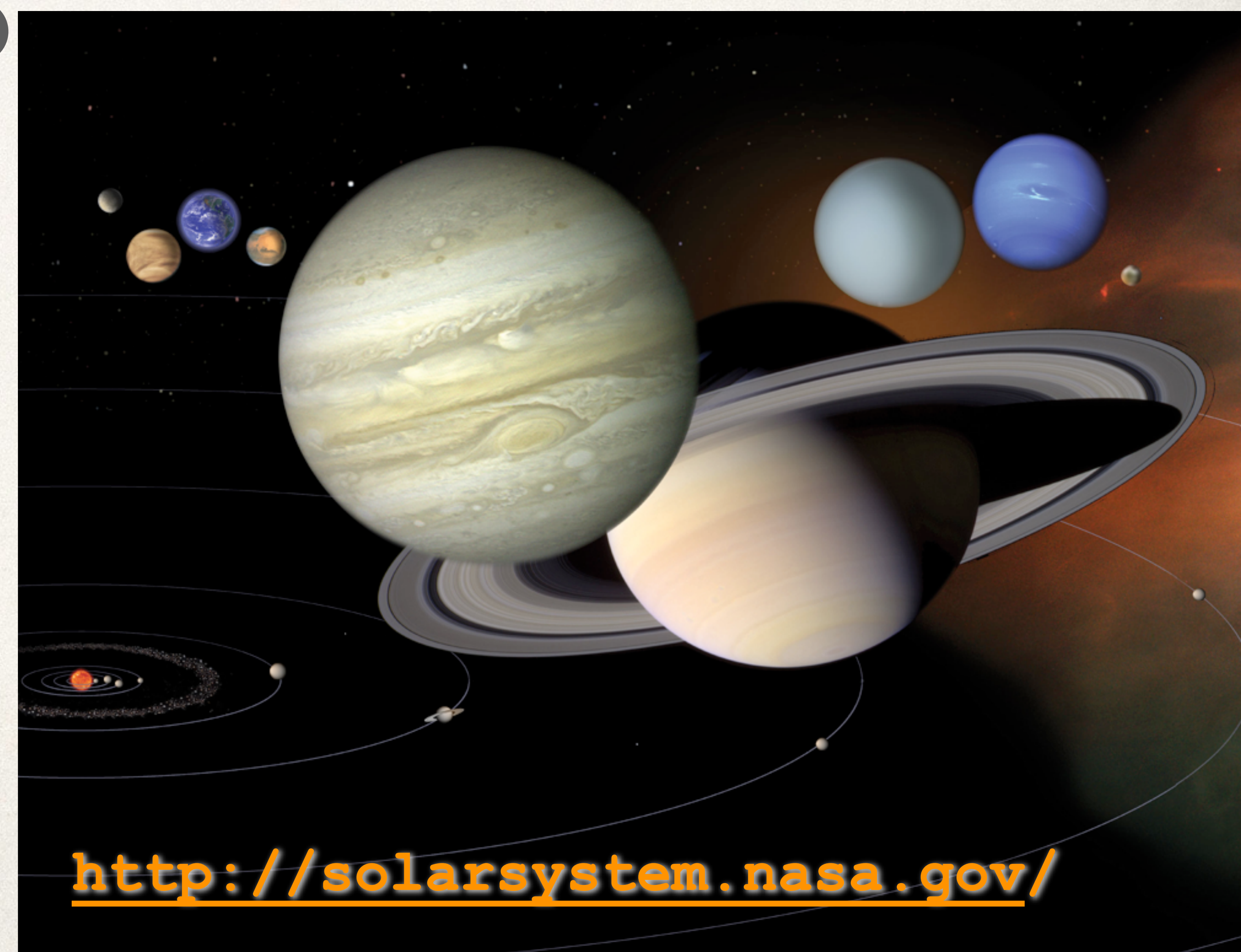
$$\mathbf{F} = G\,\frac{m_a\,m_b}{d^2}\,\vec{u_{ab}}$$

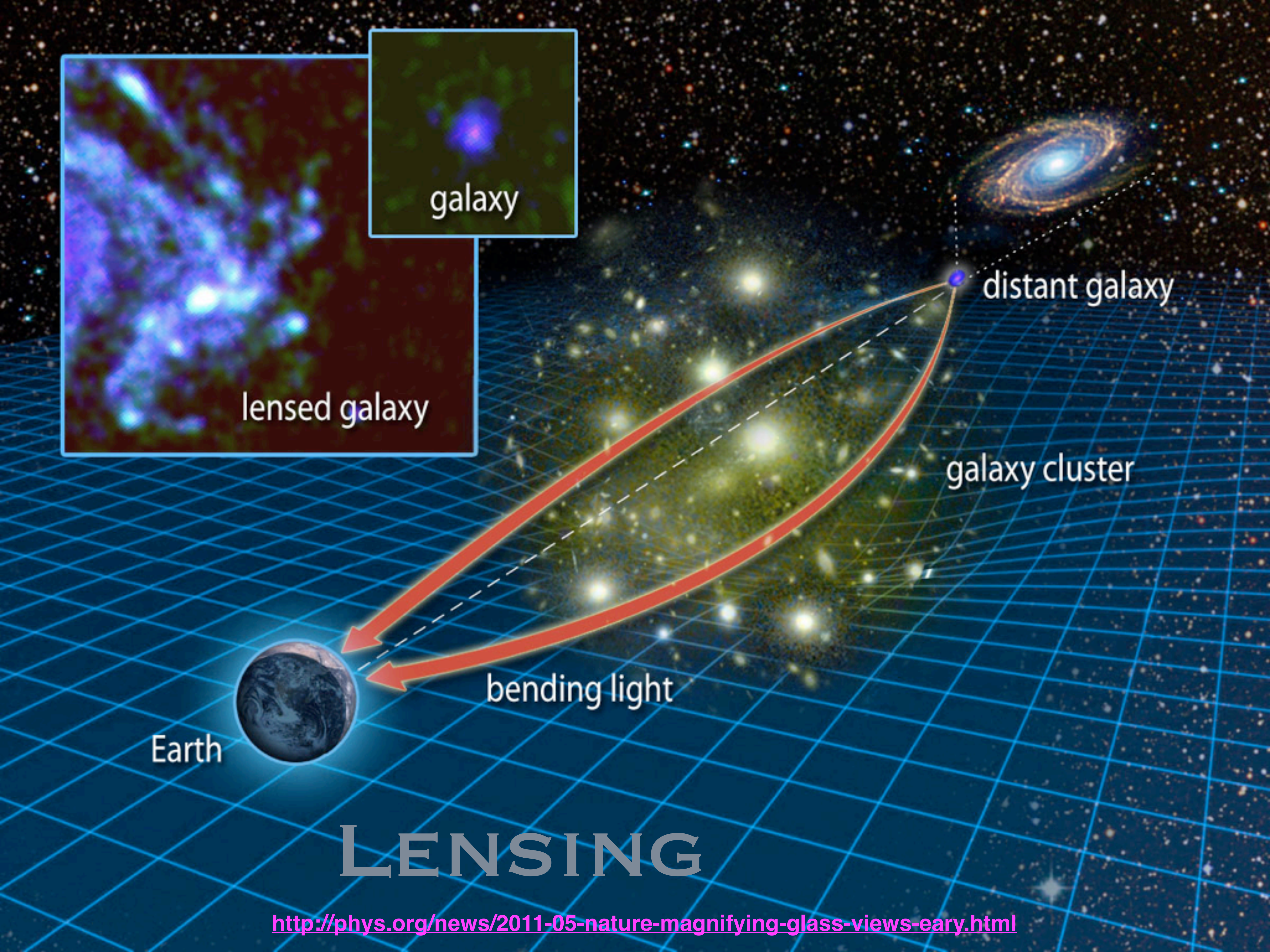
$$\Phi(r) = -G\,\frac{m}{r}$$



Urbain Le Verrier (1811-1877)

Le Verrier computed Neptune's characteristics from the Uranus movement anomalies





Lensing

http://phys.org/news/2011-05-nature-magnifying-glass-views-eary.html

Dark Energy (or Λ)

✤Cosmological observations imply a flat universe

✤Matter (including dark matter) is about a quarter of the critical density. Most of the energy density in the universe seems to be made of a mysterious component behaving like Λ

✤Λ : Repulsive gravity !

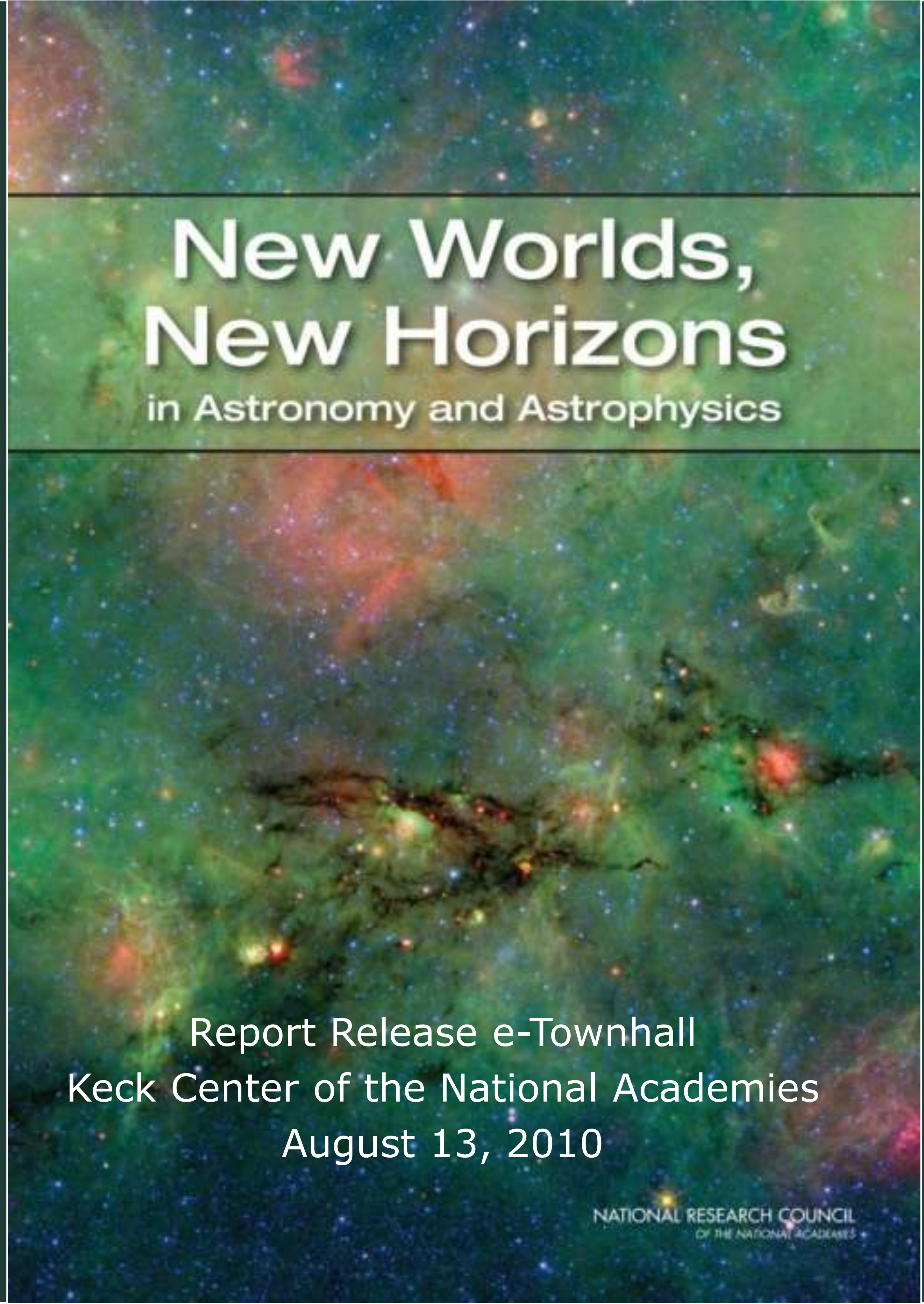
✤Vaccum energy (quantum fluctuations) ➠ Dark Energy ?

✤Determination of state equation of this cosmic fluid:

$$p = w(z)\,\varrho$$

✤$w(z) = -1$ for the cosmological constant (Λ)

Quoting from 2010 decadal survey

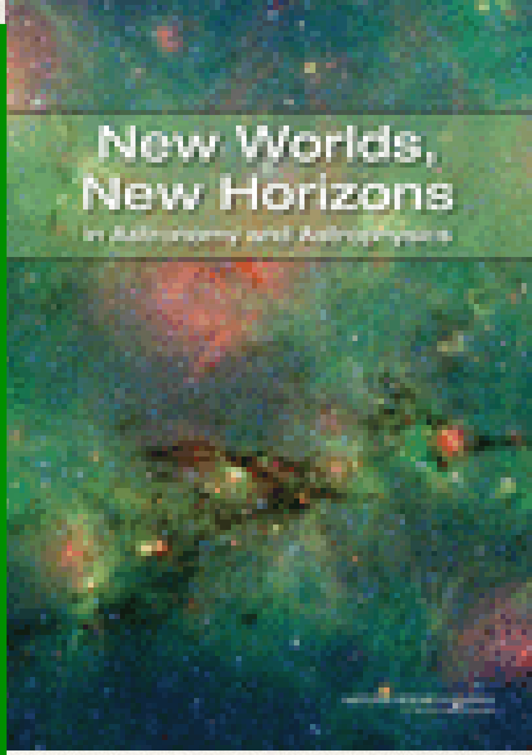


DISCOVERY

New technologies, observing strategies, theories, and computations open vistas on the universe and provide opportunities for transformational comprehension, i.e. discovery.

Science frontier discovery areas are:

- ***Identification and characterization of nearby habitable exoplanets***
- ***Gravitational wave astronomy***
- ***Time-domain astronomy***
- ***Astrometry***
- ***The epoch of reionization***



New Worls, New Horizons
Astro 2010 decadal survey

ORIGINS

Study of the origin and evolution of astronomical objects including planets, stars, galaxies, and the universe itself can elucidate our origins.

Science frontier questions in this category are:

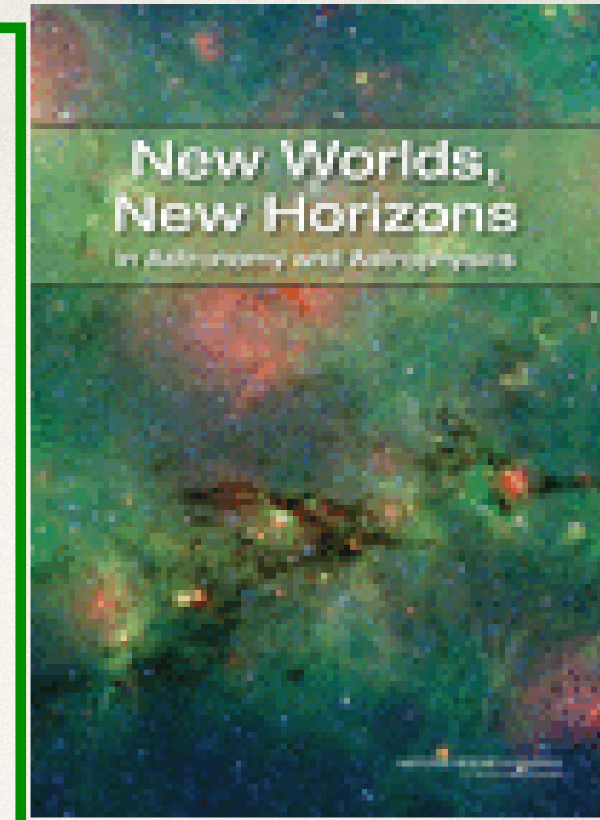
- ***How did the universe begin?***
- ***What were the first objects to light up the universe and when did they do it?***
- ***How do cosmic structures form and evolve?***
- ***What are the connections between dark and luminous matter?***
- ***What is the fossil record of galaxy assembly and evolution from the first stars to the present?***
- ***How do stars and black holes form?***
- ***How do circumstellar disks evolve and form planetary systems?***

UNDERSTANDING THE COSMIC ORDER

When known physical laws interact, often in complex ways, outcomes of great astrophysical interest and impact result and their study improves our understanding of the cosmic order.

Science frontier questions in this category are:

- *How do baryons cycle in and out of galaxies and what do they do while they are there?*
- *What are the flows of matter and energy in the circumgalactic medium?*
- *What controls the mass-energy-chemical cycles within galaxies?*
- *How do black holes work and influence their surroundings?*
- *How do rotation and magnetic fields affect stars?*
- *How do massive stars end their lives?*
- *What are the progenitors of Type Ia supernovas and how do they explode?*
- *How diverse are planetary systems and can we identify the telltale signs of life on an exoplanet?*



New Worls, New Horizons
Astro 2010 decadal survey

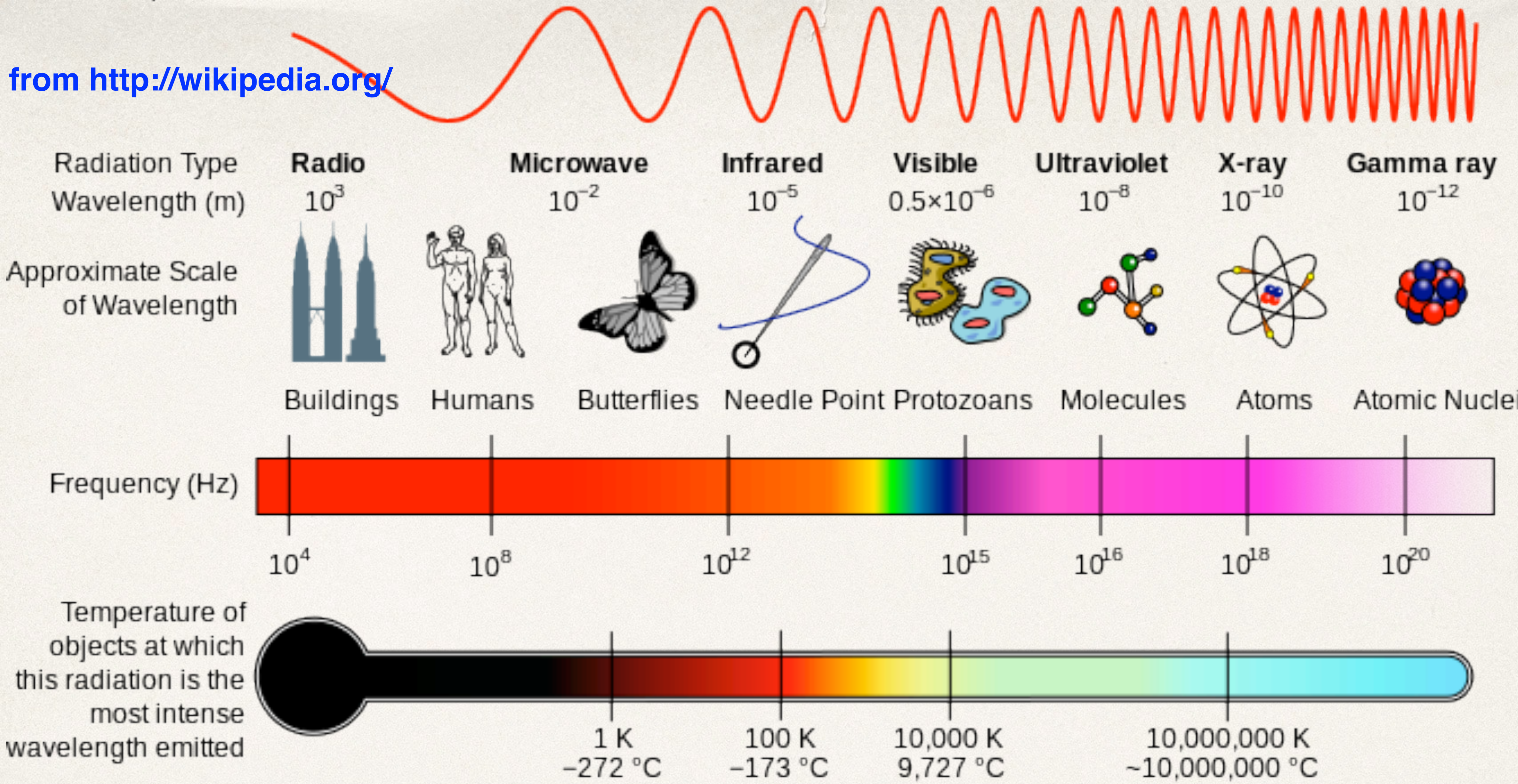
FRONTIERS OF KNOWLEDGE

New fundamental physics, chemistry, and biology can be revealed by astronomical measurements, experiments, or theory and hence push the frontiers of human knowledge.

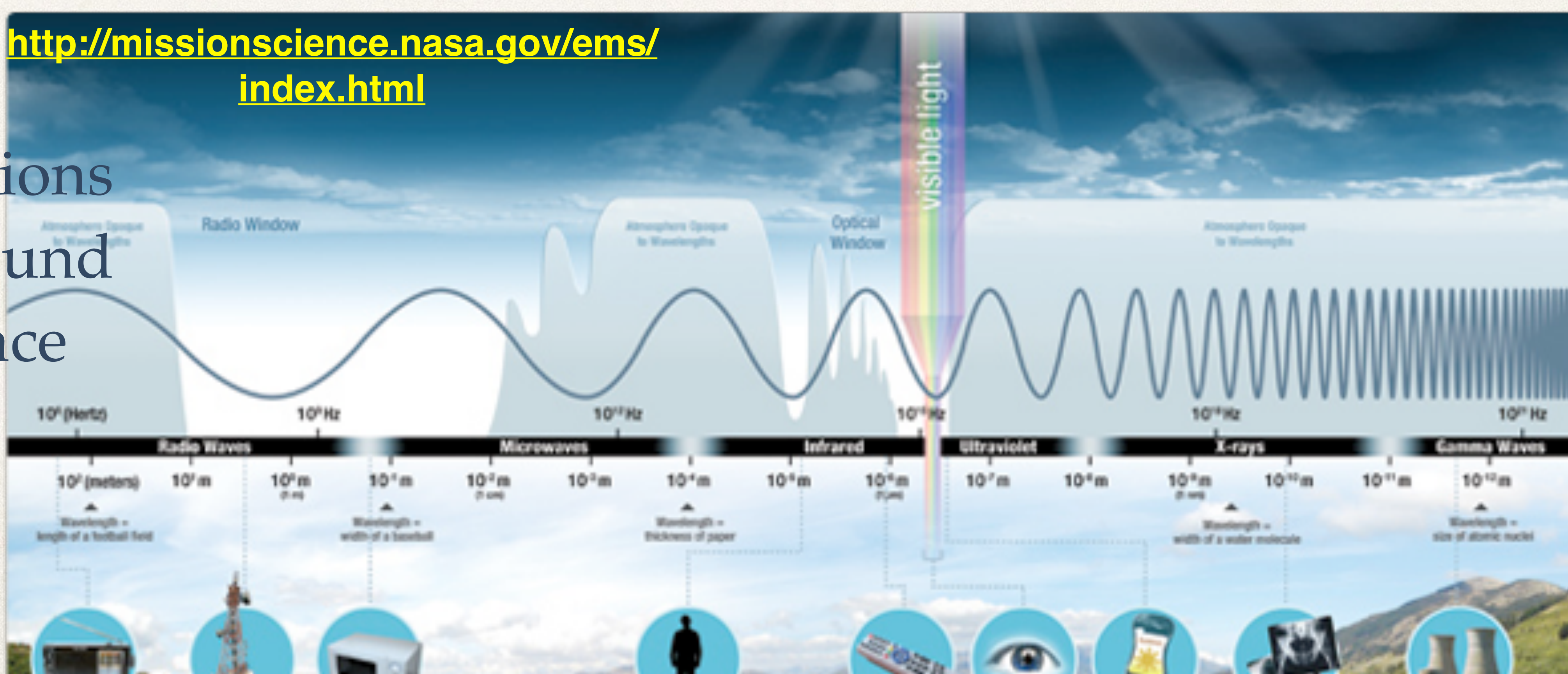
Science frontier questions in this category are:

- *Why is the universe accelerating?*
- *What is dark matter?*
- *What are the properties of the neutrinos?*
- *What controls the masses, spins and radii of compact stellar remnants?*

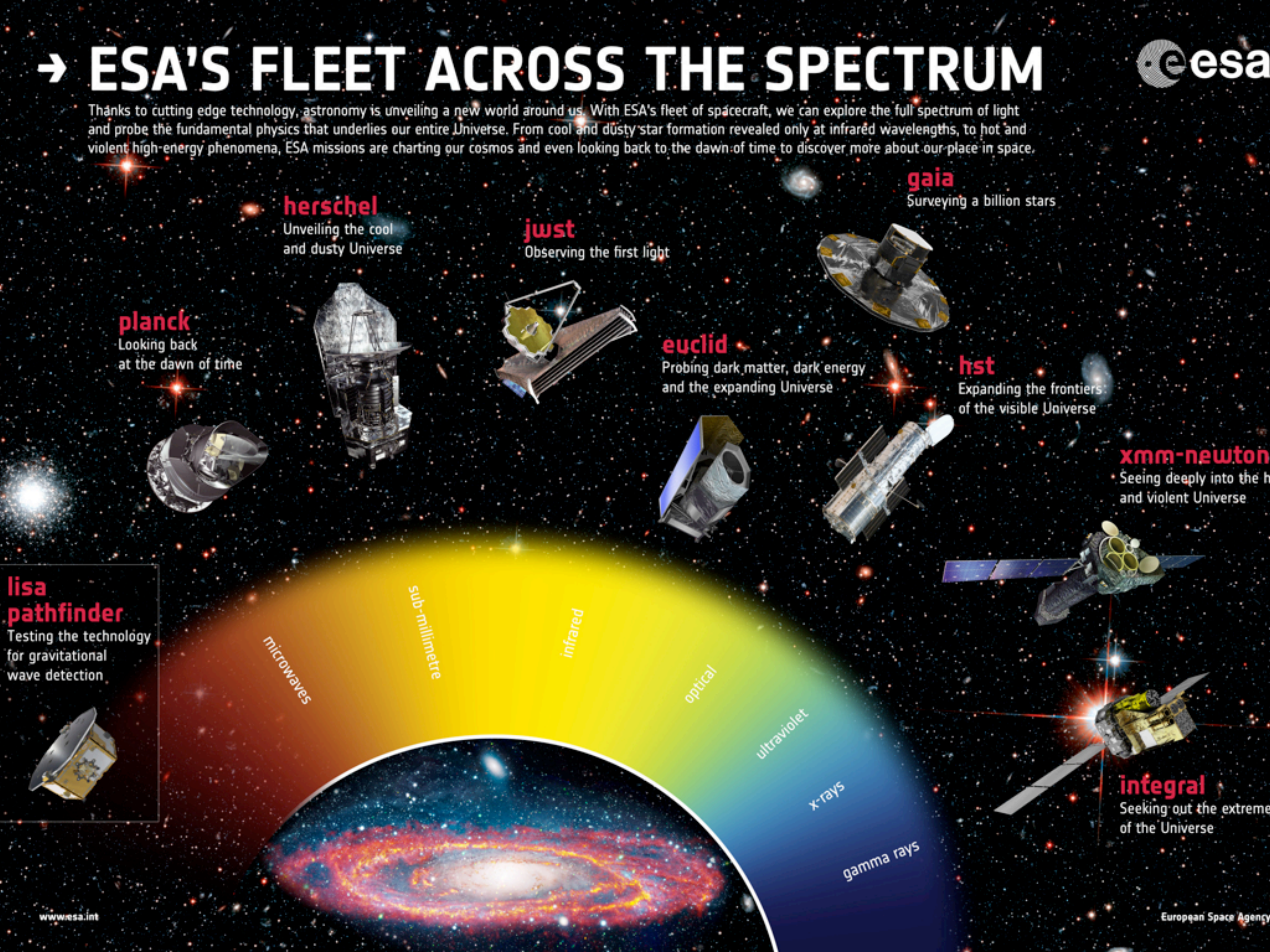
Image from http://wikipedia.org/



http://missionscience.nasa.gov/ems/index.html



Observations from Ground and space



→ ESA'S FLEET ACROSS THE SPECTRUM
esa
Thanks to cutting edge technology, astronomy is unveiling a new world around us. With ESA's fleet of spacecraft, we can explore the full spectrum of light and probe the fundamental physics that underlies our entire Universe. From cool and dusty star formation revealed only at infrared wavelengths, to hot and violent high-energy phenomena, ESA missions are charting our cosmos and even looking back to the dawn of time to discover more about our place in space.
gaia
Surveying a billion stars
herschel
Unveiling the cool and dusty Universe
jwst
Observing the first light
planck
Looking back at the dawn of time
euclid
Probing dark matter, dark energy and the expanding Universe
hst
Expanding the frontiers of the visible Universe
xmm-newton
Seeing deeply into the h
and violent Universe
lisa pathfinder
Testing the technology for gravitational wave detection
microwaves
sub-millimetre
infrared
optical
ultraviolet
x-rays
gamma rays
integral
Seeking out the extreme
of the Universe
www.esa.int
European Space Agency

Astroparticles, astrophysics and cosmology at IJCLab

A2C Astroparticles, Astrophysics & Cosmology

Teams and projects

Astrophysique & Cosmochimie

e-ASTROGAM

micro-meteorites

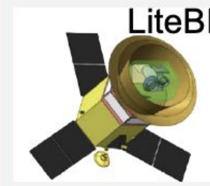
Astroparticules de Haute Énergie

Auger

CTA

CMB

LiteBIRD



Simons Observatory

Dark Matter

XENON

DAMIC

Astroparticle solid state detectors

Cupid
Ricochet
Edelweiss

GREEN

Vera Rubin (LSST)

BAO-Radio

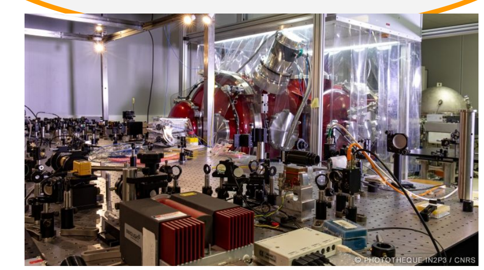
Ondes gravitationnelles

LIGO/Virgo

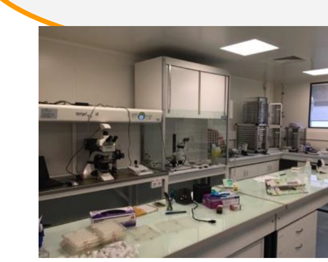
SVOM

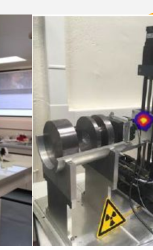
and 2 platforms:

CALVA/Exsqueez



MYRTHO





Complementarity of observations

Astroparticle solid state detectors

Cupid
Ricochet
Edelweiss

CUPID

Dark Matter

Xenon

DAMIC

Astroparticules de Haute Énergie

Auger

CTA

Astrophysique & Cosmochimie

eAstrogam

micro-meteorites

GREEN

Vera Rubin (LSST)

BAO-Radio

CMB

LiteBIRD

Simons Observatory

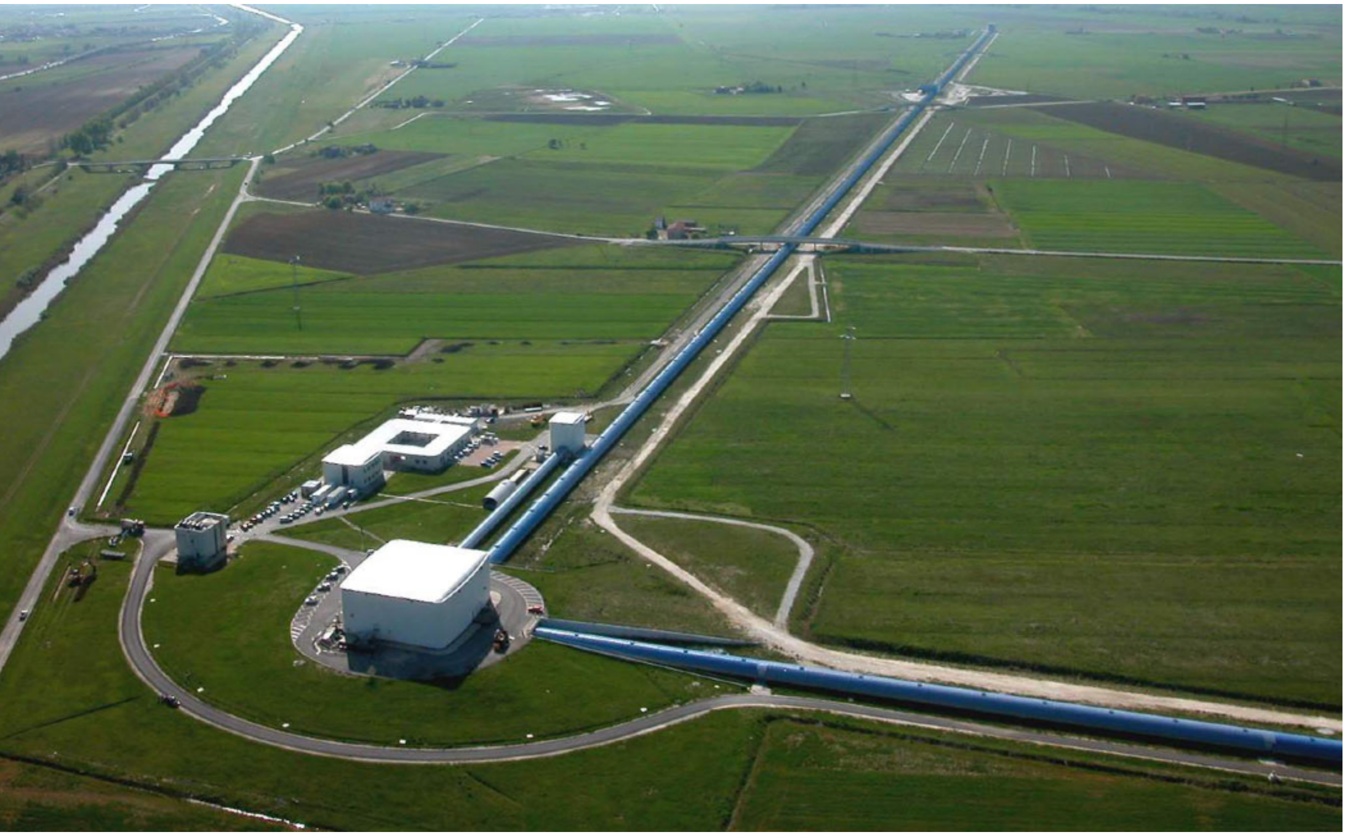
Ondes Gravitationnelles

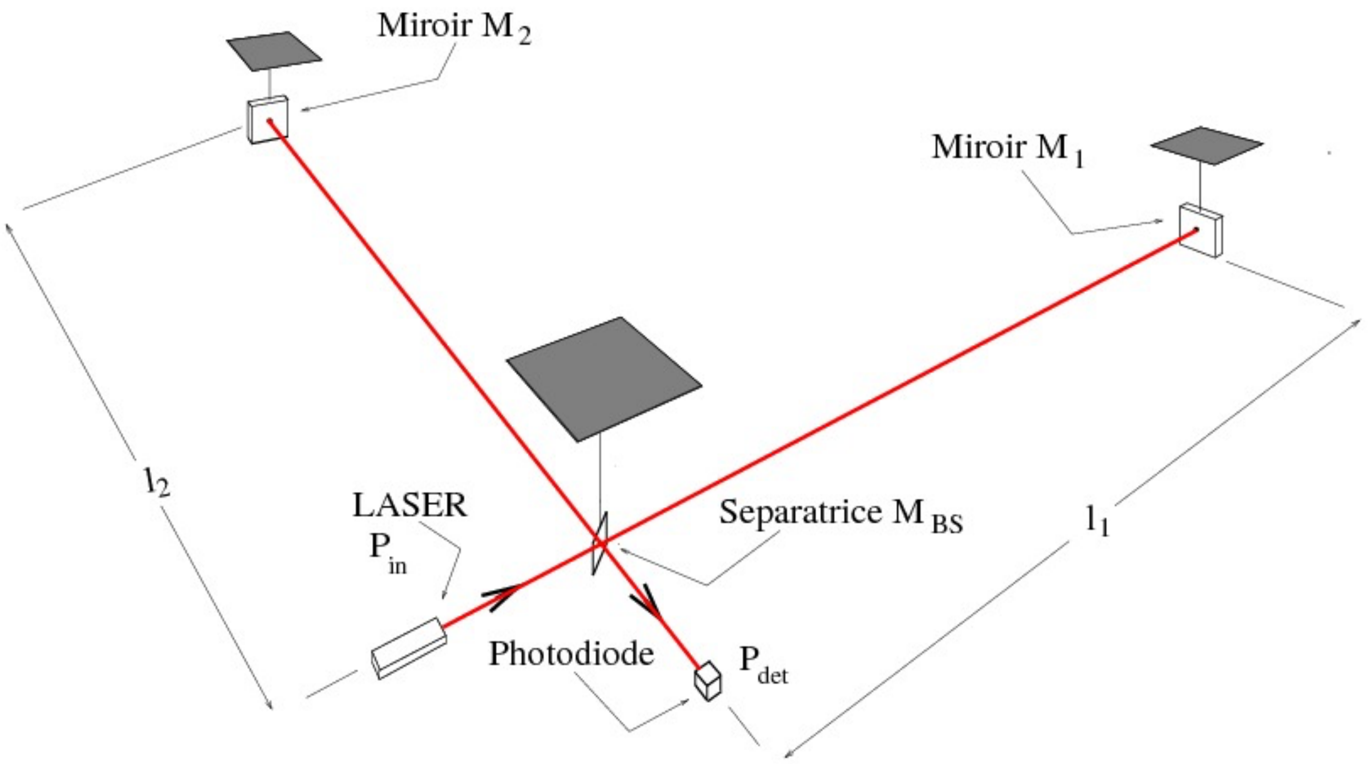
SVOM

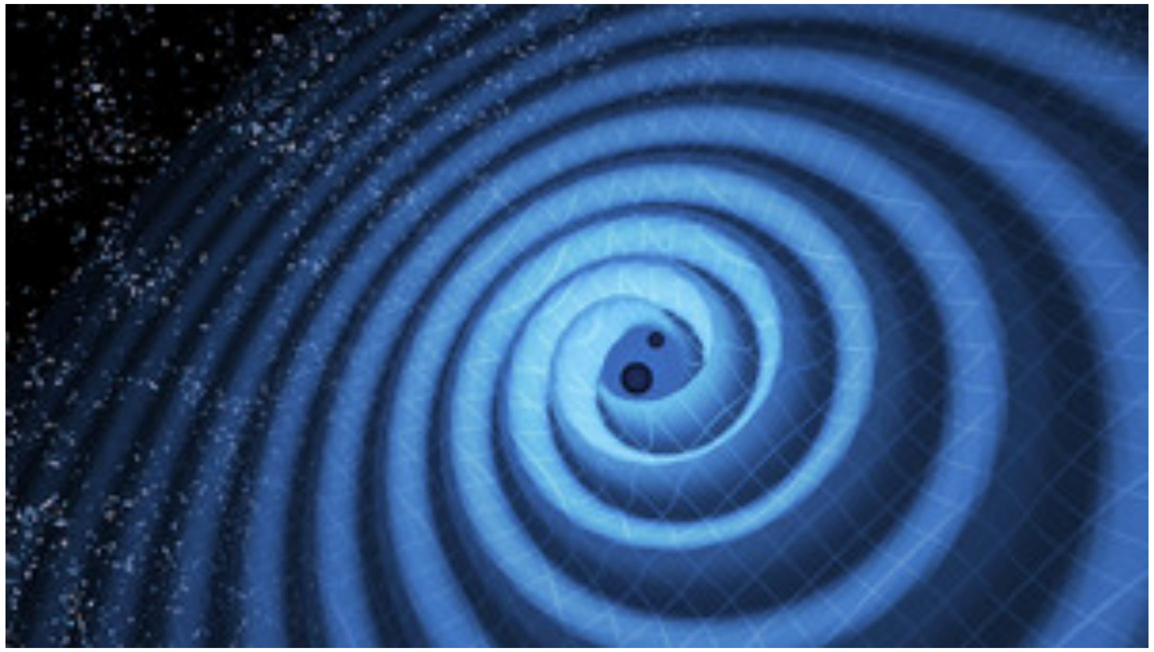
LIGO/Virgo

Einstein Telescope

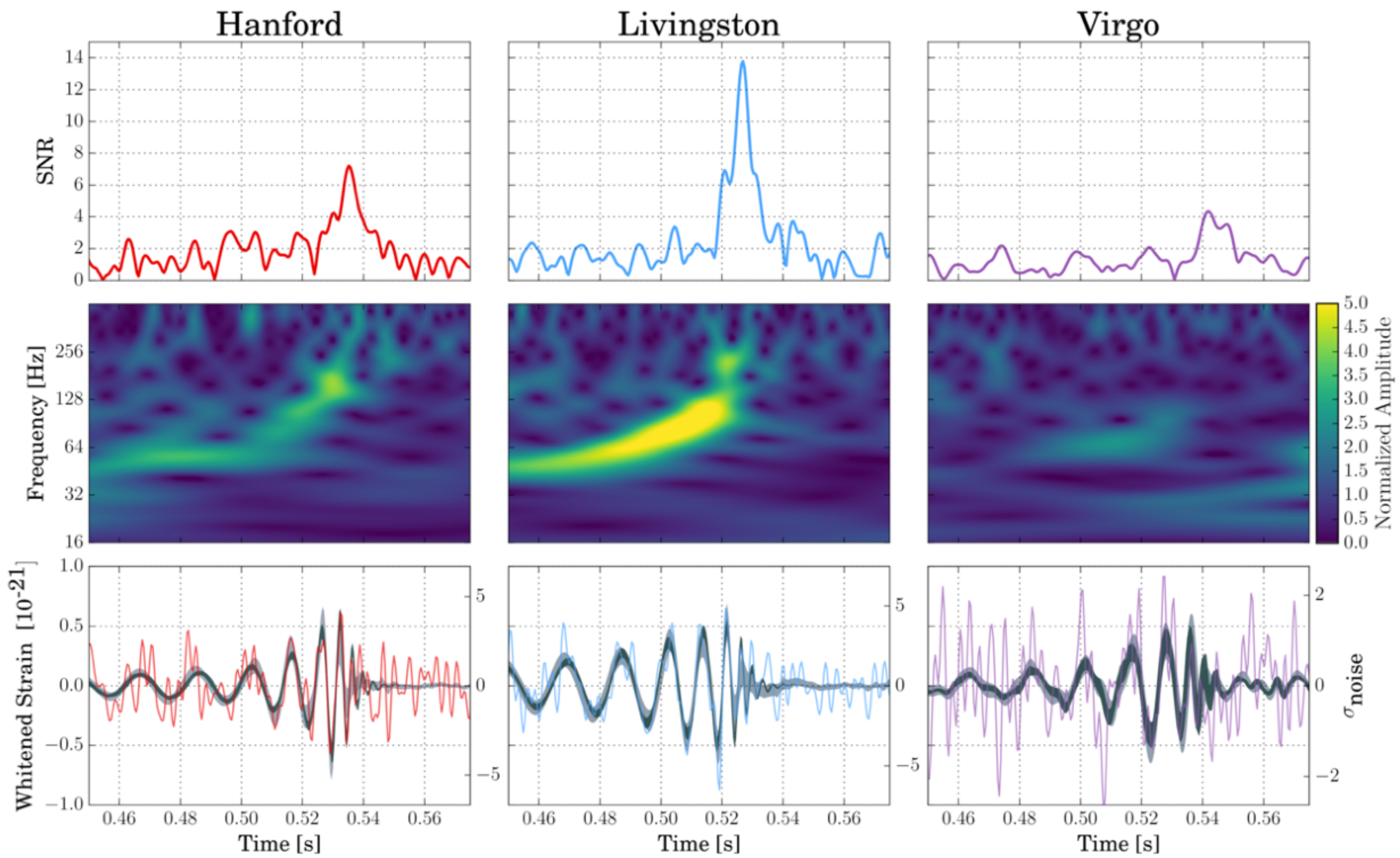
GW : Virgo & LIGO



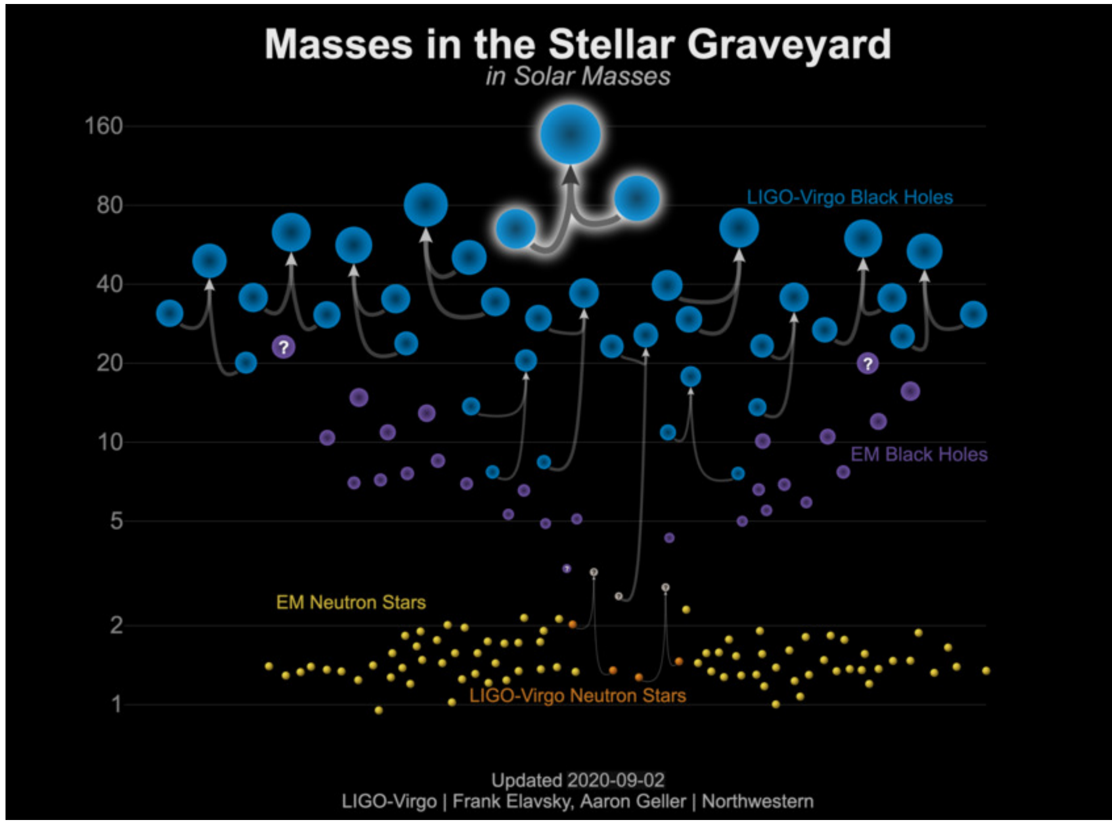




https://www.ligo.caltech.edu/video/ligo20160615v1



GW170814

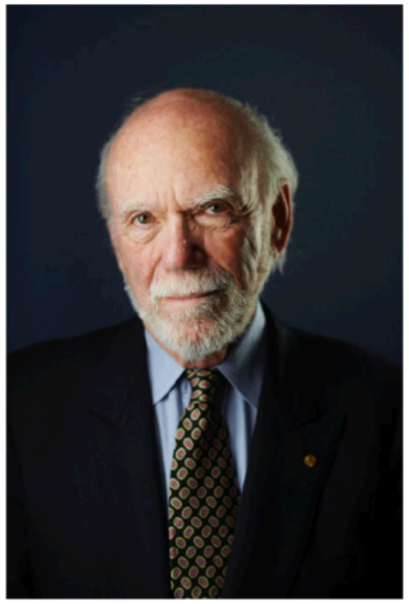


The Nobel Prize in Physics 2017

© Nobel Media AB. Photo: A. Mahmoud

Rainer Weiss

Prize share: 1/2



© Nobel Media AB. Photo: A.Mahmoud

Barry C. Barish

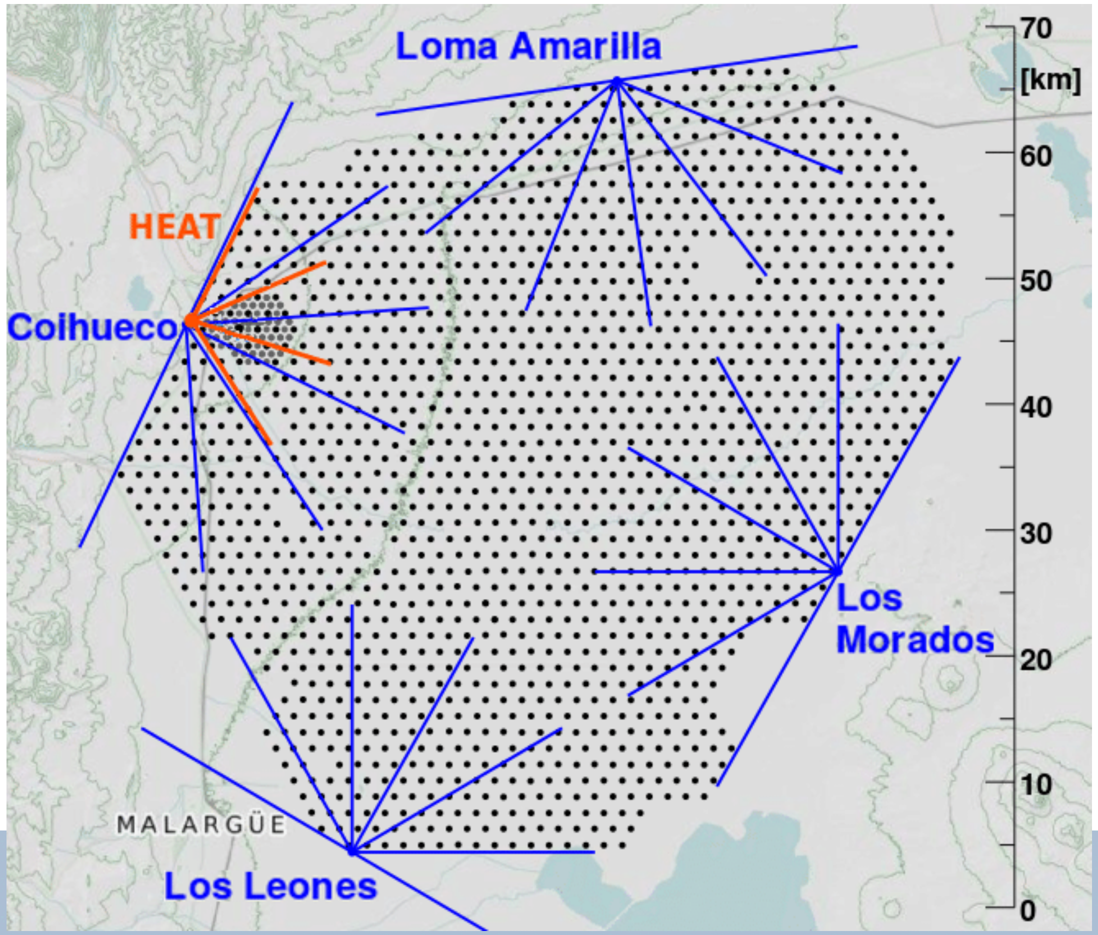
Prize share: 1/4

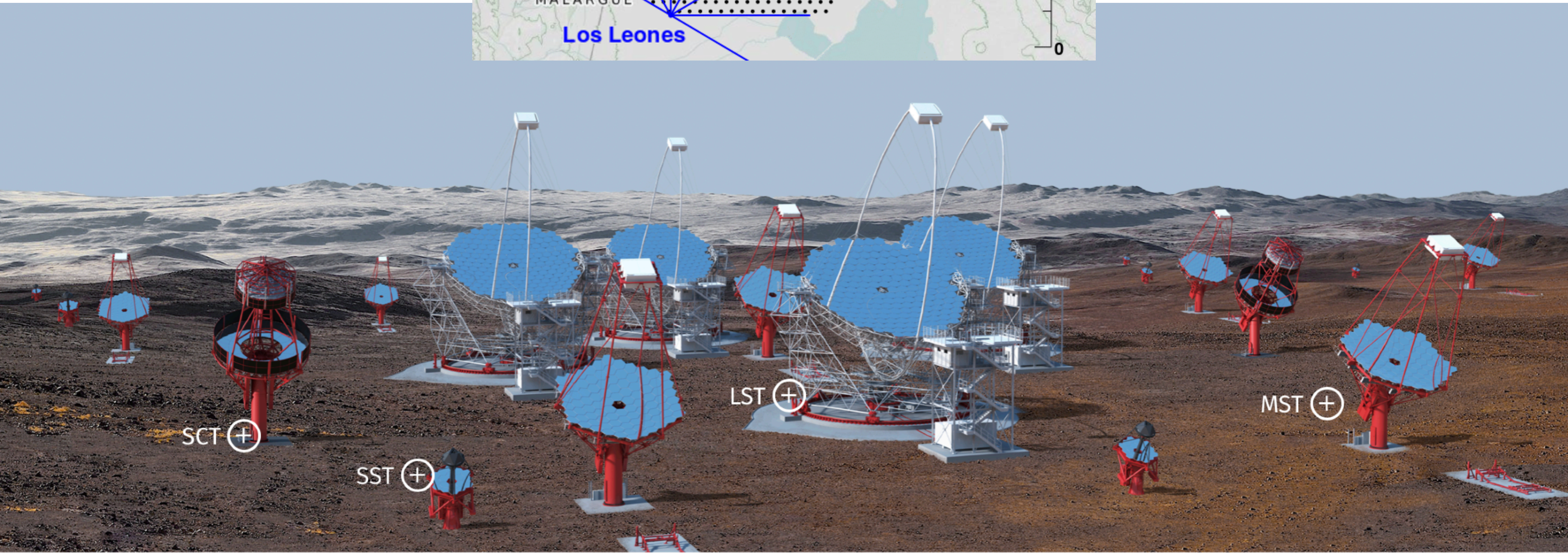
© Nobel Media AB. Photo: A.Mahmoud

Kip S. Thorne

Prize share: 1/4

HECR and gamma rays : AUGER & CTA



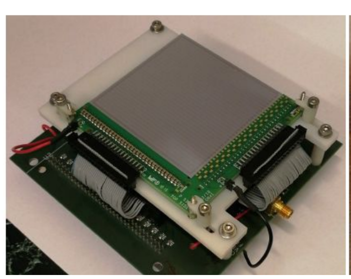
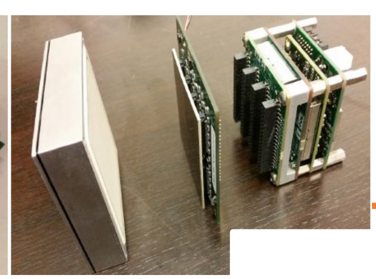
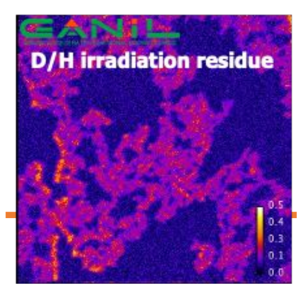


Astrophysics et Cosmochemistry (AC)

CR # 2

Gamma-ray astronomy & micro-meteorites

– **White Paper on gamma-ray astronomy at MeV** energies following the e-ASTROGAM mission proposal to ESA
– On-going integration of the **ComptonCAM** gamma camera for nuclear industry. Europe's first Compton-type gamma camera
– H2020 AHEAD2020/**COMCUBE** CubeSat project for multimessenger astronomy & gamma-ray burst polarimetry
– **Outstanding 2019 Micrometeorite collection**. Currently being investigated.
– **Hayabusa 2 first samples** arrived at IJCLab on the 24th of june
– **Precise measurement of the micrometeorite flux** on Earth (national CNRS press release)
– Participation to **review article** "Cometary Dust" (Levasseur-Regourd et al.) and white paper "AMBITION" (Bockelée-Morvan et al. for a cryogenic cometary sample return)
– **High-energy irradiation experiment** at GANIL to reproduce the isotopic heterogeneity observed in cometary micrometeorites

Research topics

- Nucleosynthesis
- Origin of cosmic rays
- Formation of the solar system

Astrophysique & Cosmochimie

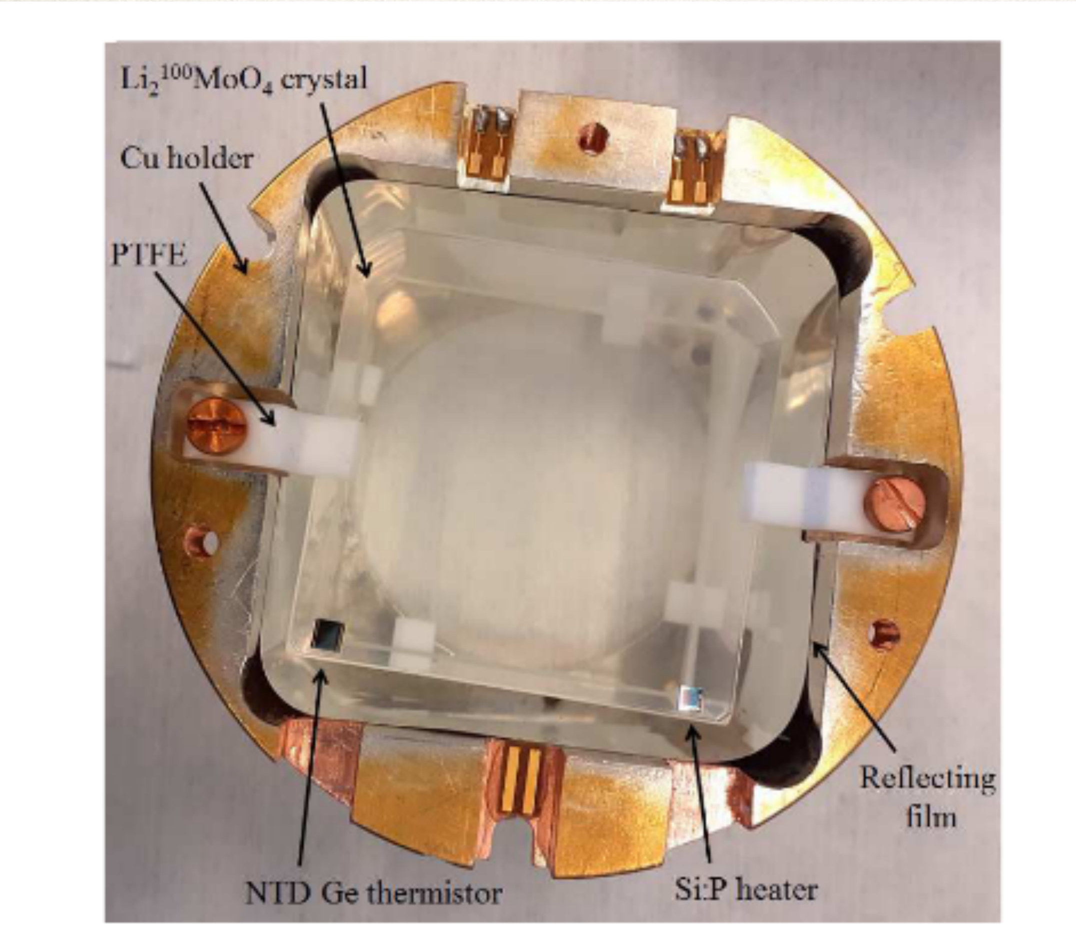
e-ASTROGAM

micro-meteorites

Future:

- The micrometeorites group is leaving by end 2024 (planned before IJCLab)
- Compton Telescope Cubesat Prototype (COMCUBE, H2020 project) for gamma ray burst polarimetry

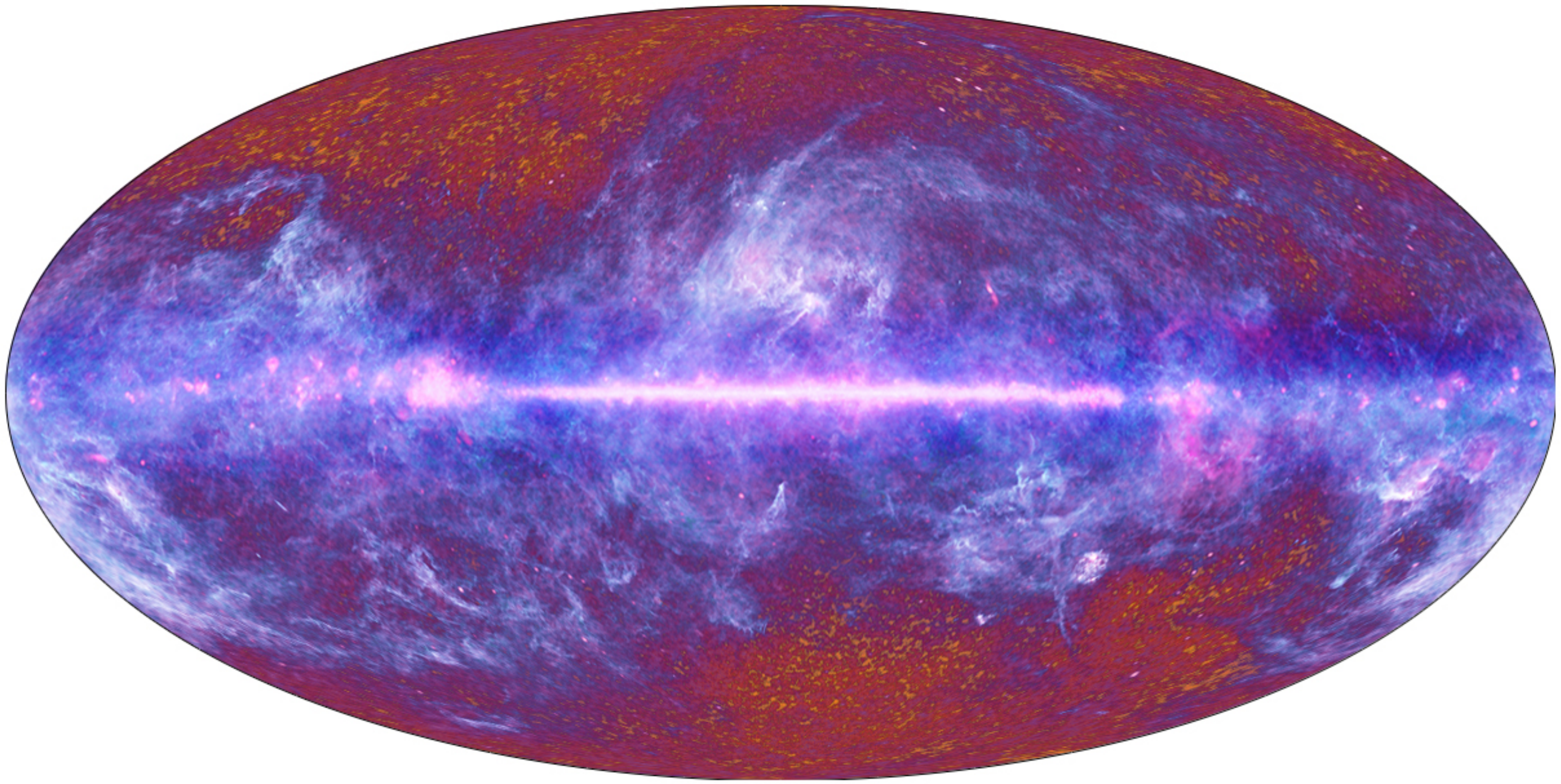
ASSD : Astroparticle Solid State Detectors

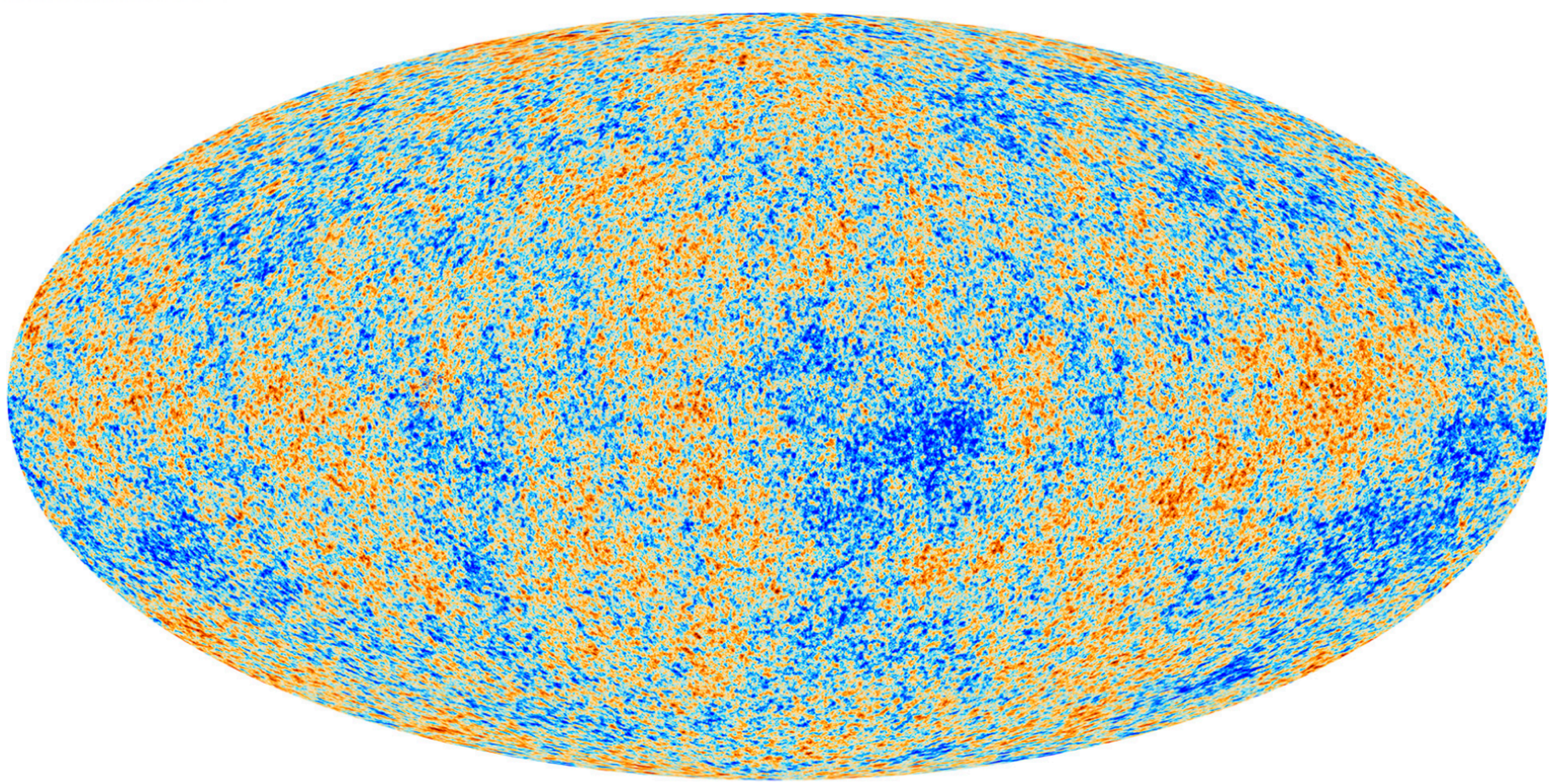


Dark Matter detectors

Xenon 1T detector

Microwave sky and the CMB as seen by **Planck**






Vera Rubin Observatory &
& Legacy Survey of Space and Time
Wide … Fast … Deep

2020: a rather fruitful year for A2C teams !

IJCLab Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis

cnrs | université PARIS-SACLAY | FACULTÉ DES SCIENCES D'ORSAY | Université de Paris

Le Japon soutient l'animation scientifique sur LiteBIRD et le Simons Observatory

Le projet « Exploration of the origin and evolution of matter and space time: a research consortium for cosmic microwave background » coordonné pour le CNRS par IJCLab (S. Henrot-Versillé, équipe CMB du Pôle

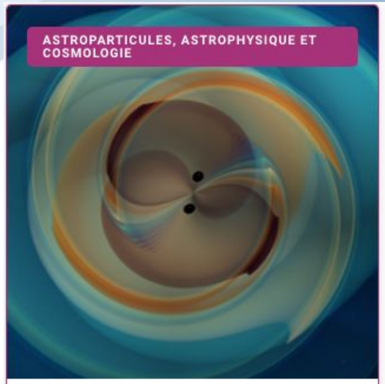
en savoir plus »

30 octobre 2020

À la une

26.10.2020

Observatoire Pierre Auger : le scénario mono-élément pour les rayons cosmiques d'ultra haute énergie de plus en plus intenable

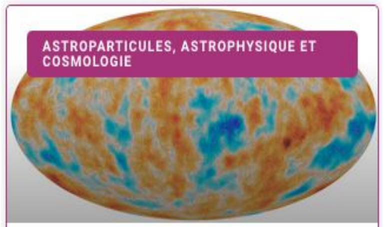


De nouvelles populations de trous noirs révélées par les ondes gravitationnelles

C'est la plus grosse prise à ce jour au tableau de chasse des détecteurs d'ondes gravitationnelles Ligo et Virgo : un trou noir ayant la masse de 142 soleils, issu de la

en savoir plus »

28 septembre 2020



De nouvelles limites sur les premiers instants de l'Univers

Une nouvelle analyse des données du satellite Planck donne des contraintes sur l'état de l'Univers dans les tous premiers instants après sa création. Il n'y a aucune indication dans les observations du

en savoir plus »

23 octobre 2020

IJCLab participe à la construction de la plus grande caméra numérique du monde

Pour la première fois, des images d'une résolution de 3,2 milliards de pixels viennent d'être prises grâce à un plan focal géant équipé de 189 capteurs photographiques CCD, maintenant assemblés à SLAC

en savoir plus »

14 octobre 2020

CUPID-Mo progresse dans la quête de la double désintégration bêta sans émission de neutrinos

Après un an de séjour dans le laboratoire souterrain de Modane, le démonstrateur CUPID-Mo, équipé de ses tous nouveaux bolomètres scintillants en Li2MoO4 a obtenu des résultats très prometteurs. Avec une masse

en savoir plus »

22 septembre 2020

CUPID-Mo à Modane : la promesse de nouveaux résultats

L'expérience internationale CUPID Mo menée au Laboratoire Souterrain de Modane par des laboratoires français notamment, du CNRS-IN2P3 dont IJCLab, et du CEA/IRFU, teste l'usage de cristaux à base de Molybdène pour rechercher des doubles désintégrations beta sans émission de neutrinos. L'analyse des données confirme les résultats très prometteurs de cette expérience qui seront prochainement complétés à la conférence Neutrino 2020.

en savoir plus »

24 juin 2020

Les « lunettes » de GRANDMA voient 90% des signaux candidats aux ondes gravitationnelles

GRANDMA, le réseau international de télescopes auquel contribue IJCLab vient enrichir l'approche multimessager d'une observation du ciel.

en savoir plus »

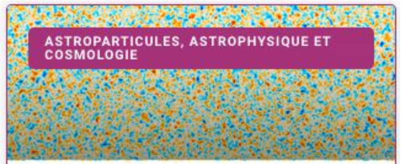
20 juillet 2020

A la poursuite de la matière noire : l'expérience XENON1T montre des résultats surprenants

Matière noire: la collaboration internationale XENON, dans laquelle IJCLab est impliqué, vient de communiquer des résultats surprenants grâce à l'expérience menée avec le détecteur XENON1T.

en savoir plus »

18 juin 2020



ACT lève le voile sur l'âge de l'Univers

Le télescope ACT (Atacama Cosmology Telescope) perché à plus de 5000 m d'altitude dans le désert d'Atacama au Chili, a produit une nouvelle image de la plus vieille lumière de l'Univers. Les données collectées suggèrent que l'Univers a 13,8 milliards d'années, relançant le débat sur l'âge de l'Univers et la compréhension du modèle standard de la cosmologie.

en savoir plus »

16 juillet 2020

IJCLab à la poursuite des blazars extrêmes, de prodigieux objets extragalactiques accélérateurs de particules

Sonder toujours plus avant la structure de l'Univers, parfaire les lois de la physique fondamentale ou de la physique des plasmas… autant d'objectifs ambitieux que visent sans relâche les astrophysiciens par leurs travaux et leurs observations.

en savoir plus »

4 avril 2020

END

THE STANDARD MODEL OF

FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model is a quantum theory that summarizes our current knowledge of the physics of fundamental particles and fundamental interactions (interactions are manifested by forces and by decay rates of unstable particles).

FERMIONS
matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

Flavor	Mass GeV/c^2	Electric charge
ν_L lightest neutrino*	$(0-2)\times10^{-9}$	0
e electron	0.000511	−1
ν_M middle neutrino*	$(0.009-2)\times10^{-9}$	0
μ muon	0.106	−1
ν_H heaviest neutrino*	$(0.05-2)\times10^{-9}$	0
τ tau	1.777	−1

Quarks spin = 1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.002	2/3
d down	0.005	−1/3
c charm	1.3	2/3
s strange	0.1	−1/3
t top	173	2/3
b bottom	4.2	−1/3

*See the neutrino paragraph below.

Spin is the intrinsic angular momentum of particles. Spin is given in units of ħ, which is the quantum unit of angular momentum where $\hbar = h/2\pi = 6.58\times10^{-25}$ GeV s $=1.05\times10^{-34}$ J s.

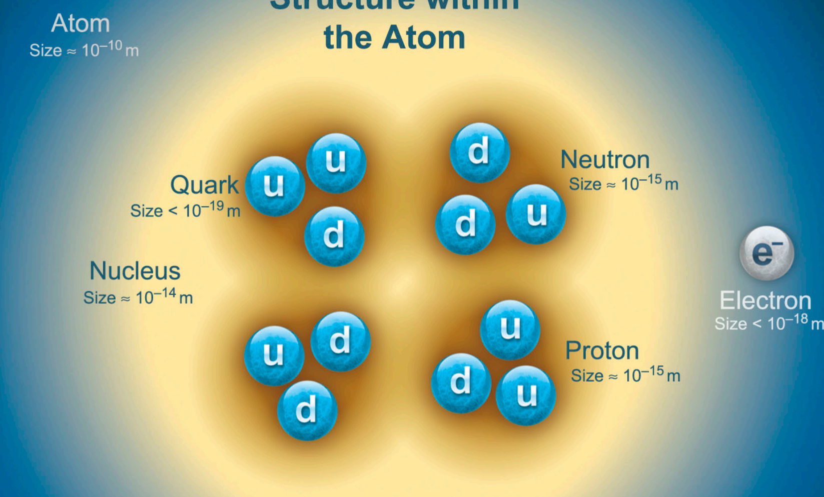
Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The energy unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c^2 (remember $E = mc^2$) where 1 GeV = 10^9 eV $=1.60\times10^{-10}$ joule. The mass of the proton is 0.938 GeV/c^2 = 1.67×10^{-27} kg.

Neutrinos
Neutrinos are produced in the sun, supernovae, reactors, accelerator collisions, and many other processes. Any produced neutrino can be described as one of three neutrino flavor states ν_e, ν_μ, or ν_τ, labelled by the type of charged lepton associated with its production. Each is a defined quantum mixture of the three definite-mass neutrinos ν_L, ν_M, and ν_H for which currently allowed mass ranges are shown in the table. Further exploration of the properties of neutrinos may yield powerful clues to puzzles about matter and antimatter and the evolution of stars and galaxy structures.

Matter and Antimatter
For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or – charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0, γ, and $\eta_c = c\bar{c}$ but not $K^0 = d\bar{s}$) are their own antiparticles.

Structure within the Atom



If the proton and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

BOSONS
force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.39	−1
W^+ (W bosons)	80.39	+1
Z^0 Z boson	91.188	0

Strong (color) spin = 1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Higgs Boson spin = 0

Name	Mass GeV/c^2	Electric charge
H Higgs	126	0

Higgs Boson
The Higgs boson is a critical component of the Standard Model. Its discovery helps confirm the mechanism by which fundamental particles get mass.

Color Charge
Only quarks and gluons carry "strong charge" (also called "color charge") and can have strong interactions. Each quark carries three types of color charge. These charges have nothing to do with the colors of visible light. Just as electrically-charged particles interact by exchanging photons, in strong interactions, color-charged particles interact by exchanging gluons.

Quarks Confined in Mesons and Baryons
Quarks and gluons cannot be isolated – they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs. The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge.

Two types of hadrons have been observed in nature **mesons** $q\bar{q}$ and **baryons** qqq. Among the many types of baryons observed are the proton (uud), antiproton ($\bar{u}\bar{u}\bar{d}$), and neutron (udd). Quark charges add in such a way as to make the proton have charge 1 and the neutron charge 0. Among the many types of mesons are the pion π^+ ($u\bar{d}$), kaon K^- ($s\bar{u}$), and B^0 ($d\bar{b}$).

Learn more at ParticleAdventure.org

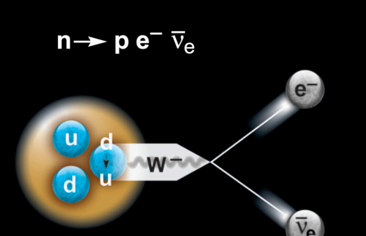
Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

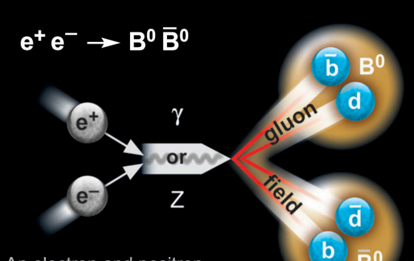
Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at 10^{-18} m	10^{-41}	0.8	1	25
Strength at 3×10^{-17} m	10^{-41}	10^{-4}	1	60

Particle Processes

These diagrams are an artist's conception. Orange shaded areas represent the cloud of gluons.



A free neutron (udd) decays to a proton (uud), an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β (beta) decay.

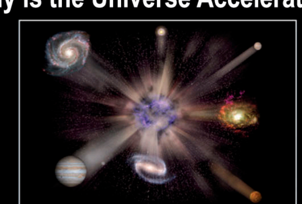


An electron and positron (antielectron) colliding at high energy can annihilate to produce $\bar{B}^0$ and B^0 mesons via a virtual Z boson or a virtual photon.

Unsolved Mysteries

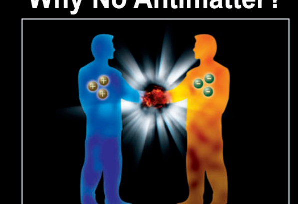
Driven by new puzzles in our understanding of the physical world, particle physicists are following paths to new wonders and startling discoveries. Experiments may even find extra dimensions of space, microscopic black holes, and/or evidence of string theory.

Why is the Universe Accelerating?



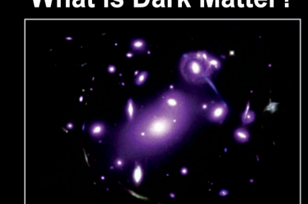
The expansion of the universe appears to be accelerating. Is this due to Einstein's Cosmological Constant? If not, will experiments reveal a new force of nature or even extra (hidden) dimensions of space?

Why No Antimatter?



Matter and antimatter were created in the Big Bang. Why do we now see only matter except for the tiny amounts of antimatter that we make in the lab and observe in cosmic rays?

What is Dark Matter?



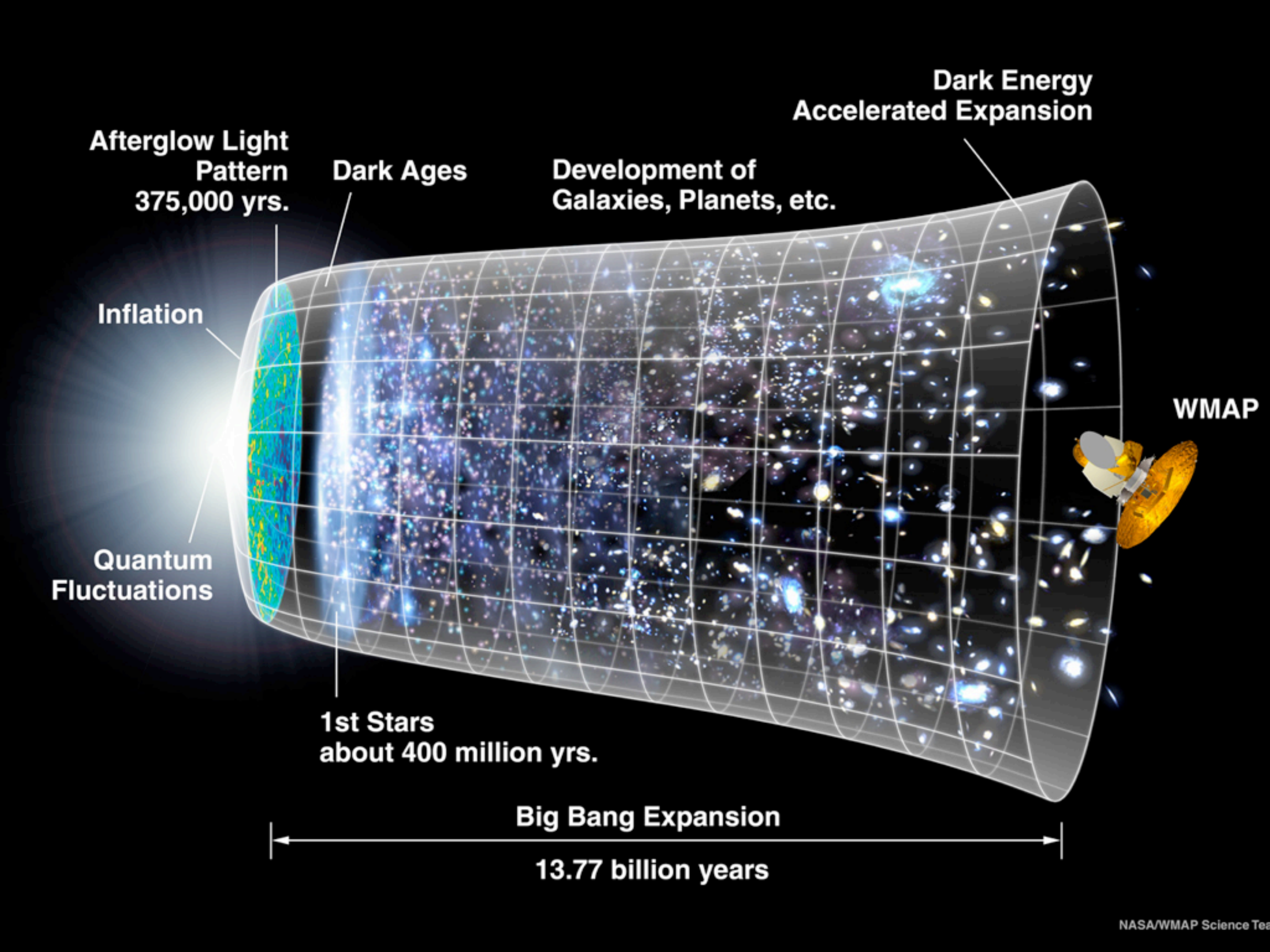
Invisible forms of matter make up much of the mass observed in galaxies and clusters of galaxies. Does this dark matter consist of new types of particles that interact very weakly with ordinary matter?

Are there Extra Dimensions?

An indication for extra dimensions may be the extreme weakness of gravity compared with the other three fundamental forces (gravity is so weak that a small magnet can pick up a paper clip overwhelming Earth's gravity).

©2014 Contemporary Physics Education Project. CPEP is a non-profit organization of teachers, physicists, and educators. Learn more about CPEP products and websites at **CPEPphysics.org**.

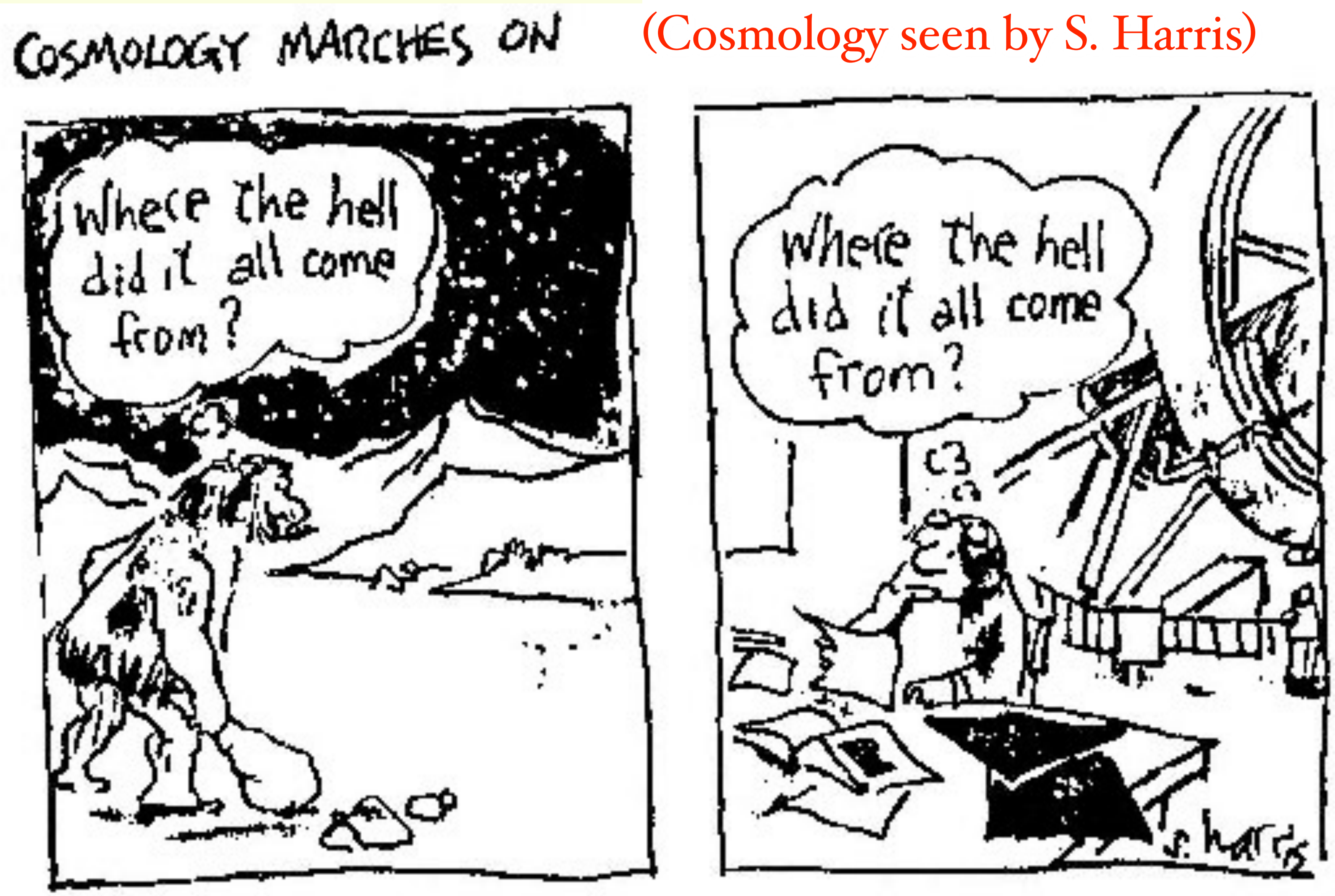
Made possible by the generous support of:
U.S. Department of Energy, U.S. National Science Foundation, & Lawrence Berkeley National Laboratory.


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
375,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.77 billion years
NASA/WMAP Science Tea

Cosmology

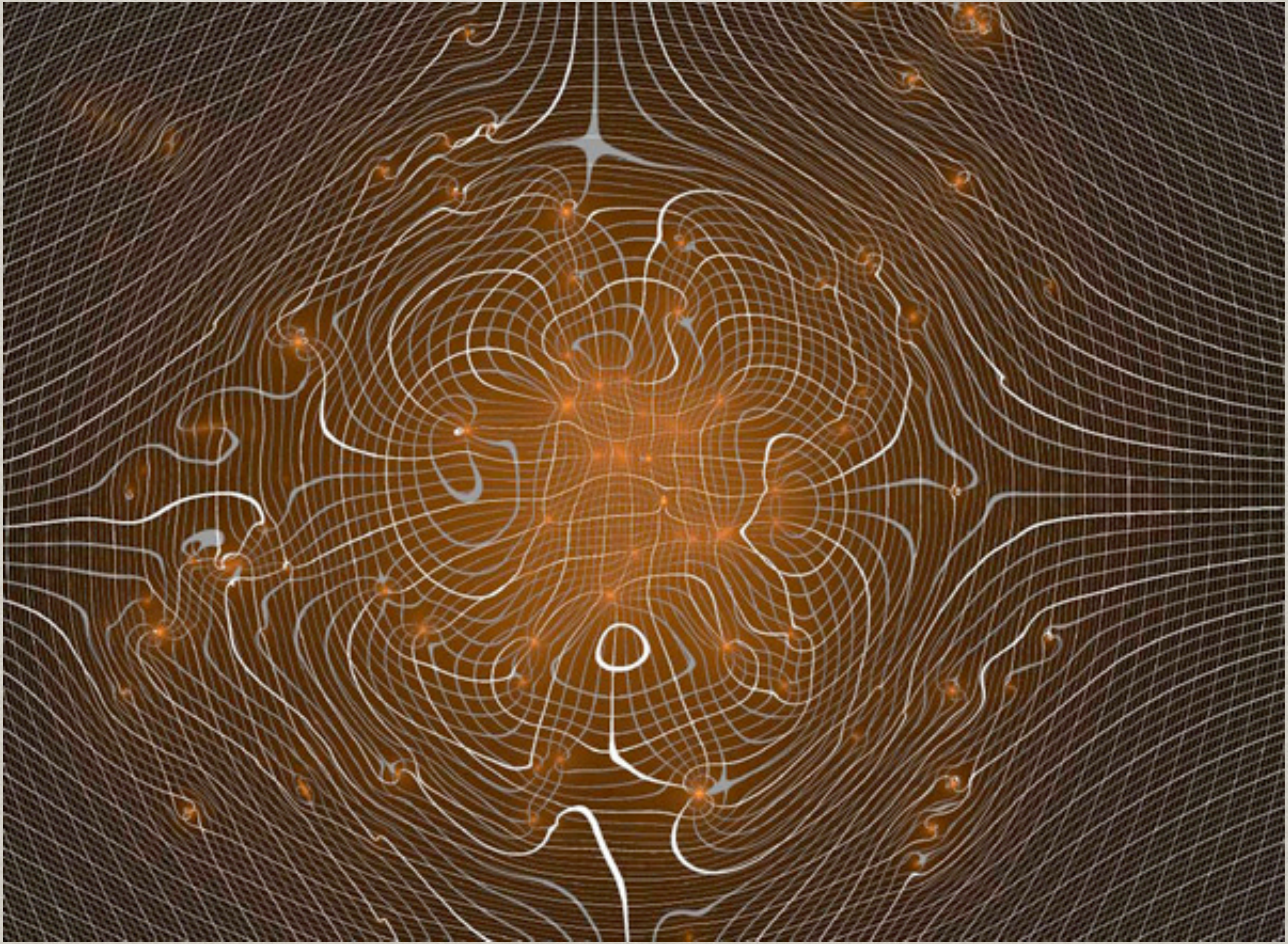
Oxford dictionary of english

cosmology |kɒzˈmɒlədʒi|
noun (pl. **cosmologies**) [mass noun]
the science of the origin and development of the universe. Modern cosmology is dominated by the Big Bang theory, which brings together observational astronomy and particle physics.
• [count noun] an account or theory of the origin of the universe.
DERIVATIVES
cosmological |-məˈlɒdʒɪk(ə)l|adjective,
cosmologist noun
ORIGIN mid 17th cent.: from French ***cosmologie*** or modern Latin ***cosmologia***, from Greek ***kosmos 'order or world'*** + ***-logia 'discourse'***.

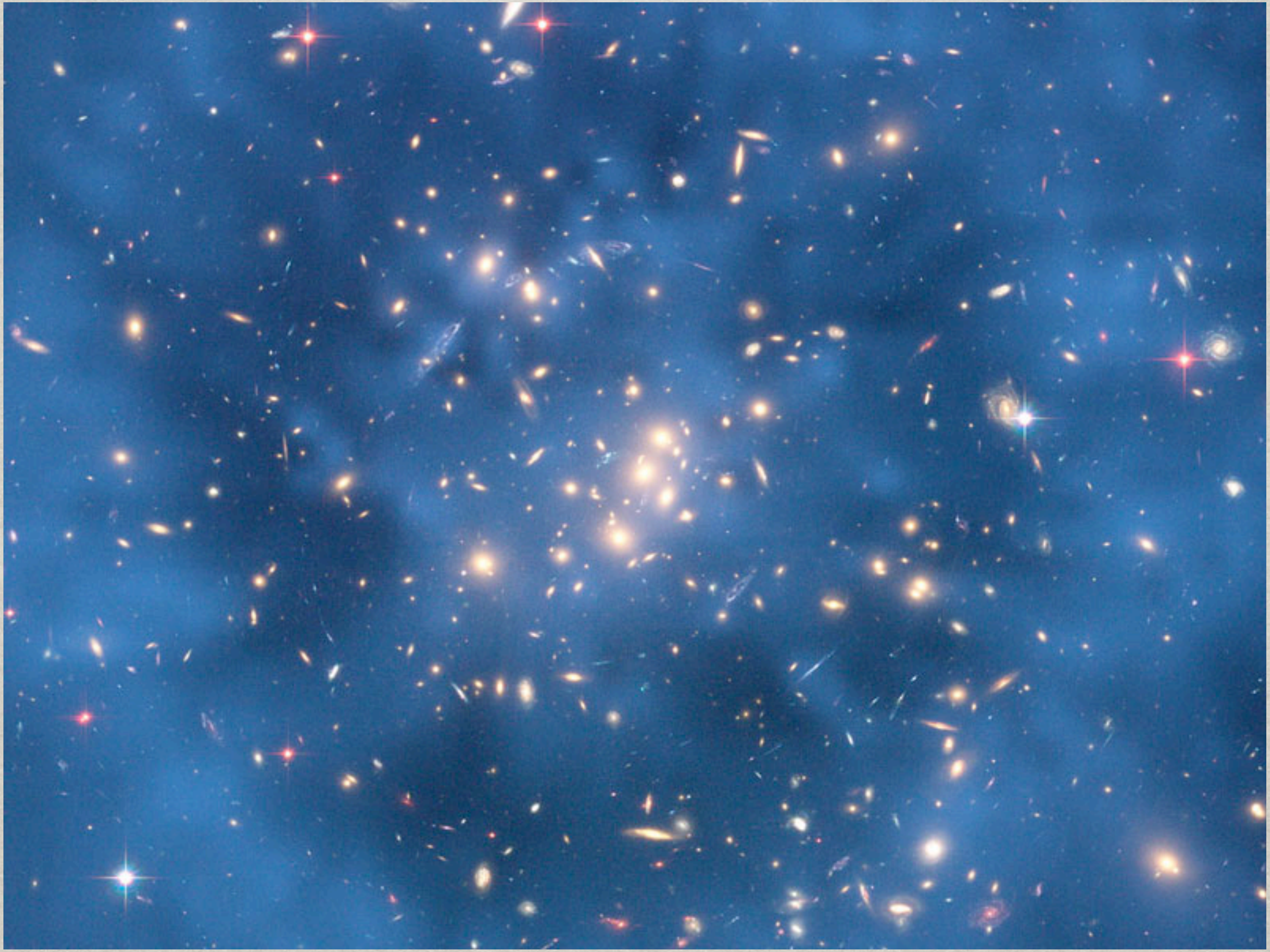


(Cosmology seen by S. Harris)

Gravitational reconstruction of the gravitational potential for CL0024+17



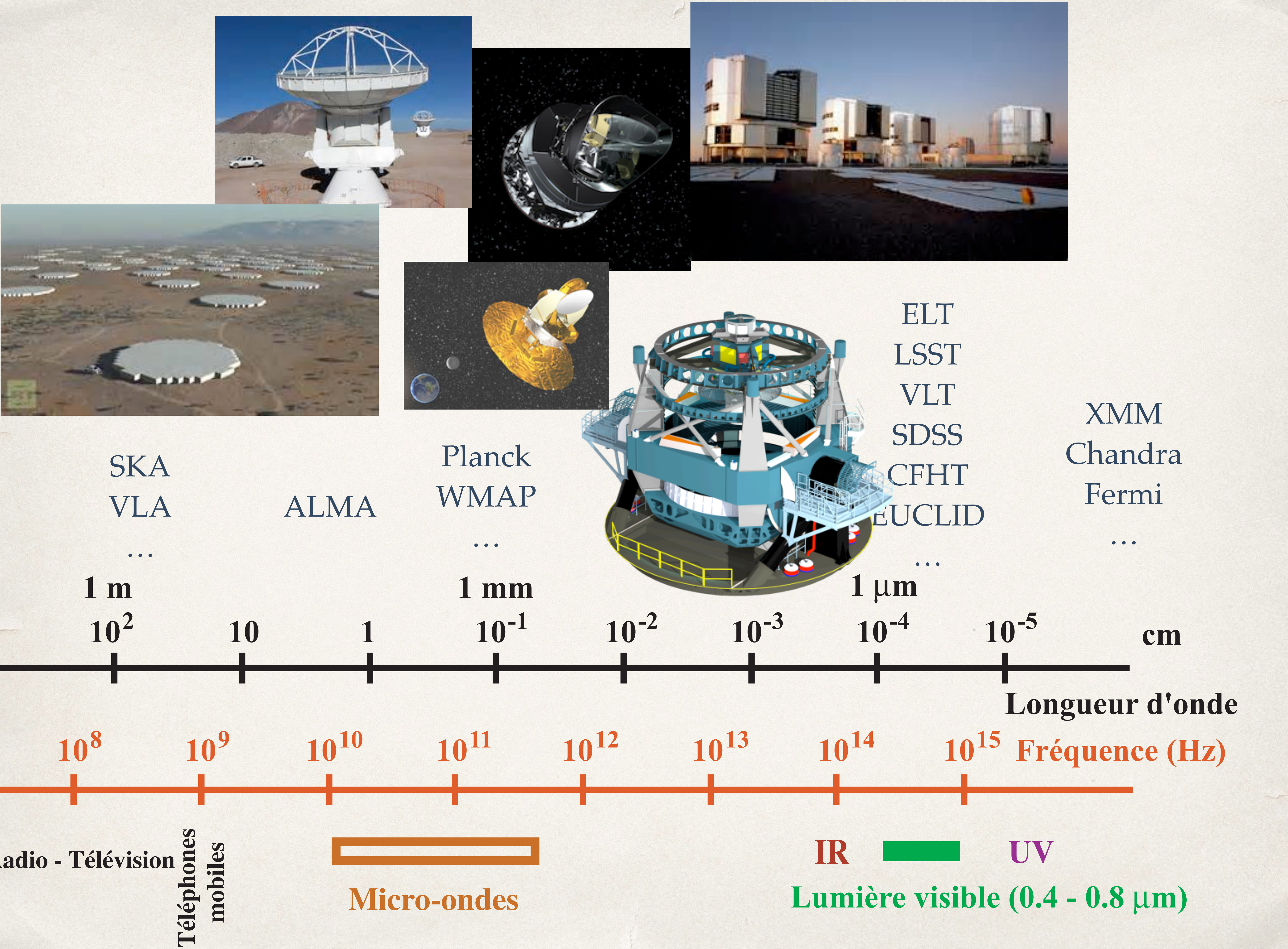
http://www.lsst.org/lsst/science



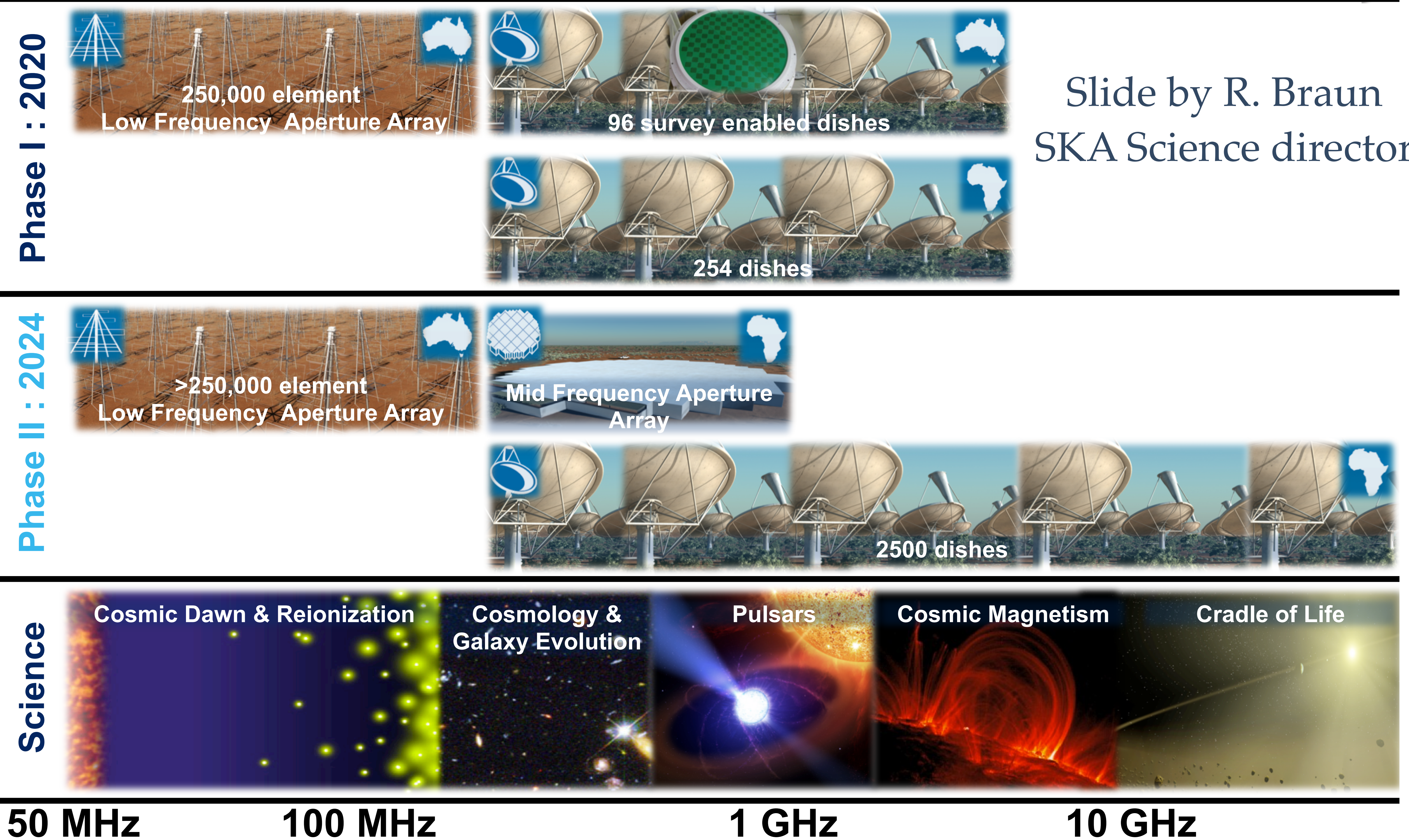
Galaxy cluster CL0024+17 (z ~ 0.39 , ~ 5. 10^9 AL) seen by HST

Observing the universe …

- Through the electromagnetic spectrum, but also energetic particles (cosmic rays) and GW (gravitational waves) in the future
- Neutrinos are also another cosmic probe
- SKA (future very large radio telescope ; ground based ; 2020-2030)
- Planck (ESA CMB mission, 2009-2013 - space mission)
- EUCLID (future ESA optical/IR dark energy mission - 2024)
- …

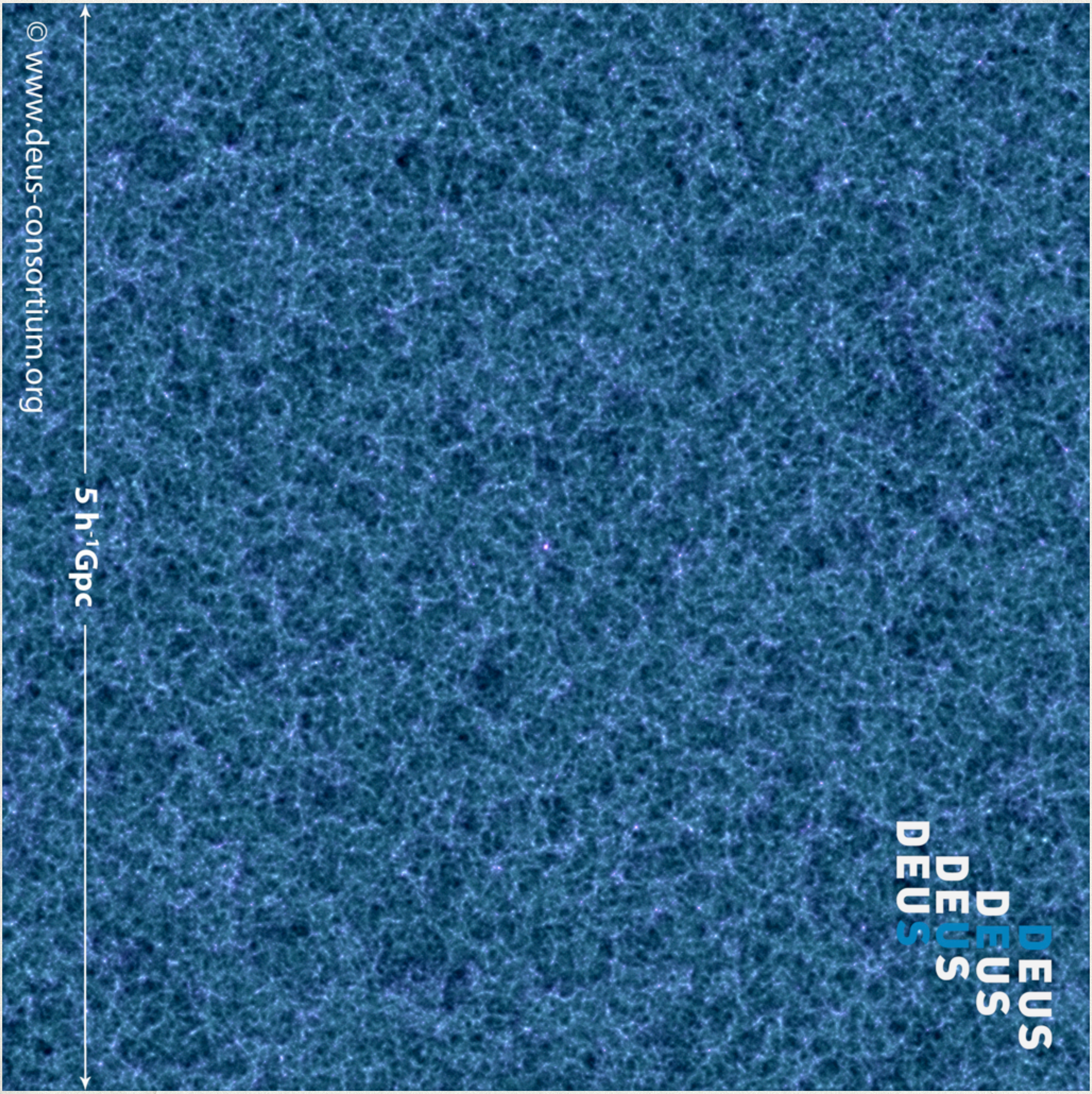

SKA
VLA
...
ALMA
Planck
WMAP
...
ELT
LSST
VLT
SDSS
CFHT
EUCLID
...
XMM
Chandra
Fermi
...
1 m
1 mm
1 µm
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
cm
Longueur d'onde
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
Fréquence (Hz)
adio - Télévision
Téléphones mobiles
Micro-ondes
IR
UV
Lumière visible (0.4 - 0.8 µm)

Exploring the Universe with the world's largest radio telescope

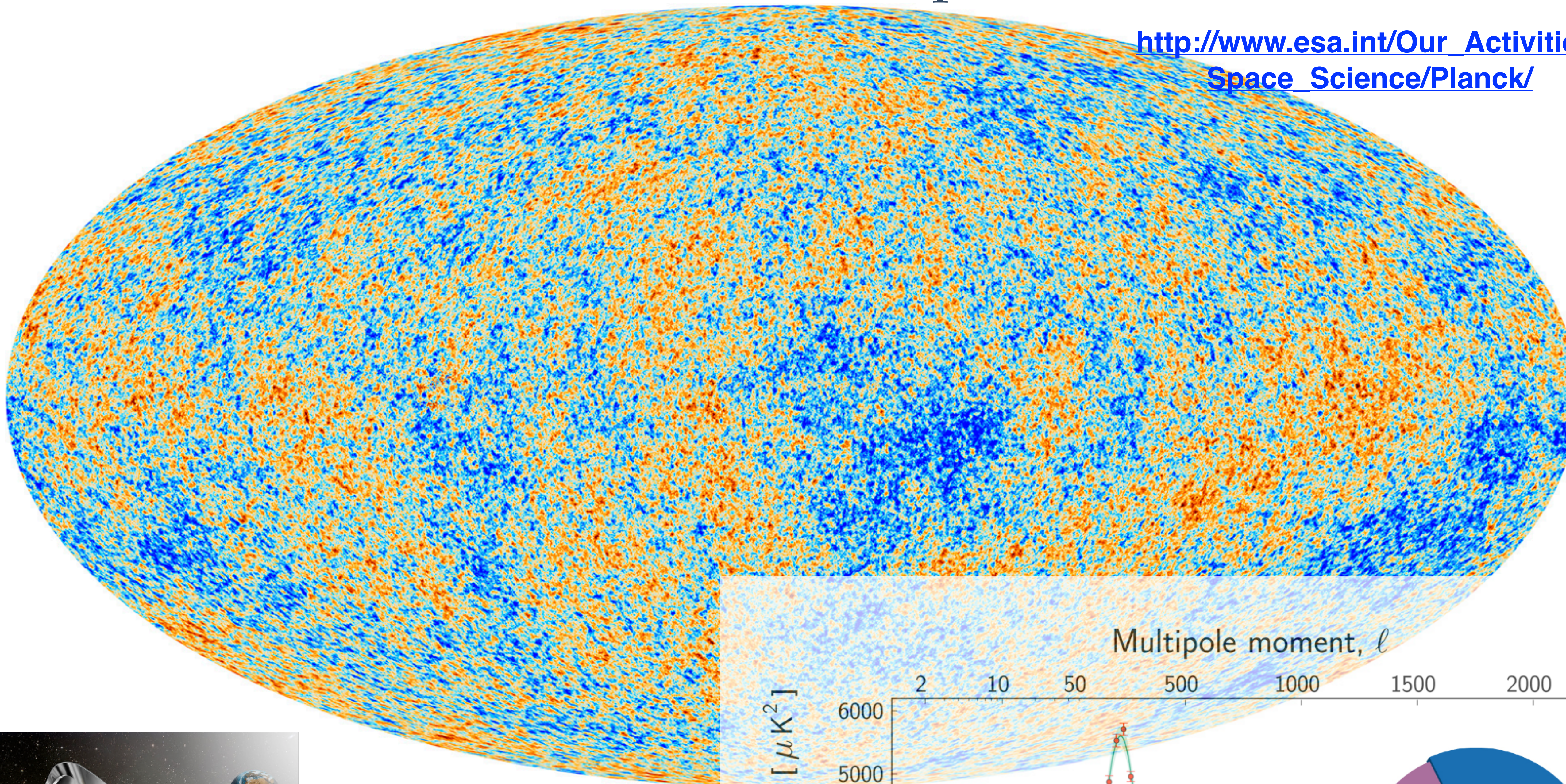


Large scale cosmological simulations :
High performance computing, millions hours of CPU …

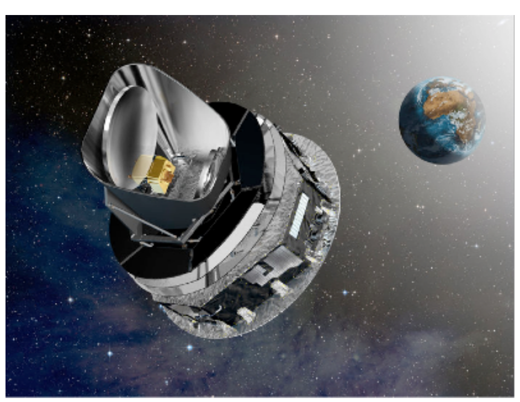
http://www.deus-consortium.org

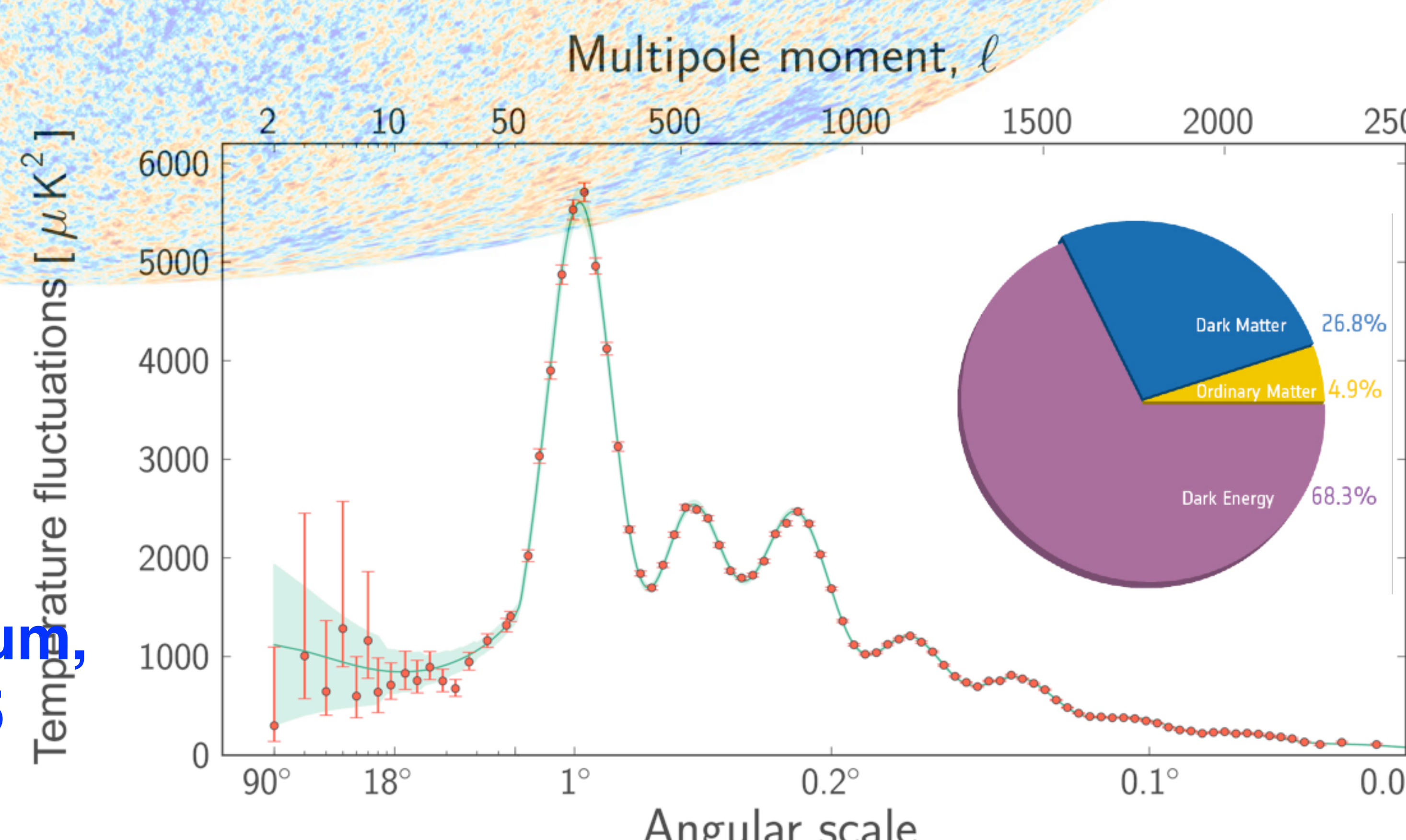


Planck CMB map (2013)



http://www.esa.int/Our_Activities/Space_Science/Planck/





Planck CMB map, and TT power spectrum, Planck collaboration arXiv 1303.5075