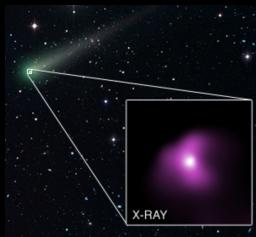


# Radiative Processes in Astrophysics

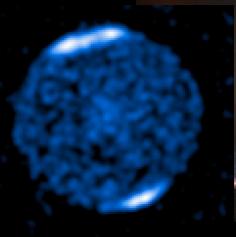
Observation

Up to cosmic size scale

C/2012S1  
(comet)



Jupiter  
(planet)



Sun  
(star)



Cas A  
(SNR)



M82  
(galaxy)



Goal

Theory

Down to atomic size scale

Phoenix  
(gal. cluster)



Cosmic web filament

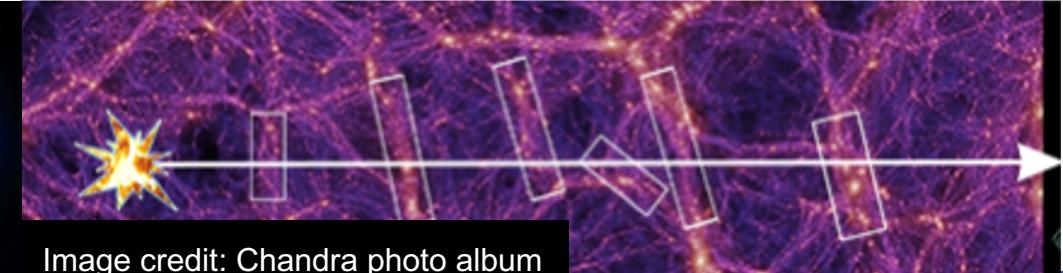
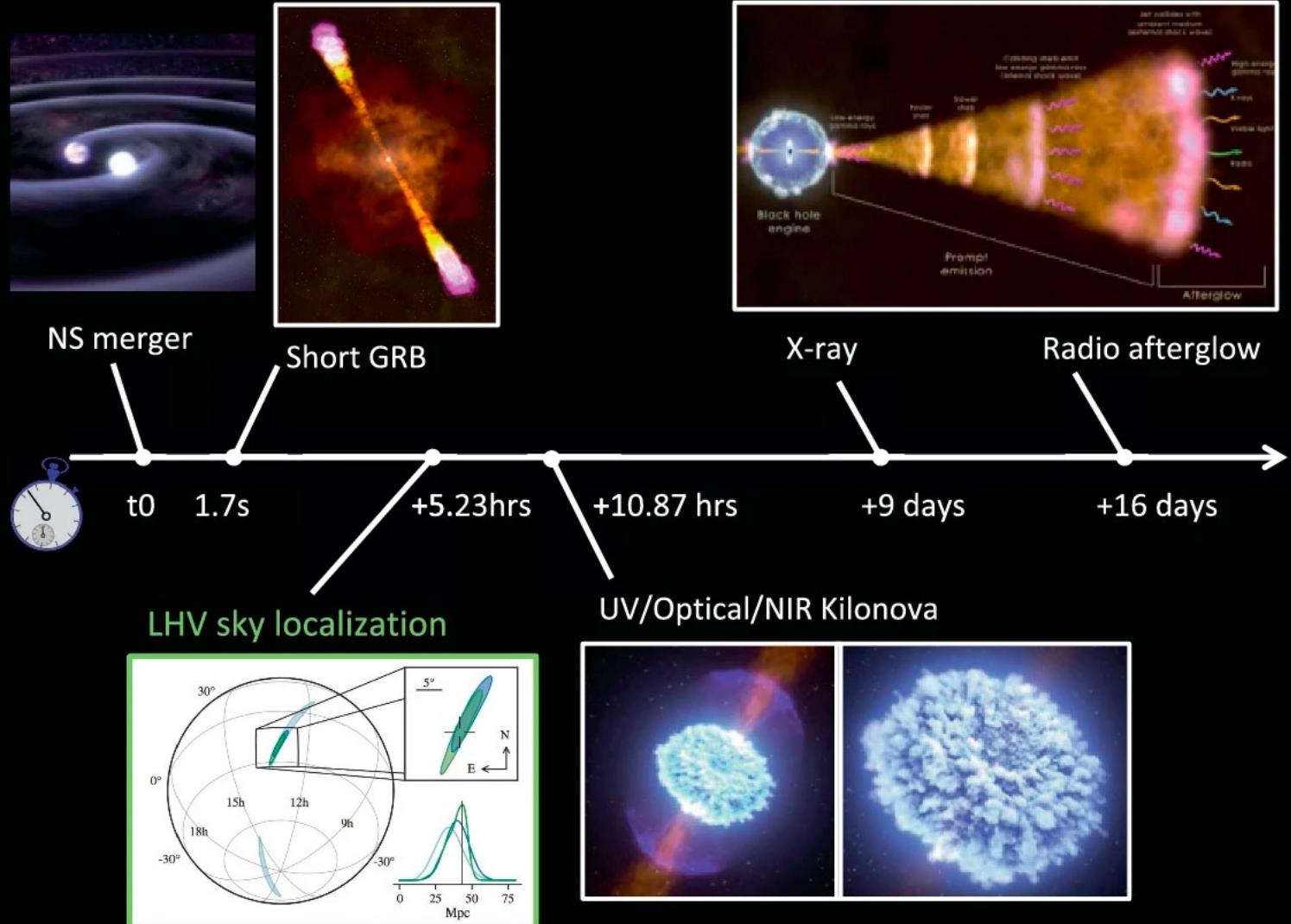


Image credit: [Chandra photo album](#)

# Chpt.1 Astrophysical messengers

- 1.1 Electromagnetic waves
- 1.2 Neutrinos
- 1.3 Cosmic rays
- 1.4 Gravitational waves

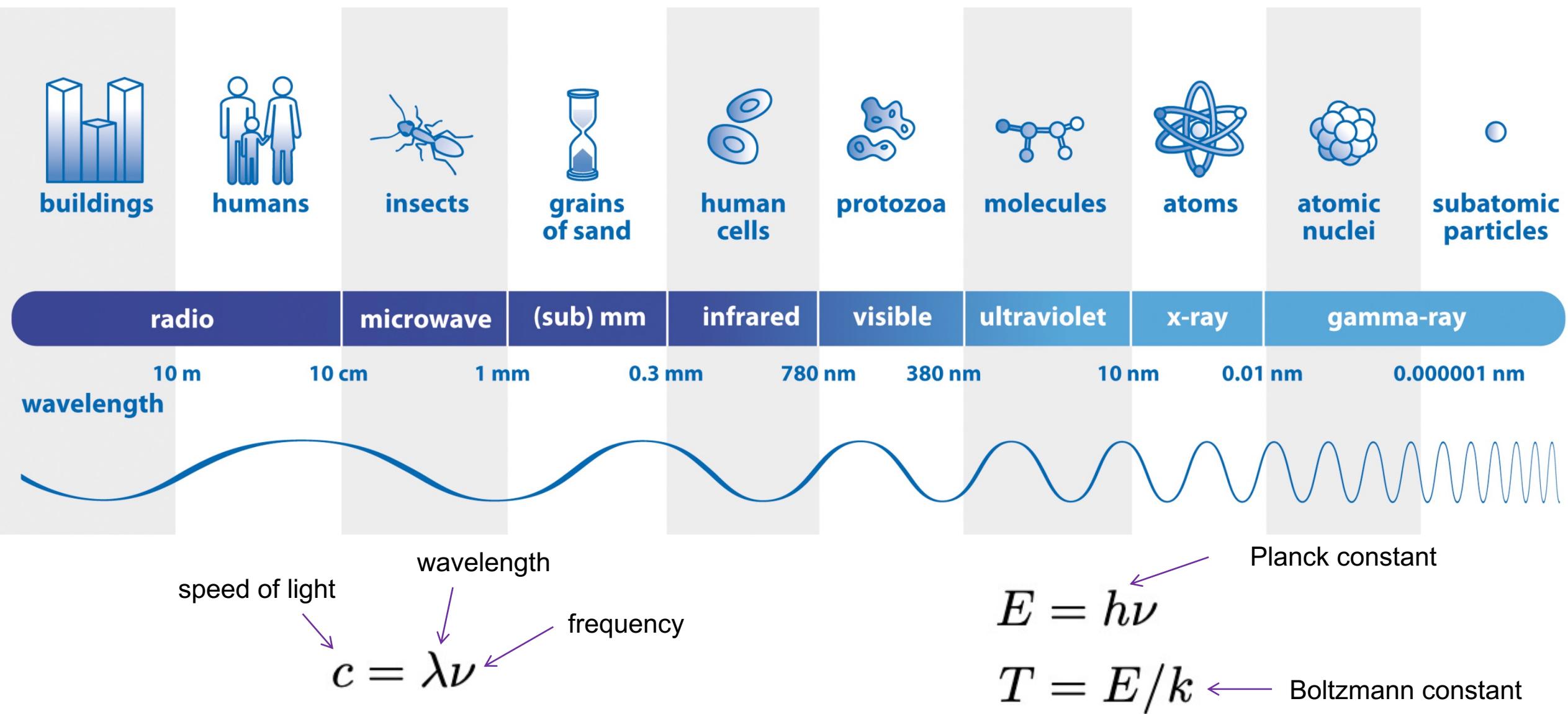


GW170817 (GW)  
+GRB170817A ( $\gamma$ -ray)  
+AT2017gfo (NIR to UV)  
+ GRB afterglow (X-ray + radio)

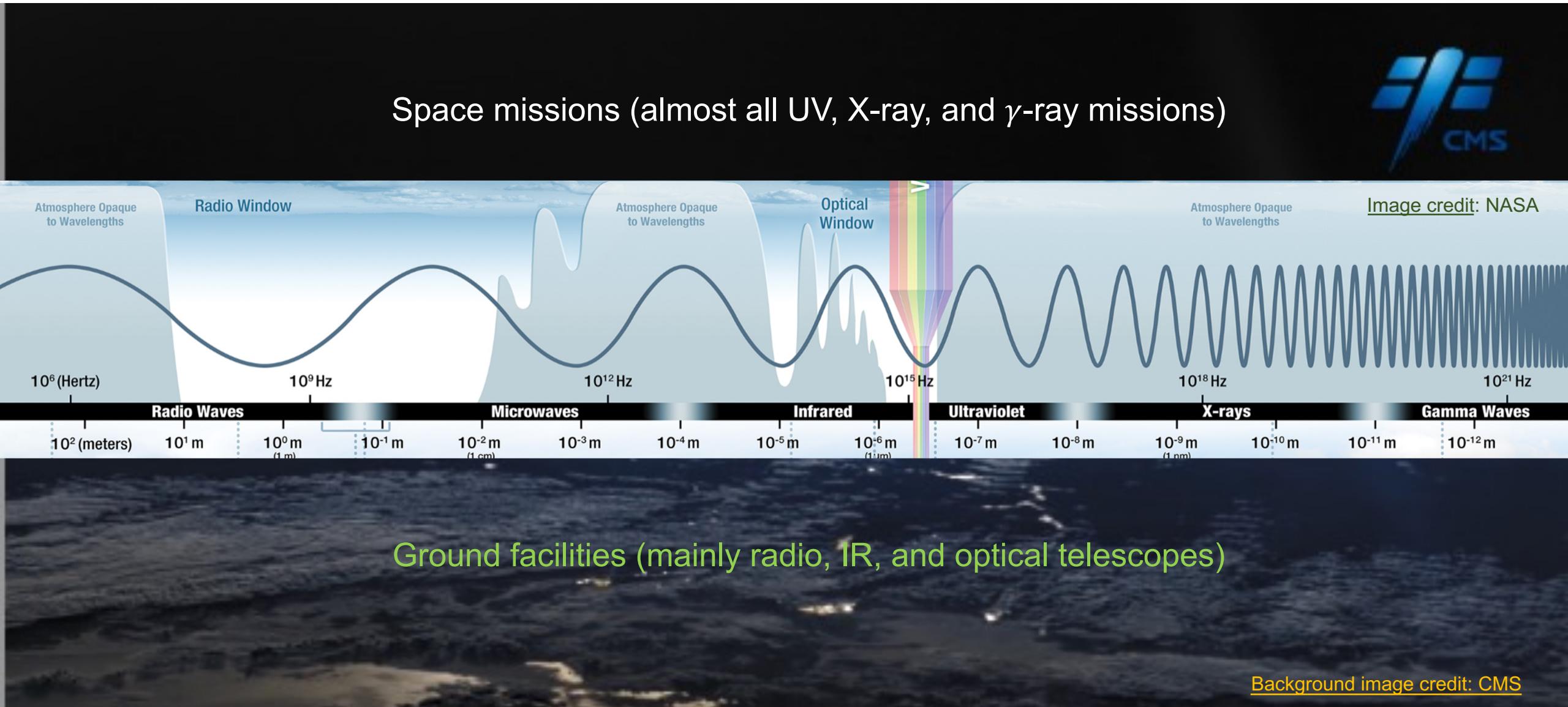
Image credit: Branchesi (2023)

# Electromagnetic waves

Image credit: ESA



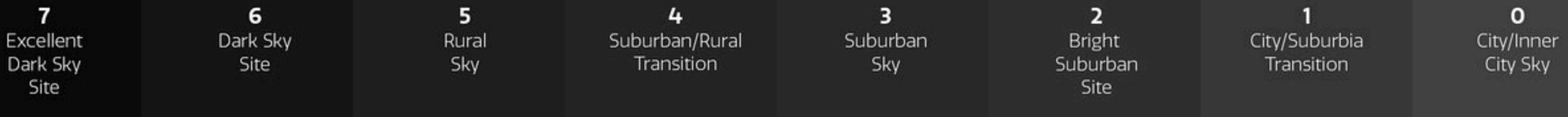
# Atmospheric window



# Not just atmospheric window

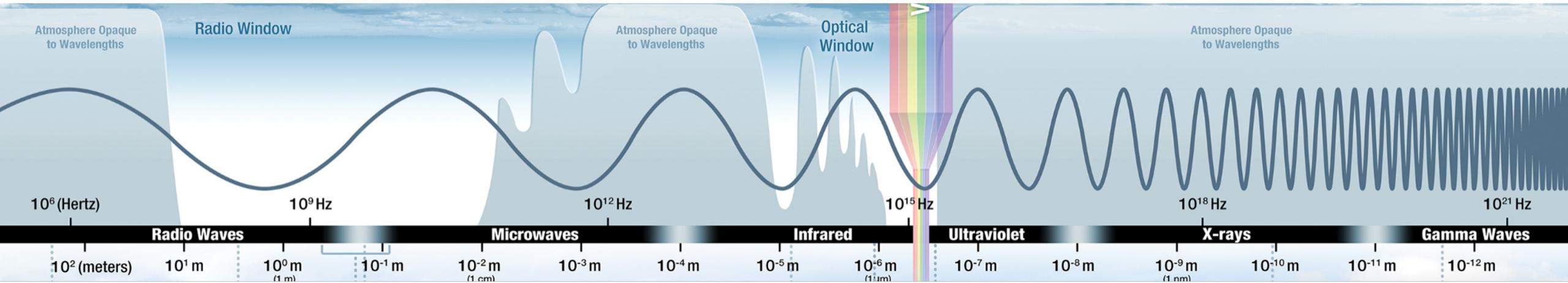


Background image credit: NOIRLab/NSF/AURA, P. Marenfeld



# EM observing facilities

[Image credit: NASA](#)



LOFAR (radio)  
[Image credit:](#)  
ASTRON



ALMA (microwave)  
[Image credit:](#) ESO



Planck (microwave)  
[Image credit:](#) ESA



JWST (IR to optical)  
[Image credit:](#)  
NASA



HST (IR to UV)  
[Image credit:](#)  
HST.org



Gemini (IR to optical)  
[Image credit:](#)  
NOIRLab



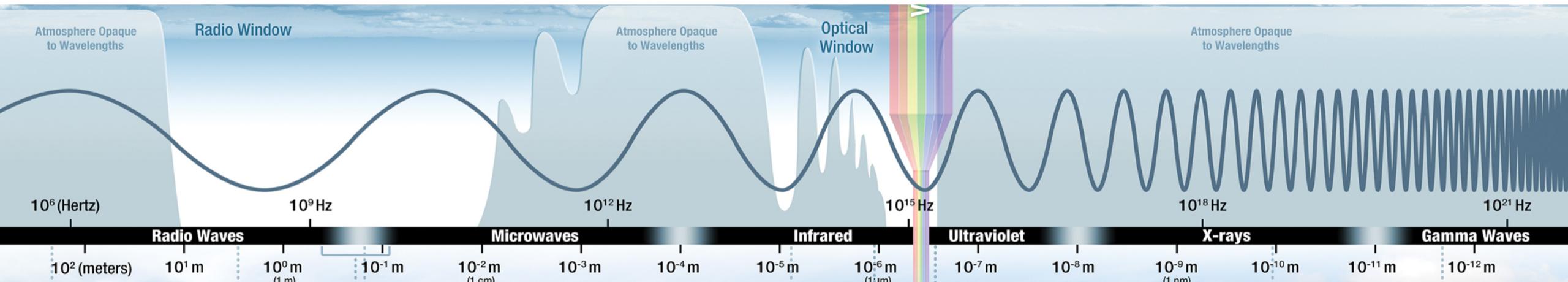
XRISM(X-ray)  
[Image credit:](#)  
JAXA



Fermi ( $\gamma$ -ray)  
[Image credit:](#)  
NASA

# EM observing facilities (cont.)

[Image credit: NASA](#)



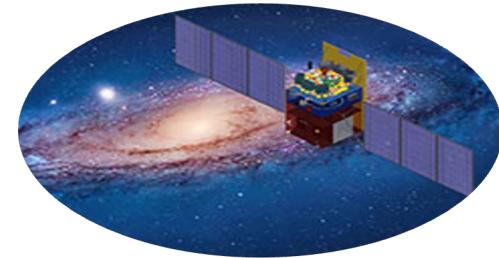
FAST (radio)  
[Image credit: Nature](#)



LAMOST (optical)  
[Image credit: NAOC](#)



ASO-S (UV to X-ray)  
[Image credit: PMO](#)

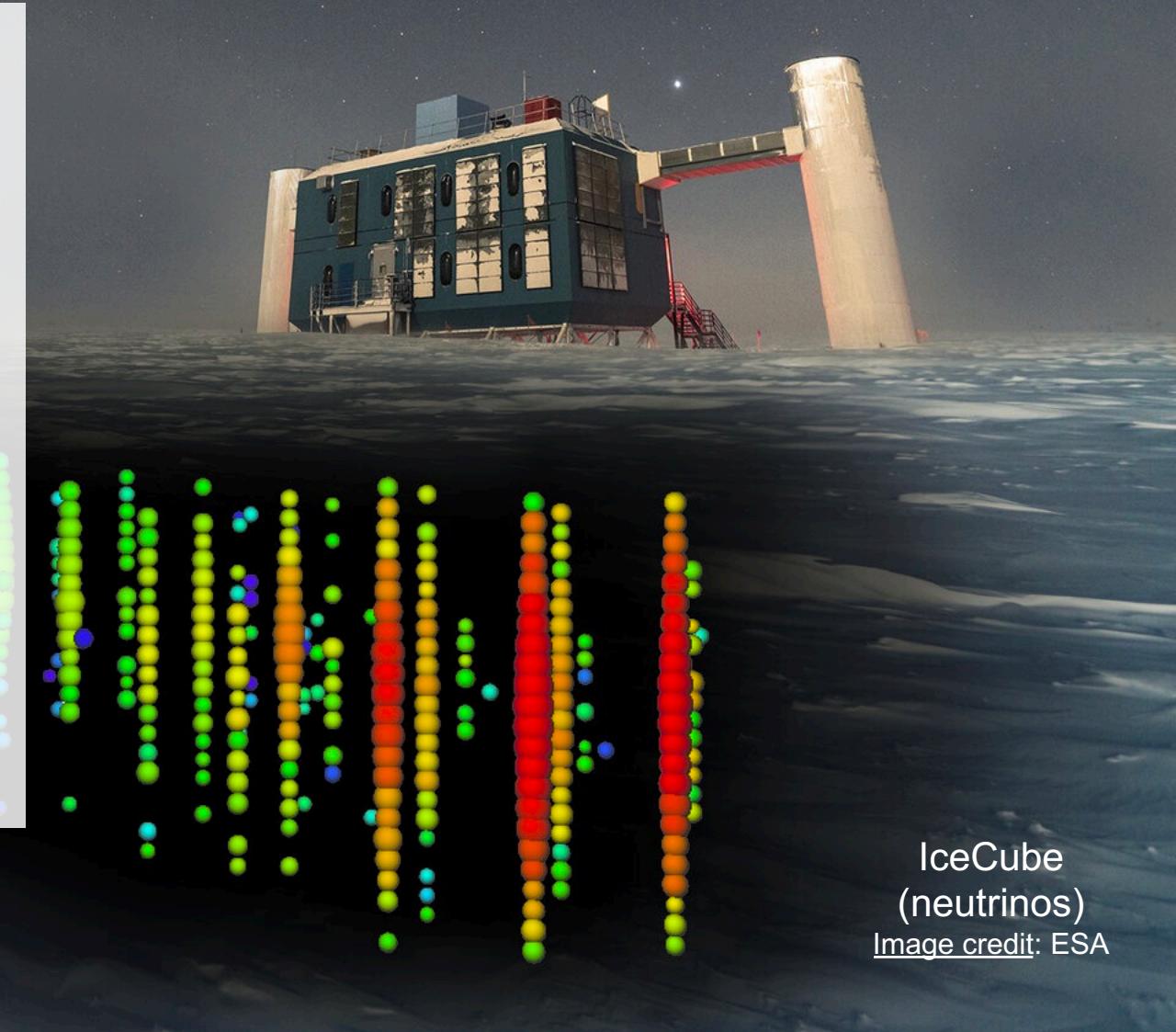


insight-HMXT  
(X-ray to  $\gamma$ -ray)  
[Image credit: IHEP](#)

# Neutrinos

- Symbol is lowercase Greek letter:  $\nu$ 
  - Three flavors: electron  $\nu_e$ , muon  $\nu_\mu$ , tau  $\nu_\tau$
  - Oscillates between flavors
- Produced by nuclear processes
- Basic properties
  - Electrically neutral
  - Nearly massless
  - Travels close to the speed of light
- Interaction
  - Reacts to gravity and the weak nuclear force
  - Mostly passes through matter
  - Billions of neutrinos pass through our body every second

The neutrino was postulated by Wolfgang Pauli in the early 1930s but could only be detected for the first time in the 1950s



IceCube  
(neutrinos)  
Image credit: ESA

# Neutrinos (IceCube)

High energy ( $\sim 290$  TeV) neutrino from IceCube-170922A was detected in association with a known gamma-ray blazar TXS 0506+056 ( $z \sim 0.3365$ ). This is the third detections of individual astrophysical sources of neutrinos, after the Sun and SN1987A.

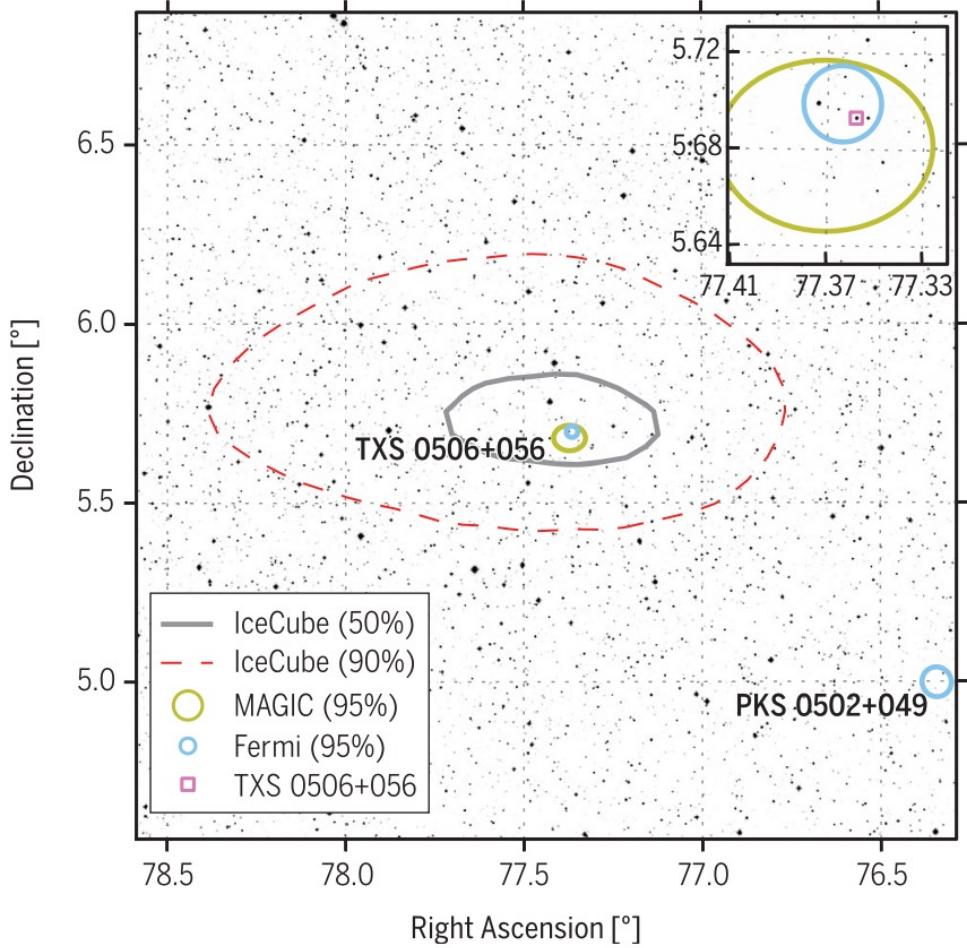
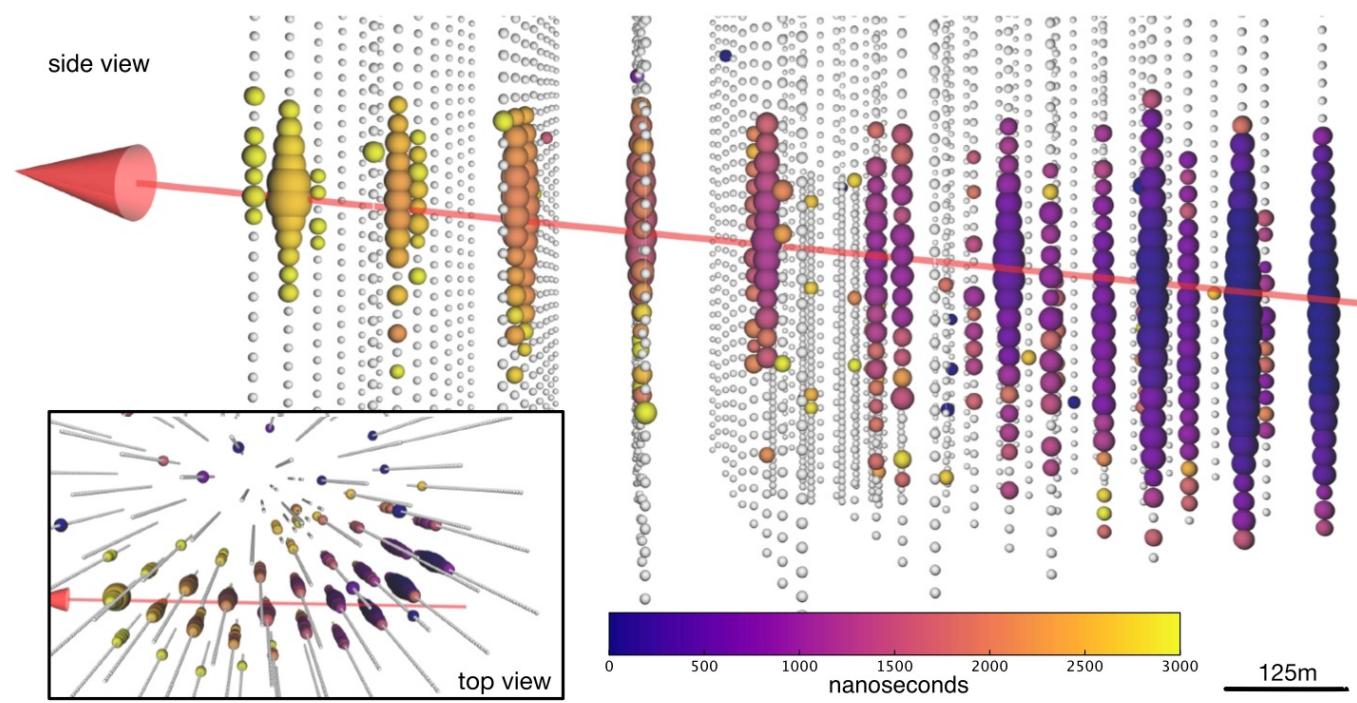
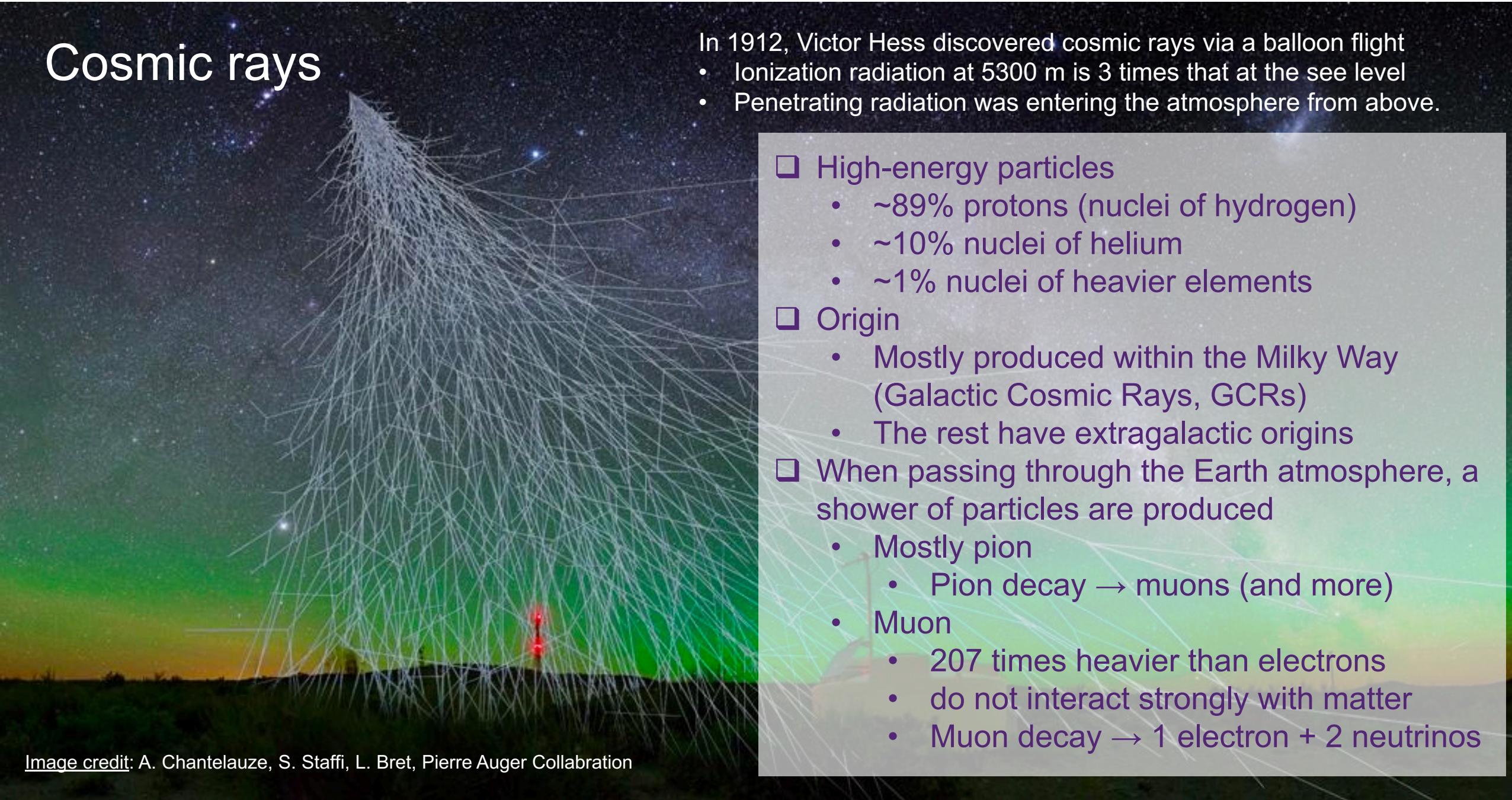


Image credit: IceCube collaboration (2023)

$\sim 5800$  photoelectrons in  $\sim 3000$  ns (from left to right)



# Cosmic rays



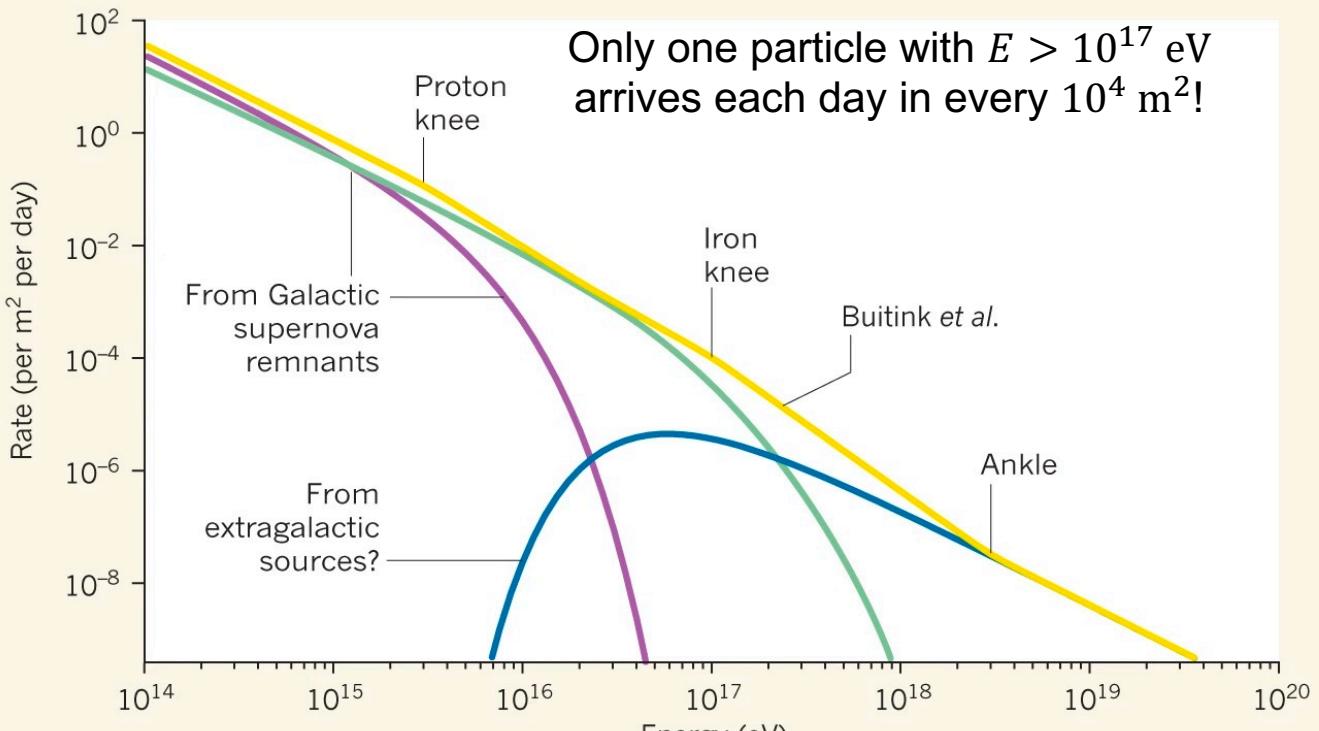
In 1912, Victor Hess discovered cosmic rays via a balloon flight

- Ionization radiation at 5300 m is 3 times that at the sea level
- Penetrating radiation was entering the atmosphere from above.

- High-energy particles
  - ~89% protons (nuclei of hydrogen)
  - ~10% nuclei of helium
  - ~1% nuclei of heavier elements
- Origin
  - Mostly produced within the Milky Way (Galactic Cosmic Rays, GCRs)
  - The rest have extragalactic origins
- When passing through the Earth atmosphere, a shower of particles are produced
  - Mostly pion
    - Pion decay → muons (and more)
  - Muon
    - 207 times heavier than electrons
    - do not interact strongly with matter
    - Muon decay → 1 electron + 2 neutrinos

Image credit: A. Chantelauze, S. Staffi, L. Bret, Pierre Auger Collaboration

# Cosmic rays (LHAASO)



Clues about the origin of cosmic rays come from both their composition and their energy spectra.

Large High Altitude Air Shower Observatory (LHAASO) (cosmic rays)  
Image credit: Science

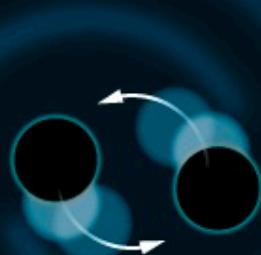


Tera (trillion):  $\text{TeV} = 10^{12} \text{ eV}$   
Peta (quadrillion):  $\text{PeV} = 10^{15} \text{ eV}$   
Exa (quintillion):  $\text{EeV} = 10^{18} \text{ eV}$   
Zetta (sextillion):  $\text{ZeV} = 10^{21} \text{ eV}$

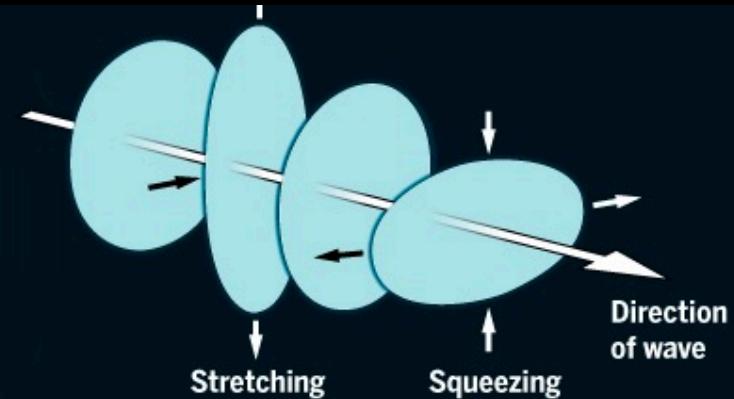
# Gravitational wave

Image credit: V. Altounian/Science

As Einstein calculated, a whirling barbell-shaped mass, such as two black holes spiraling together, radiates ripples in space-time: gravitational waves.



Zipping along at light speed, a wave stretches space in one direction and squeezes in the perpendicular direction, then reverses the distortions.



THE ASTRO-PH READER'S DIGEST | SUPPORTED BY THE AAS

[link: Astrobites](#)

## Guide to Gravitational Waves

by Astrobites | Nov 8, 2023 | Daily Paper Summaries, Guides | 0 comments

- Gravitational waves
  - “Ripples” in space-time caused
- Origin
  - Mostly produced by mergers of massive objects

# Gravitational waves (LIGO)

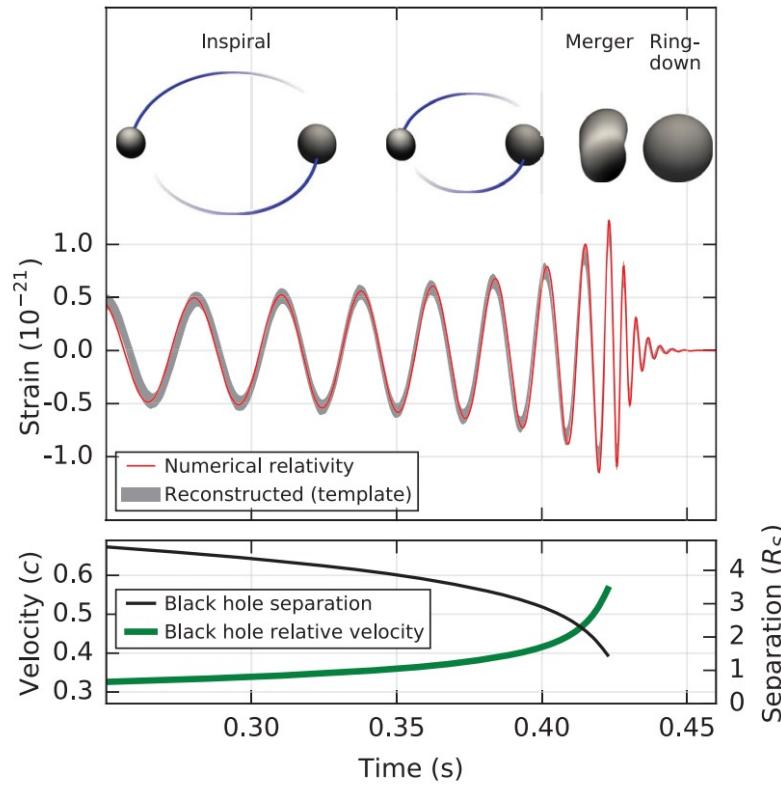


Image credit: Abbott et al. 2016

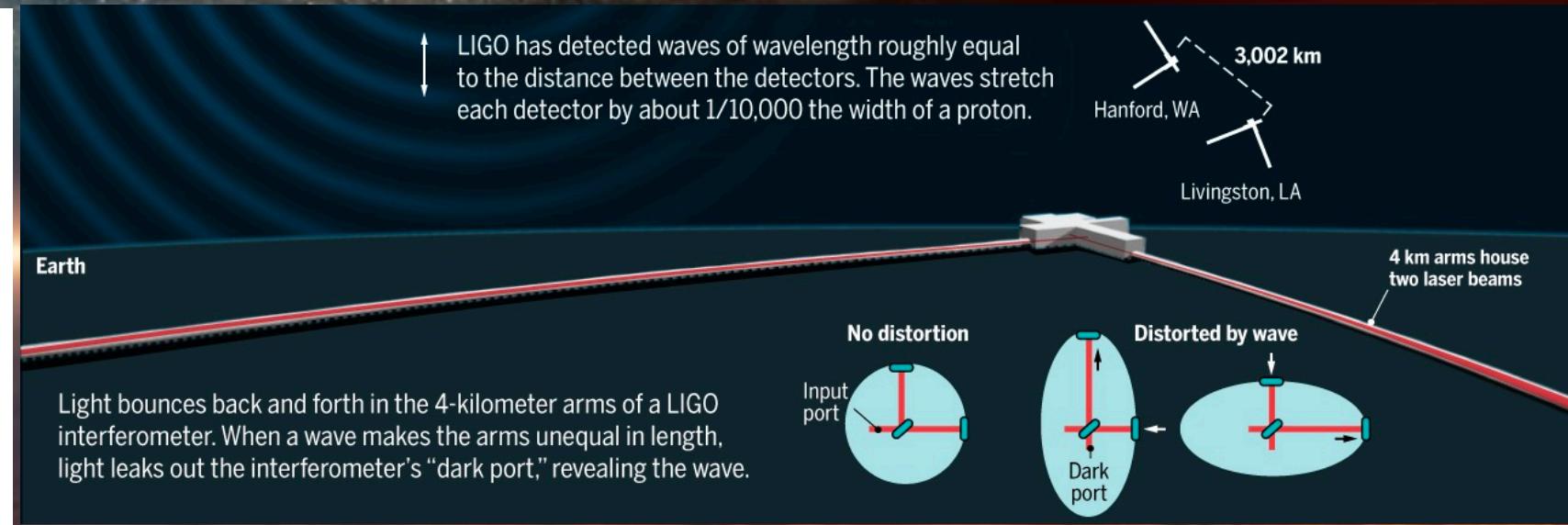


Image credit: V. Altounian/Science