

Introduction to astrophysics

A journey through the galaxies and beyond ...

Yoann Génolini



GRASPA school
July 16th, 2025

What do we name astrophysics?

- 1 – Science devoted to the study of the Universe content/objects.
 - Understand their properties, structure and evolution
 - Study the fundamental laws through astrophysical objects
- 2 – As a science : Theory Observations
- 3 – Multi-field science
 - Planetary science
 - Astro-chemistry
 - Solar physics
 - Galactic science
 - Cosmology
 - ...

Outline

- I – Introduction to astrophysical scales**
- II – Astrophysical objects (from close to far)**
- III – Observations in astrophysics**

Outline

I – Introduction to astrophysical scales

II – Astrophysical objects (from close to far)

III – Observations in astrophysics

wooclap.com + use the code ZCMXRY



A – Lengths

Solar system scales

Human size ≈ 1 m

Earth radius ($R_{\oplus}$) $\approx$? km

Solar radius ($R_{\odot}$) $\approx$? km

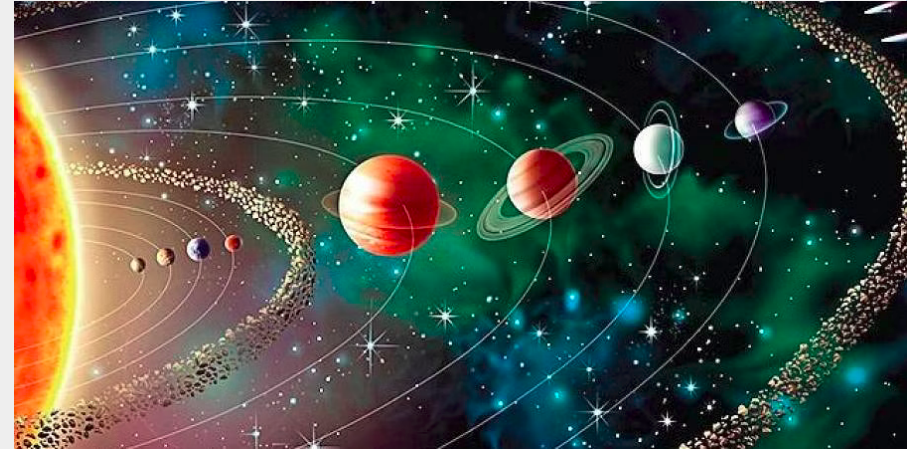
Astronomical Unit (AU) $\approx$? km

Asteroid belt $\approx$? AU

Neptune orbital radius $\approx$? AU

Kuiper belt $\approx$? AU

Oort Cloud $\approx$? AU



A – Lengths

Solar system scales

Human size ≈ 1 m

Earth radius ($R_{\oplus}$) $\approx 6.4 \times 10^3$ km

Solar radius ($R_{\odot}$) $\approx 7 \times 10^5$ km

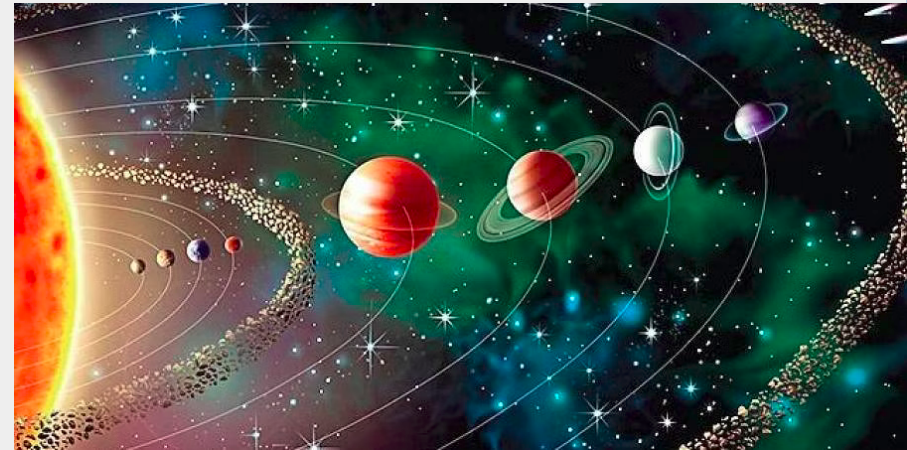
Astronomical Unit (AU) $\approx 150 \times 10^6$ km

Asteroid belt $\approx 1.5 - 5$ AU

Neptune orbital radius ≈ 30 AU

Kuiper belt $\approx 30 - 50$ AU

Oort Cloud $\approx 50 - 10^5$ AU



A – Lengths

Solar system scales

Human size ≈ 1 m

Earth radius ($R_{\oplus}$) $\approx 6.4 \times 10^3$ km

Solar radius ($R_{\odot}$) $\approx 7 \times 10^5$ km

Astronomical Unit (AU) $\approx 150 \times 10^6$ km

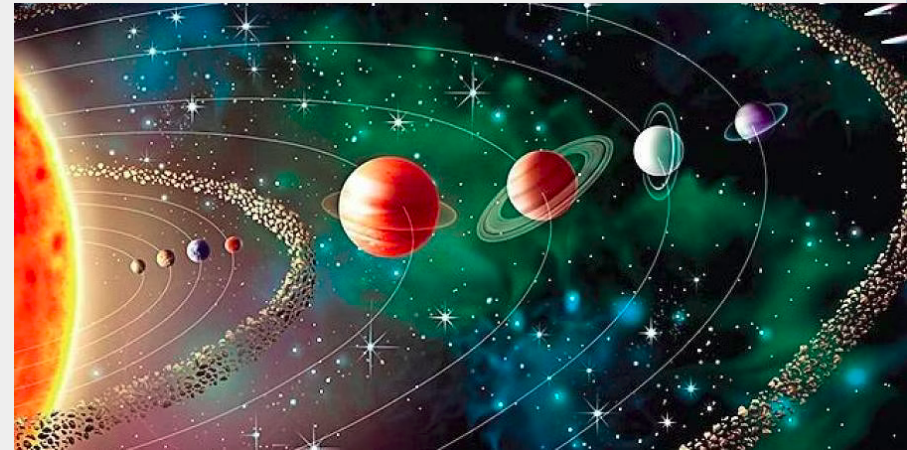
Asteroid belt $\approx 1.5 - 5$ AU

Neptune orbital radius ≈ 30 AU

Kuiper belt $\approx 30 - 50$ AU

Oort Cloud $\approx 50 - 10^5$ AU

We need a new unit : ly or parsec $\rightarrow$ [Blackboard]



A – Lengths

Solar system scales

Human size ≈ 1 m

Earth radius ($R_{\oplus}$) $\approx 6.4 \times 10^3$ km

Solar radius ($R_{\odot}$) $\approx 7 \times 10^5$ km

Astronomical Unit (AU) $\approx 150 \times 10^6$ km

Asteroid belt $\approx 1.5 - 5$ AU

Neptune orbital radius ≈ 30 AU

Kuiper belt $\approx 30 - 50$ AU

Oort Cloud $\approx 50 - 10^5$ AU

We need a new unit : ly or parsec $\rightarrow$ [Blackboard]

Galactic scales

Dist. to Proxima Centauri ≈ 1.3 pc

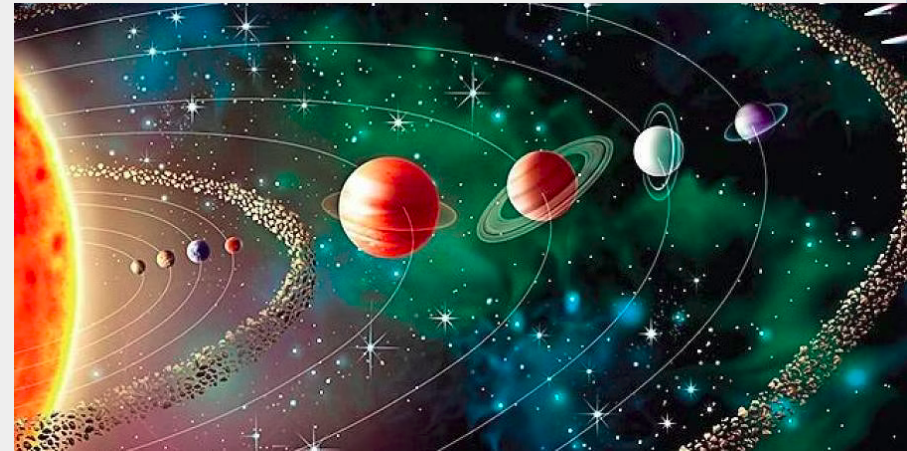
Galactic thickness (h_g) ≈ 200 pc

Galactic radius (R_g) ≈ 20 kpc

Dist. to Andromeda ≈ 1 Mpc

Local group size ≈ 3 Mpc

Observable universe ≈ 30 Gpc



B – Masses

Solar system scales

Asteroid belt mass $\approx$? kg

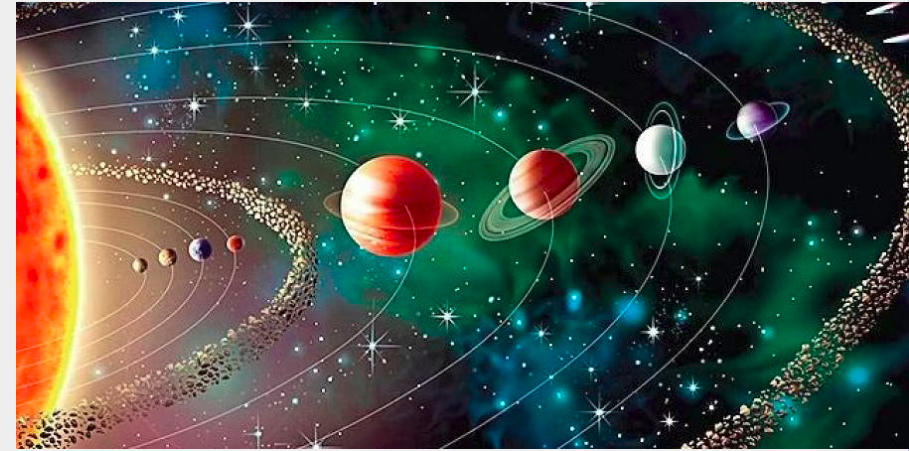
Moon mass $\approx$? kg

Earth mass ($M_{\oplus}$) $\approx$? kg

Jupiter mass (M_{J}) $\approx$? kg

Solar mass ($M_{\odot}$) $\approx$? kg

Heaviest stars $\approx$? $M_{\odot}$



B – Masses

Solar system scales

Asteroid belt mass $\approx 2.4 \times 10^{21}$ kg

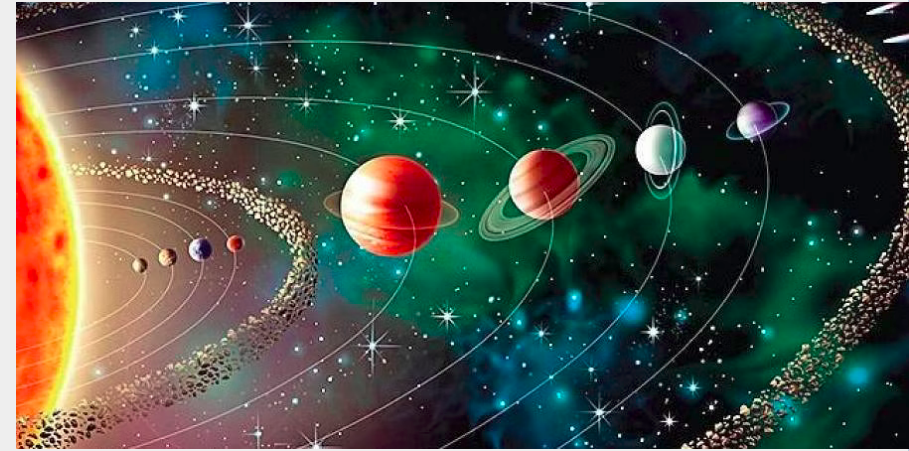
Moon mass $\approx 7 \times 10^{22}$ kg

Earth mass ($M_{\oplus}$) $\approx 6 \times 10^{24}$ kg

Jupiter mass ($M_{\oplus}$) $\approx 2 \times 10^{27}$ kg

Solar mass ($M_{\odot}$) $\approx 2 \times 10^{30}$ kg

Heaviest stars $\approx 250 M_{\odot}$



B – Masses

Solar system scales

Asteroid belt mass $\approx 2.4 \times 10^{21}$ kg

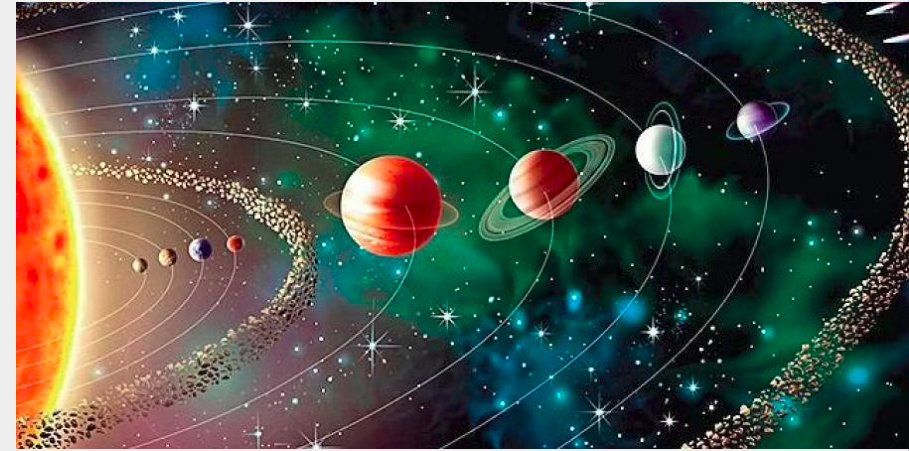
Moon mass $\approx 7 \times 10^{22}$ kg

Earth mass ($M_{\oplus}$) $\approx 6 \times 10^{24}$ kg

Jupiter mass ($M_{\oplus}$) $\approx 2 \times 10^{27}$ kg

Solar mass ($M_{\odot}$) $\approx 2 \times 10^{30}$ kg

Heaviest stars $\approx 250 M_{\odot}$



Galactic scales

Dwarf galaxy mass $\approx$? $M_{\odot}$

Supermassive black hole $\approx$? $M_{\odot}$

Milky Way mass (M_G) $\approx$? $M_{\odot}$

Milky Way bulge stellar mass $\approx$? M_G

Observable Universe mass $\approx$? M_G



B – Masses

Solar system scales

Asteroid belt mass $\approx 2.4 \times 10^{21}$ kg

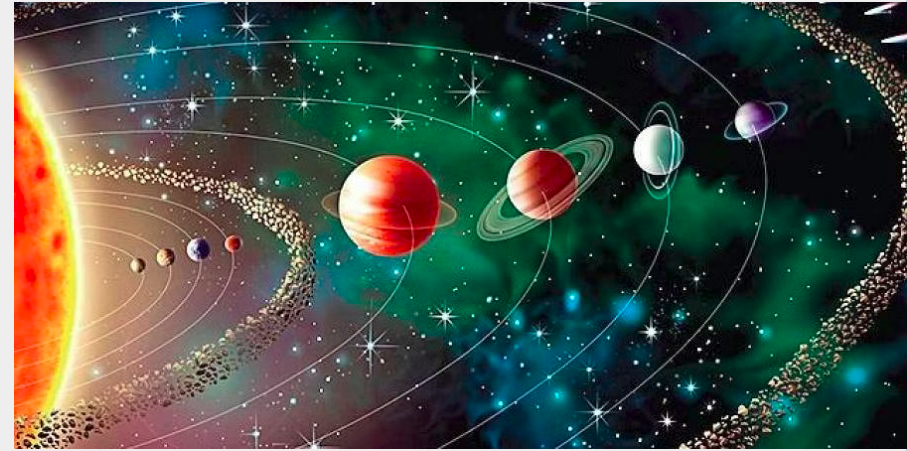
Moon mass $\approx 7 \times 10^{22}$ kg

Earth mass ($M_{\oplus}$) $\approx 6 \times 10^{24}$ kg

Jupiter mass ($M_{\oplus}$) $\approx 2 \times 10^{27}$ kg

Solar mass ($M_{\odot}$) $\approx 2 \times 10^{30}$ kg

Heaviest stars $\approx 250 M_{\odot}$



Galactic scales

Dwarf galaxy mass $\approx 10^7 M_{\odot}$

Supermassive black hole $\approx 10^5 - 10^9 M_{\odot}$

Milky Way mass (M_g) $\approx 1000 \times 10^9 M_{\odot}$

Milky Way bulge stellar mass $\approx 10^{-2} M_g$

Observable Universe mass $\approx 1000 \times 10^9 M_g$



C – Timescales

Solar system scales

Solar rotation period ≈ 28 d

One year (yr) $\approx 3 \times 10^7$ s

Orbital period Jupiter ≈ 12 yr

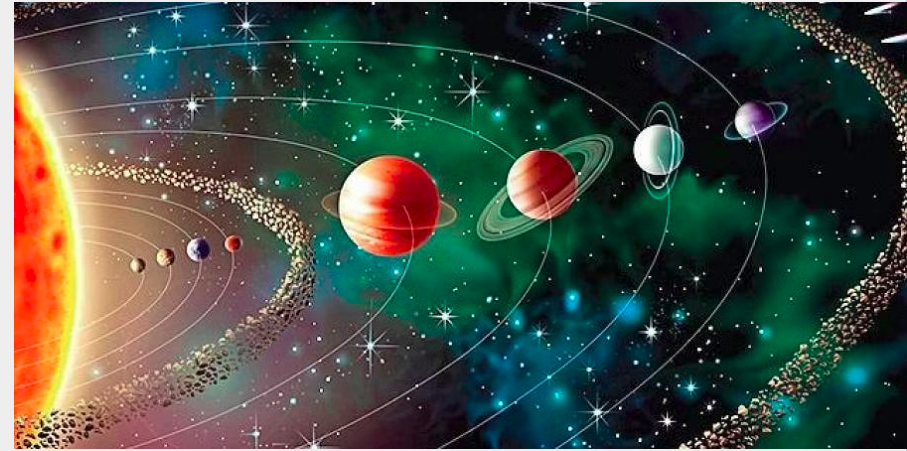
Orbital period Neptune ≈ 165 yr

Galactic scales

Milky Way rotation period ≈ 200 Myr

Traces of life on Earth ≈ 4 Gyr (ago)

Age of the Universe ≈ 13.8 Gyr



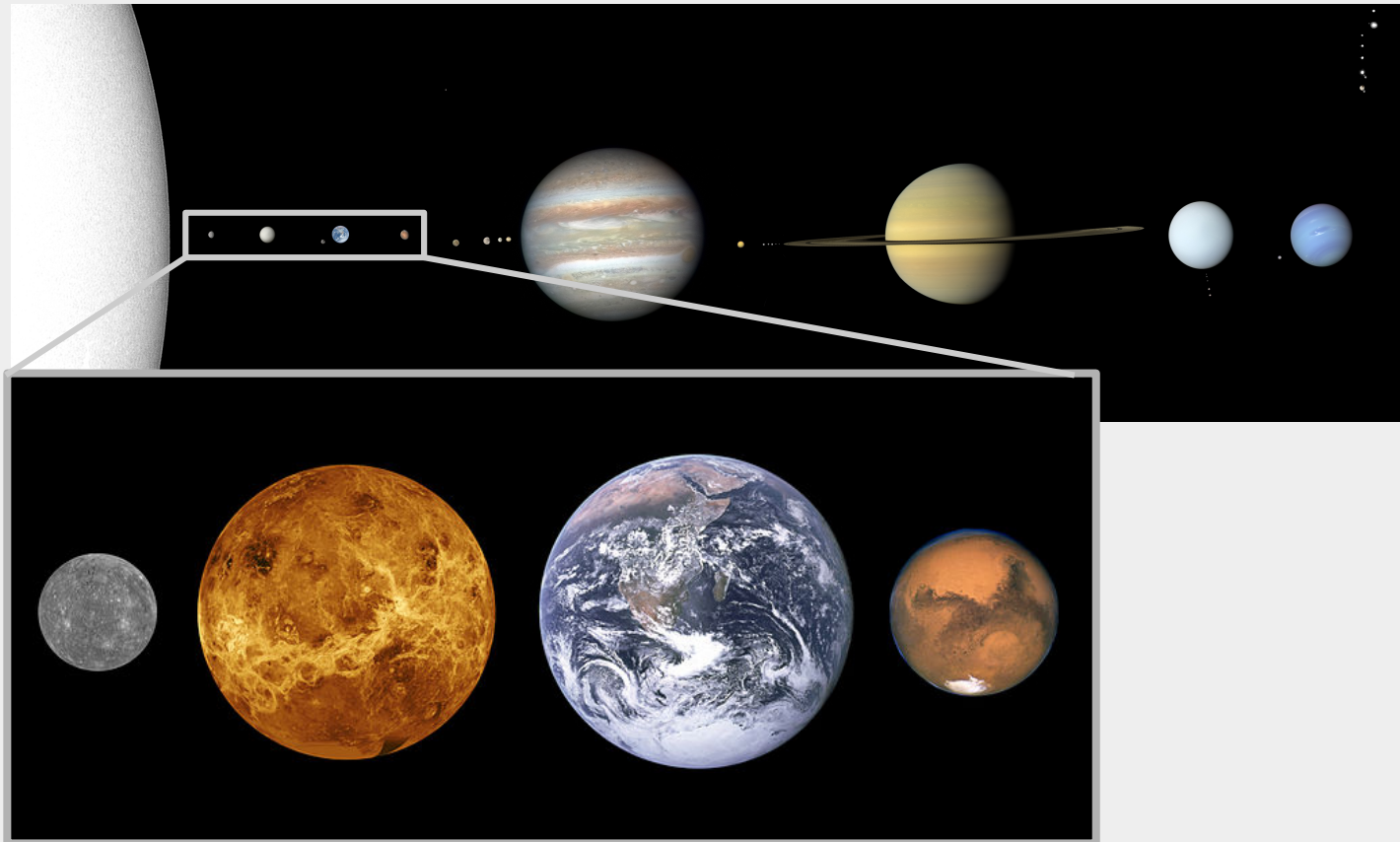
Outline

- I – Introduction to astrophysical scales
- II – Astrophysical objects (from close to far)**
- III – Observations in astrophysics

A – Planets

Solar system

Telluric vs Gaseous

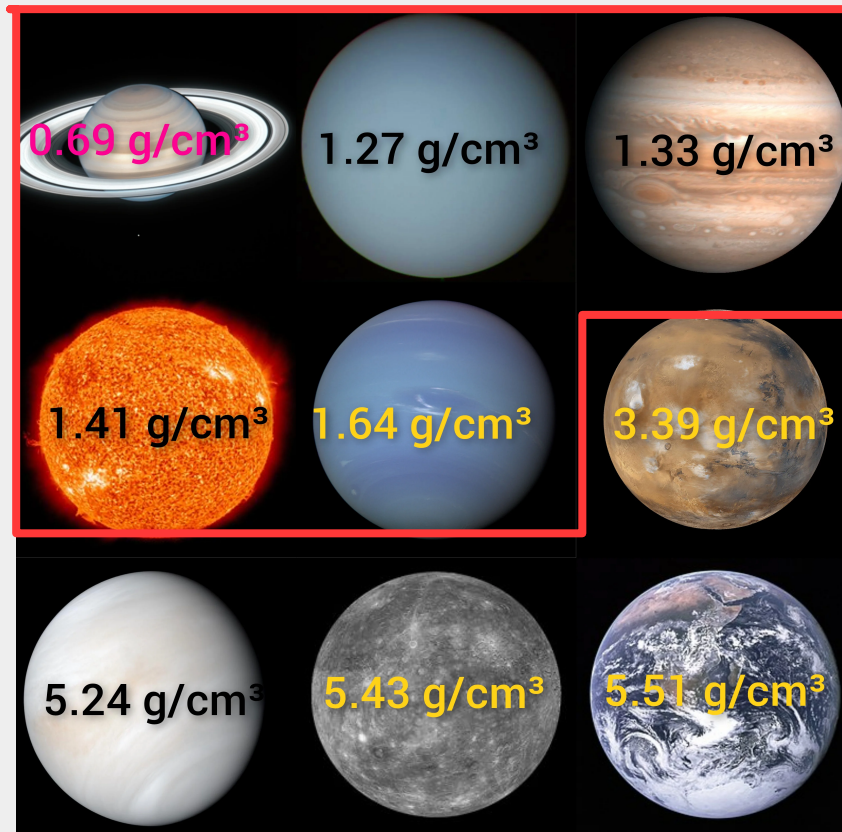


A – Planets

Solar system

Telluric vs Gaseous

- Differences : e.g. mass, density, composition
- Similarities : e.g. shell-like internal structure



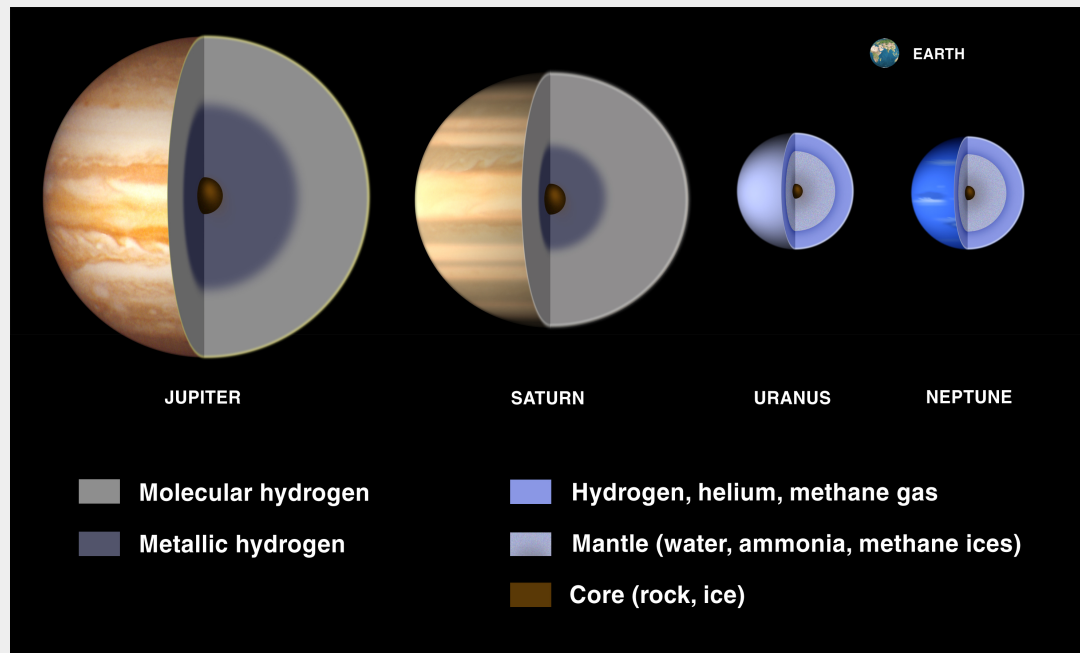
A – Planets

Solar system

Telluric vs Gaseous

→ Differences : e.g. mass, density, composition

→ Similarities : e.g. shell-like internal structure



A – Planets

Solar system

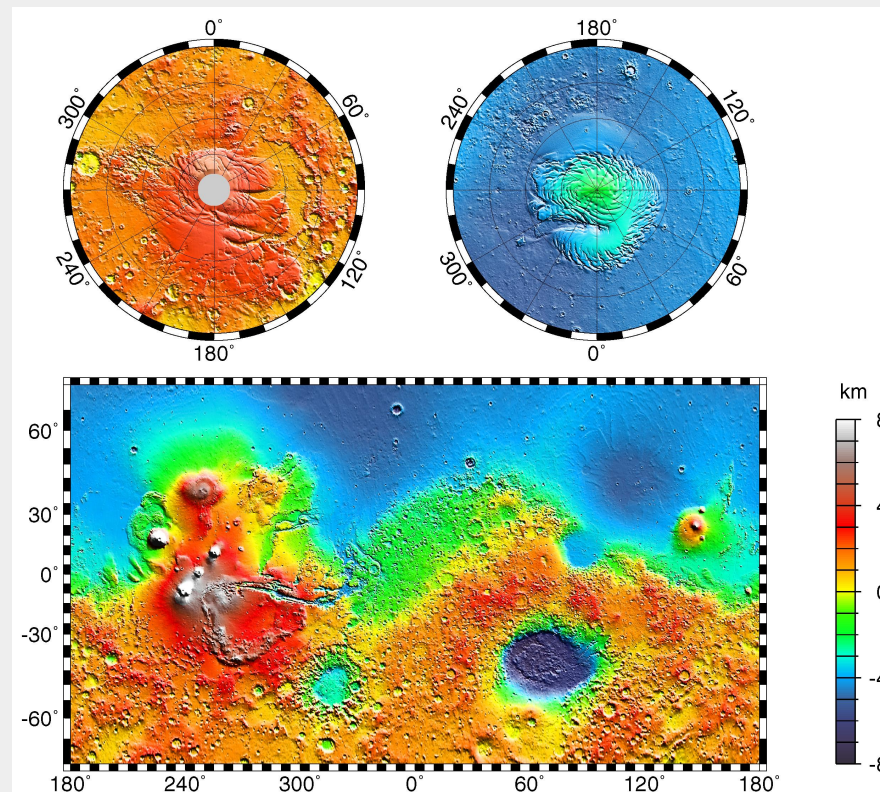
Telluric vs Gaseous

- Differences : e.g. mass, density, composition
- Similarities : e.g. shell-like internal structure

Bodies surfaces

- Shaped by their composition & past/present volcanic activity

Mars topography:



A – Planets

Solar system

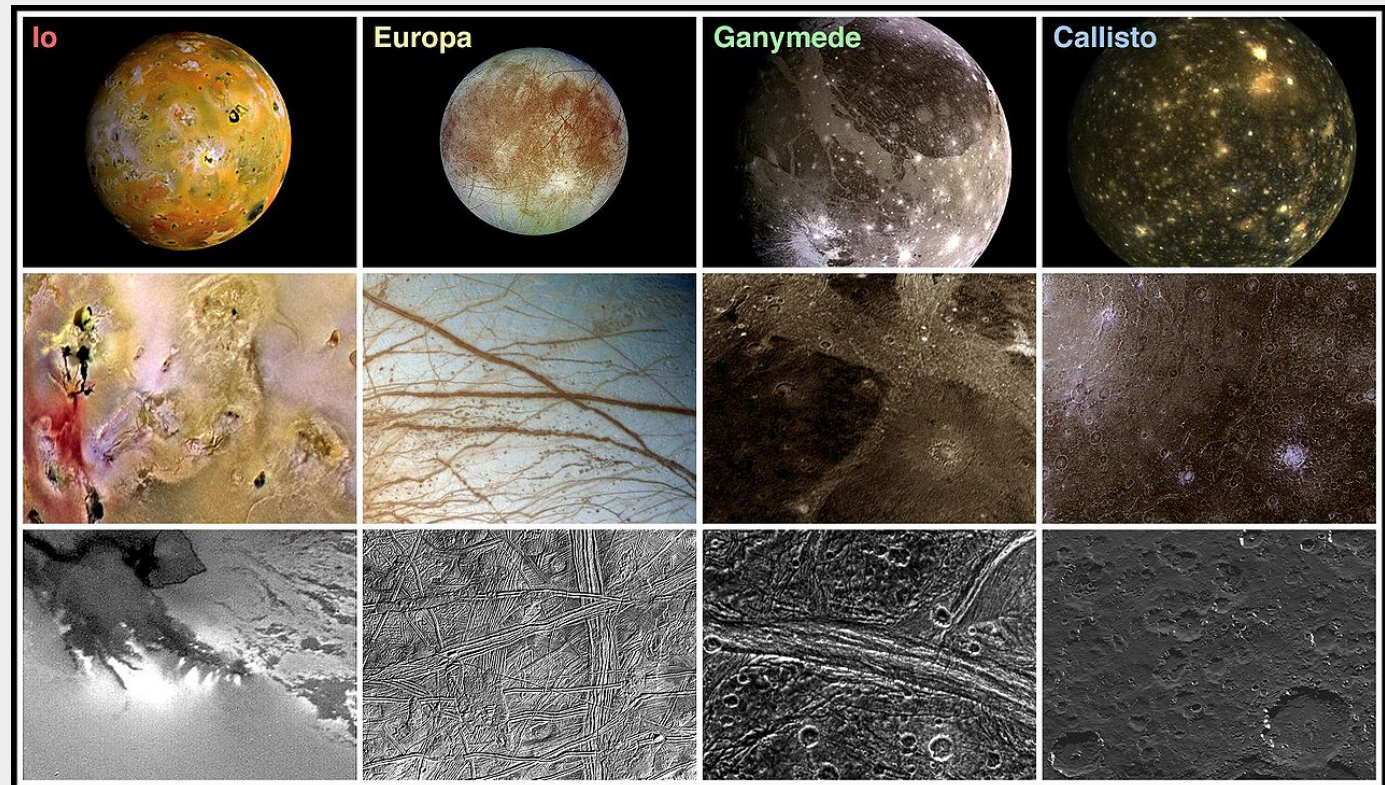
Telluric vs Gaseous

- Differences : e.g. mass, density, composition
- Similarities : e.g. shell-like internal structure

Bodies surfaces

- Shaped by their composition & past/present volcanic activity

Galilean moons of Jupiter:



A – Planets

Solar system

Telluric vs Gaseous

- Differences : e.g. mass, density, composition
- Similarities : e.g. shell-like internal structure

Bodies surfaces

- Shaped by their composition & past/present volcanic activity

Matter under extreme conditions w.r.t. Earth

- Temperature (few 10K → 464°C → 30000°C → [27 million°C])
- Pressure (3.6 million atm, ~50 million atm, [265 billion atm])

A – Planets

Solar system

Telluric vs Gaseous

- Differences : e.g. mass, density, composition
- Similarities : e.g. shell-like internal structure

Bodies surfaces

- Shaped by their composition & past/present volcanic activity

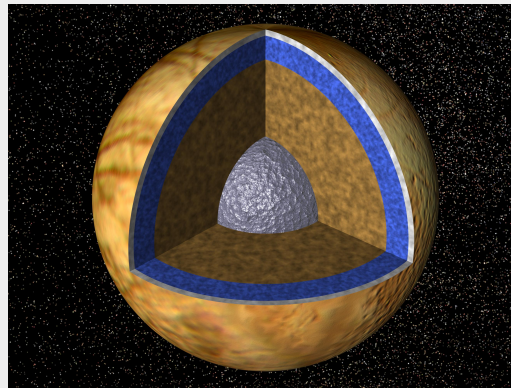
Matter under extreme conditions w.r.t. Earth

- Temperature (few 10K → 464°C → 30000°C → [27 million°C])
- Pressure (3.6 million atm, ~50 million atm, [265 billion atm])

What about water?

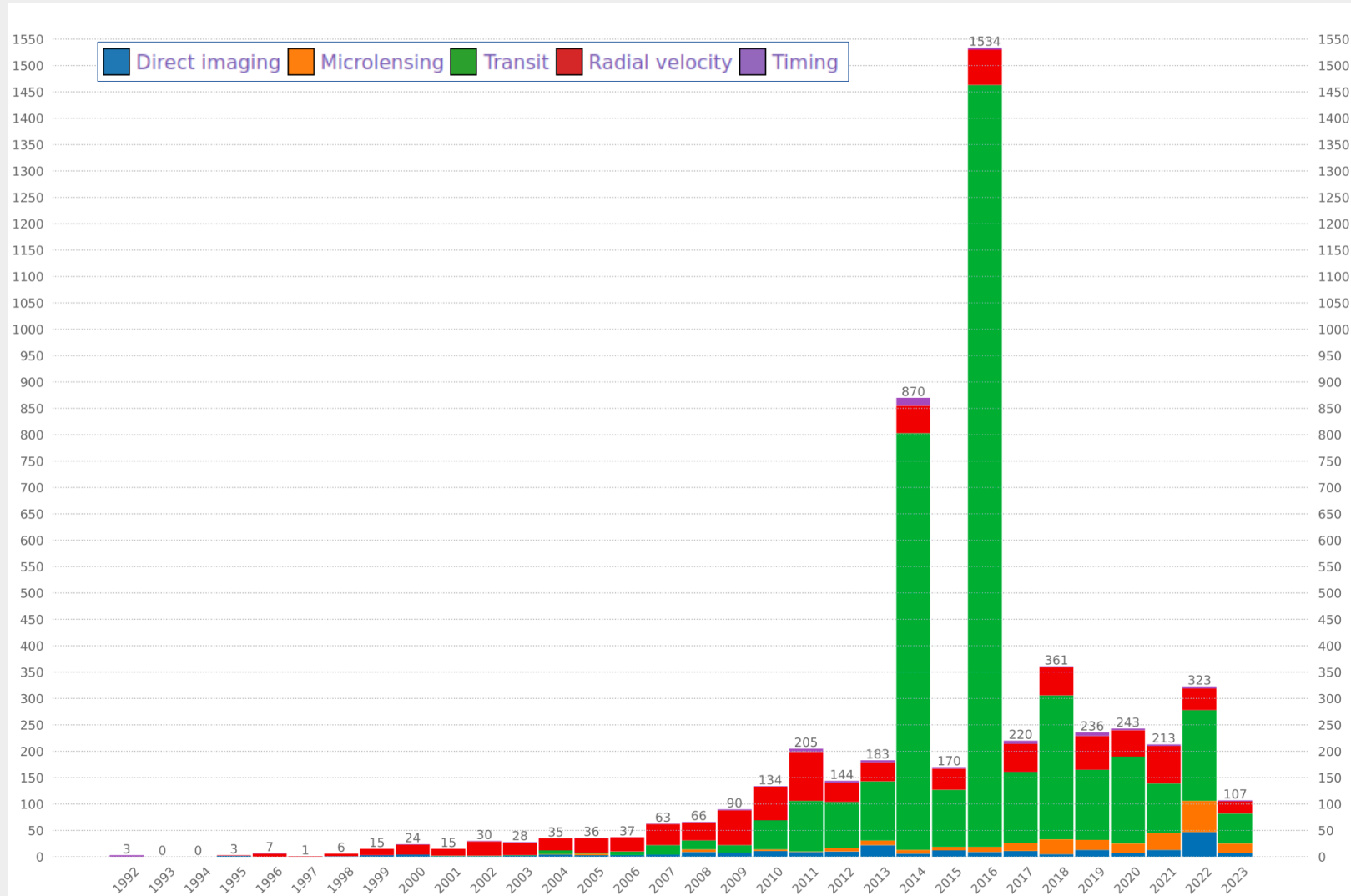
- Detected in many bodies (ice or gas) but not liquid yet!

Europa presumed internal structure:



A – Planets

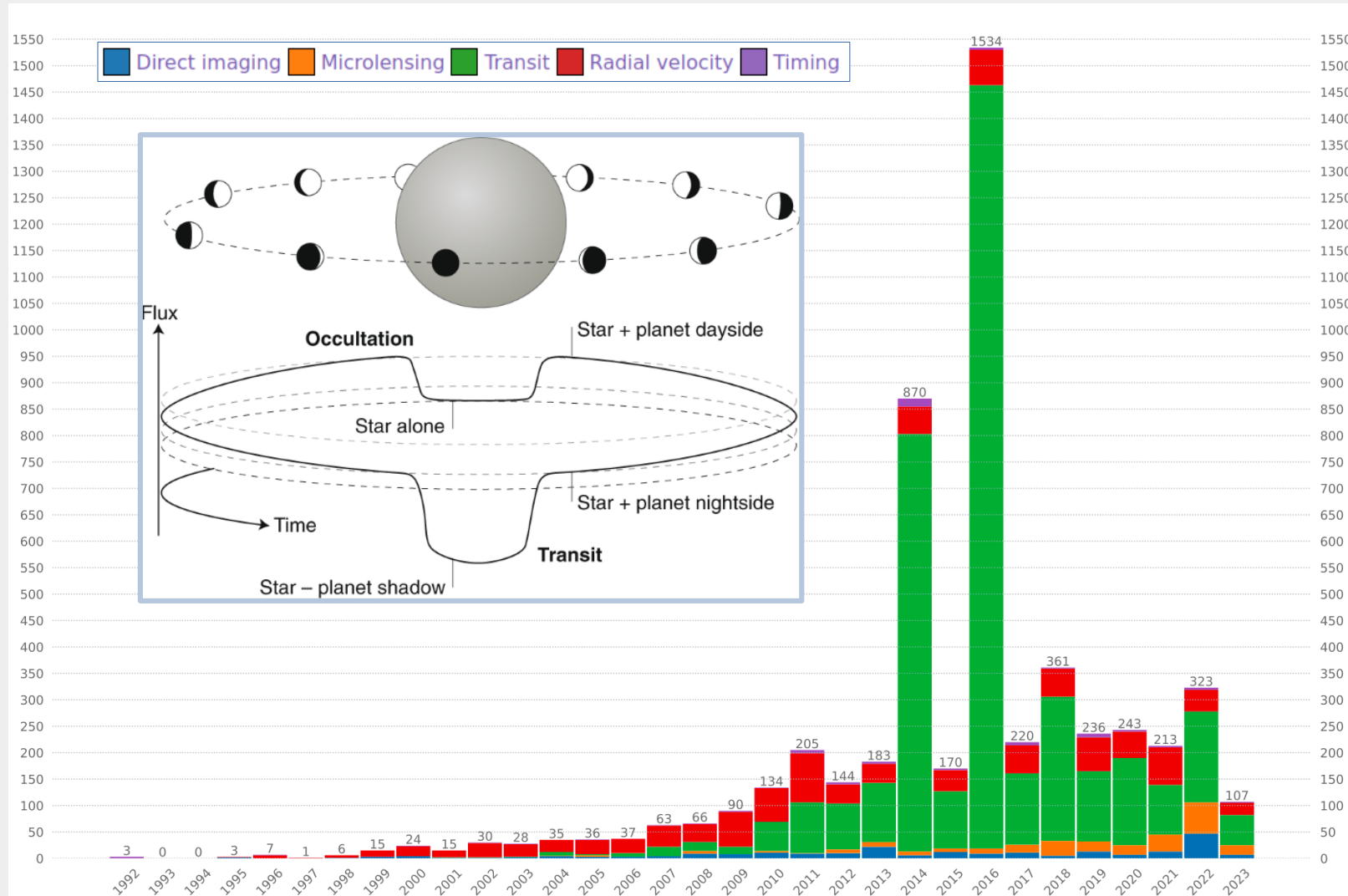
Exoplanets : the quest!



<http://exoplanet.eu/>

A – Planets

Exoplanets : the quest!



<http://exoplanet.eu/>

B – Stars

Stars luminosity

→ Stefan Boltzmann law $L(R,T)$

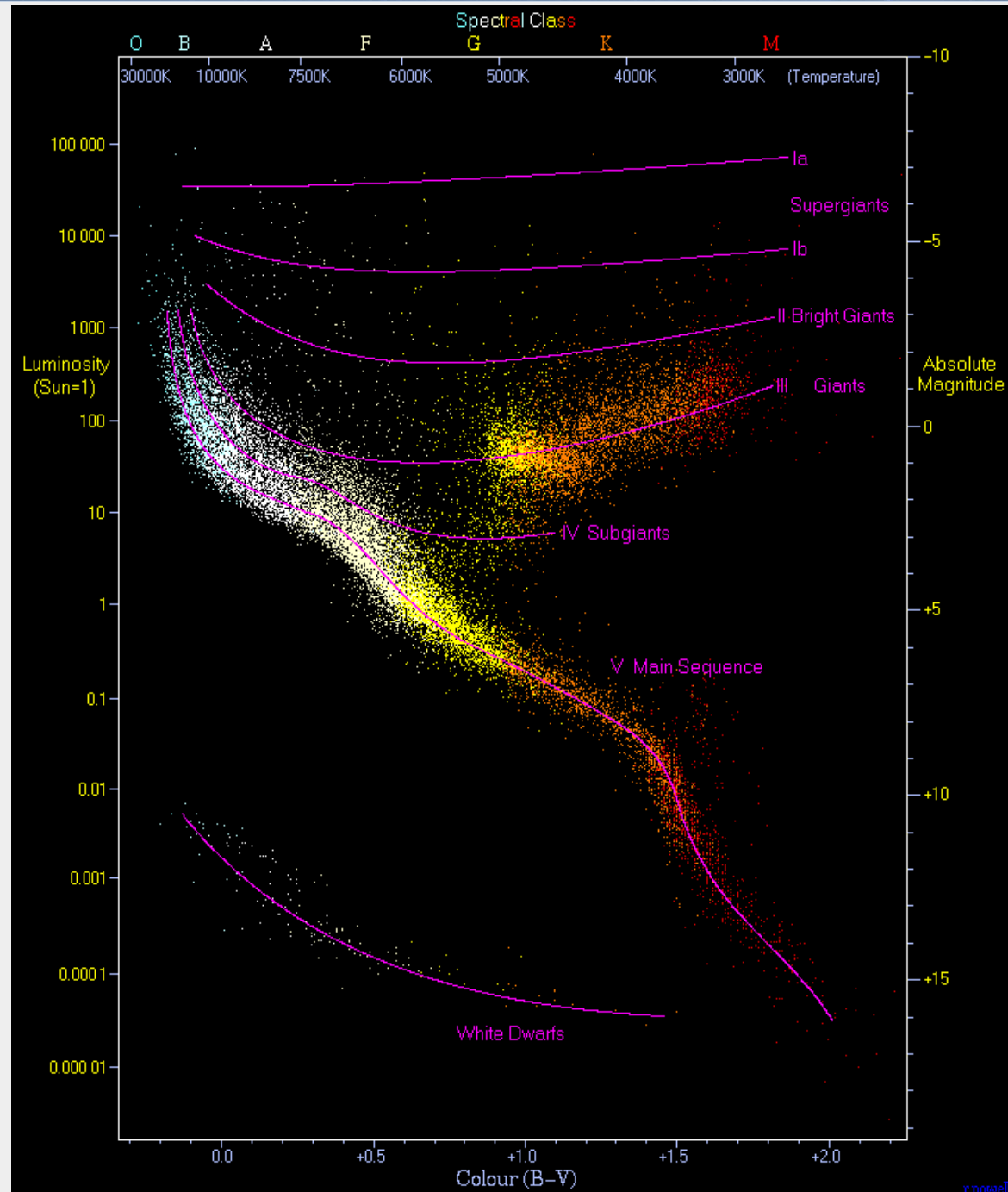
[Blackboard]

B – Stars

Stars luminosity

→ Stefan Boltzmann law $L(R,T)$

[Blackboard]



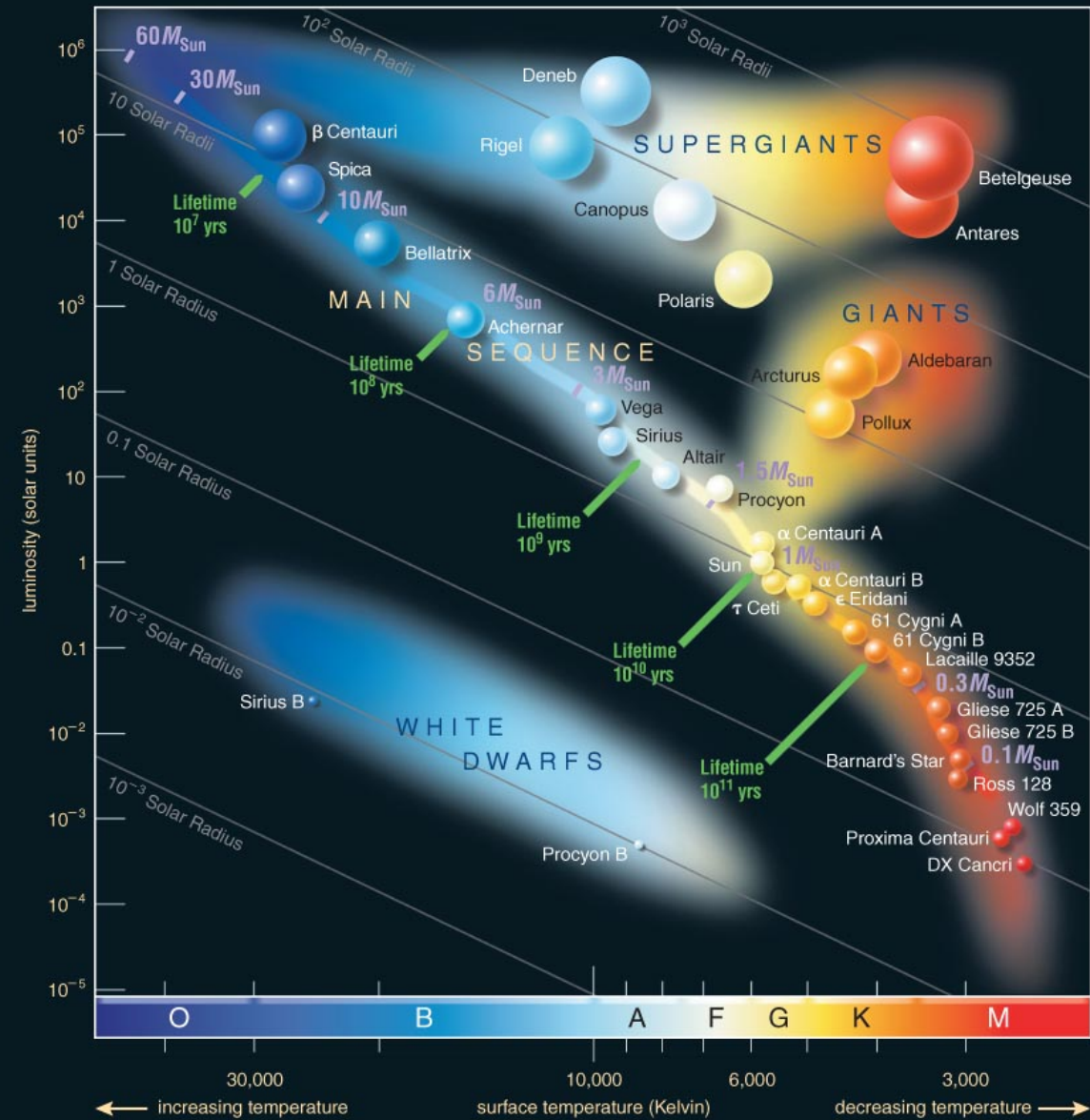
II – Astrophysical objects (from close to far)

B – Stars

Stars luminosity

→ Stefan Boltzmann law $L(R,T)$

[Blackboard]



II – Astrophysical objects (from close to far)

B – Stars

Stars luminosity

→ Stefan Boltzmann law $L(R,T)$

[Blackboard]

HR diagram

→ Hertzsprung–Russell (1905-1913)

→ Static view of the star pop.

→ Main sequence:

Most of the stars, H fusion

The heavier the shorter the lifetime

Heavy/sun-like stars/red dwarfs

Brown dwarfs (^2H fusion)

→ Horizontal branch (Giants, Supergiants)

He fusion in core, H fusion in shell

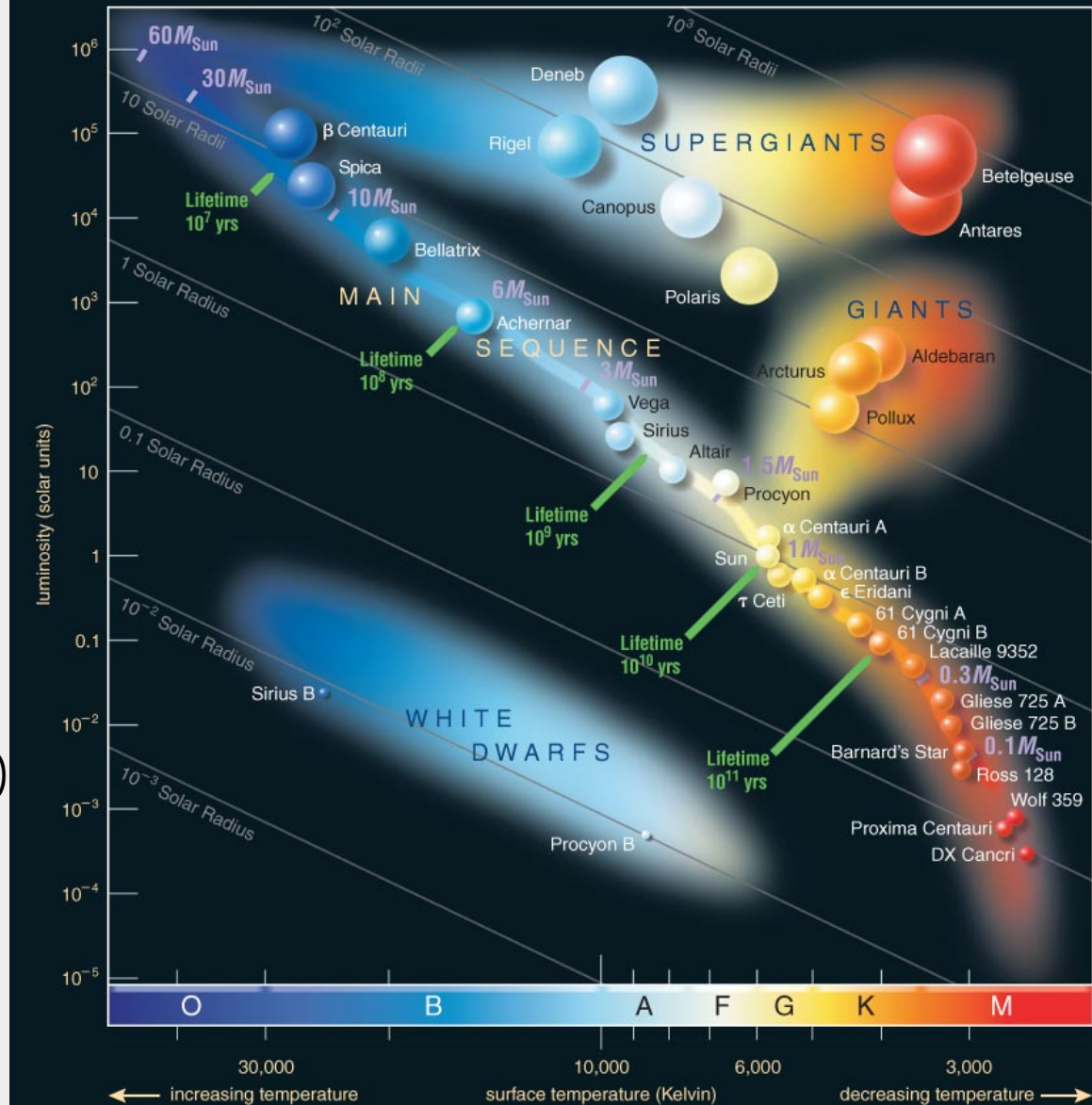
→ White dwarfs branch

Stellar remnants

→ White dwarfs ($M < 8M_{\odot}$)

→ Neutron stars ($8M_{\odot} < M < 20M_{\odot}$? + SN Ia)

→ Black holes ($M > 20M_{\odot}$?)



II – Astrophysical objects (from close to far)

B – Stars

Stars luminosity

→ Stefan Boltzmann law $L(R,T)$

[Blackboard]

HR diagram

→ Hertzsprung–Russell (1905-1913)

→ Static view of the star pop.

→ Main sequence:

Most of the stars, H fusion

The heavier the shorter the lifetime

Heavy/sun-like stars/red dwarfs

Brown dwarfs (^2H fusion)

→ Horizontal branch (Giants, Supergiants)

He fusion in core, H fusion in shell

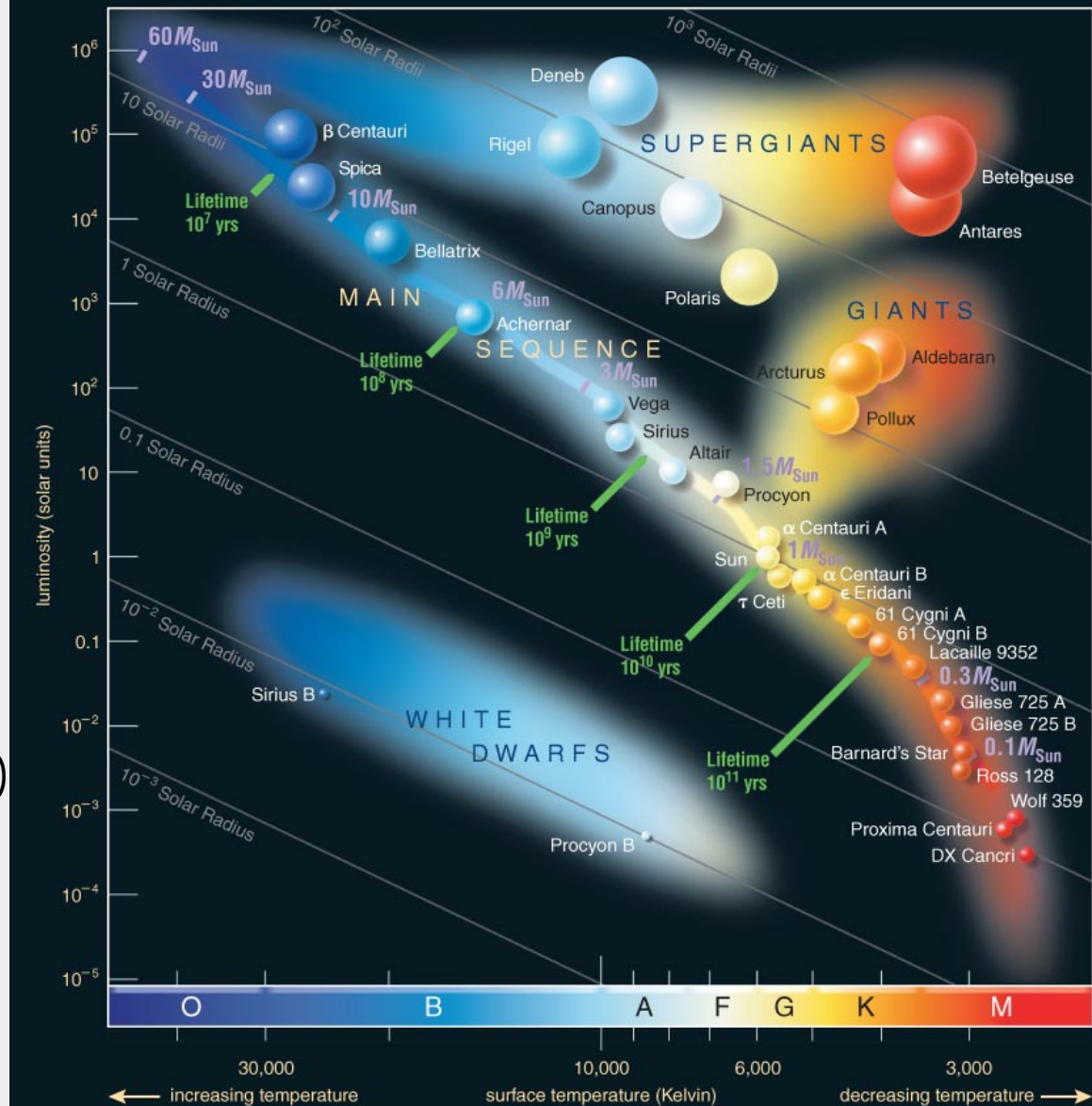
→ White dwarfs branch

Stellar remnants

→ White dwarfs ($M < 8M_{\odot}$)

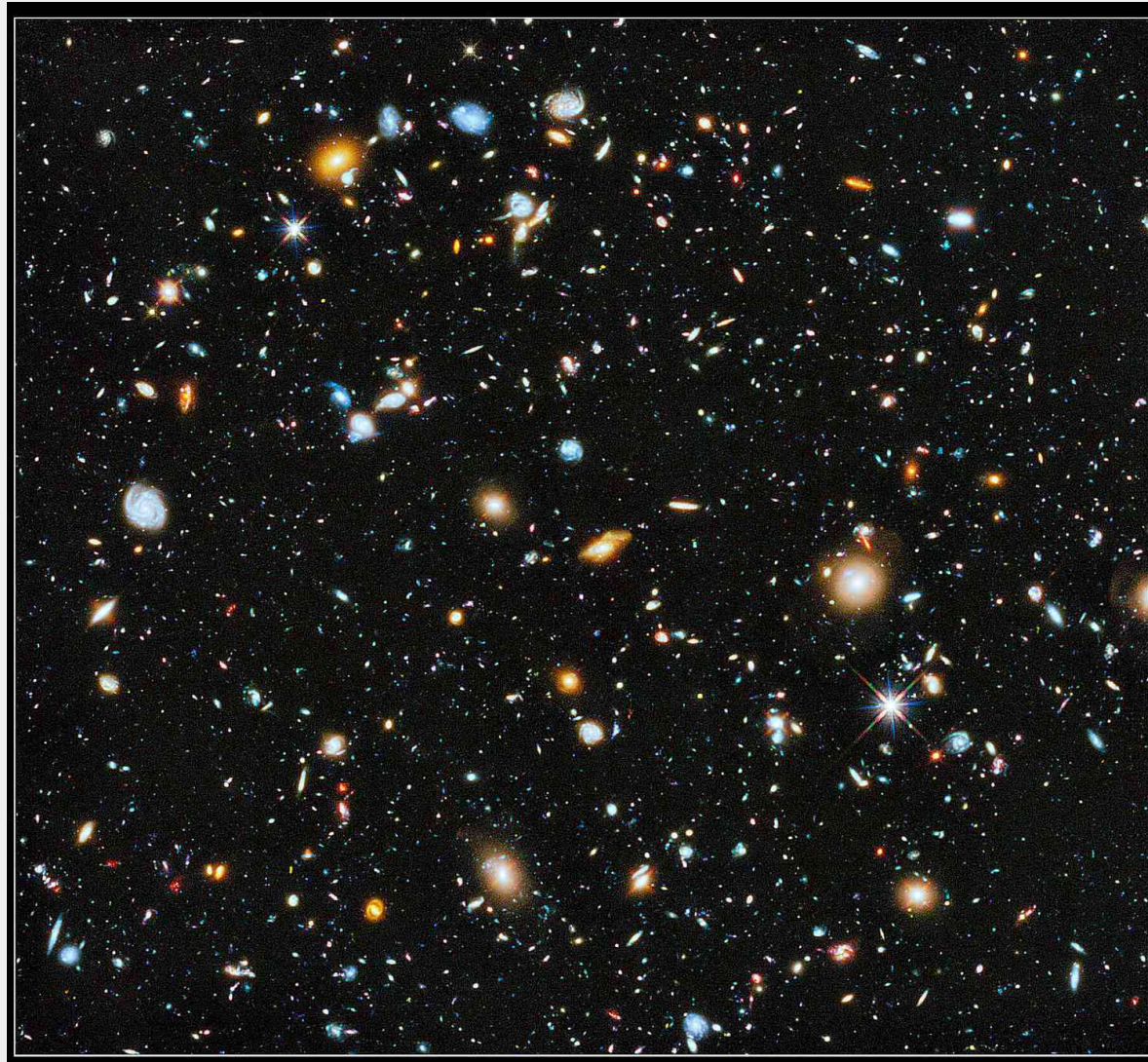
→ Neutron stars ($8M_{\odot} < M < 20M_{\odot}$? + SN Ia)

→ Black holes ($M > 20M_{\odot}$?)



© 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

C – Galaxies



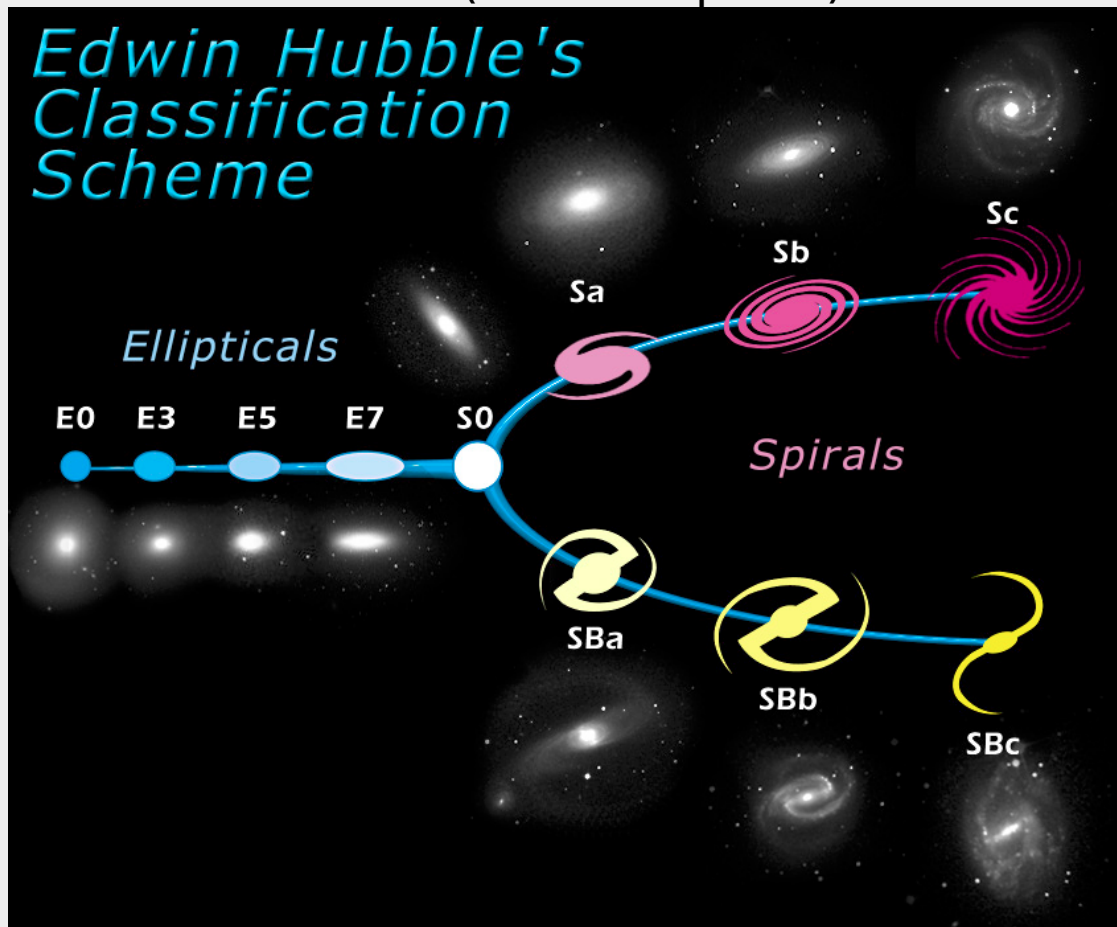
Hubble Space Telescope

C – Galaxies

Generalities

- Galaxy = Dark matter + Stars + Gas + Dust
 - ~90% ~10% ~1% ~1‰
- Size from dwarf to supergiants ($10^7 \rightarrow 10^{14}$ stars)

Galaxies classification (Hubble sequence)



- Ellipticals [$\sim 25\%$]
 - Featureless light distribution
 - $E = 10 \times (1 - b/a)$
 - Little interstellar matter / old stars
 - Incl. largest galaxies
- Lenticular galaxies [$\sim 25\%$]
 - S0 : bulge + flattened disk
- Spiral [$\sim 45\%$]
 - Bulge + flattened disk + spiral structure
 - 50% with a bar
- Irregular galaxies [$\sim \text{few } \%$]
 - no specific regular shape

C – Galaxies

Generalities

- Galaxy = Dark matter + Stars + Gas + Dust
 ~90% ~10% ~1% ~1‰
- Size from dwarf to supergiants ($10^7 \rightarrow 10^{14}$ stars)

Galaxies classification (Hubble sequence)

- Ellipticals [~25%]
- Lenticular galaxies [~25%]
- Spiral [~45%]
- Irregular galaxies [~ few %]
- Resulting from : init. cond. (M, AM), density waves, tidal int.
- Dwarf galaxies : most numerous, ~ 1% MW

C – Galaxies

Generalities

- Galaxy = Dark matter + Stars + Gas + Dust
 ~90% ~10% ~1% ~1‰
- Size from dwarf to supergiants ($10^7 \rightarrow 10^{14}$ stars)

Galaxies classification (Hubble sequence)

- Ellipticals [~25%]
- Lenticular galaxies [~25%]
- Spiral [~45%]
- Irregular galaxies [~ few %]
- Resulting from : init. cond. (M, AM), density waves, tidal int.
- Dwarf galaxies : most numerous, ~ 1% MW

Sytems of virialized stars

- [Virial's theorem on Blackboard] : $2T+U=0$

C – Galaxies

Generalities

- Galaxy = Dark matter + Stars + Gas + Dust
~90% ~10% ~1% ~1‰
- Size from dwarf to supergiants ($10^7 \rightarrow 10^{14}$ stars)

Galaxies classification (Hubble sequence)

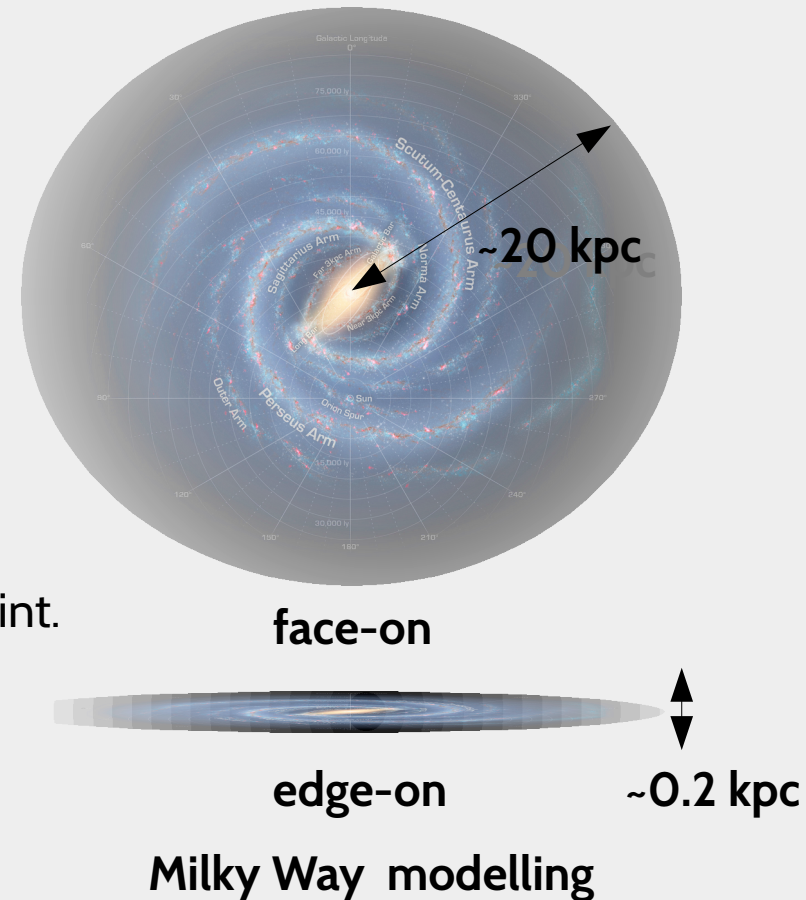
- Ellipticals [$\sim 25\%$]
- Lenticular galaxies [$\sim 25\%$]
- Spiral [$\sim 45\%$]
- Irregular galaxies [$\sim \text{few } \%$]
- Resulting from : init. cond. (M, AM), density waves, tidal int.
- Dwarf galaxies : most numerous, $\sim 1\%$ MW

Sytems of virialized stars

- [Virial's theorem on Blackboard] : $2T+U=0$

Milky Way

- Computing the gas surface density?
 - Gas $\sim 1\%$ MW mass
 - $1H/m^3$
- Milky Way < Local group < Virgo supercluster < Laniakea



D – Galaxy clusters

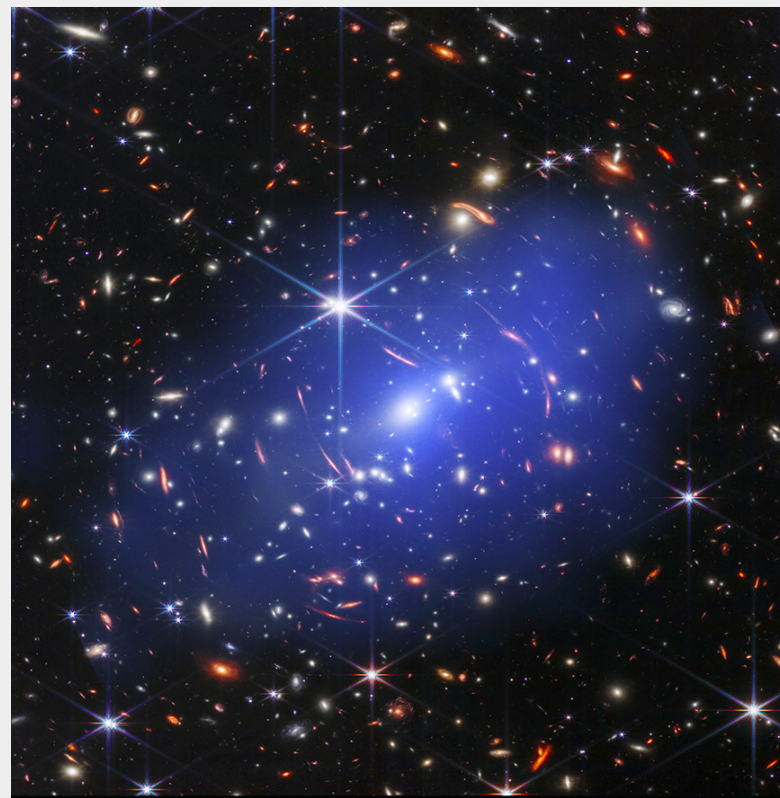
Generalities

- Gravitationally bound system of galaxies
- Galaxy cluster = Dark matter + Gas + Stars
 - ~90% ~10% ~1%
- Typical mass 10^{14} - 10^{15} Ms = 100-1000 galaxies
- Typical size 1-5 Mpc



JSWT Galaxy cluster SMACS 0723, ~1Gpc away

+ X-rays 0.1-10 keV

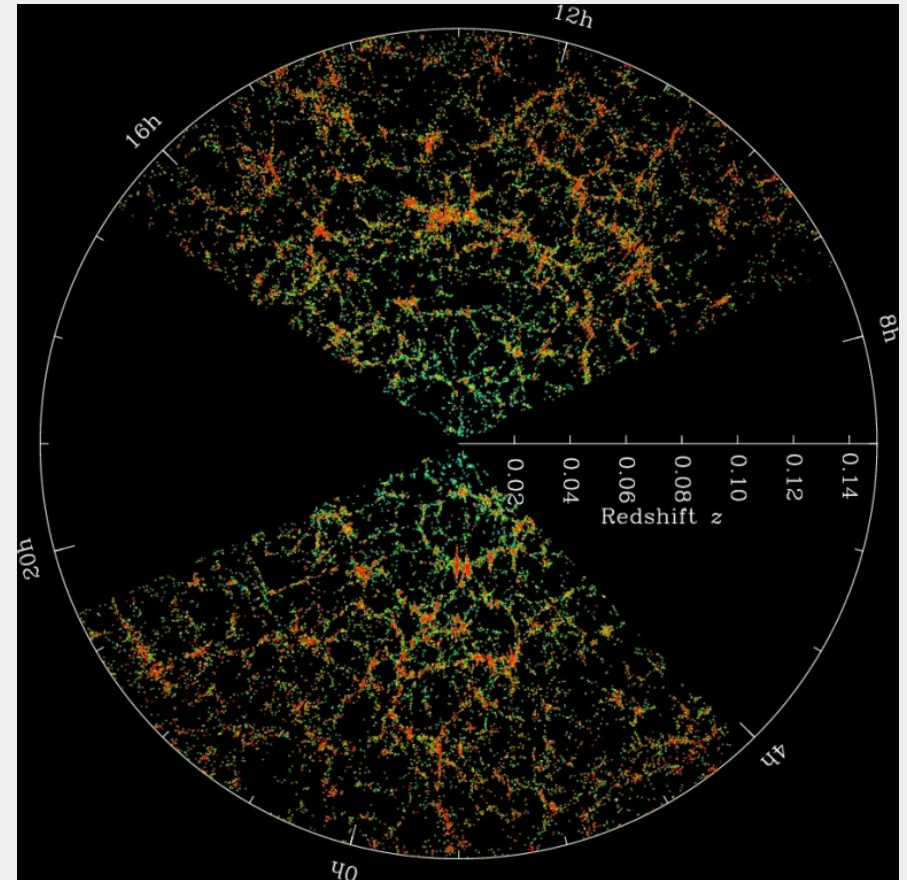


+ Chandra, X-rays
<https://chandra.si.edu/photo/2022/chandrawebb/>

E – Large scale structures

Generalities

- Largest structures gravitationally bound
- Correlations over $\sim 1\text{Gpc}$ scales
- Dominated by Dark Matter (+ gas and galaxies)
- Filaments, sheets, voids = cosmic web
- Reveal : - history of structure formation
- role of Dark Matter & Dark Energy
- Evidence of the relic sound wave (BAO)



Sloan Digital Sky Survey (SDSS)

Outline

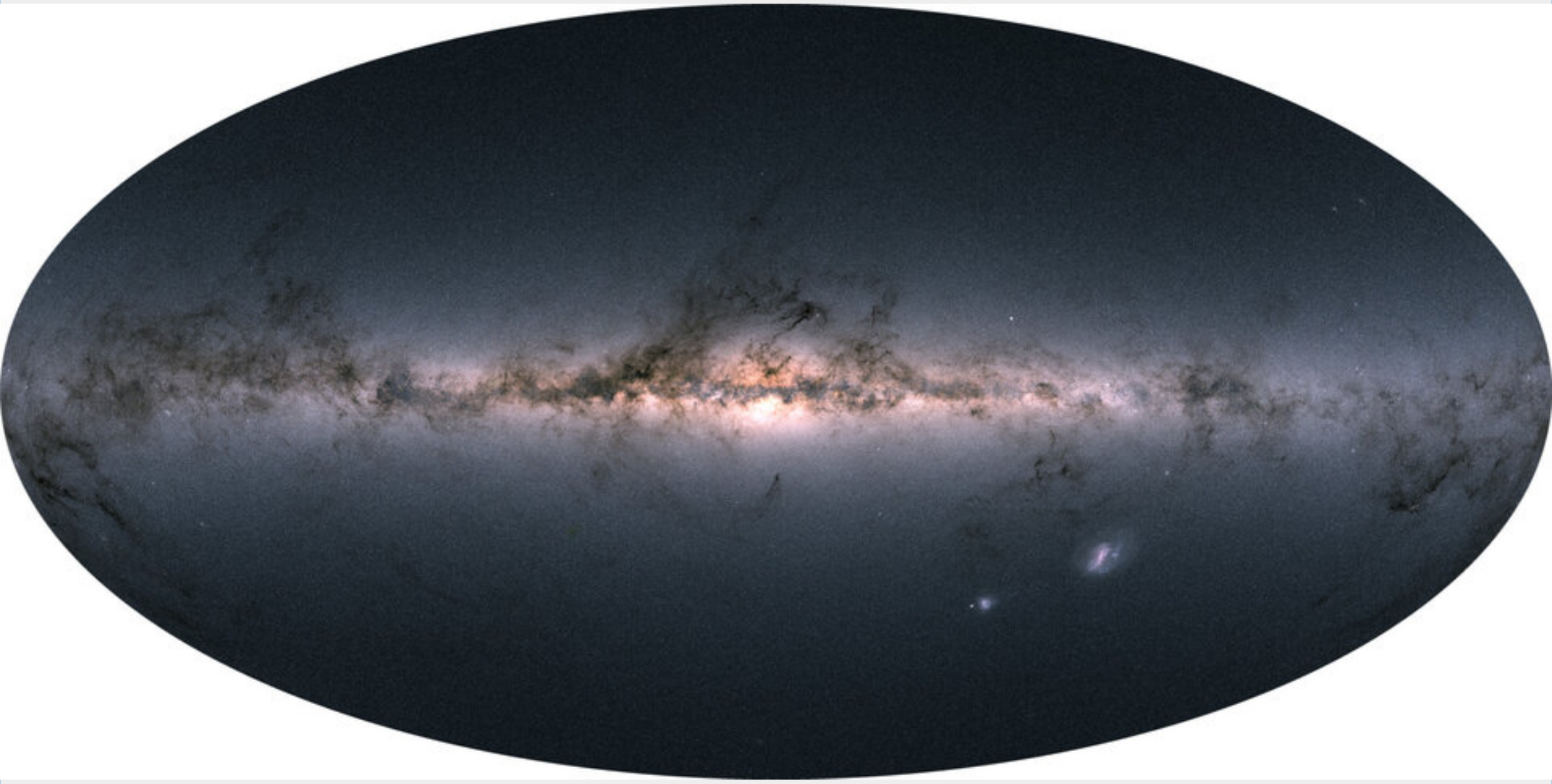
- I – Introduction to astrophysical scales
- II – Astrophysical objects (from close to far)
- III – Observations in astrophysics**

A – The differential photon flux

[Blackboard]

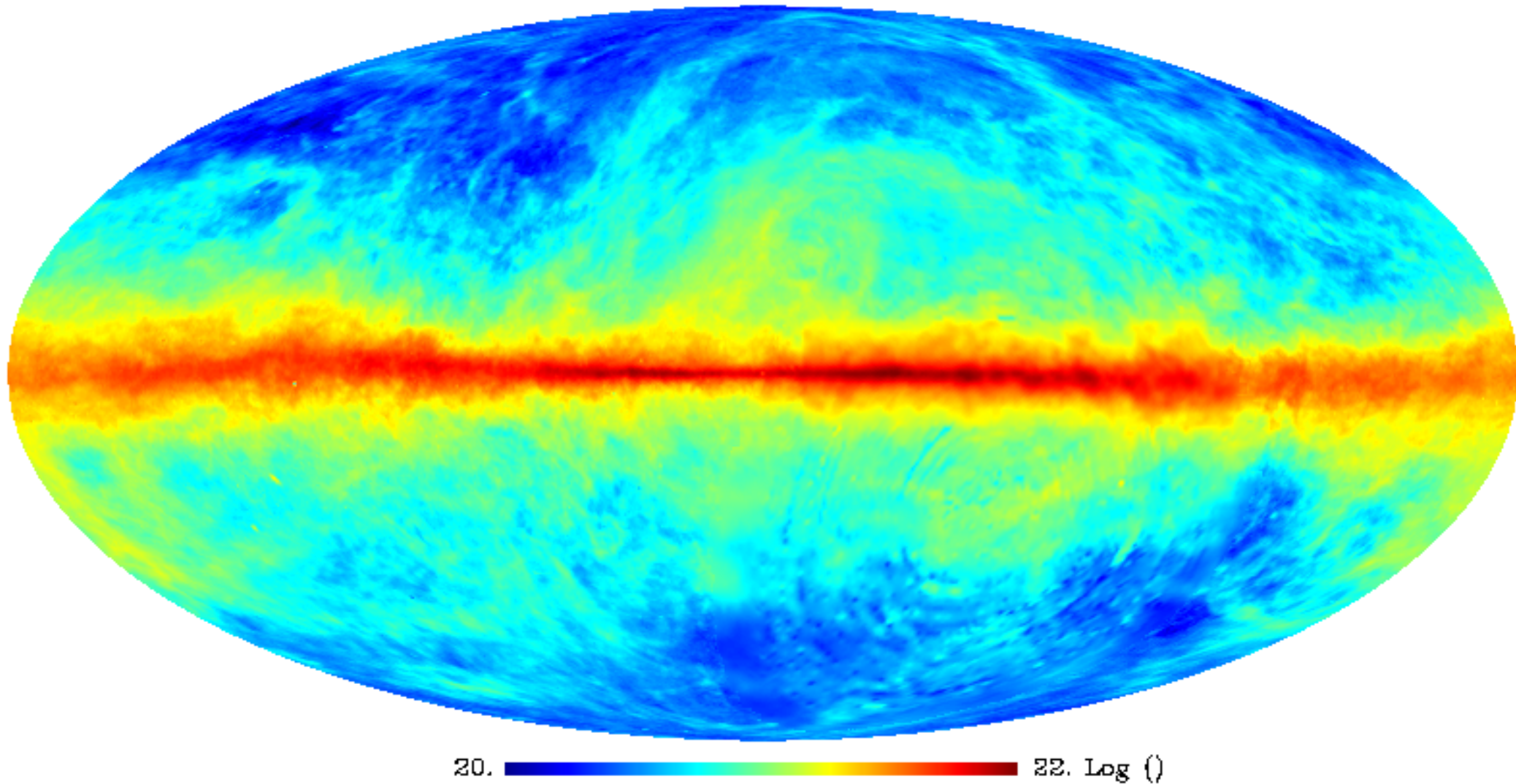
B – The multi-wavelength Galactic plane

B – The multi-wavelength Galactic plane → Visible light

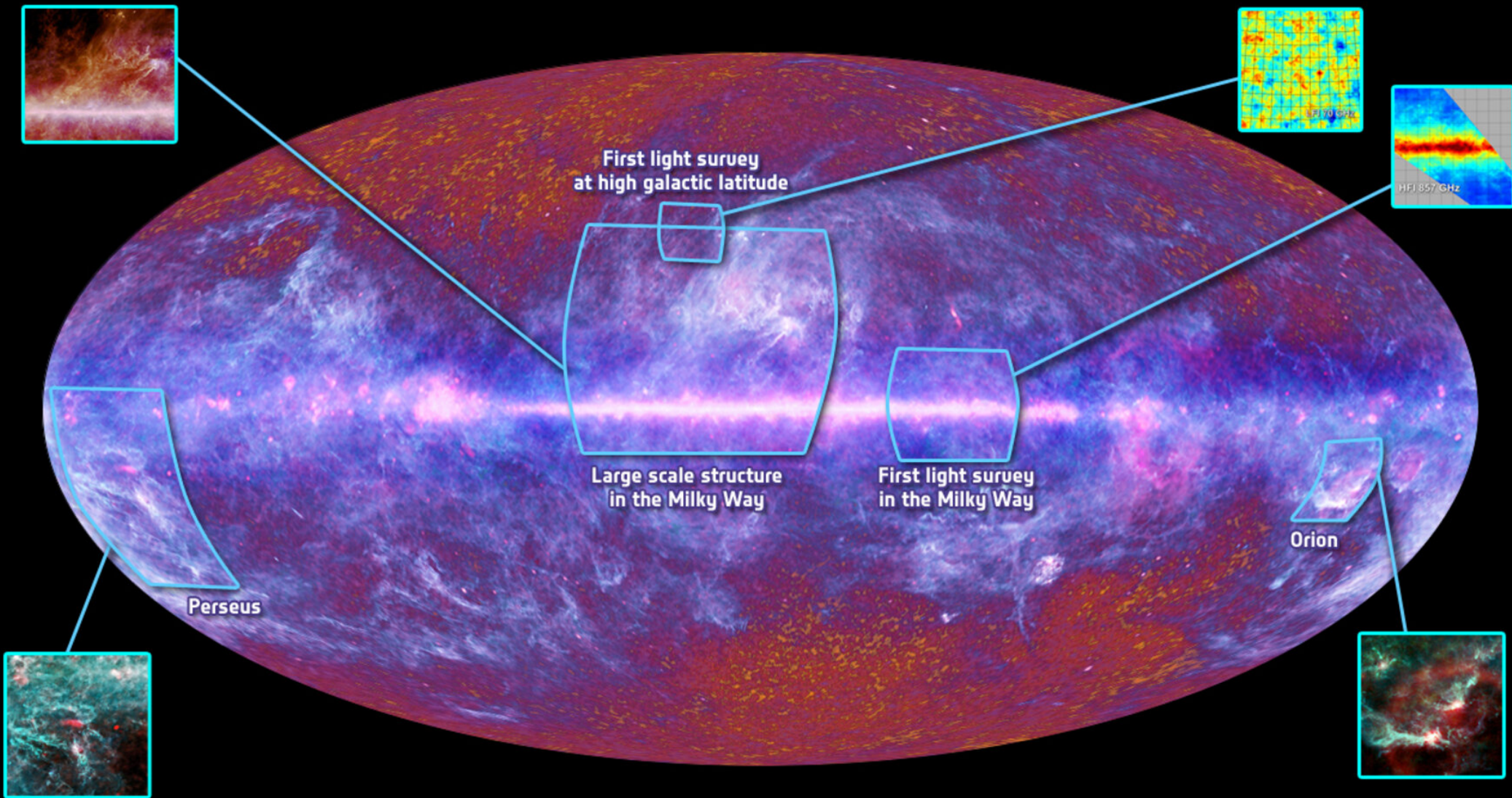


The entire sky -- 1.7 billion stars' worth — mapped by Gaia and displayed using color information also obtained by the satellite. You can see we live in a flat galaxy with a large central bulge, festooned with dark filaments of dust. Credit: [Gaia/DPAC/ESA](#)

B – The multi-wavelength Galactic plane → Radiowave [21cm]

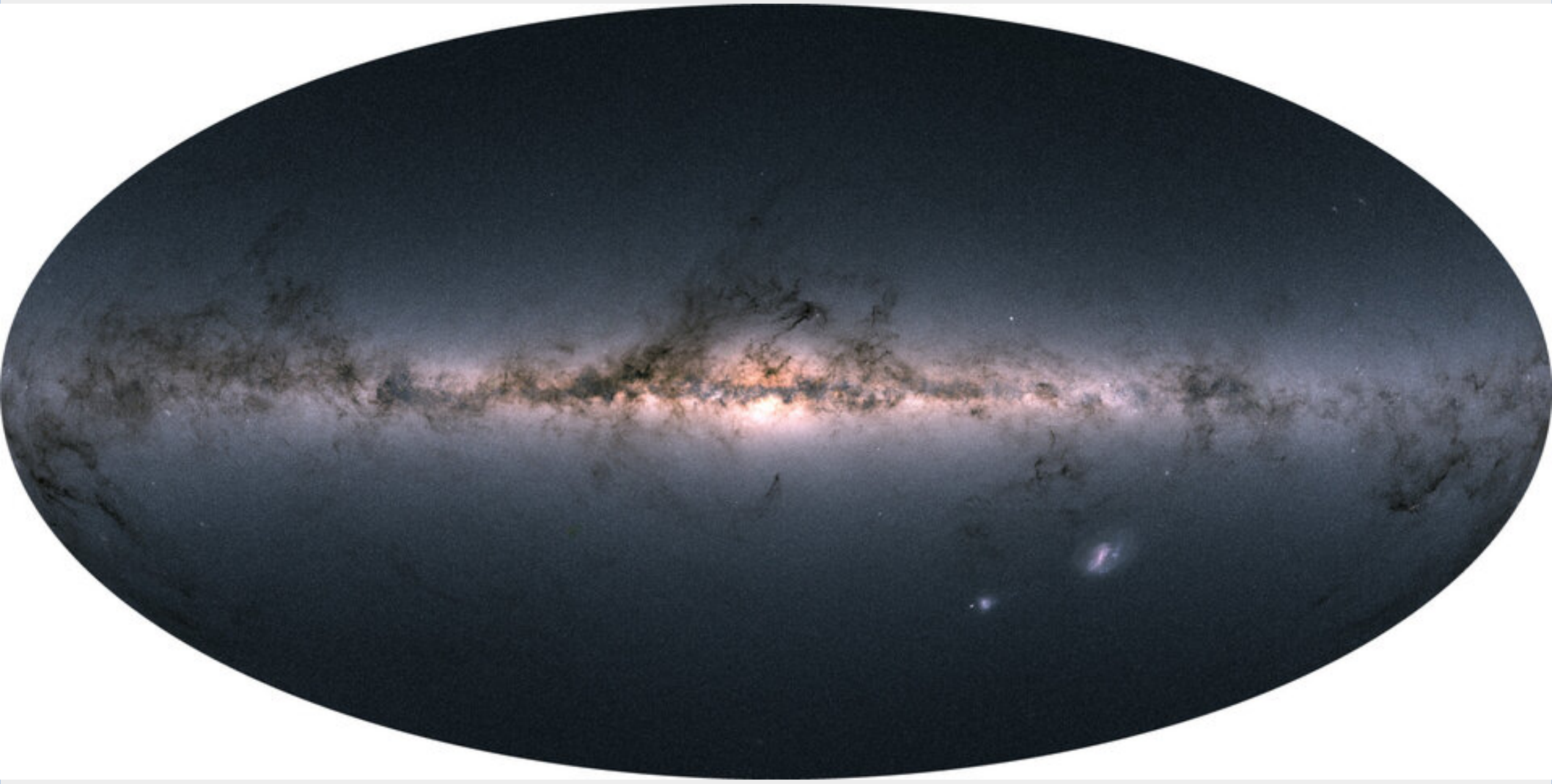


B – The multi-wavelength Galactic plane → Microwave [30, 857 GHz]



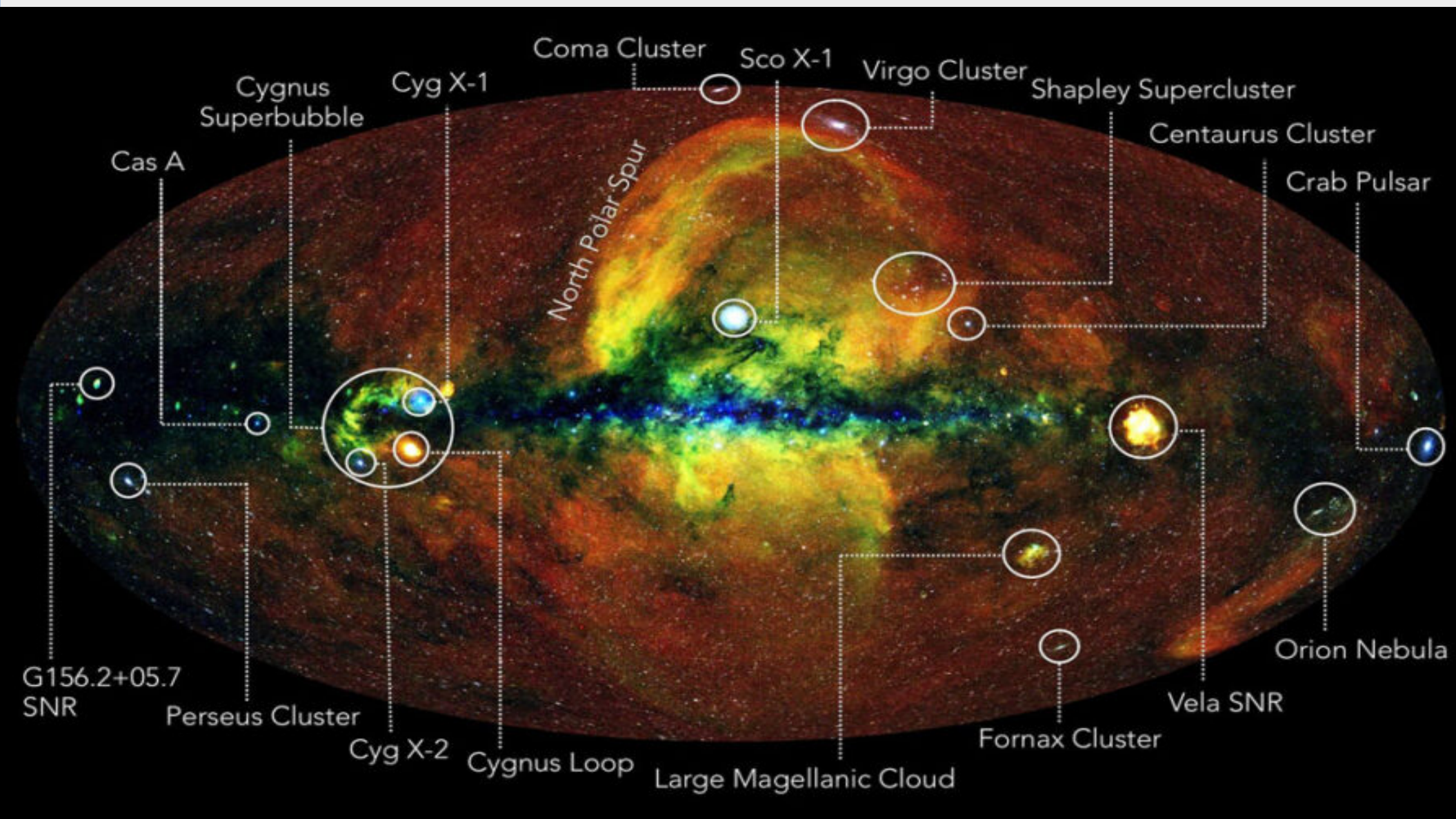
Planck (2010) First year all-sky survey map, Copyright: ESA, HFI and LFI consortia

B – The multi-wavelength Galactic plane → Visible light

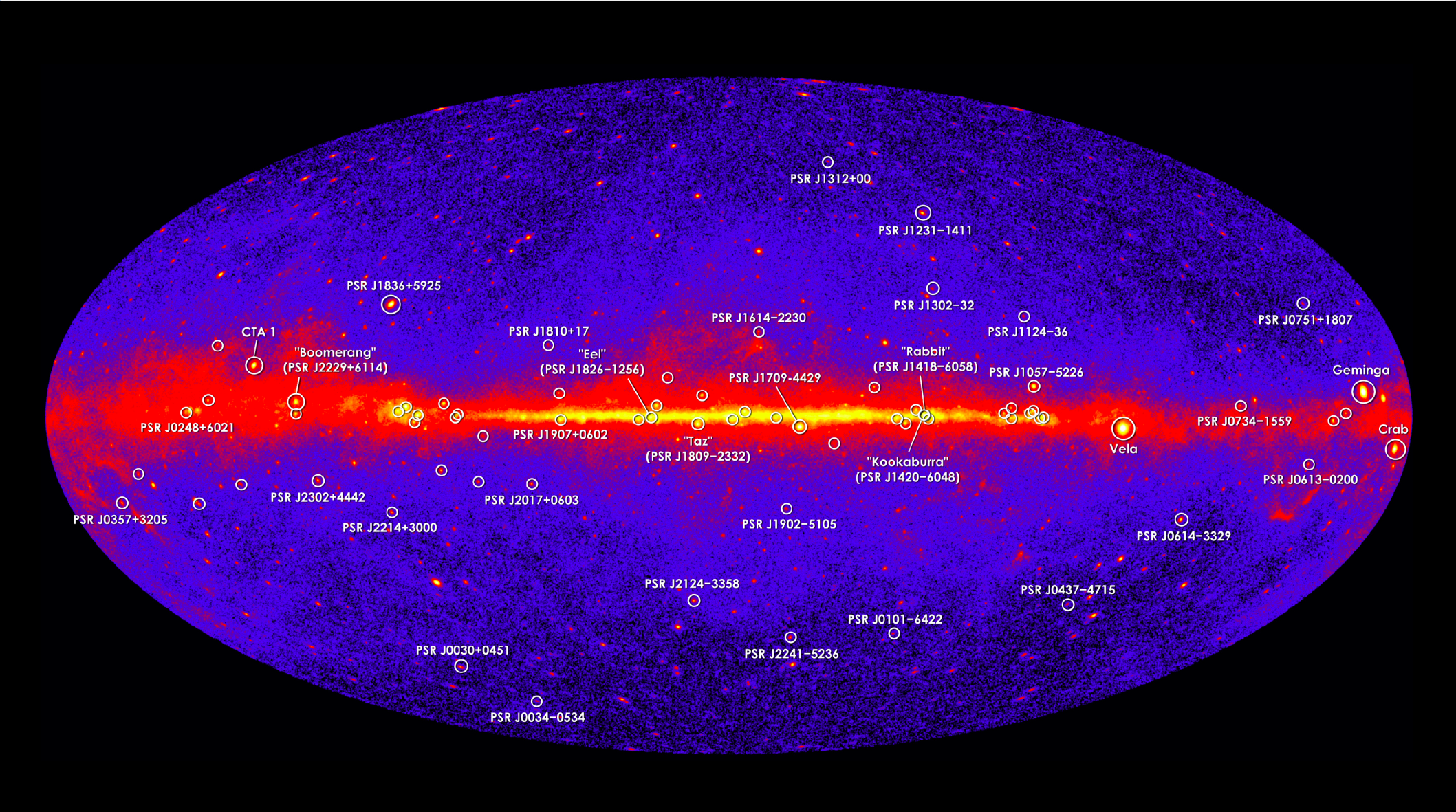


The entire sky -- 1.7 billion stars' worth — mapped by Gaia and displayed using color information also obtained by the satellite. You can see we live in a flat galaxy with a large central bulge, festooned with dark filaments of dust.
Credit: [Gaia/DPAC/ESA](#)

B – The multi-wavelength Galactic plane → X-rays [0.3-2.3keV]

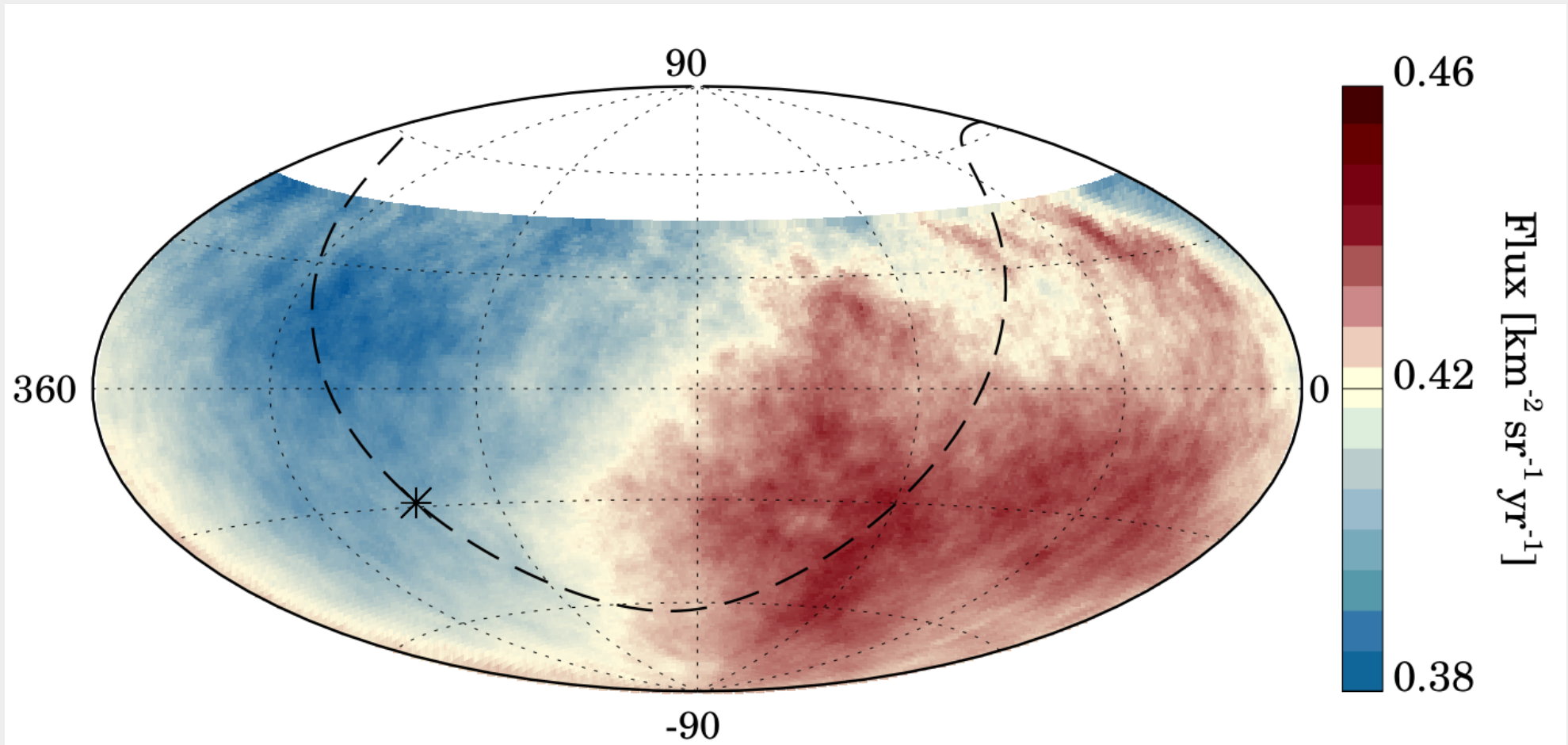


B – The multi-wavelength Galactic plane → Gamma-rays [$>1\text{GeV}$]



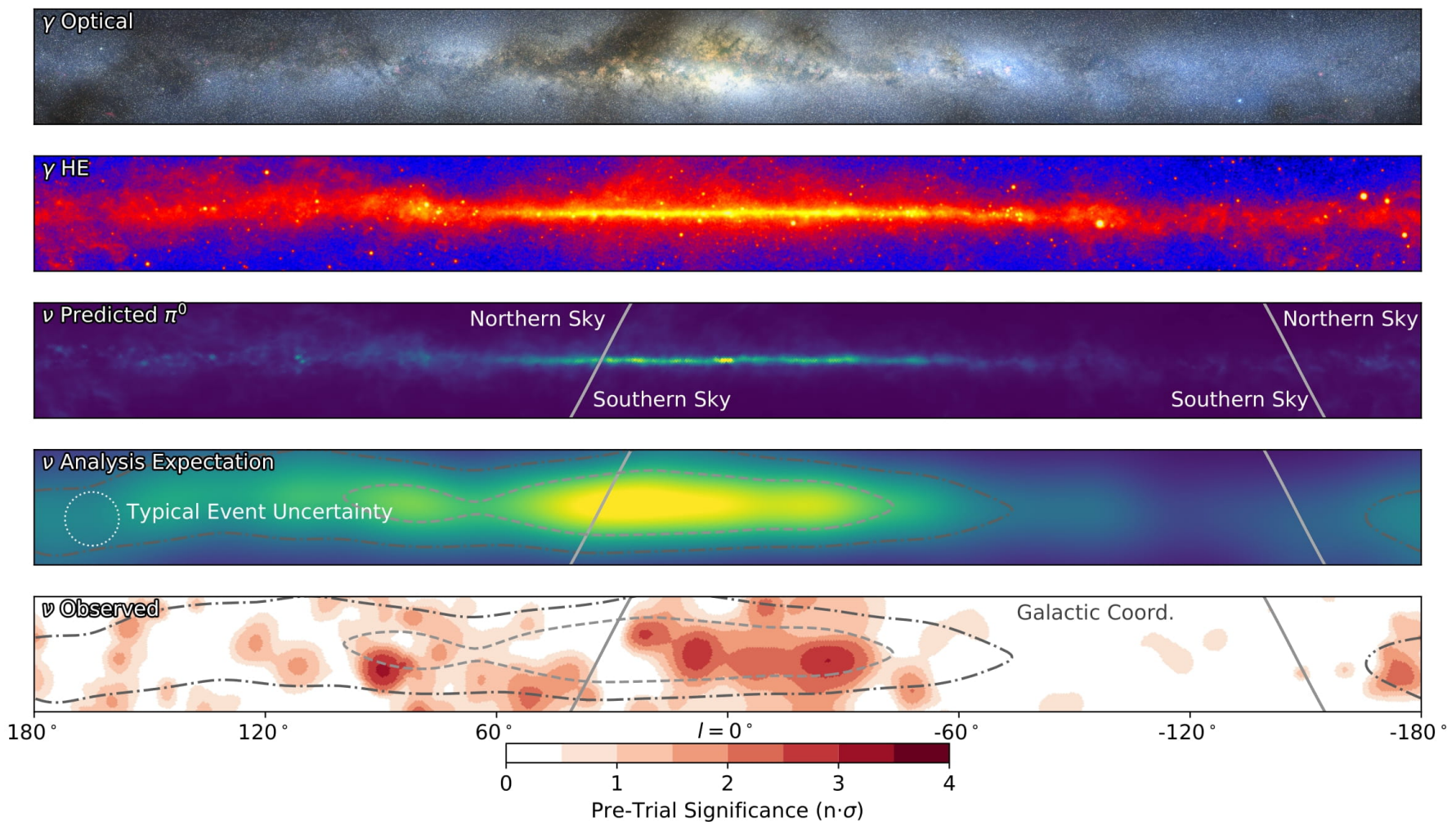
The Fermi LAT 60-month image, NASA/DOE/Fermi LAT Collaboration

C – Other messengers? → Cosmic-rays



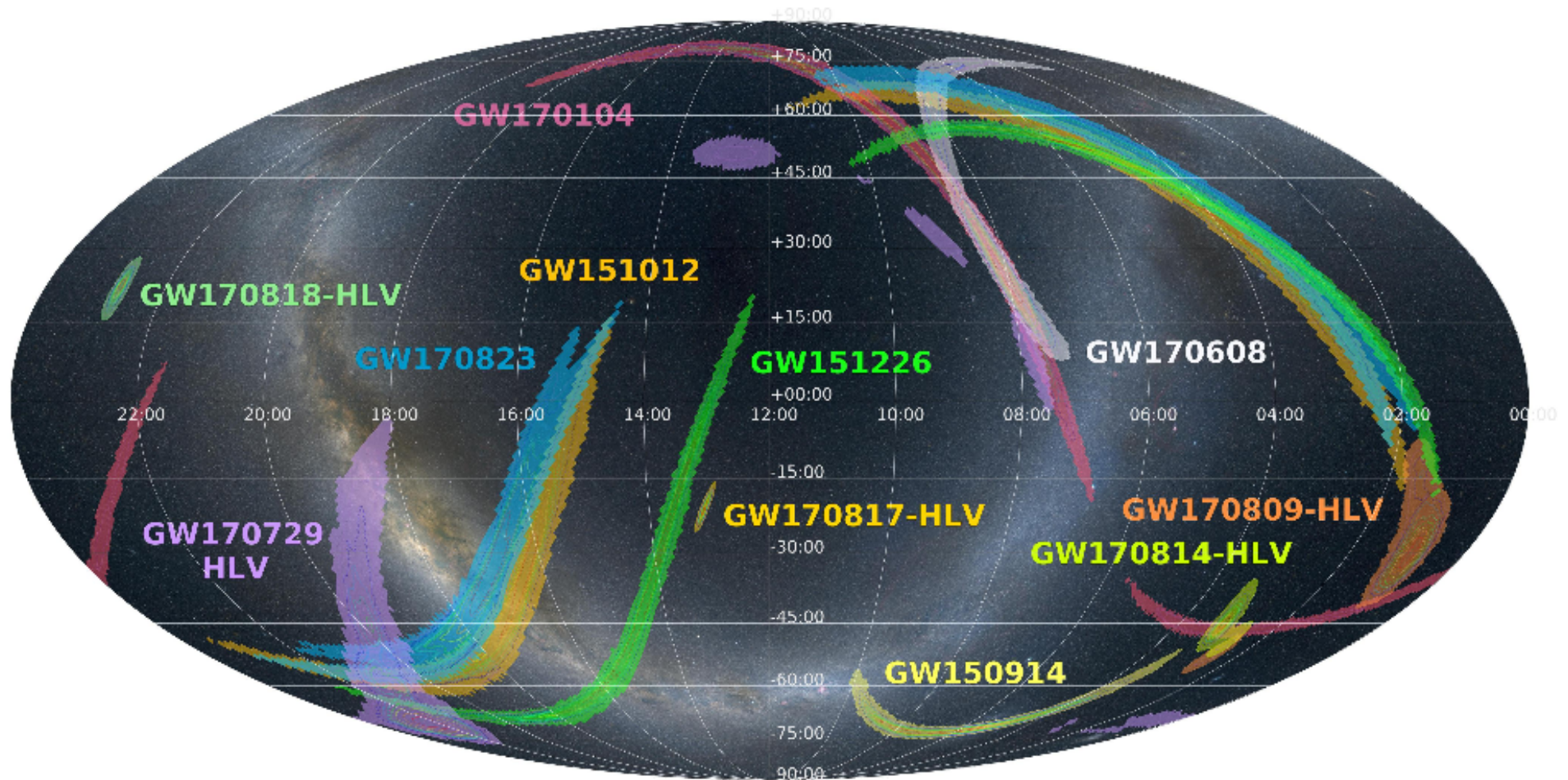
UHECR Flux with $E > 8$ EeV measured by the Pierre AUGER observatory. <https://arxiv.org/pdf/1808.03579.pdf>

C – Other messengers? → Neutrinos



IceCube Collaboration: R. Abbasi et al. (journal) Science 380, 6652 (2023)

C – Other messengers? → Gravitational waves

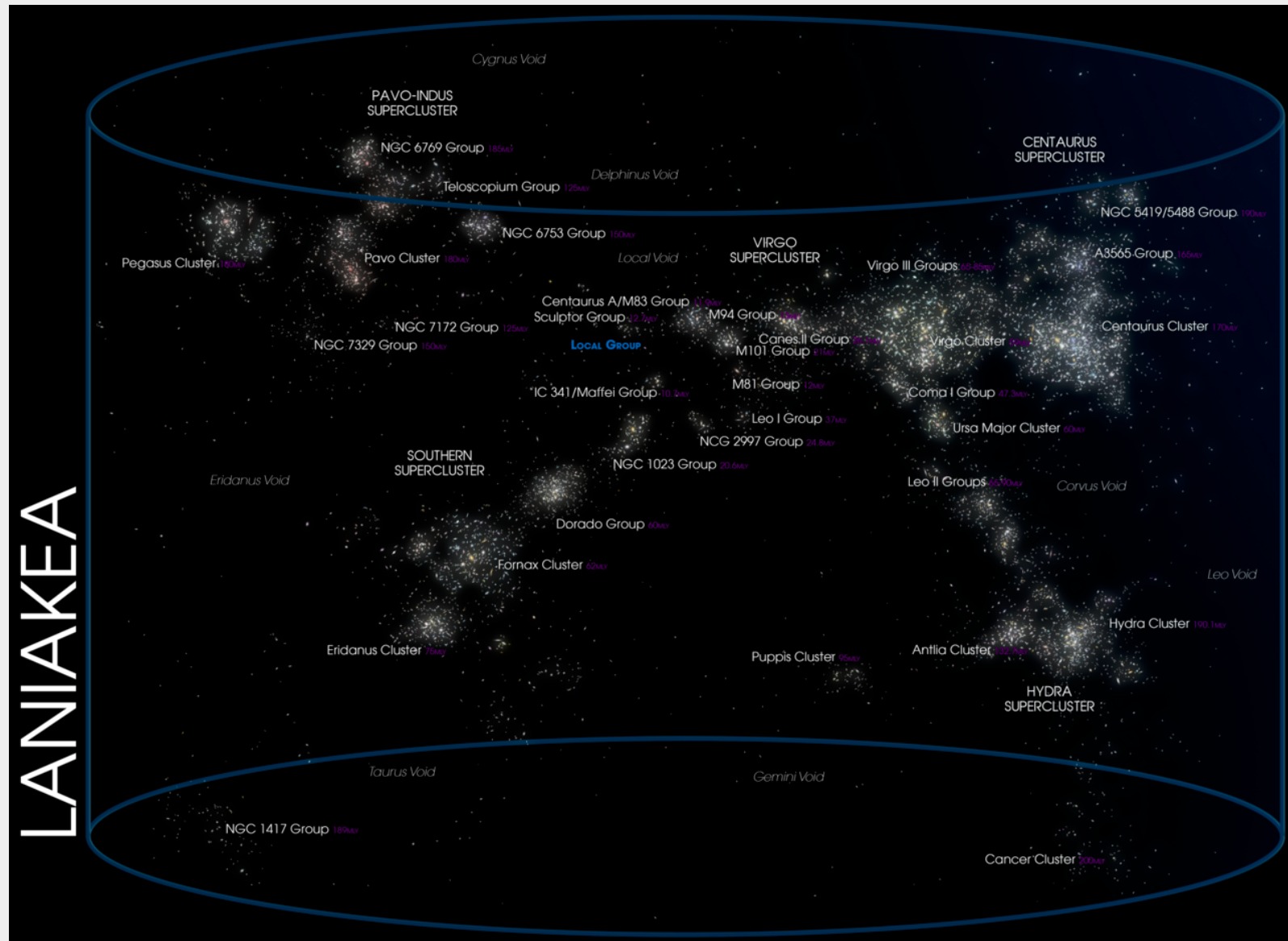


Questions?

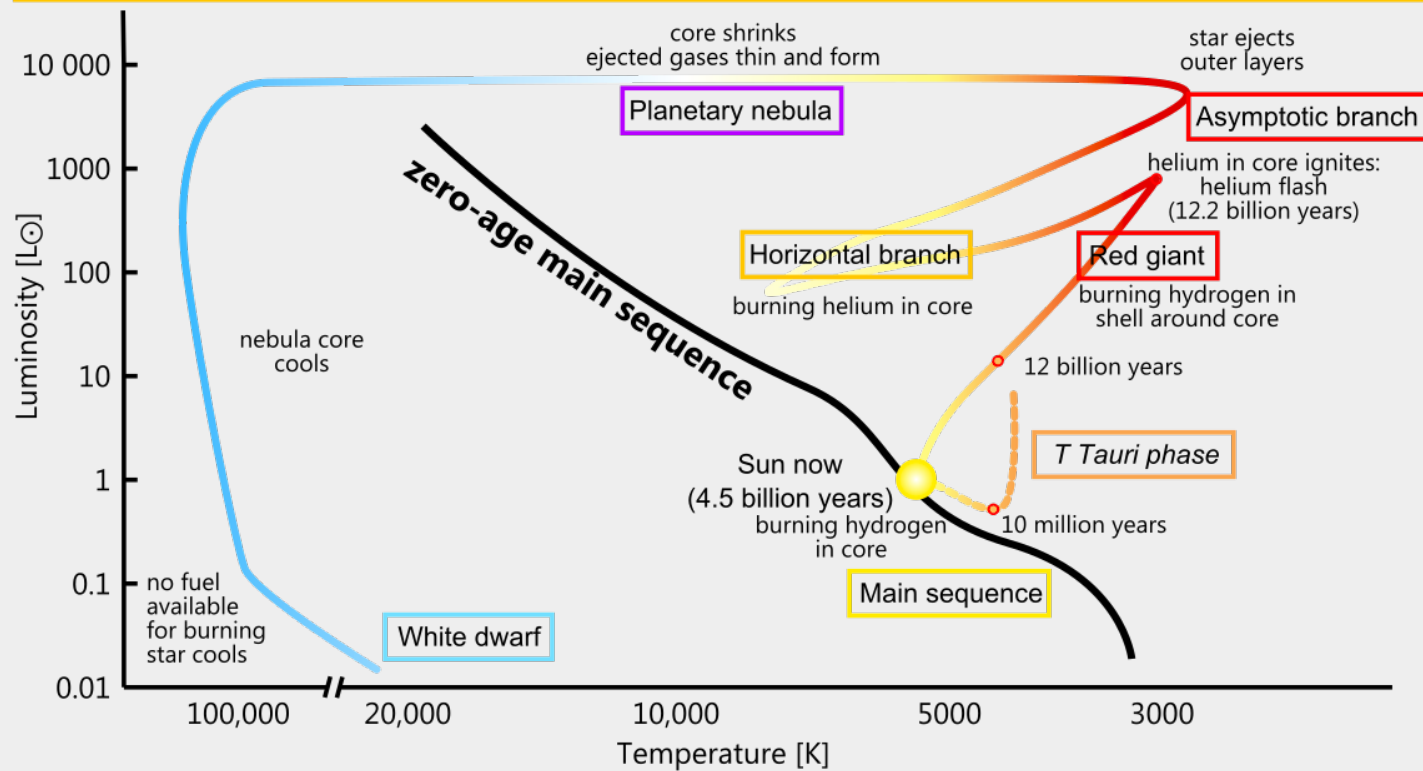
Backups

II – Astrophysical objects (from close to far)

D – Galaxy clusters



	~9 Ga	~1 Ga	~100 Ma	~10 000 a	
Stage:	Main sequence	> Red giant	> Horizontal branch	> Planetary nebula	> White dwarf
Sun's age:	4.5 Ga (now)	12.2 Ga	12.3 Ga	12.3305 Ga	12.3306 Ga



Differences in Stellar Structures Regarding the Energy Transport

