Introduction to astrophysics

A journey through the galaxies and beyond …

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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

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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 ($R_\oplus$) ≈ ? km
Solar radius ($R_\odot$) ≈ ? km
Astronomical Unit (AU) ≈ ? km
Asteroid belt ≈ ? AU
Neptune orbital radius ≈ ? AU
Kuiper belt ≈ ? AU
Oort Cloud ≈ ? 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

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Galactic scales

Dist. to Proxima Centauri $\approx$? pc
Galactic thickness ($h_{\mathcal{G}}$) $\approx$? pc
Galactic radius ($R_{\mathcal{G}}$) $\approx$? kpc
Dist. to Andromeda $\approx$? pc
Local group size $\approx$? pc
Observable universe $\approx$? Gpc

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We need a new unit : ly or parsec → [Blackboard]

Galactic scales

Dist. to Proxima Centauri $\approx 1.3\,\mathrm{pc}$
Galactic thickness ($h_{\mathcal{G}}$) $\approx 200\,\mathrm{pc}$
Galactic radius ($R_{\mathcal{G}}$) $\approx 20\,\mathrm{kpc}$
Dist. to Andromeda $\approx 1\,\mathrm{Mpc}$
Local group size $\approx 3\,\mathrm{Mpc}$
Observable universe $\approx 30\,\mathrm{Gpc}$

B – Masses

Solar system scales

- Asteroid belt mass $\approx$? kg
- Moon mass $\approx$? kg
- Earth mass ($M_\oplus$) $\approx$? kg
- Jupiter mass ($M_\oplus$) $\approx$? 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 $\approx 250\,M_{\odot}$

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Galactic scales

Dwarf galaxy mass $\approx$? $M_{\odot}$
Supermassive black hole $\approx$? $M_{\odot}$
Milky Way mass ($M_{\mathcal{G}}$) $\approx$? $M_{\odot}$
Milky Way bulge stellar mass $\approx$? $M_{\mathcal{G}}$
Observable Universe mass $\approx$? $M_{\mathcal{G}}$

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Galactic scales

Dwarf galaxy mass $\approx 10^7\,M_\odot$
Supermassive black hole $\approx 10^5 - 10^9\,M_\odot$
Milky Way mass ($M_\mathcal{G}$) $\approx 1000 \times 10^9\,M_\odot$
Milky Way bulge stellar mass $\approx 10^{-2}\,M_\mathcal{G}$
Observable Universe mass $\approx 1000 \times 10^9\,M_\mathcal{G}$

C – Timescales

Solar system scales

Solar rotation period $\approx 28\,\mathrm{d}$
One year (yr) $\approx 3 \times 10^7\mathrm{s}$
Orbital period Jupiter $\approx 12\,\mathrm{yr}$
Orbital period Neptune $\approx 165\,\mathrm{yr}$

Galactic scales

Milky Way rotation period $\approx 200\,\mathrm{Myr}$
Traces of life on Earth $\approx 4\,\mathrm{Gyr}$ (ago)
Age of the Universe $\approx 13.8\,\mathrm{Gyr}$

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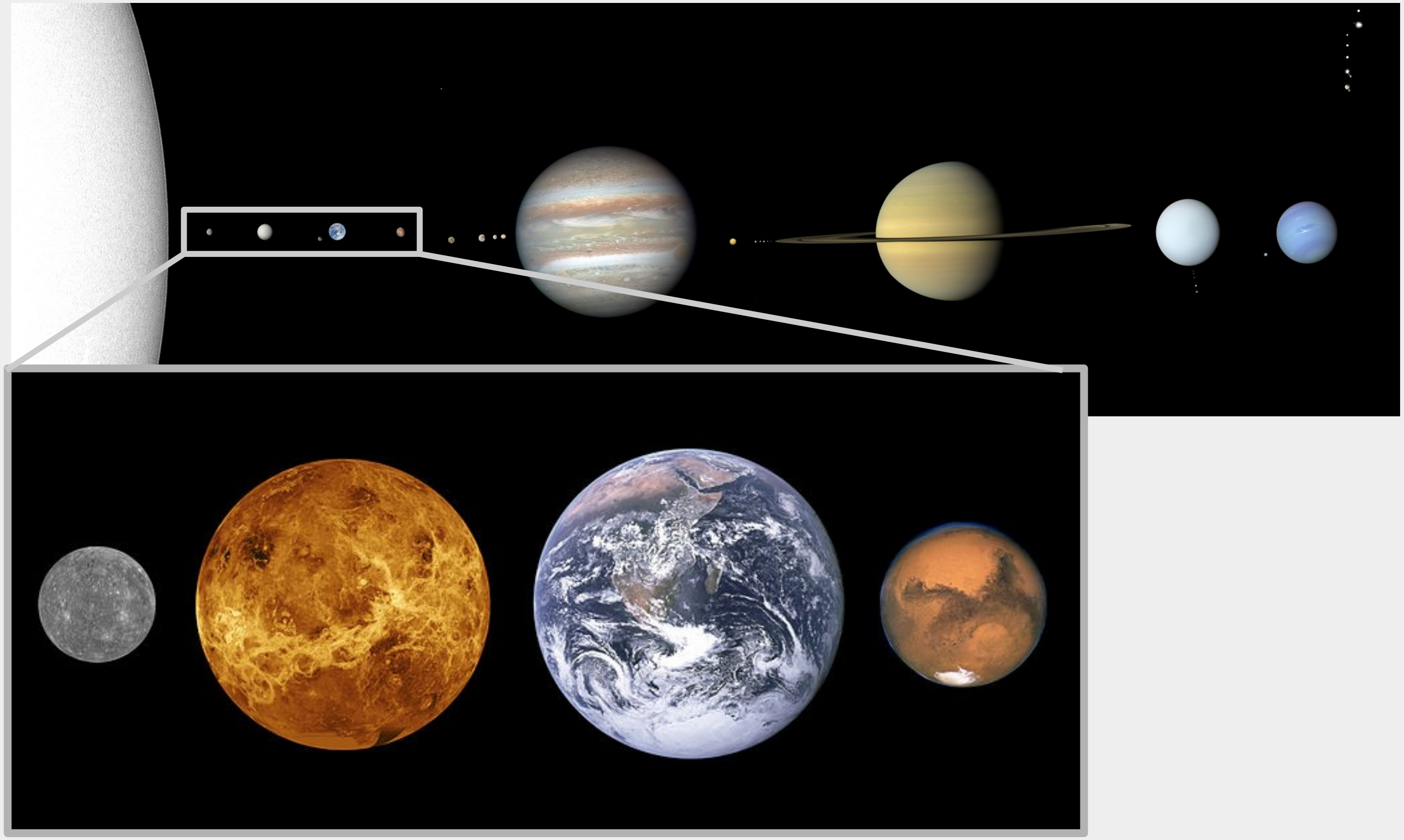
A – Planets

Solar system

Telluric vs Gazeous



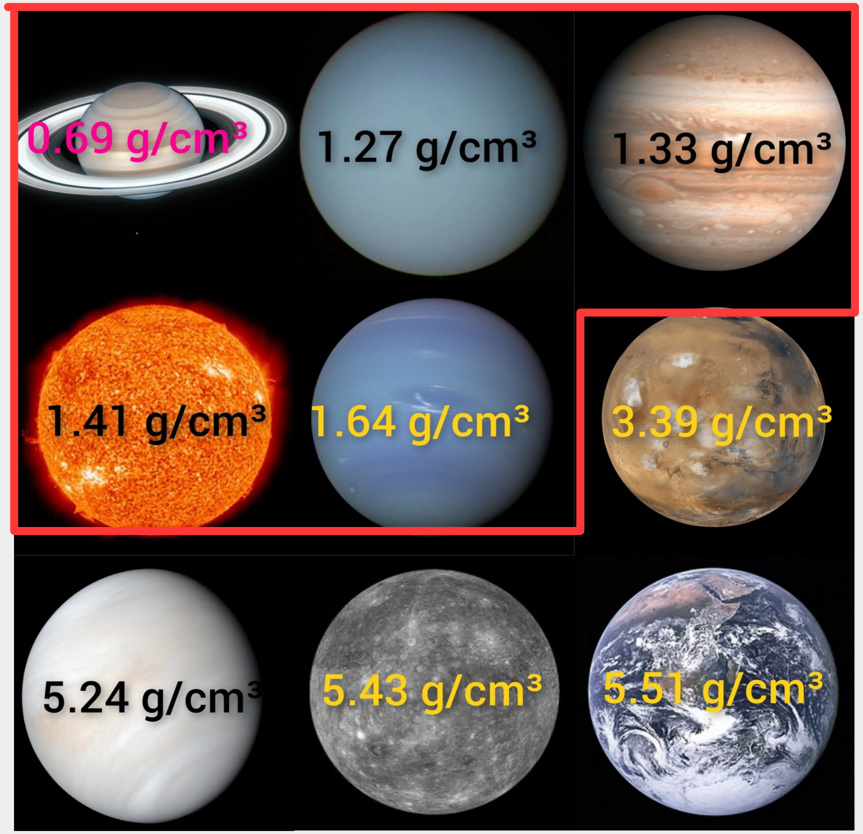
A – Planets

Solar system

Telluric vs Gazeous

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

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



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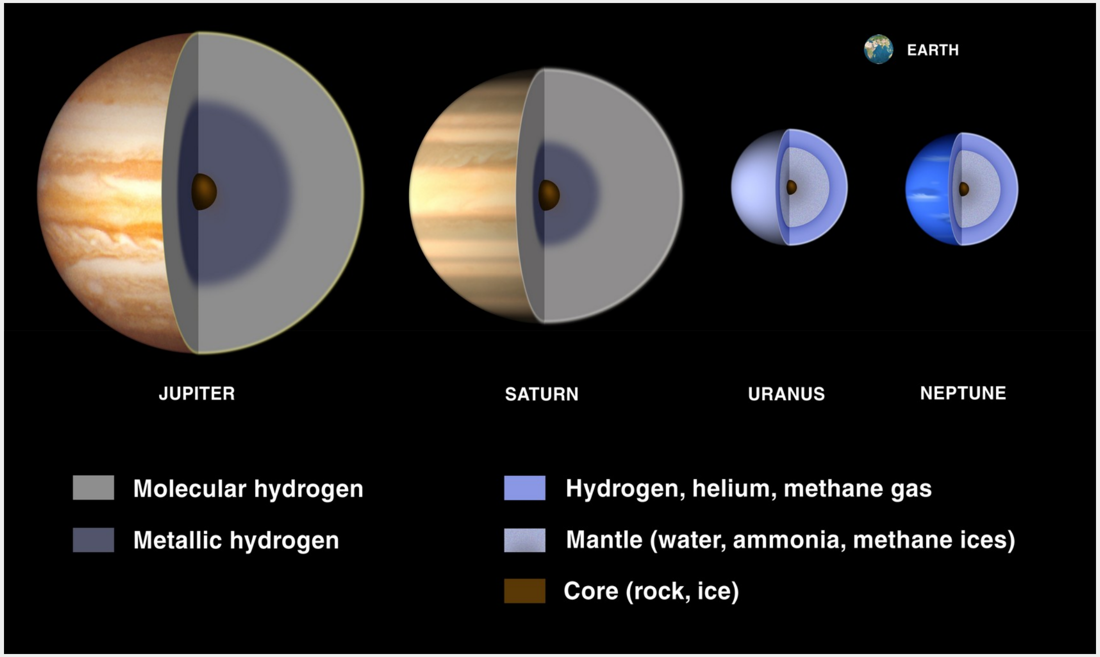

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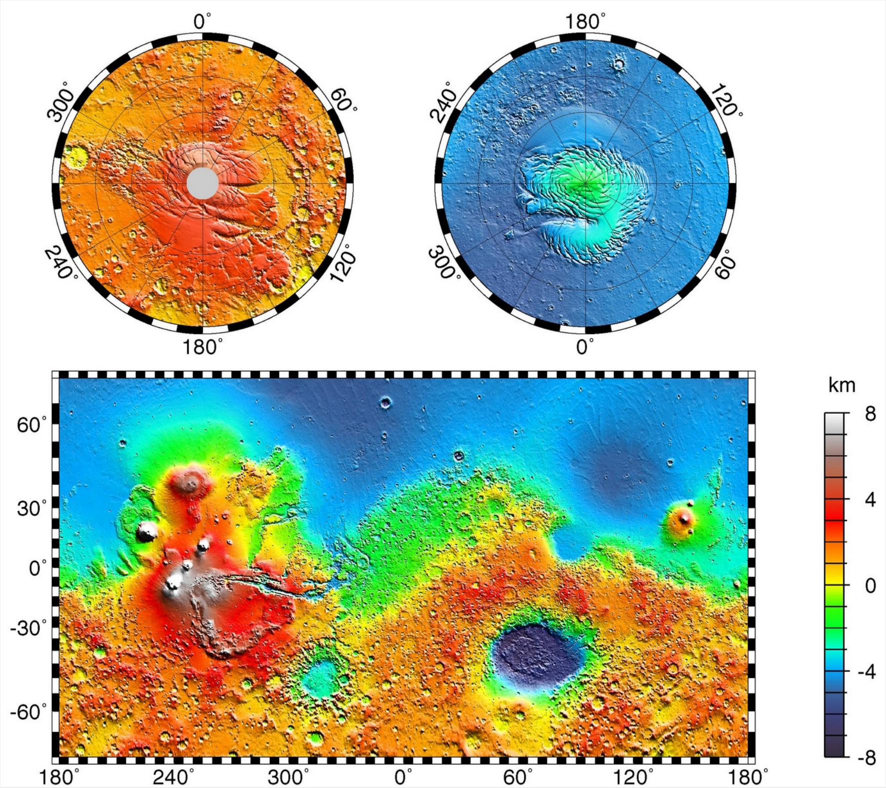
Bodies surfaces

→ Shaped by their composition & past/present volcanic activity

Mars topography:



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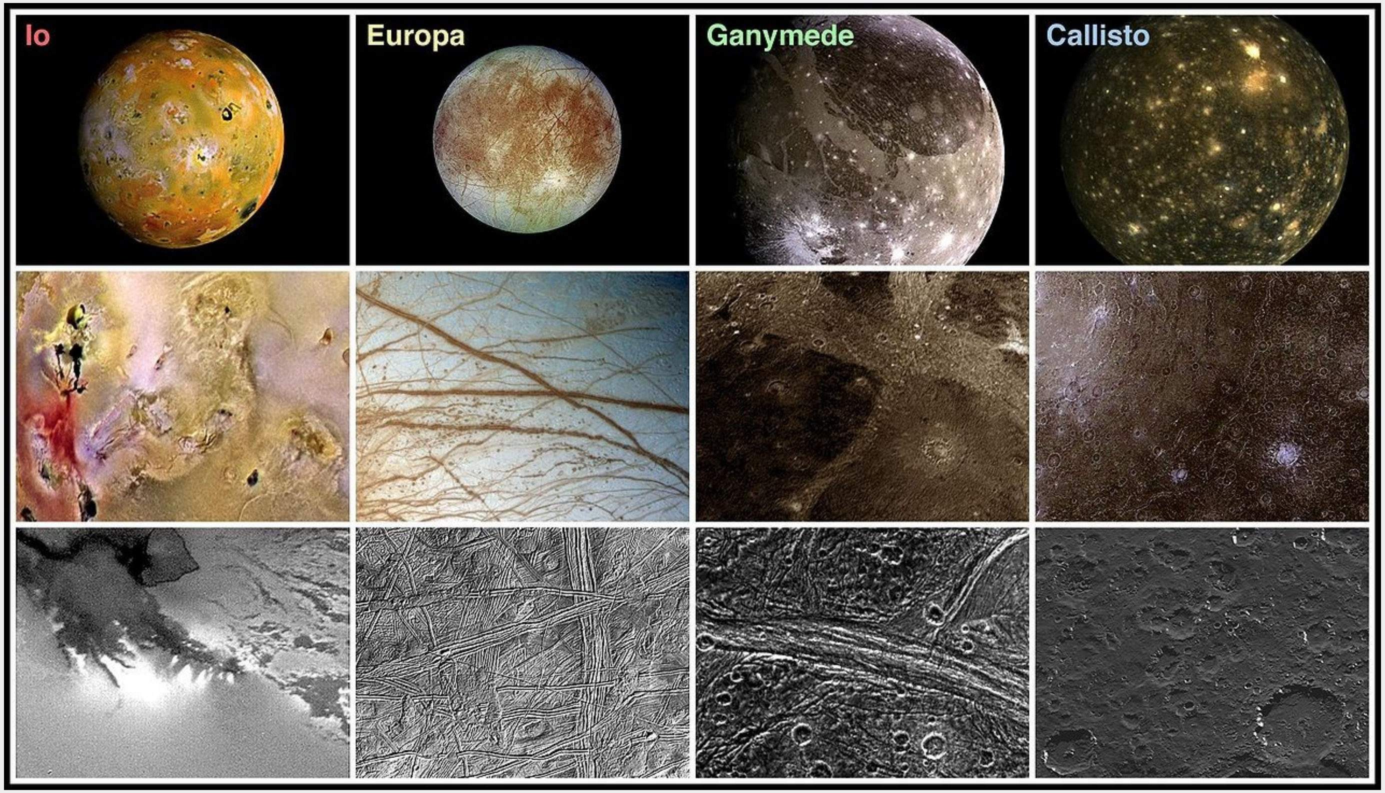
Galilean moons of Jupiter:



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Matter under extreme conditions w.r.t. Earth

→ Temperature (few 10K → 464°C → 27 million°C)

→ Pressure (3.6 million atm, ~50 million atm, 265 billion atm)

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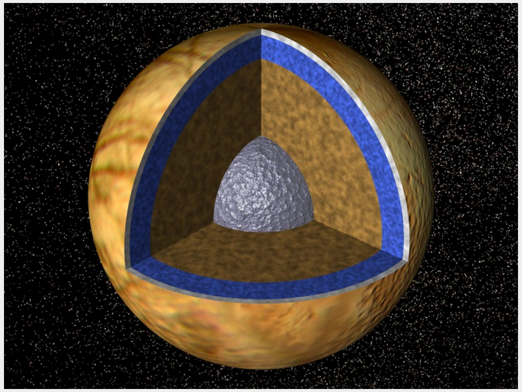
What about water?

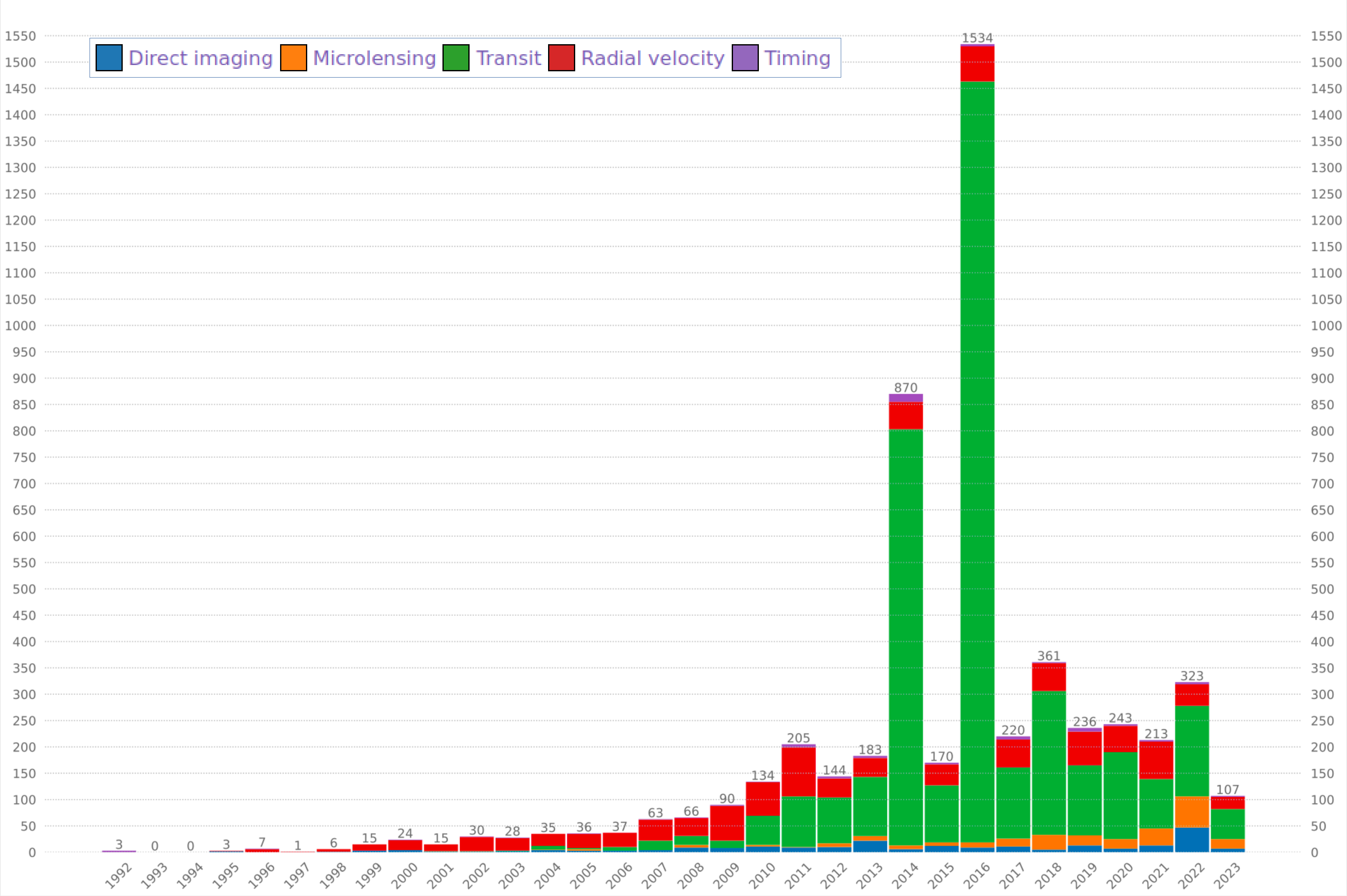
→ Detected in many bodies (ice or gas) but not liquid yet!

Europa presumed internal structure:



A – Planets

Exoplanets : the quest!



http://exoplanet.eu/

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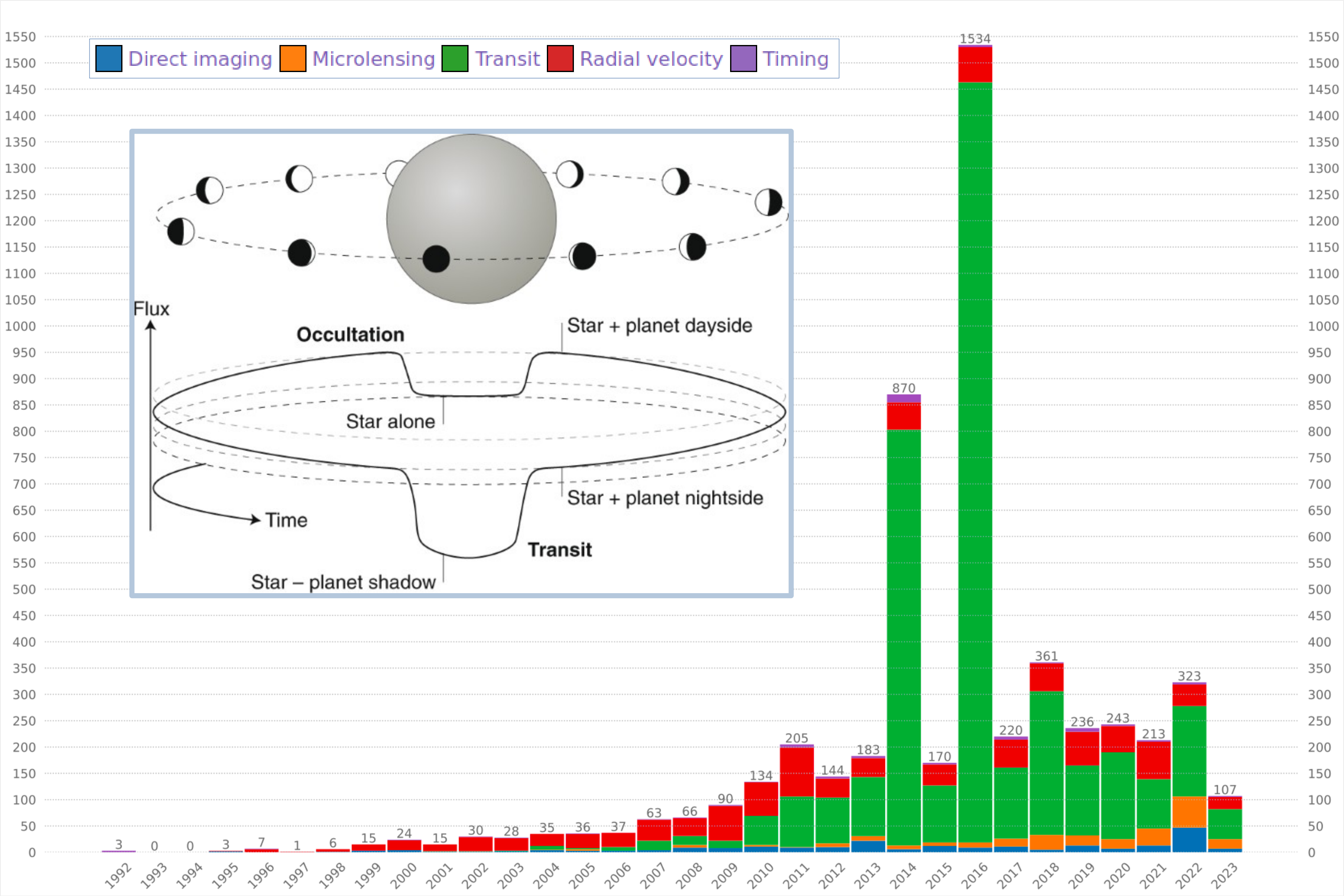

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B – Stars

Stars luminosity

→ Stephan Boltzmann law L(R,T)

[Blackboard]

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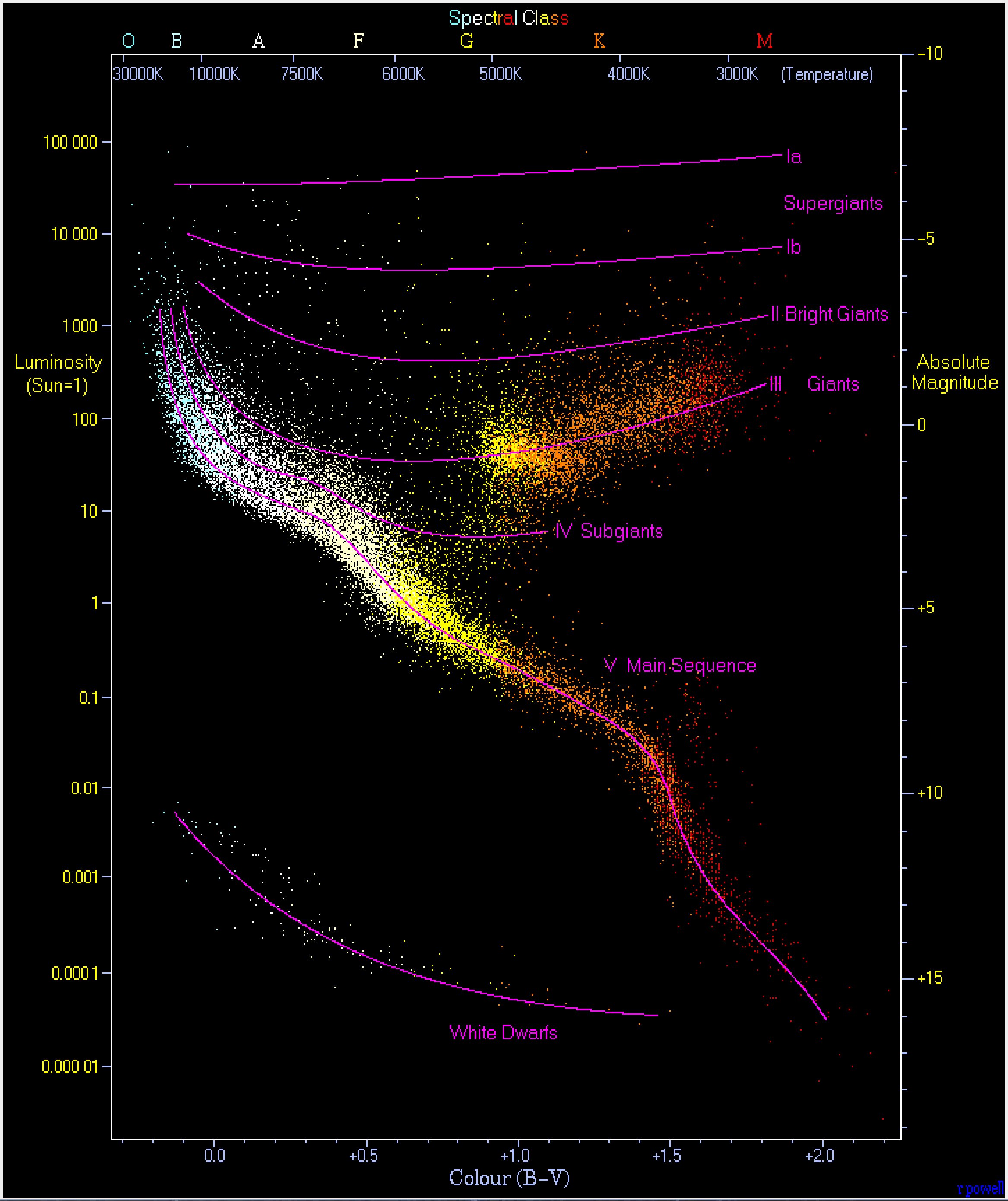

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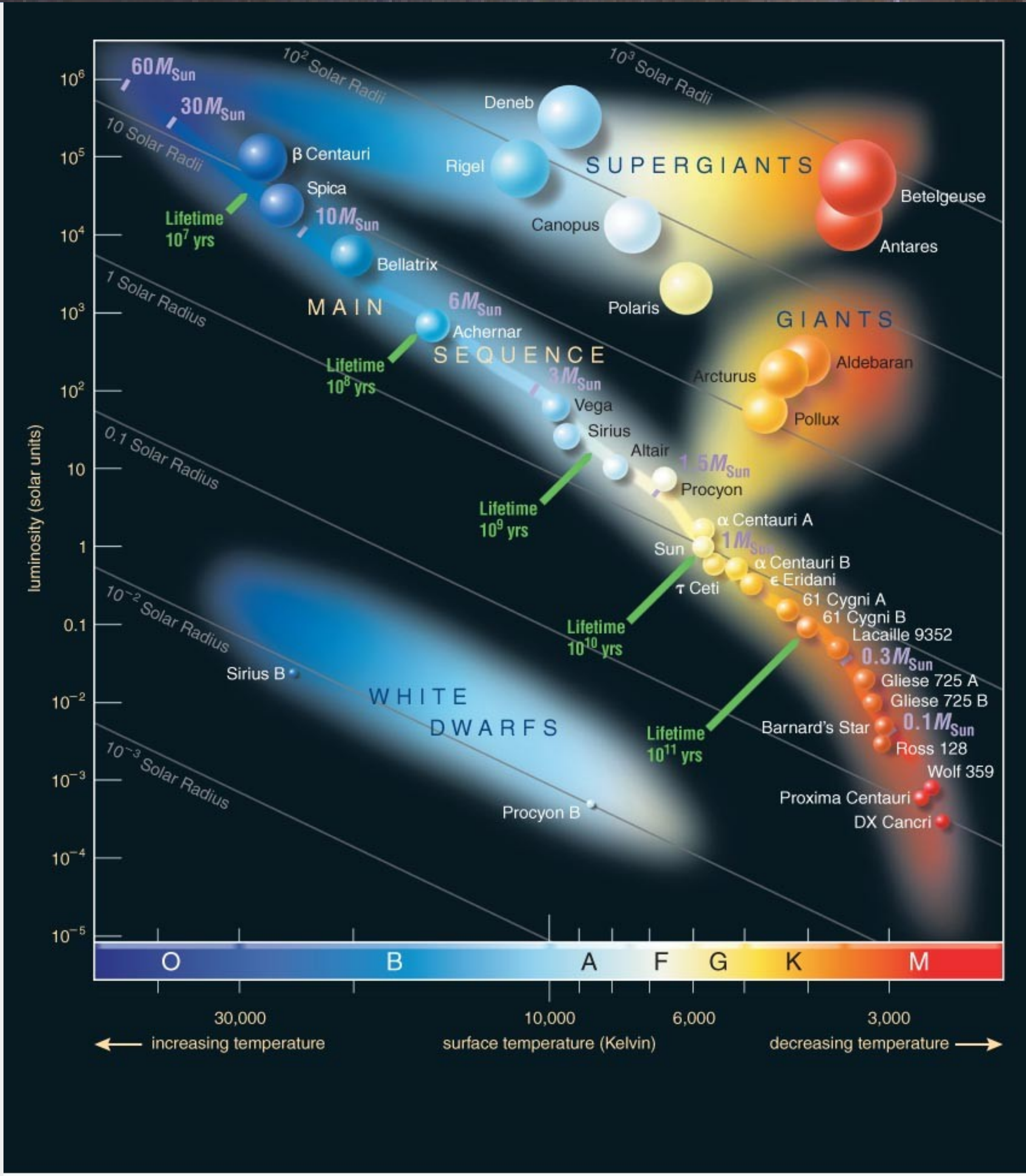

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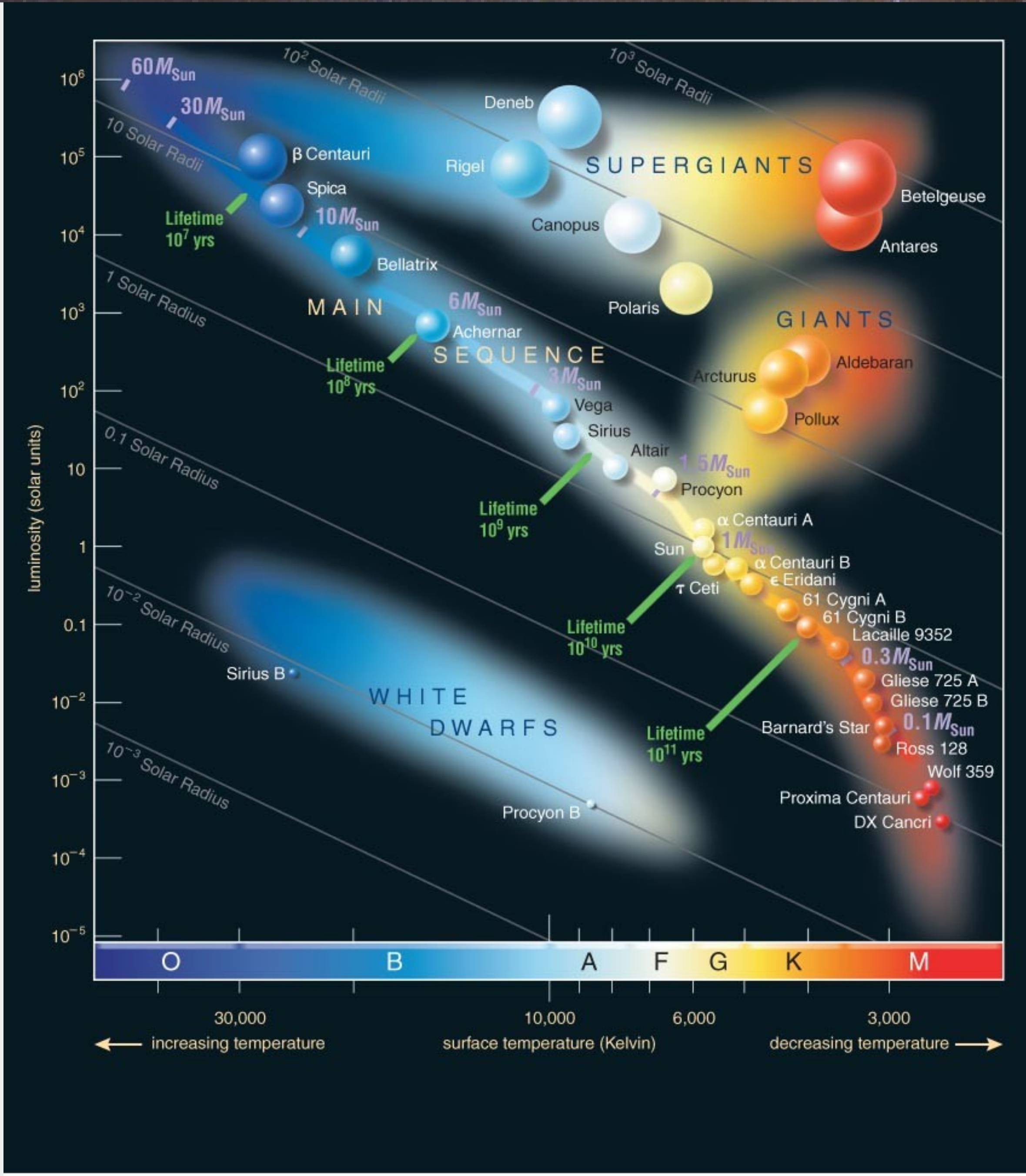
HR diagram

→ 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 (^{2}H fusion)
→ Horizontal branch (Giants, Supergiants)
He fusion in core, H fusion in shell
→ White dwarfs branch

Stellar remnants

→ White dwarfs (M<8Ms)
→ Neutron stars (8Ms<M<20Ms? + SNIa)
→ Black holes (M>20Ms?)



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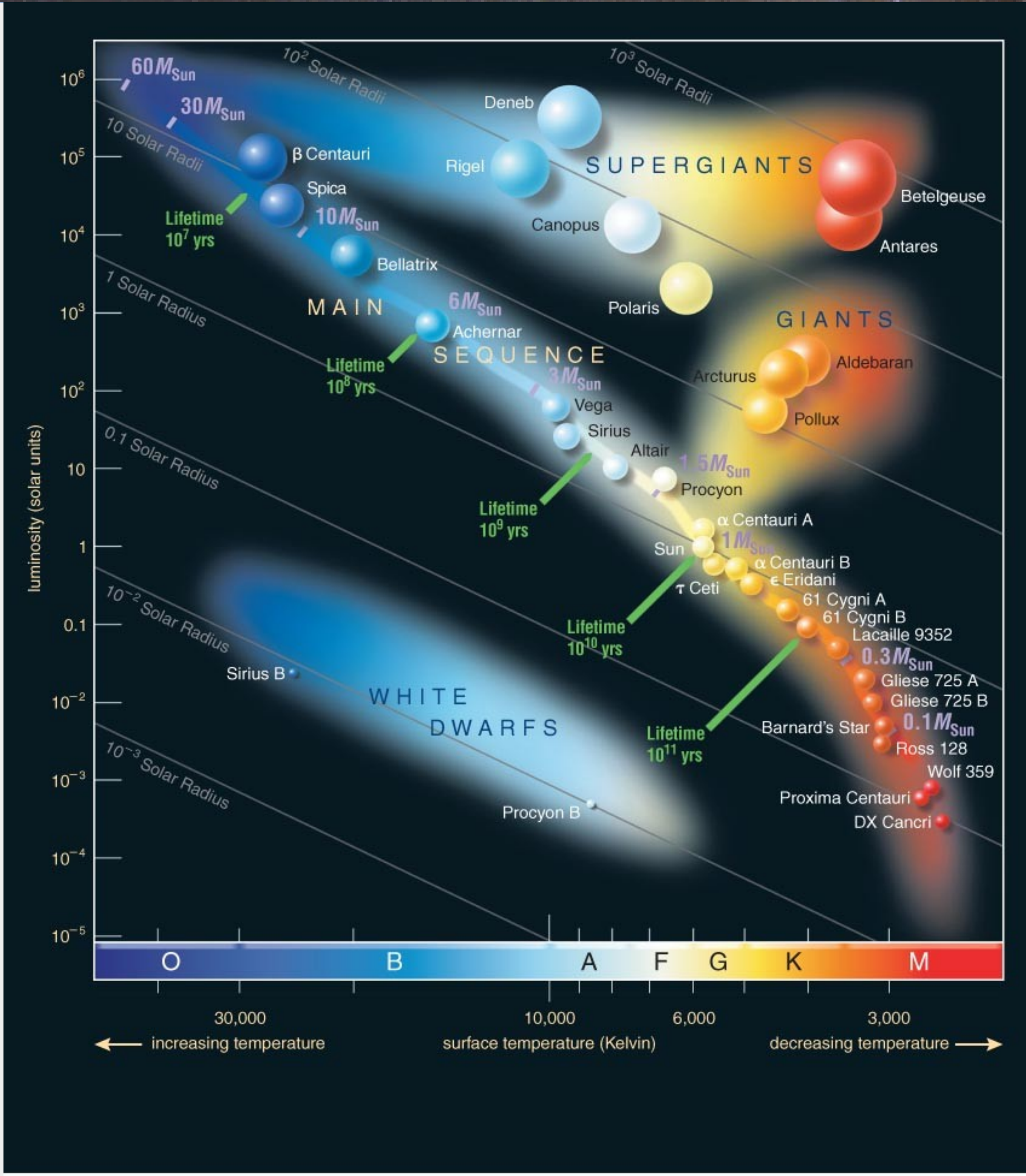
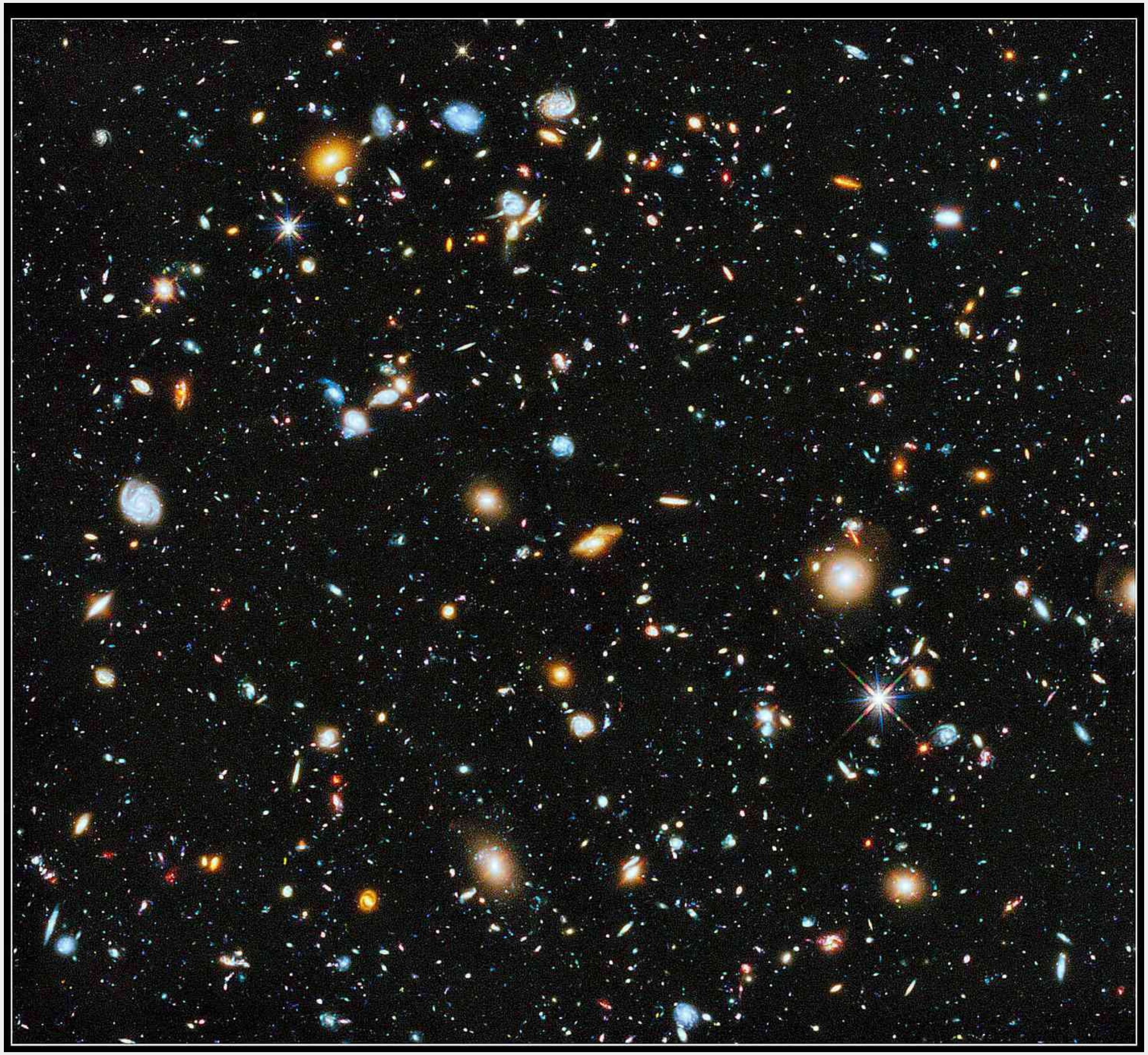


C – Galaxies



Hubble Space Telescope

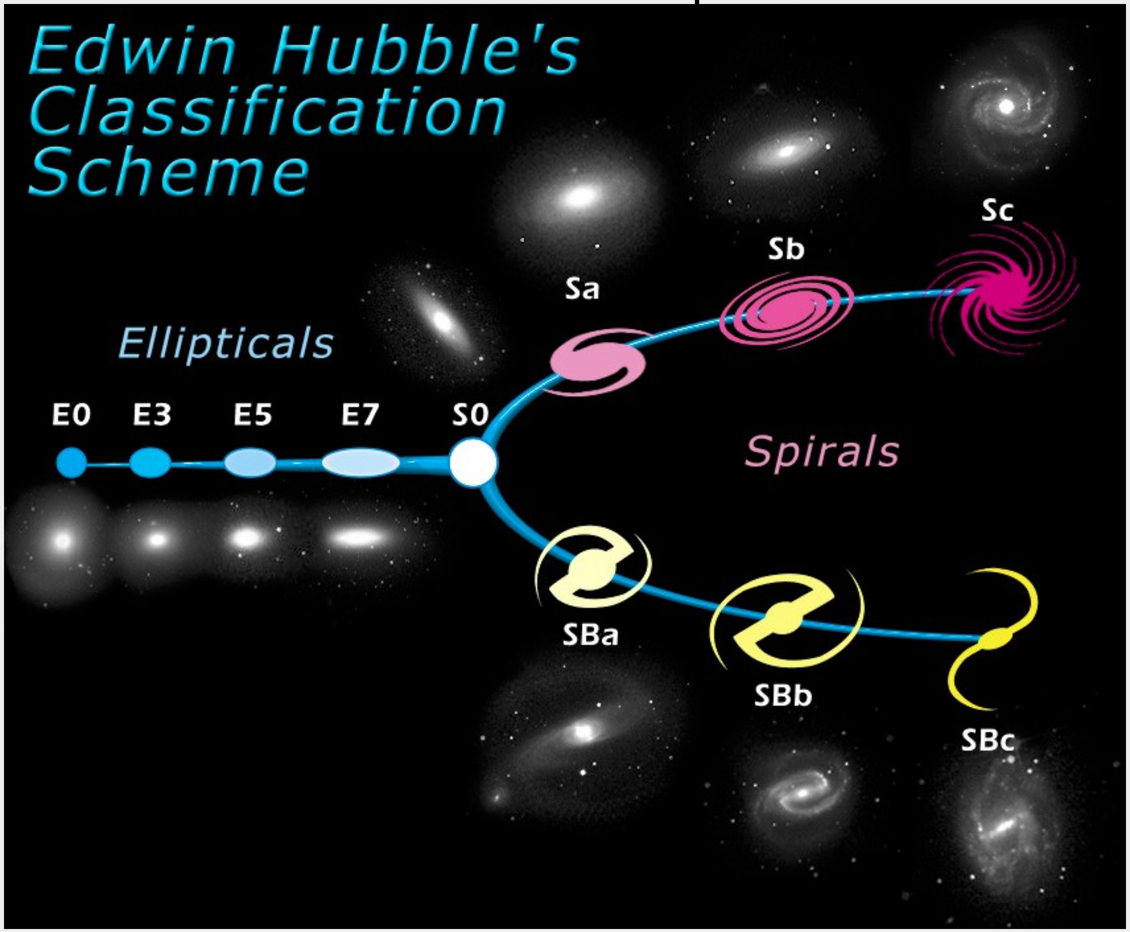
C – Galaxies

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 [~25%]
- Featureless light distribution
- E= 10 x (1-b/a)
- Little interstellar matter / old stars
- Incl. largest galaxies

→ Lenticular galaxies [~25%]
- S0 : bulge + flattened disk

→ Spiral [~45%]
- Bulge + flattened disk + spiral structure
- 50% with a bar

→ Irregular galaxies [~ few %]
- no specific regular shape

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Sytems of virialized stars

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

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Sytems of virialized stars

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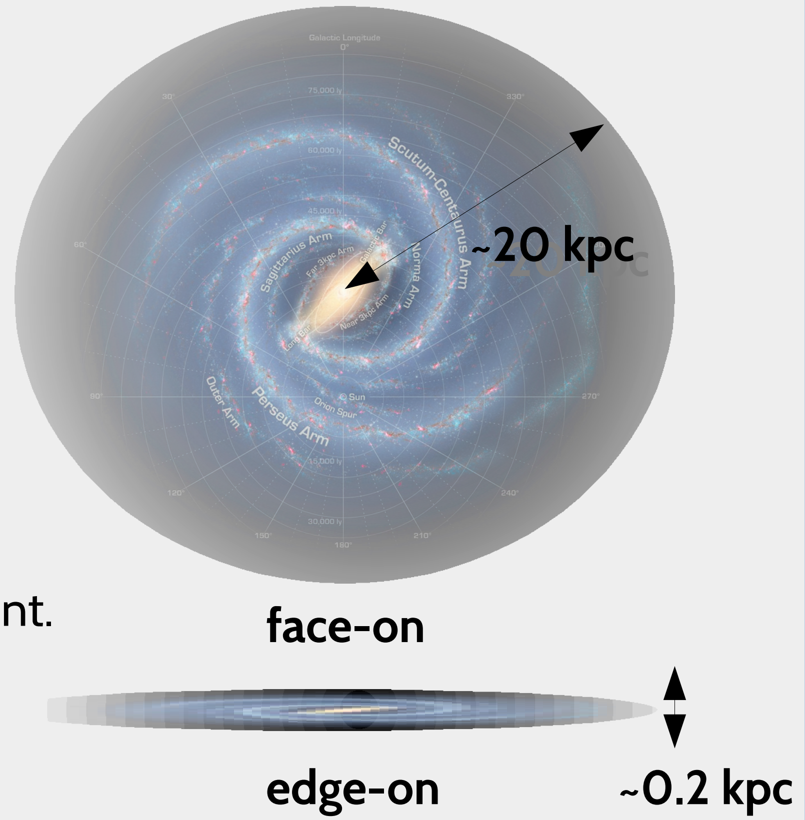
Milky Way

→ Computing the gas surface density?

- Gas ~ 1% MW mass
- 1H/m^3

→ Milky Way < Local group < Virgo supercluster < Laniakea



Milky Way modelling

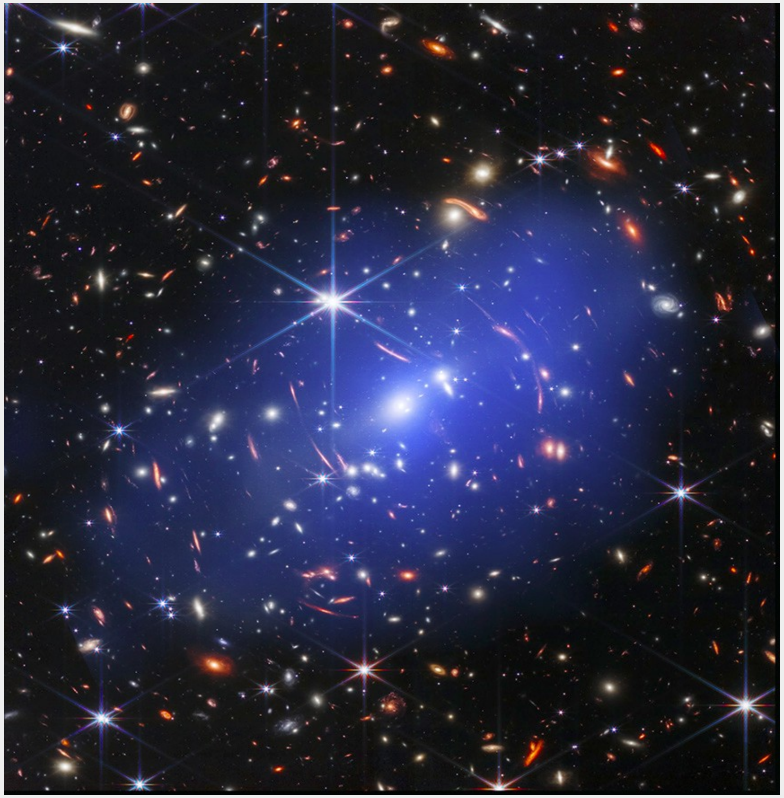
D – Galaxy clusters

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 →

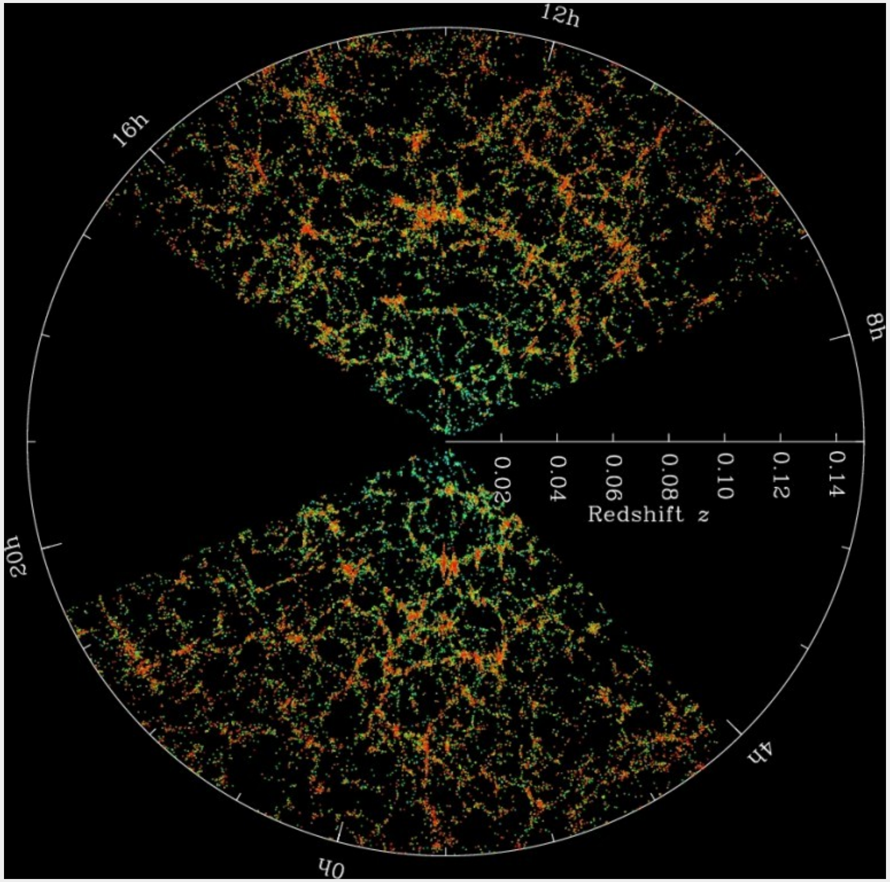


+ Chandra, X-rays
https://chandra.si.edu/photo/2022/chandrawebb/

E – Large scale structures

Generalities

→ Largest structures gravitationally bound
→ Correlations over ~1Gpc scales
→ Dominated by Dark Matter (+ gas and galaxies)
→ Filaments, sheets, voids = cosmic webb
→ 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

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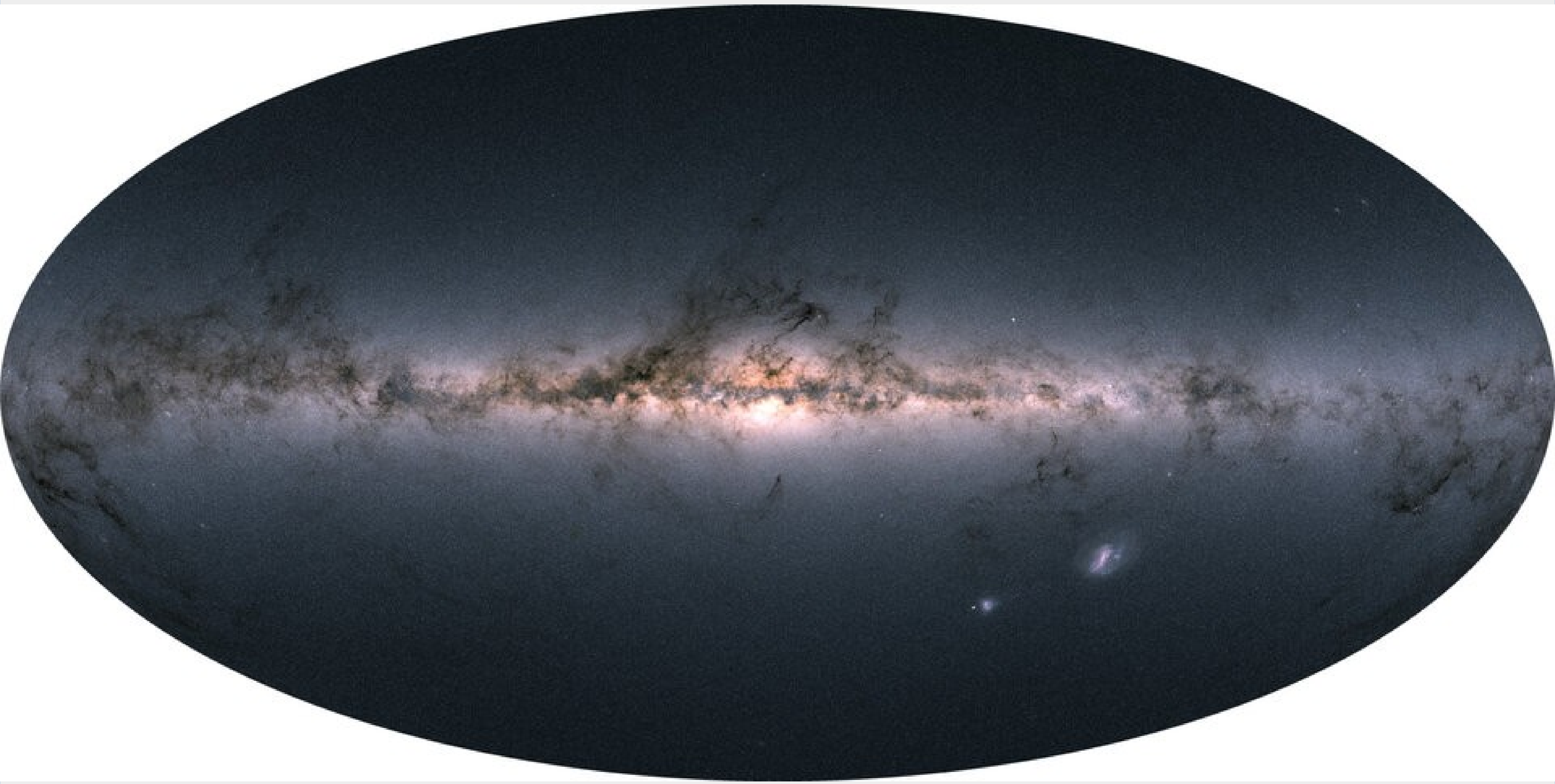
A – The differential photon flux

[Blackboard]

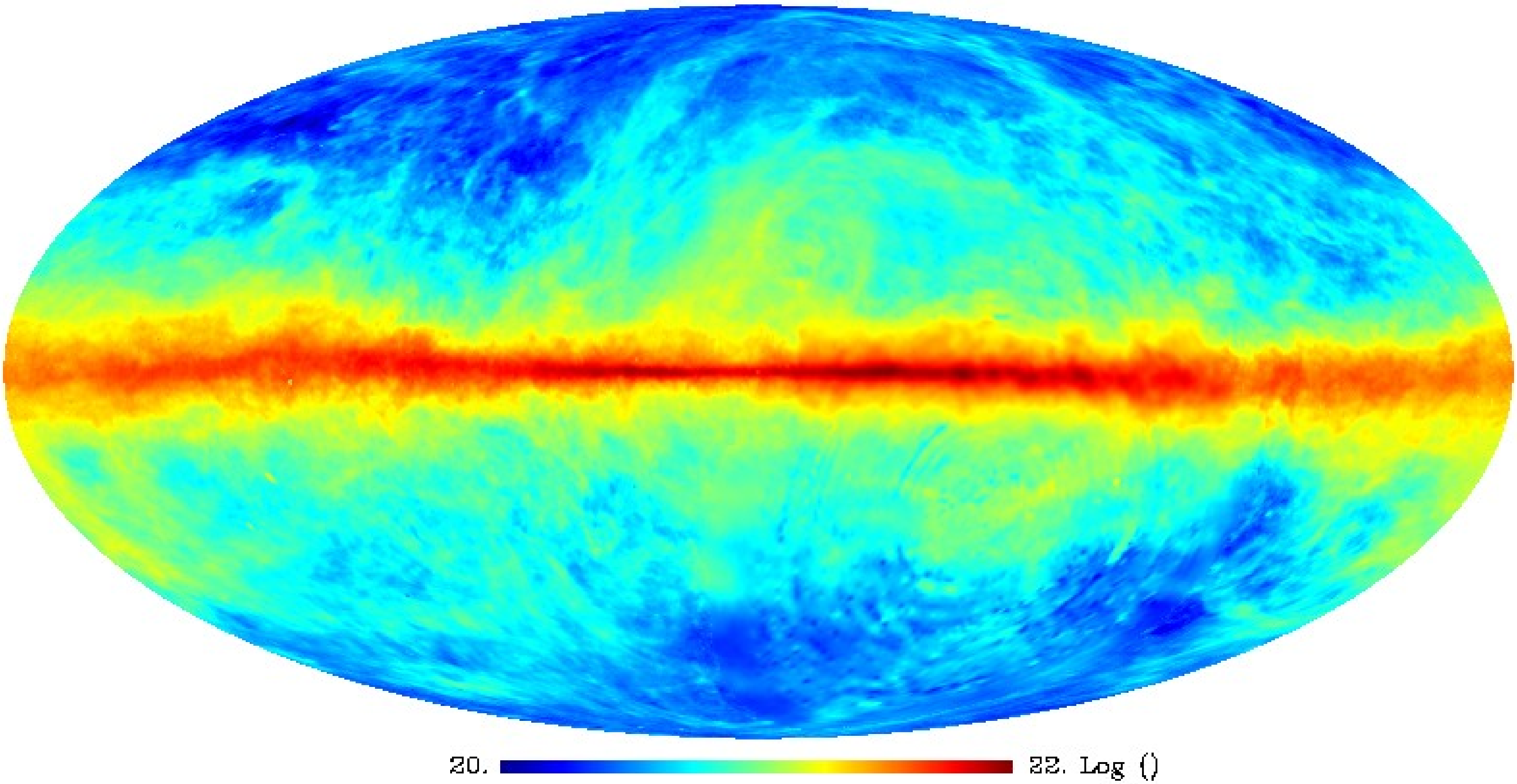
B – The multi-wavelength Galactic plane

B – The multi-wavelength Galactic plane → Visible light



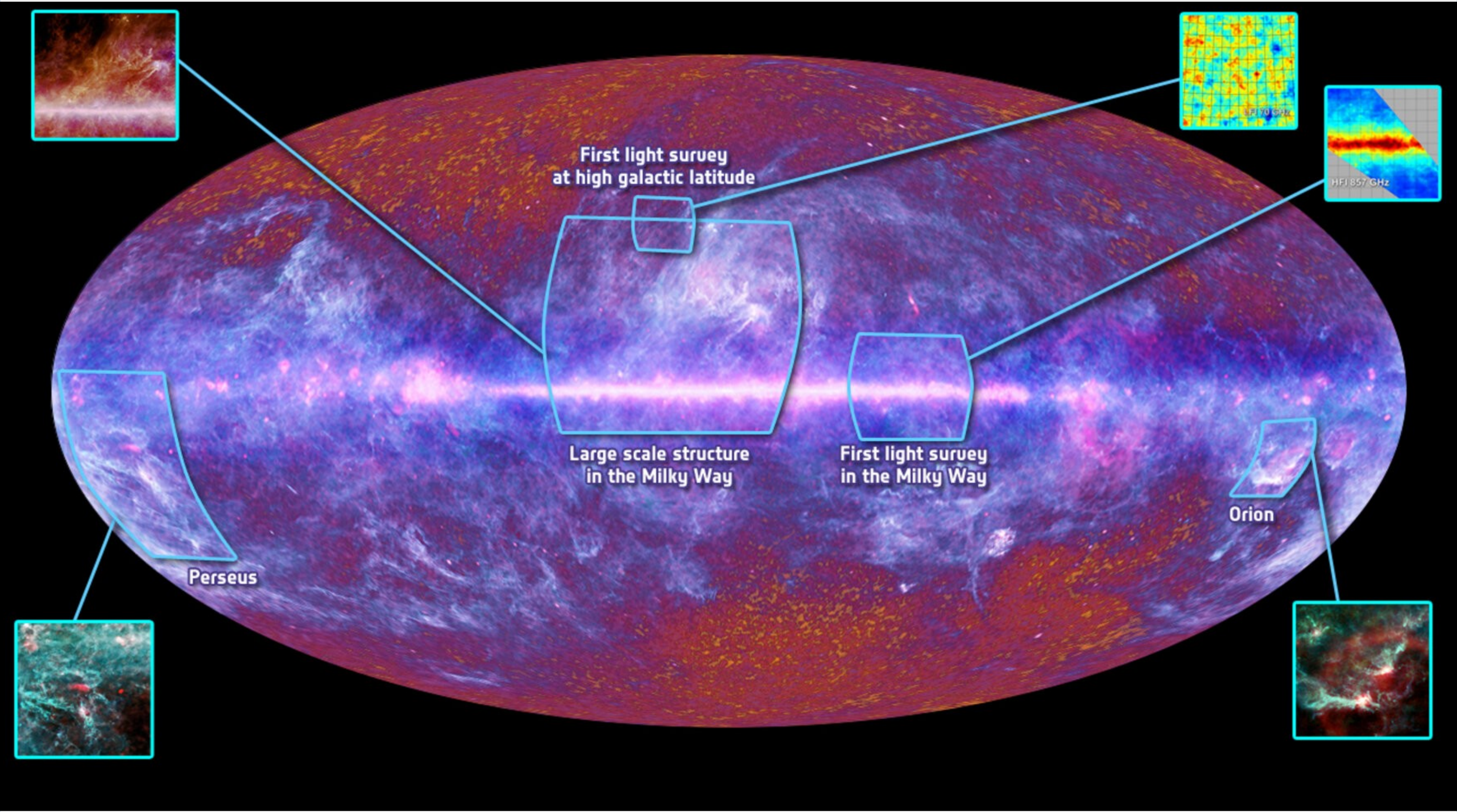
The entire sky -- 1.7 billion stars' worth — mapped by Gaia and displayed using color information also obtained by the satellite. You can see we live in a flat galaxy with a large central bulge, festooned with dark filaments of dust.
Credit: Gaia/DPAC/ESA

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



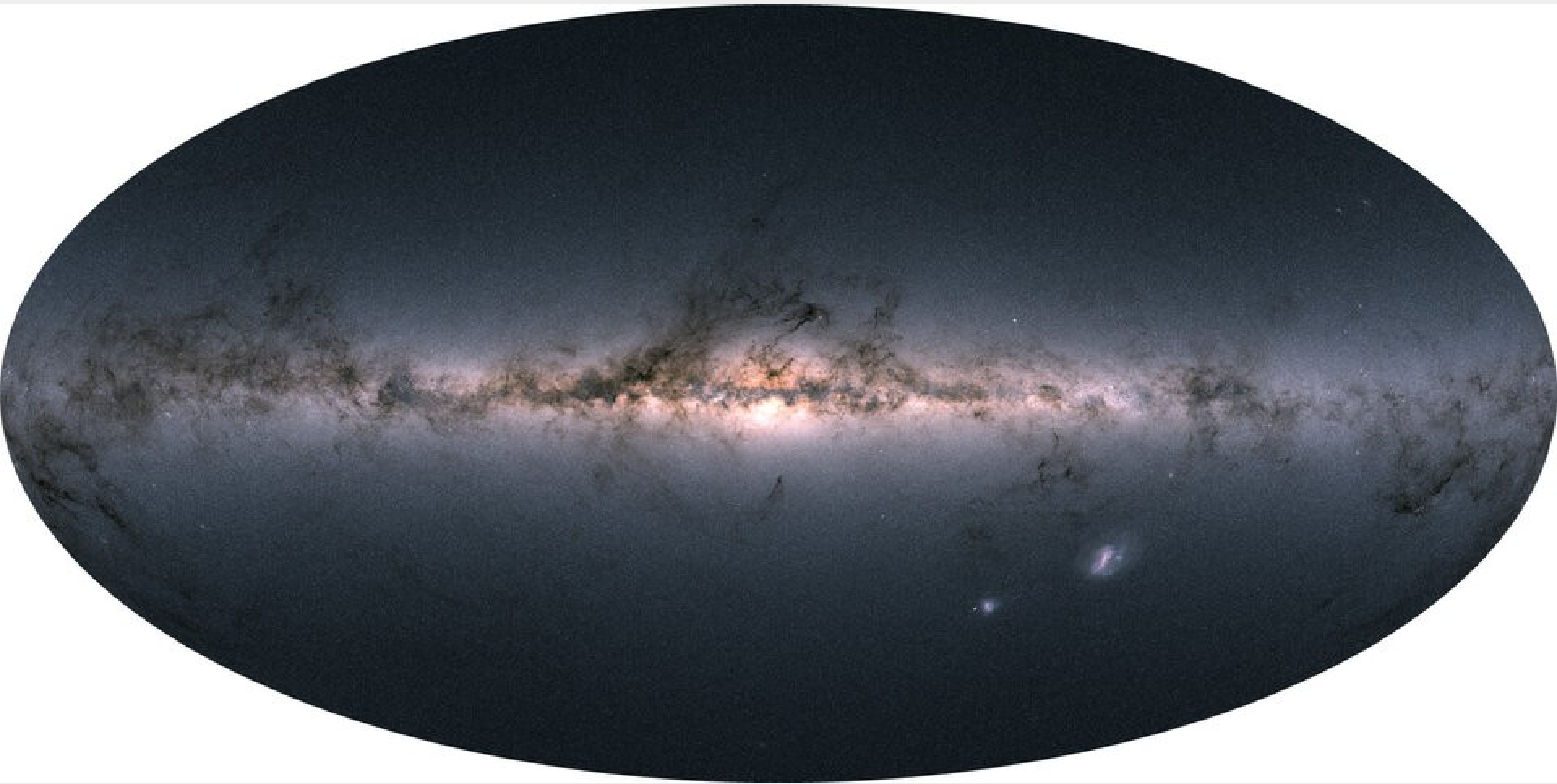
Leiden/Dwingeloo HI survey and composite NHI map of Dickey and Lockman , F.J. 1990 ARA&A 28 215 .

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



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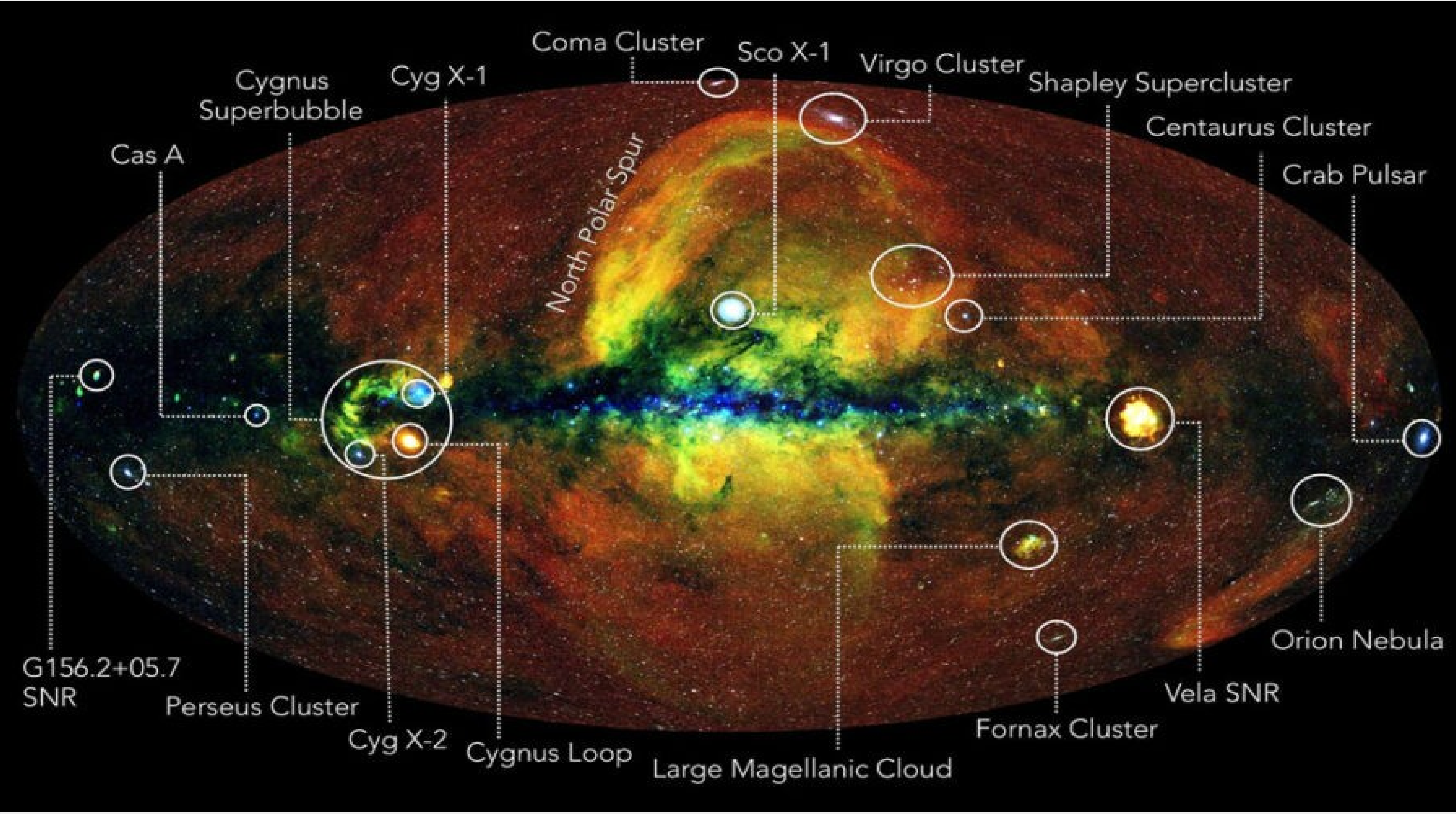
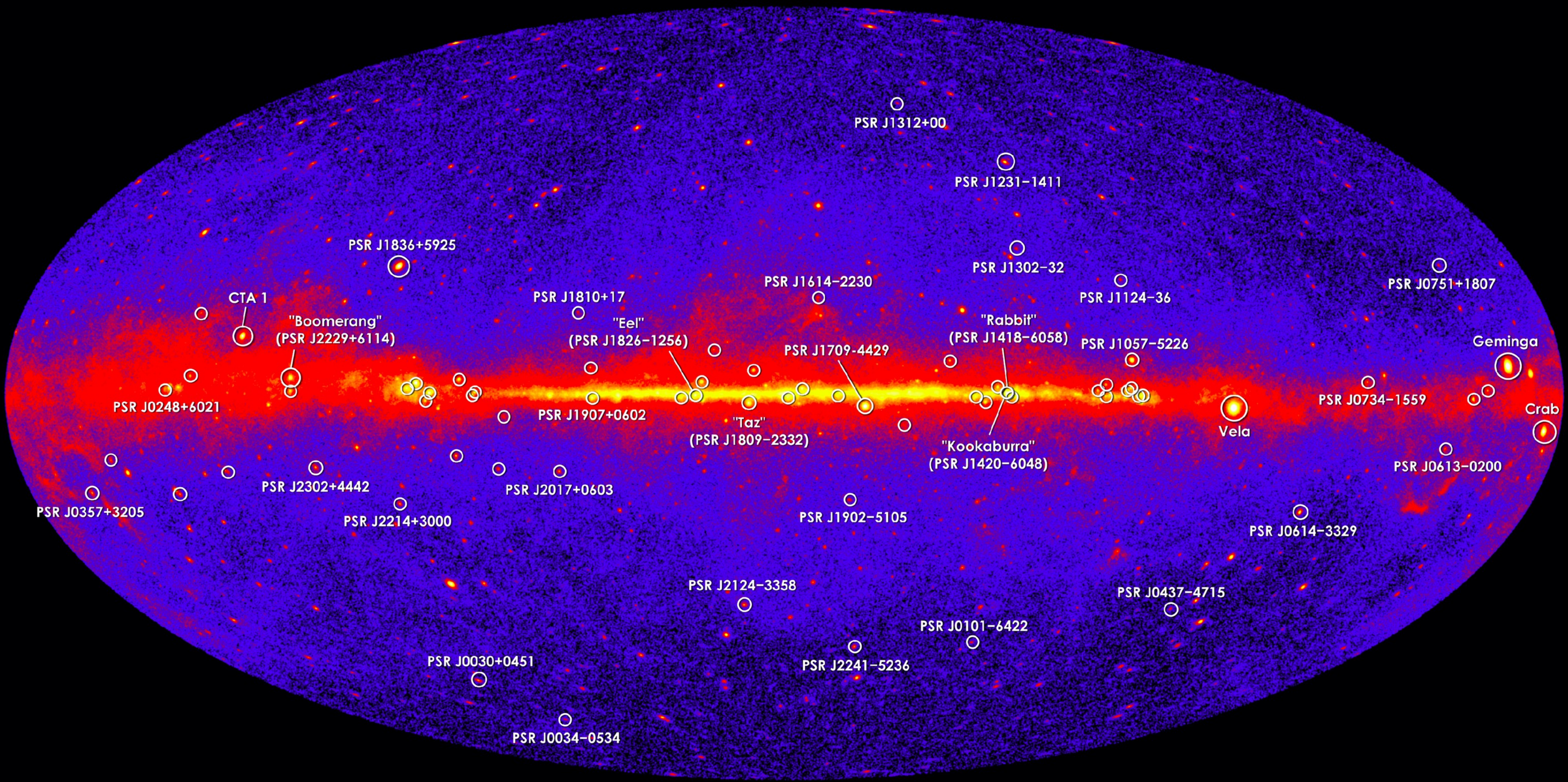
B – The multi-wavelength Galactic plane → X-rays [0.3-2.3keV]



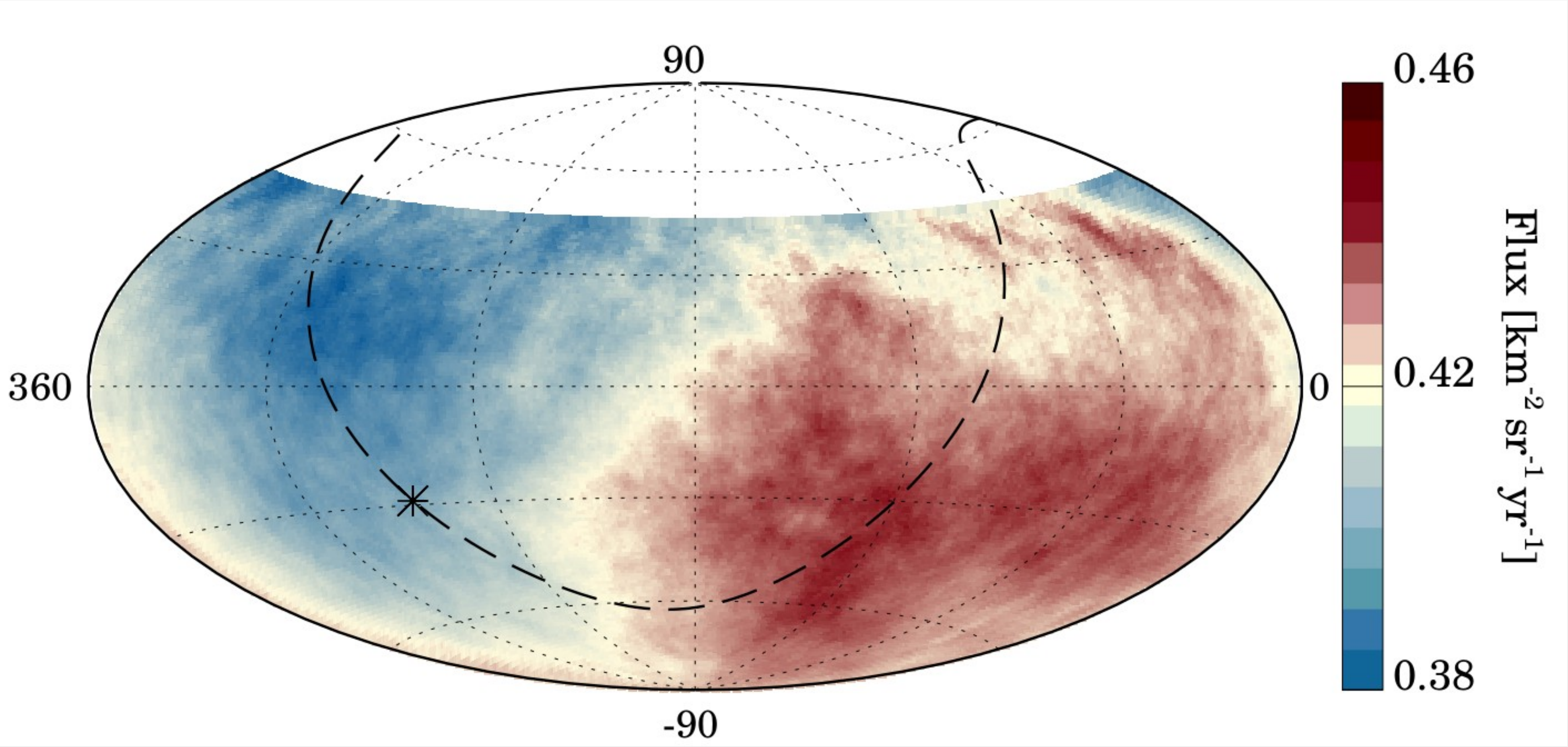
The eRosita mission : J. Sanders, H. Brunner & eSASS team (MPE) / E. Churazov, M. Gilfanov (on behalf of IKI)

B – The multi-wavelength Galactic plane → Gamma-rays [>1GeV]



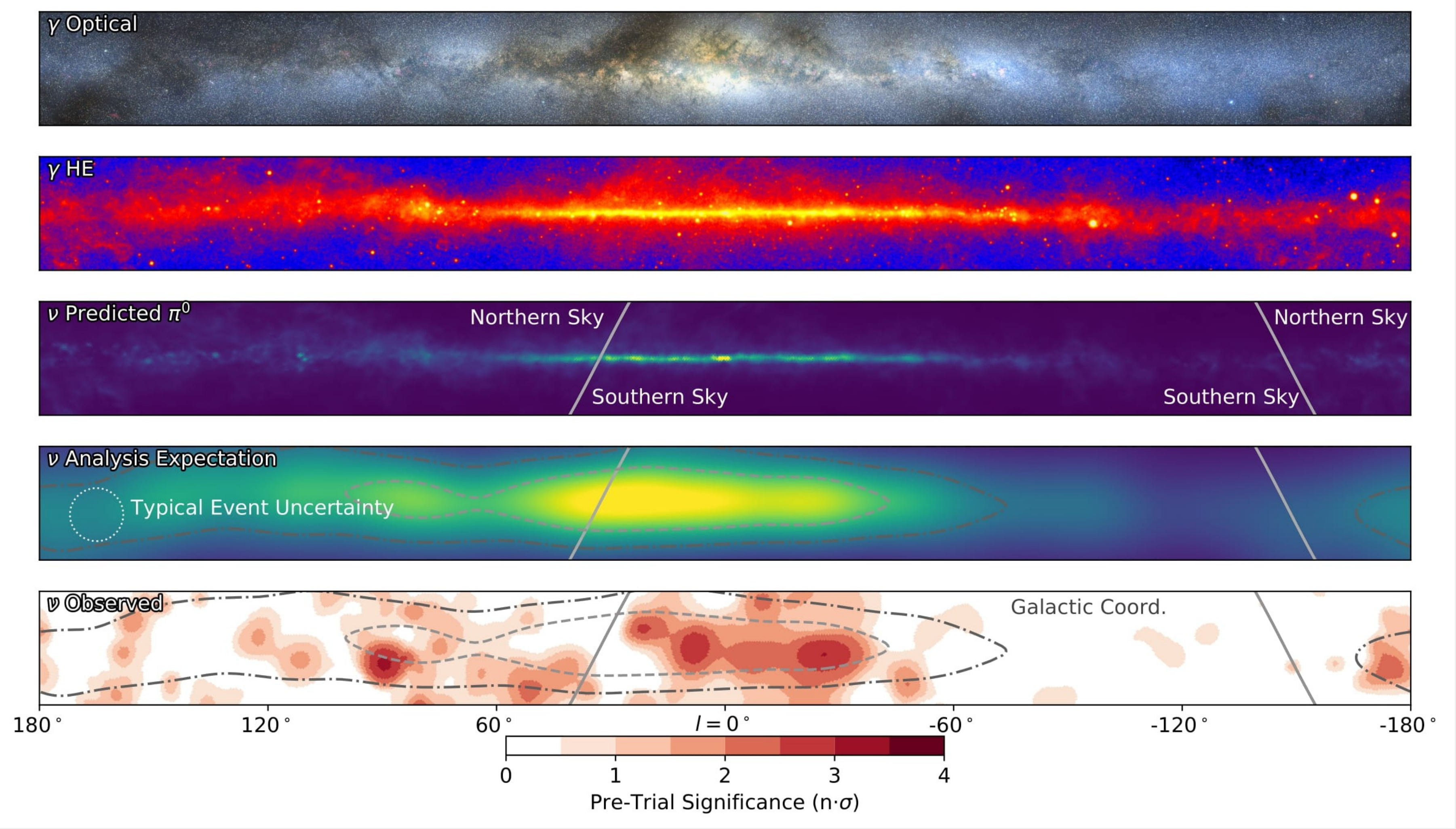
The Fermi LAT 60-month image, NASA/DOE/Fermi LAT Collaboration

C – Other messengers? → Cosmic-rays



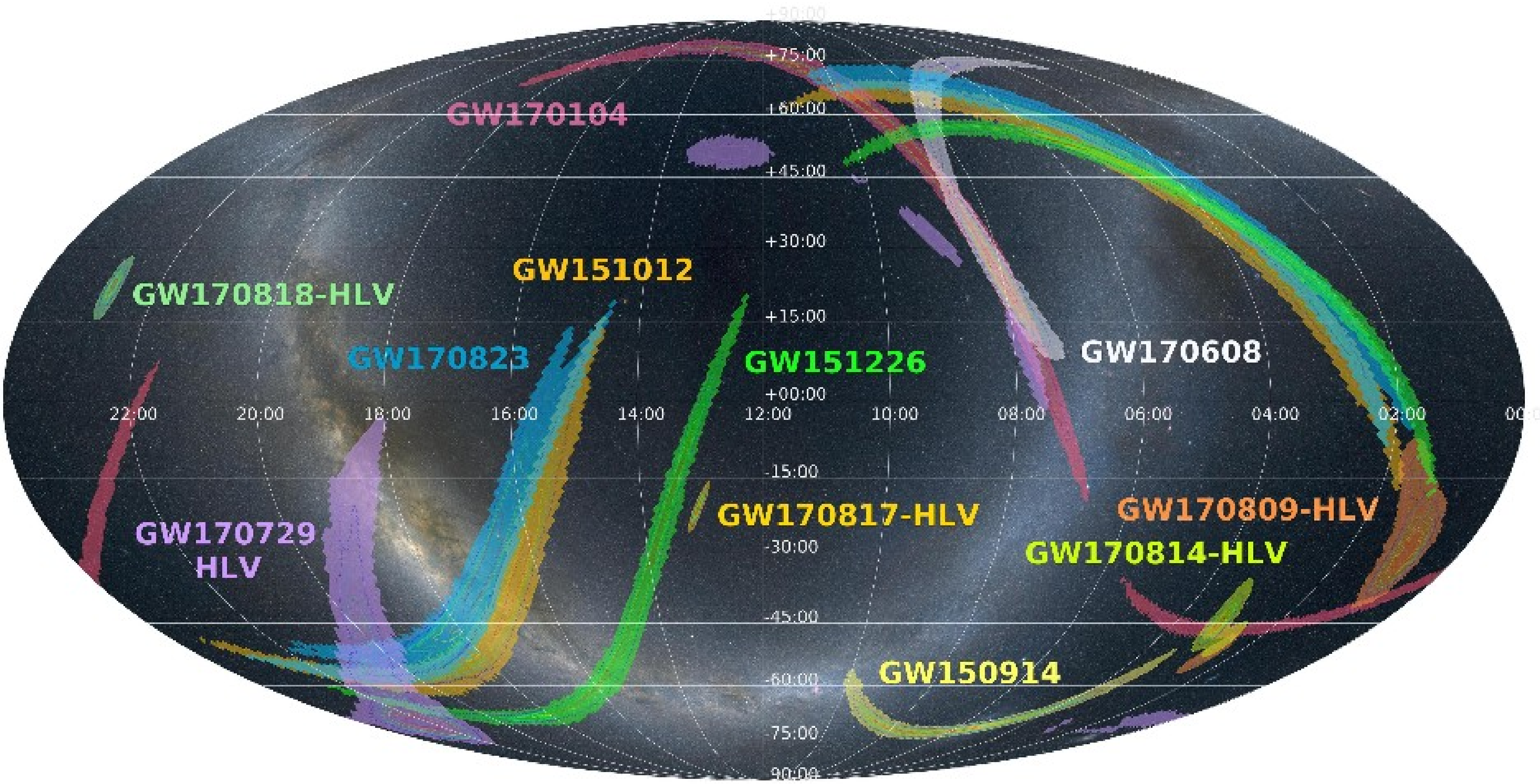
UHECR Flux with E > 8 EeV measured by the Pierre AUGER observatory. https://arxiv.org/pdf/1808.03579.pdf

C – Other messengers? → Neutrinos



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

C – Other messengers? → Gravitational waves

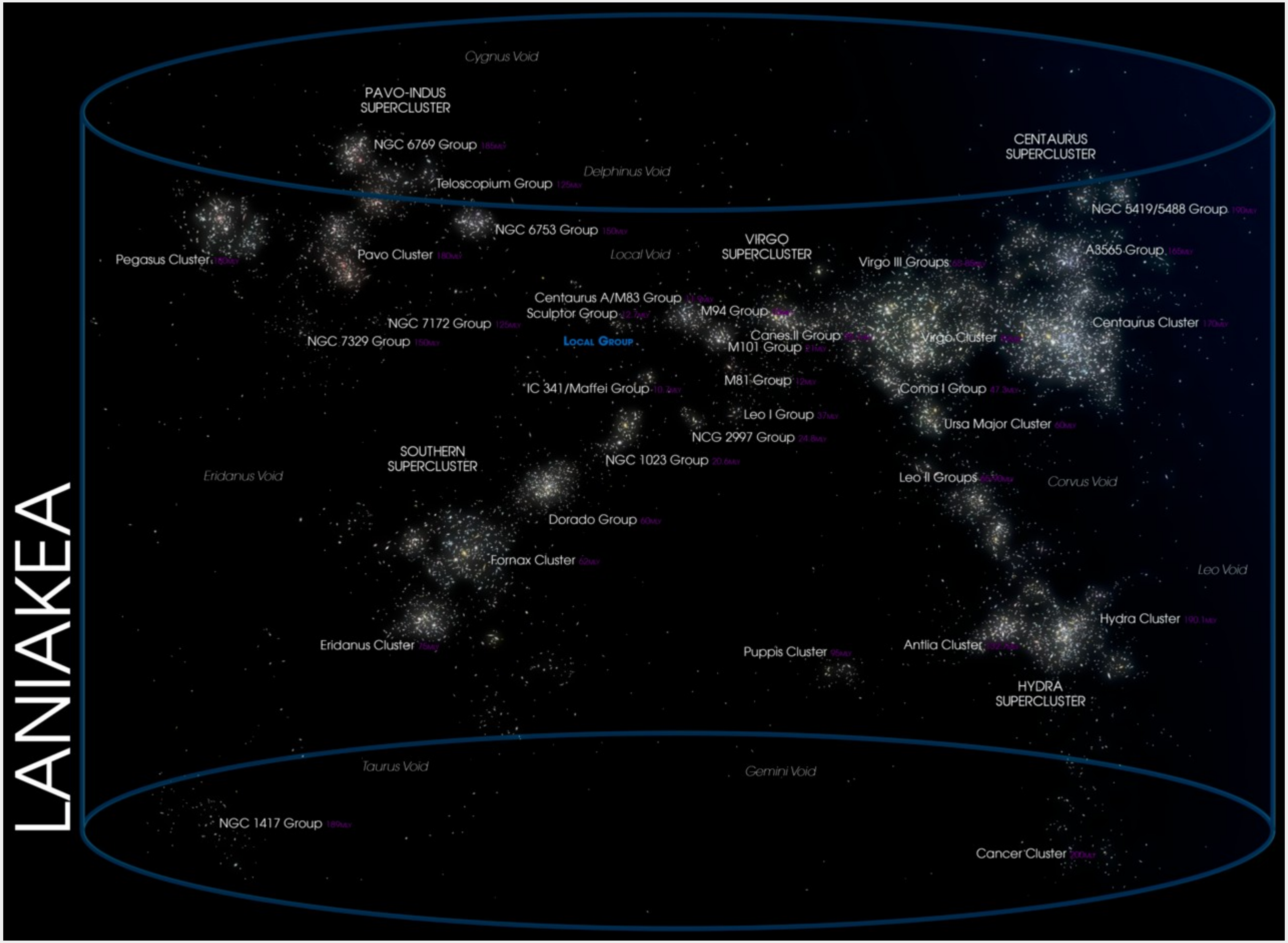


https://dcc.ligo.org/public/0094/P1200087/057/ObservingScenarios.pdf

Questions?

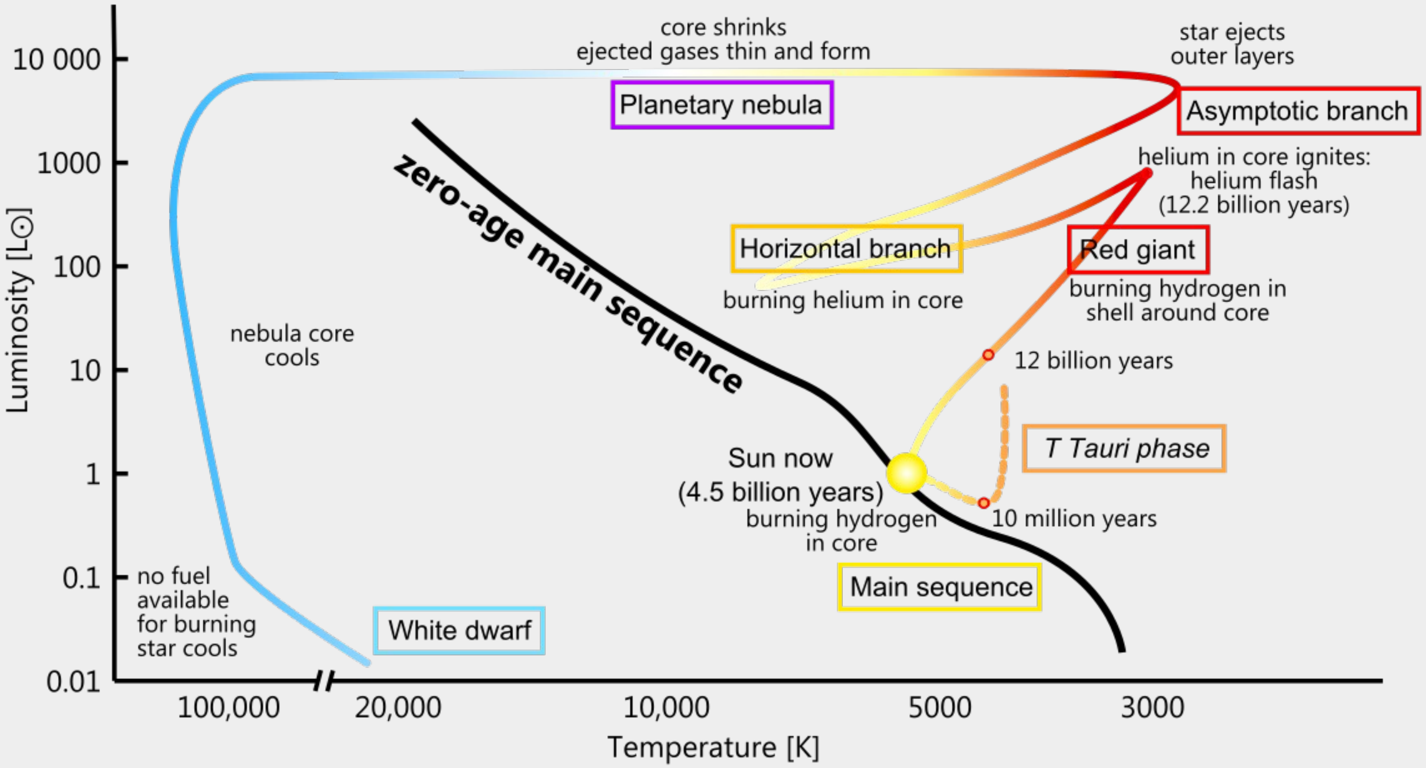
Backups

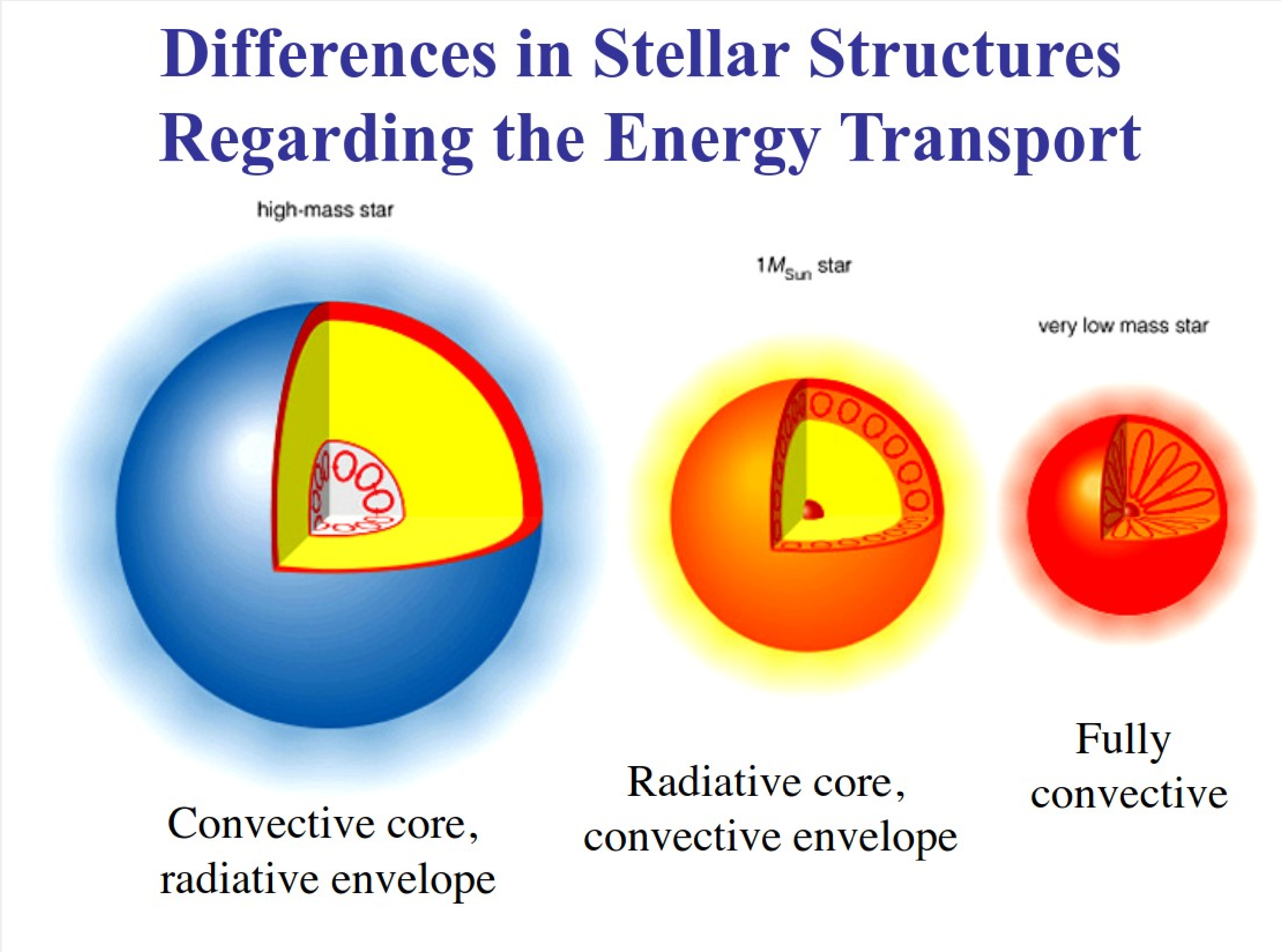
D – Galaxy clusters



Backups

	~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





https://sites.astro.caltech.edu/~george/ay1/lec_pdf/Ay1_Lec09.pdf