Basi di astronomia gamma

Stanford University

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SLAC (Stanford University)

SLAC NATIONAL ACCELERATOR LABORATORY

Dipartimento di Fisica Torino, Fermi-LAT Masterclass, April 5, 2017

http://www.bbc.com/earth/story/20160610-it-took-centuries-but-we-now-know-the-size-of-the-universe

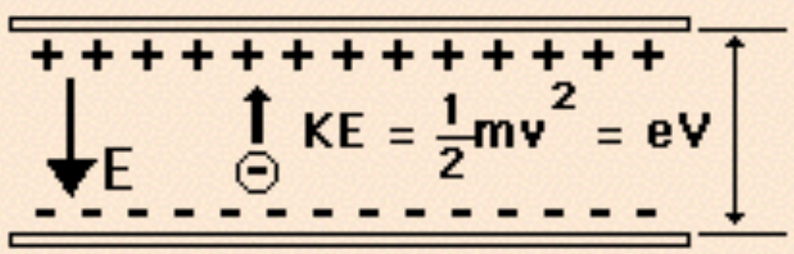
Who I am?

- Post-Doctoral researcher in University of Stanford since 2015.
- I got my master degree in Physics in the University if Turin (Italy).
- I graduated with a joint program between the University of Turin and University of Grenoble in indirect search of Dark Matter.
- I am working for the Fermi Large Area Telescope a satellite that measures gamma rays the most energetic form of light on the Universe.
- Personal websites:
    A. https://profiles.stanford.edu/mattia-di-mauro
    B. https://sites.google.com/site/dimauromattia/home-1
- email: mdimauro@slac.stanford.edu

Definition of eV

Electron Volts

A convenient energy unit, particularly for atomic and nuclear processes, is the energy given to an electron by accelerating it through 1 volt of electric potential difference. The work done on the charge is given by the charge times the voltage difference, which in this case is:



$E = qV = (1.6 \times 10^{-19}\ C)(1\ \frac{J}{C})$

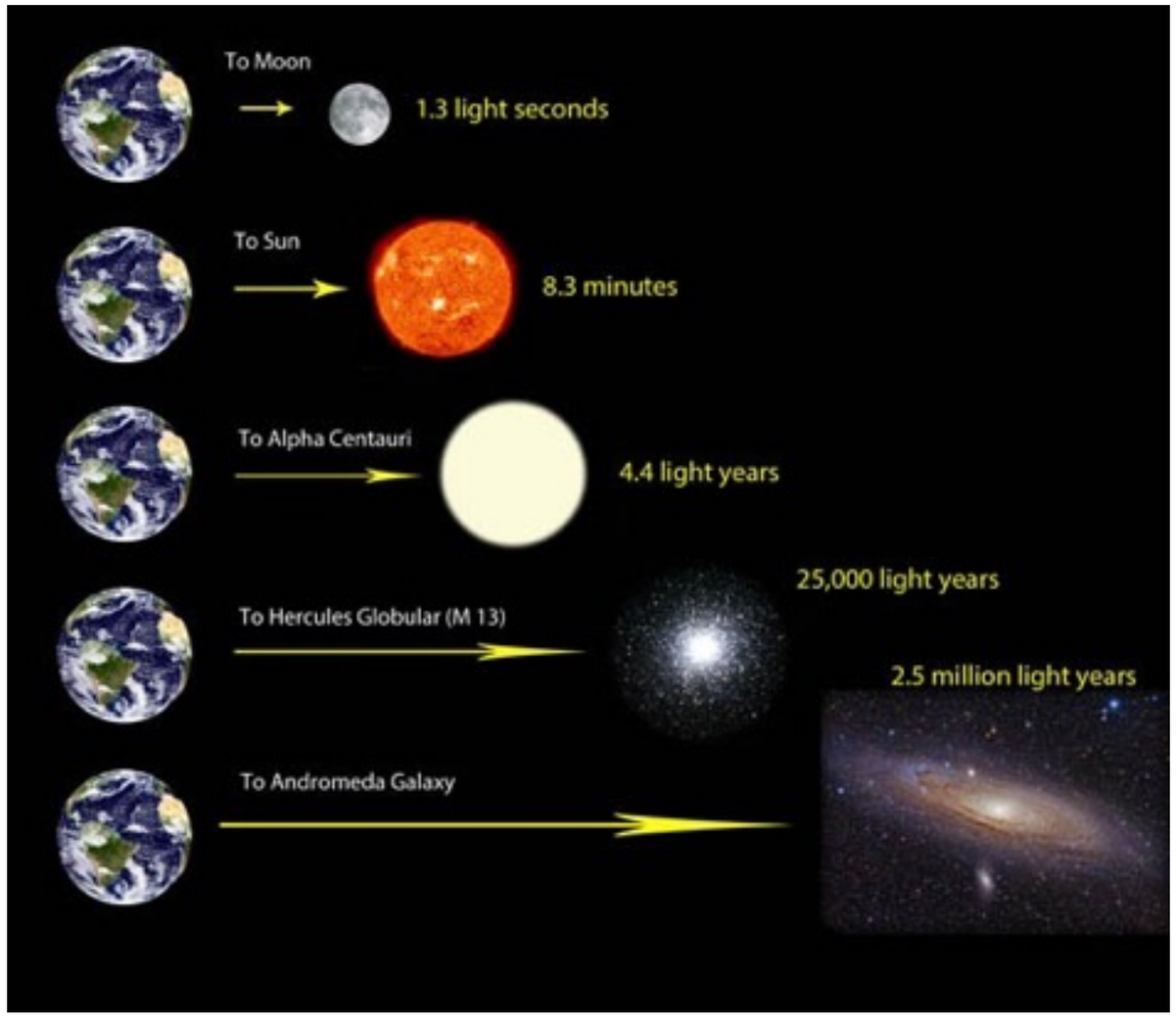
1 electron volt = 1.6×10^{-19} J

e = electron charge = 1.6×10^{-19} C
V = voltage

The abbreviation for electron volt is eV.

Measurement of the distance in astronomy

- Distances in astronomy are measured in light years (ly).
- 1ly is the distance travelled by the light in one year.
- $1ly=9.5x10^{+12}km$
- This is equivalent of traveling around the Earth for 24 billion times.
- An other measurement is the kpc=3000ly



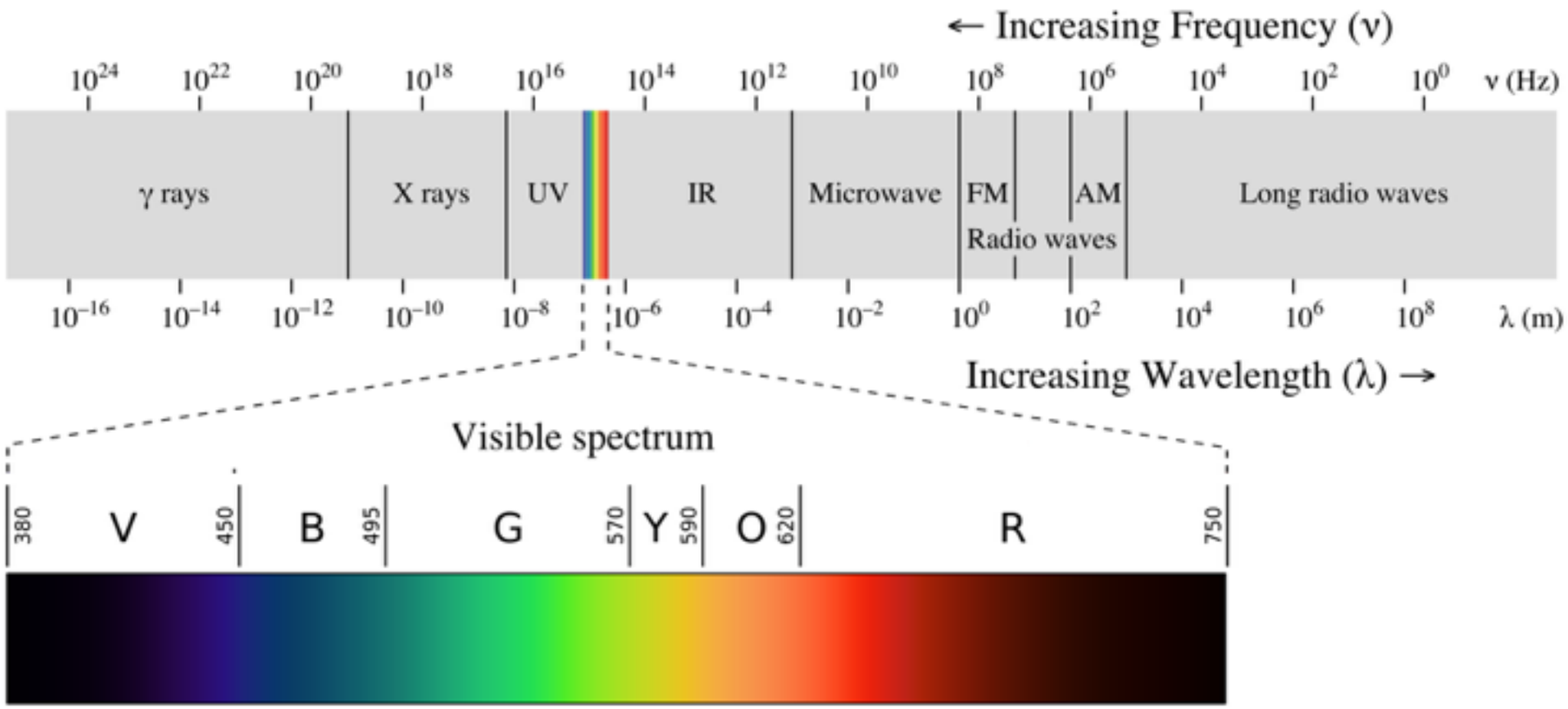
Multipli e sottomultipli

Prefissi del Sistema Internazionale

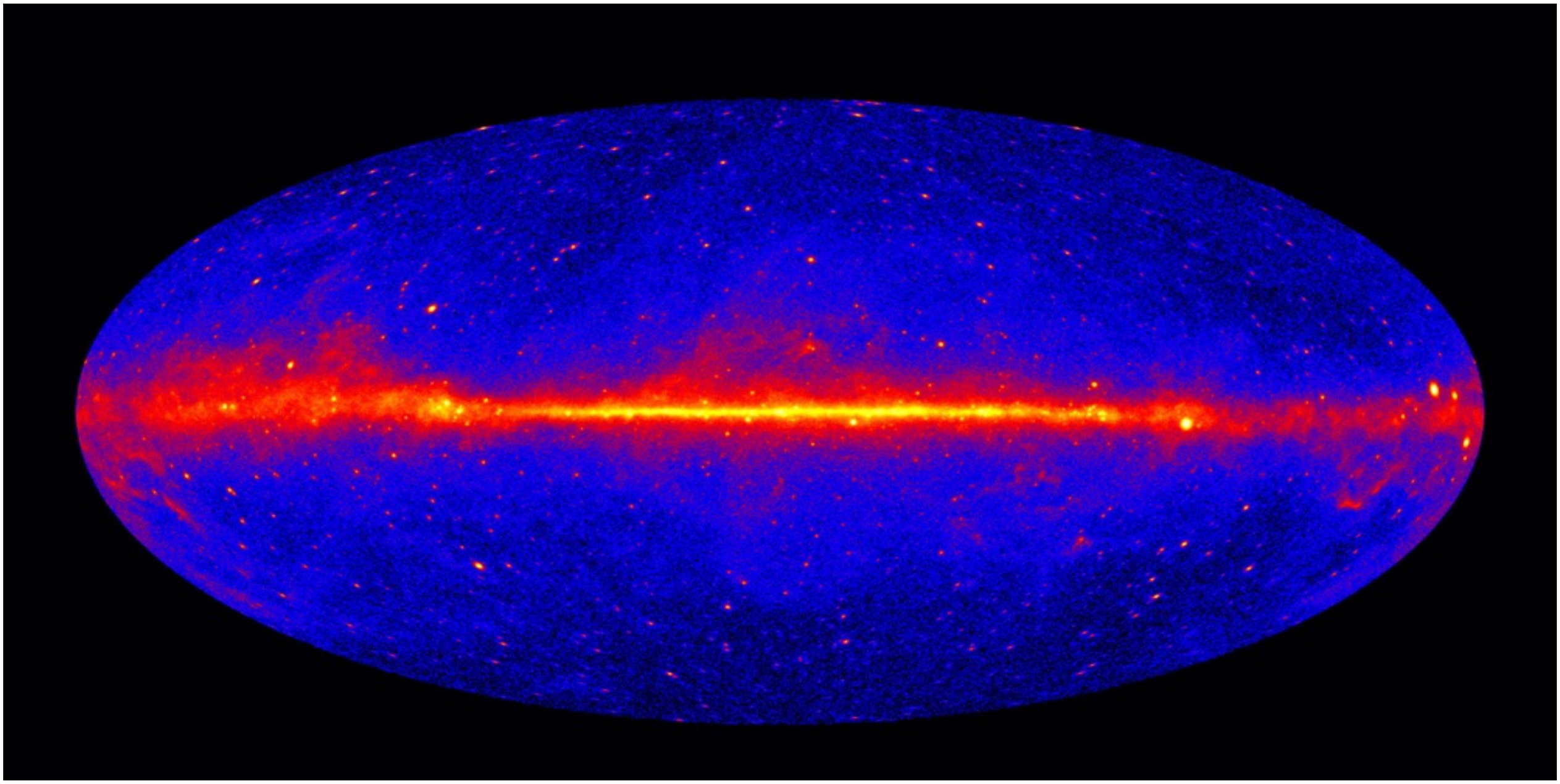
10^n	Prefisso	Simbolo	Nome	Equivalente decimale
10^{24}	yotta	Y	Quadrilione	1 000 000 000 000 000 000 000 000
10^{21}	zetta	Z	Triliardo	1 000 000 000 000 000 000 000
10^{18}	exa	E	Trilione	1 000 000 000 000 000 000
10^{15}	peta	P	Biliardo	1 000 000 000 000 000
10^{12}	tera	T	Bilione	1 000 000 000 000
10^{9}	giga	G	Miliardo	1 000 000 000
10^{6}	mega	M	Milione	1 000 000
10^{3}	kilo o chilo	k	Mille	1 000
10^{2}	etto	h	Cento	100
10	deca	da	Dieci	10
10^{-1}	deci	d	Decimo	0,1
10^{-2}	centi	c	Centesimo	0,01
10^{-3}	milli	m	Millesimo	0,001
10^{-6}	micro	μ	Milionesimo	0,000 001
10^{-9}	nano	n	Miliardesimo	0,000 000 001
10^{-12}	pico	p	Bilionesimo	0,000 000 000 001
10^{-15}	femto	f	Biliardesimo	0,000 000 000 000 001
10^{-18}	atto	a	Trilionesimo	0,000 000 000 000 000 001
10^{-21}	zepto	z	Triliardesimo	0,000 000 000 000 000 000 001
10^{-24}	yocto	y	Quadrilionesimo	0,000 000 000 000 000 000 000 001

Electromagnetic band

- A **photon** is an elementary particle. **E=hf and f=v/λ.**
- It is the quantum of all forms of electromagnetic radiation including light. It is the force carrier for electromagnetic force, even when static via virtual photons.
- The photon has zero rest mass and has a double nature of wave and particle.
- The speed of light in a vacuum is defined to be exactly 299,792,458 m/s.
- None particle in a vacuum can travel faster than the light.

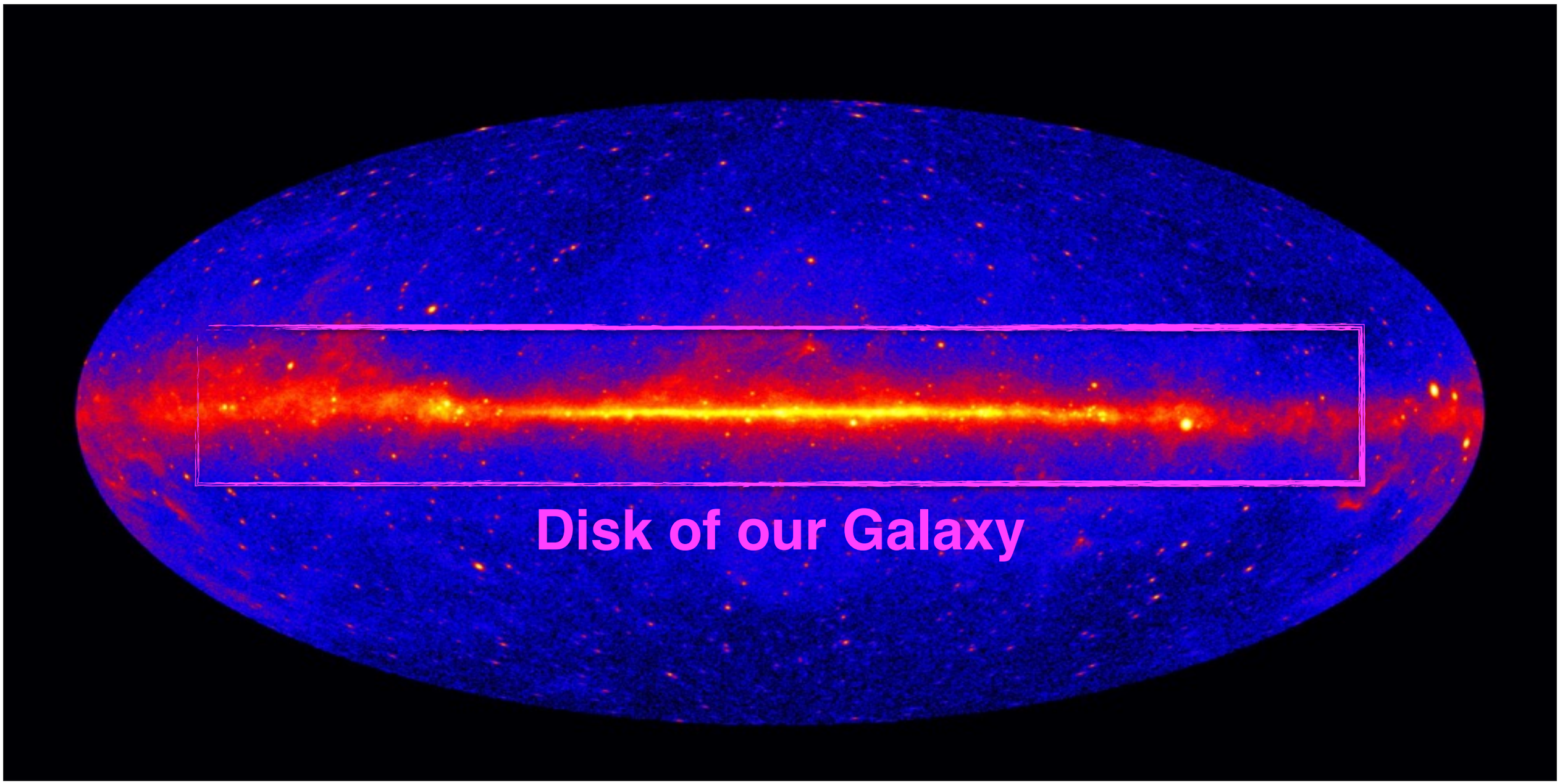


Fermi-LAT view of the Universe



NASA/DOE/Fermi LAT Collaboration

Milky Way: gamma rays



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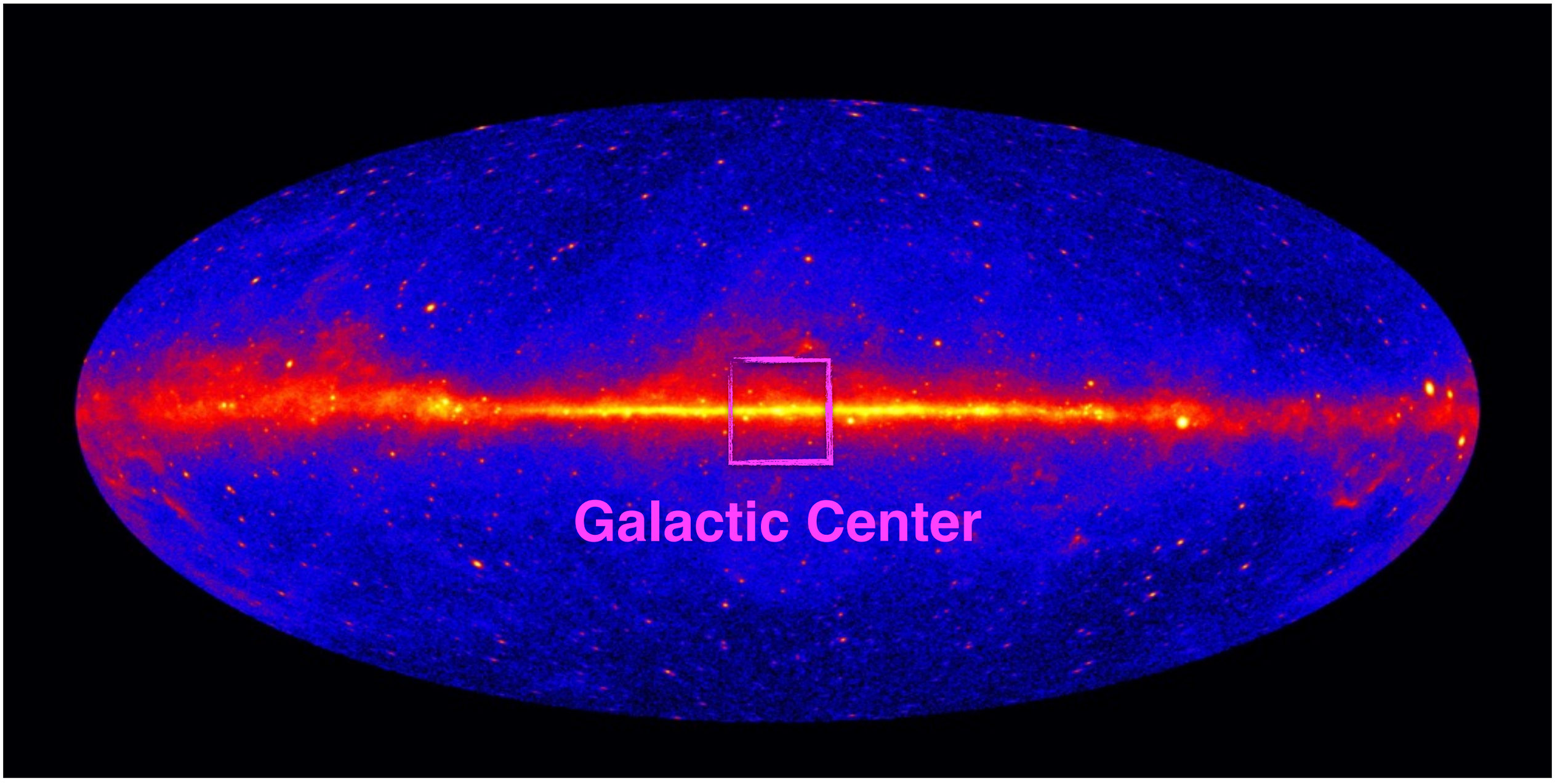
Milky Way: gamma rays



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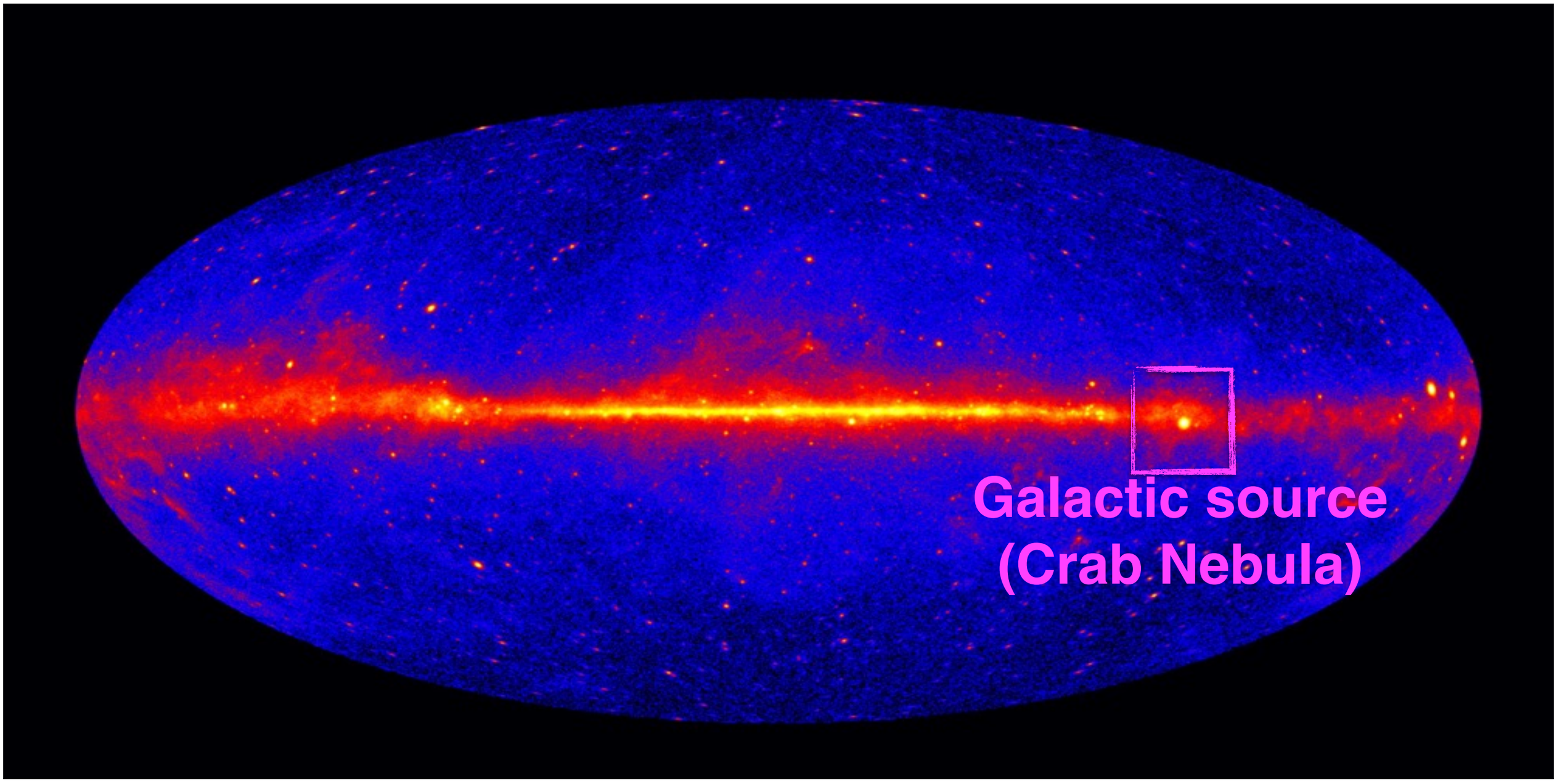
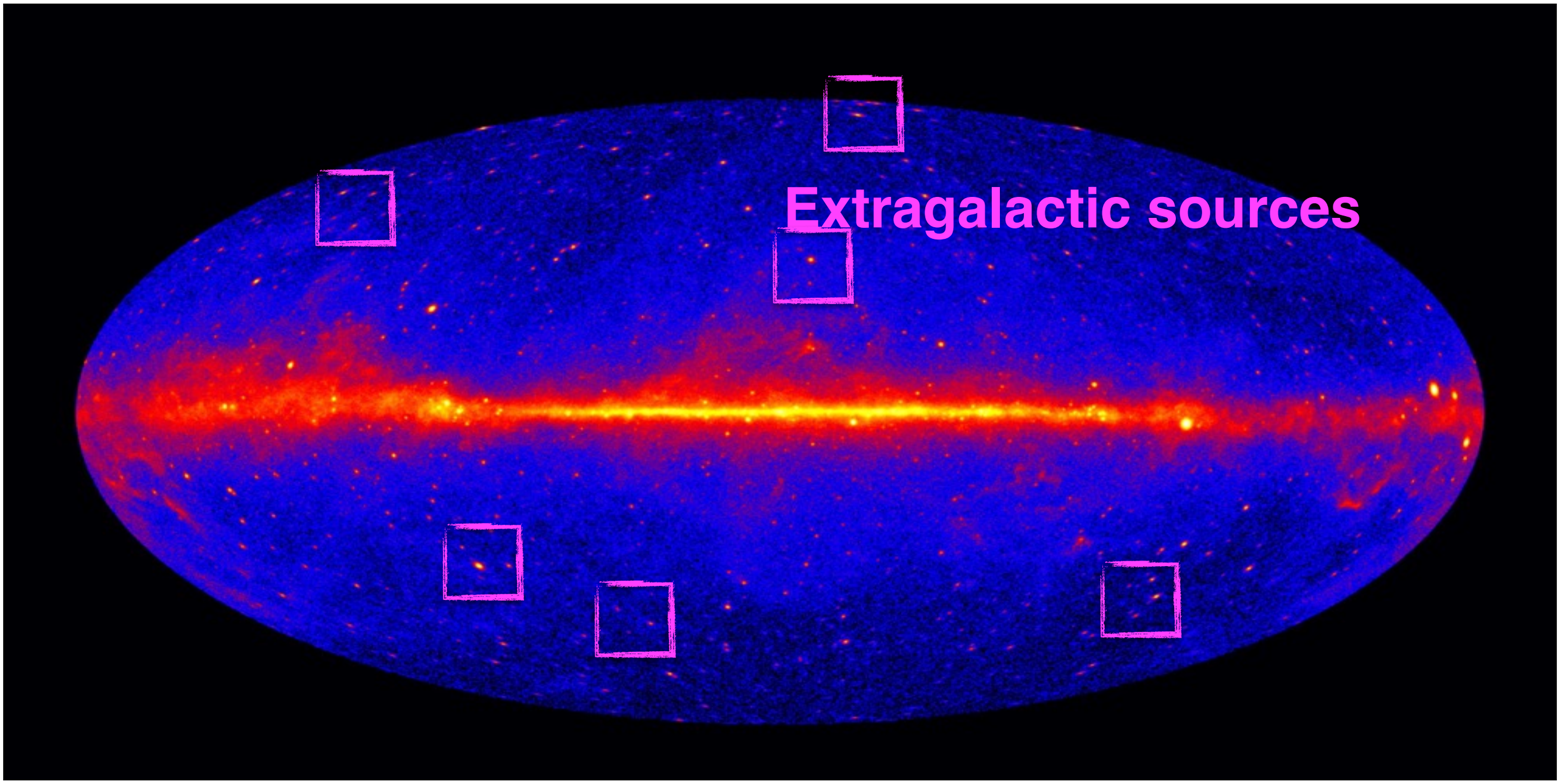
Milky Way: gamma rays



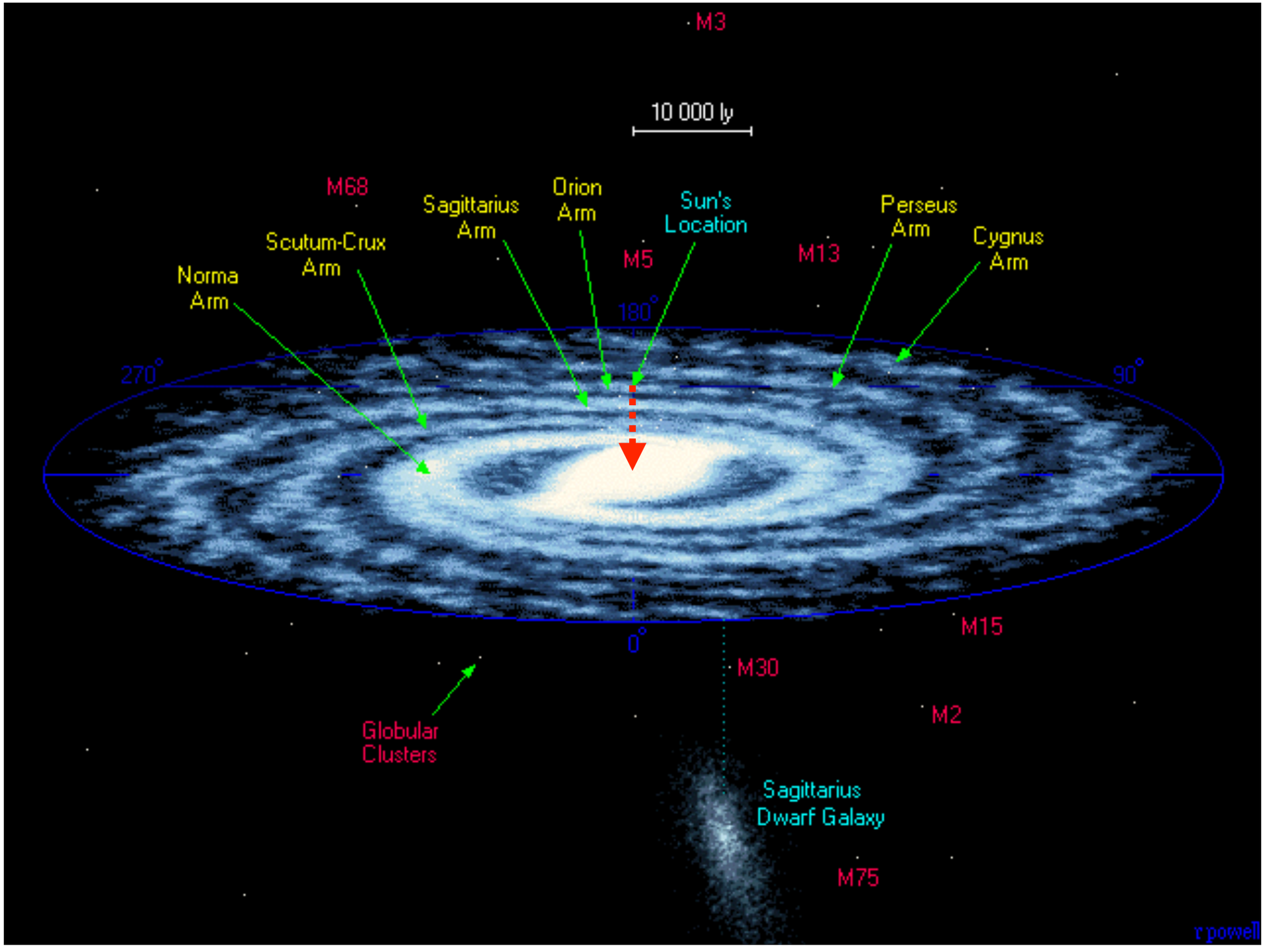
NASA/DOE/Fermi LAT Collaboration

Milky Way: gamma rays



NASA/DOE/Fermi LAT Collaboration

The Milky Way



http://www.atlasoftheuniverse.com/galaxy.html

NGC 6744, a Milky Way Galaxy

This picture of the nearby galaxy NGC 6744, a Milky Way look-alike, was taken with the Wide Field Imager on the MPG/ESO 2.2-metre telescope at La Silla.
Credit: ESO

Milky Way: some numbers 1

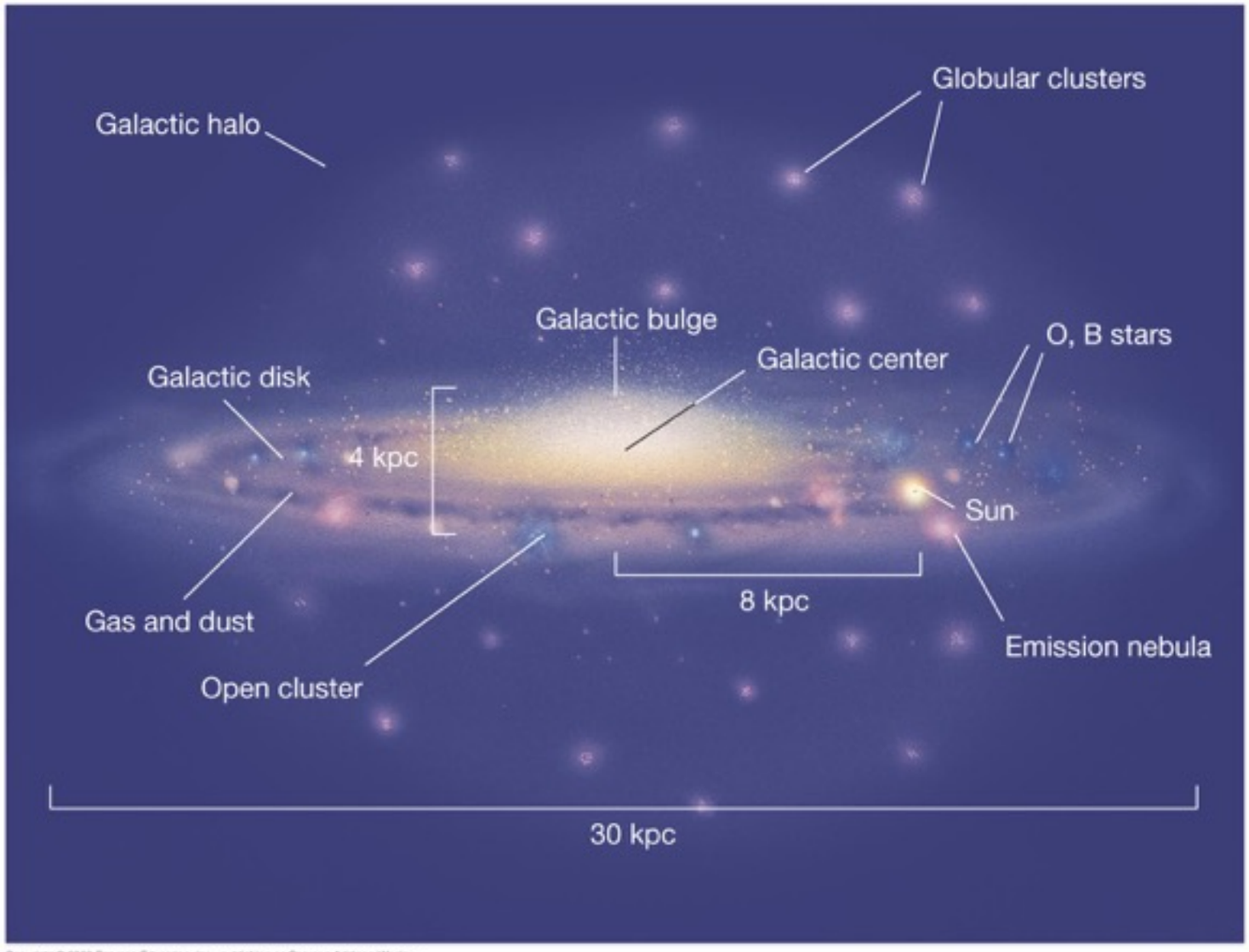
- The **Milky Way** is the barred spiral galaxy that contains our Solar System. The descriptive "milky" is derived from the appearance from Earth of the galaxy – a band of light seen in the night sky formed from stars that cannot be individually distinguished by the naked eye.
- **The Milky Way contains over 200 billion stars**, and enough dust and gas to make billions more. The solar system lies about 30,000 light-years from the galactic center, and about 20 light-years above the plane of the galaxy.
- There are likely at least **100 billion planets** in the Milky Way
- More than half the stars found in the Milky Way are older than the 4.5 billion year old sun.

http://www.eso.org/gallery/v/ESOPIA/Paranal/phot-33a-07.tif.html

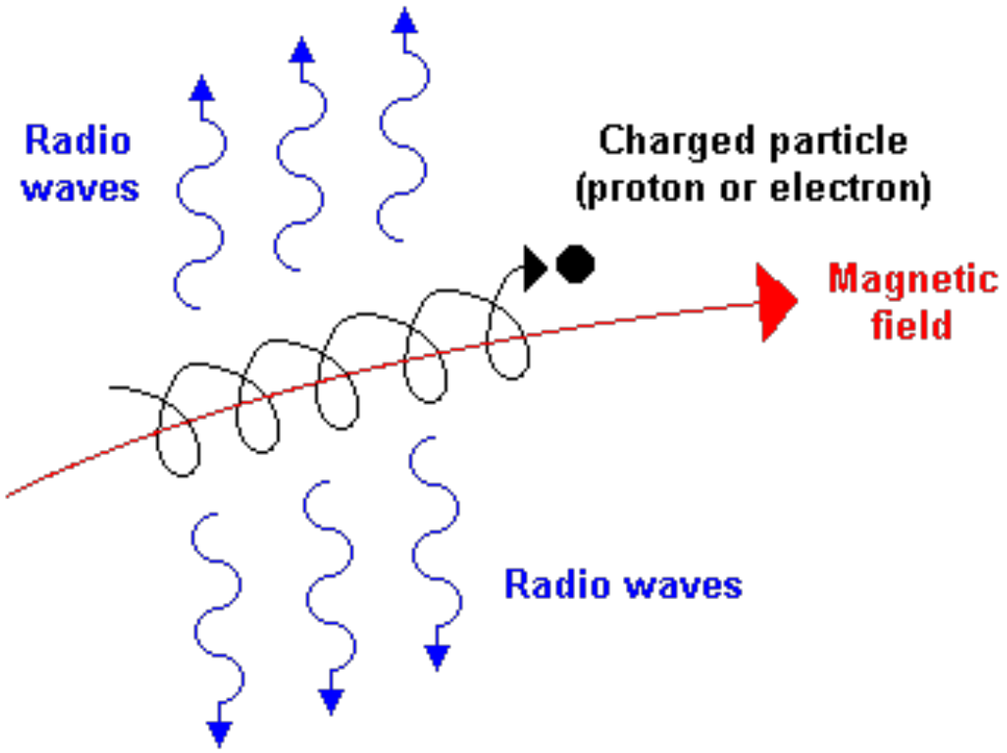
Milky Way: some numbers

- **1pc=3 10^{16}m**.
- The **Solar System** is located within the disk, about 27,000 light-years from the Galactic Center, on the inner edge of one of the spiral-shaped concentrations of gas and dust called the Orion Arm.
- The **stars in the inner ≈10,000 light-years** form a bulge and one or more bars that radiate from the bulge. The very center is marked by an intense radio source, named Sagittarius A*, which is likely to be a supermassive black hole.

1kpc=3300ly



Production of radio emission



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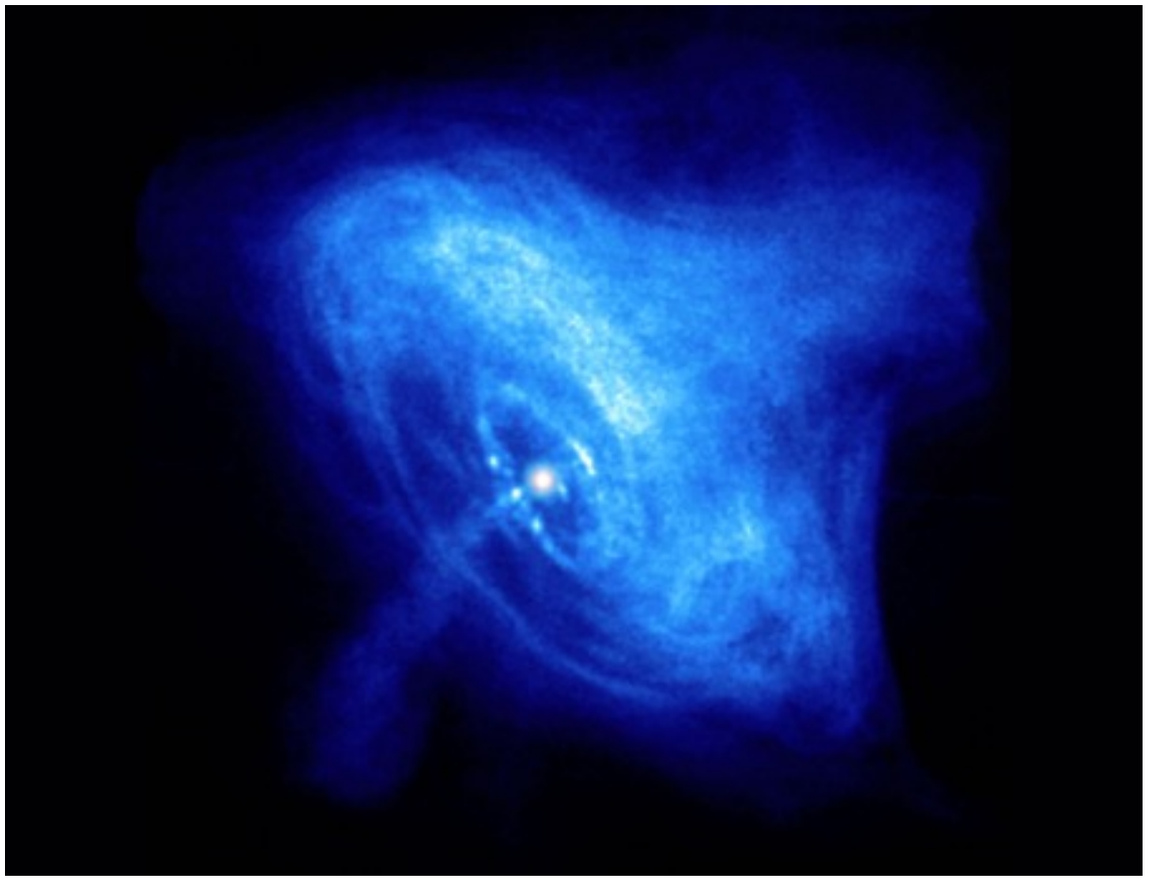
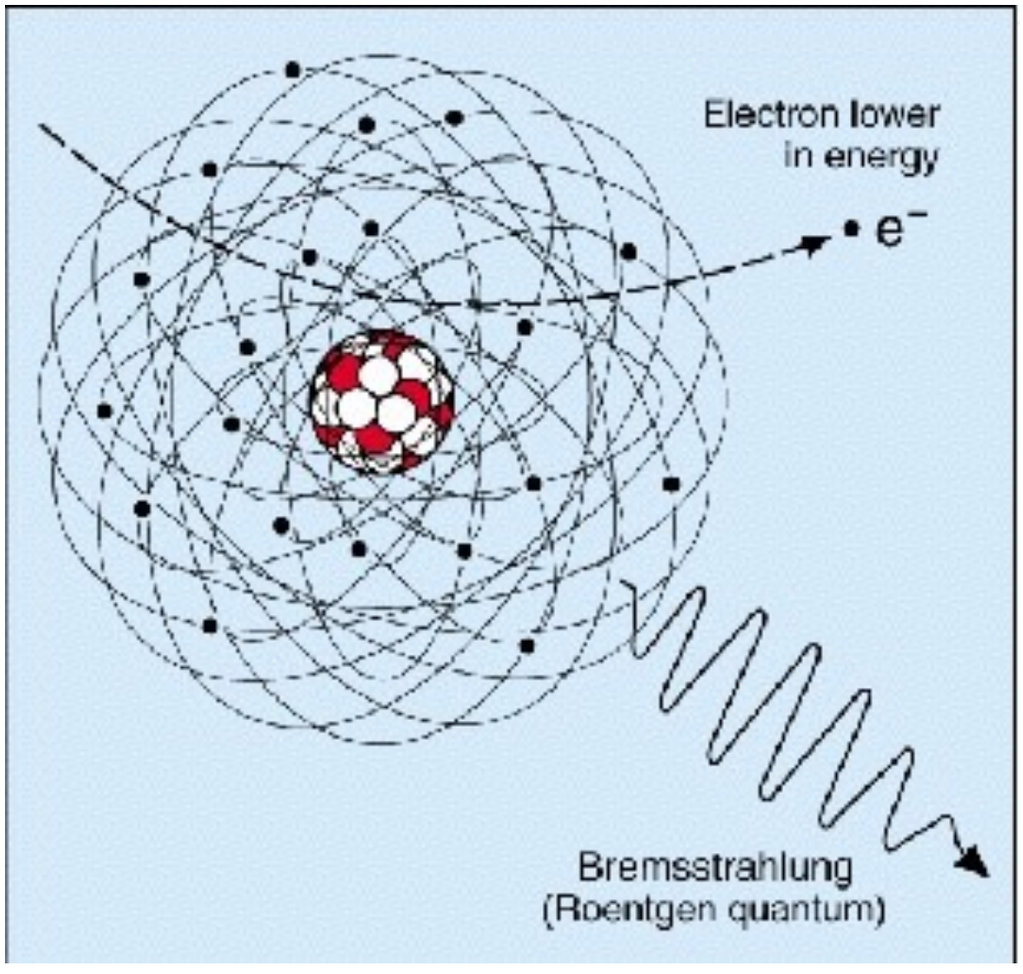
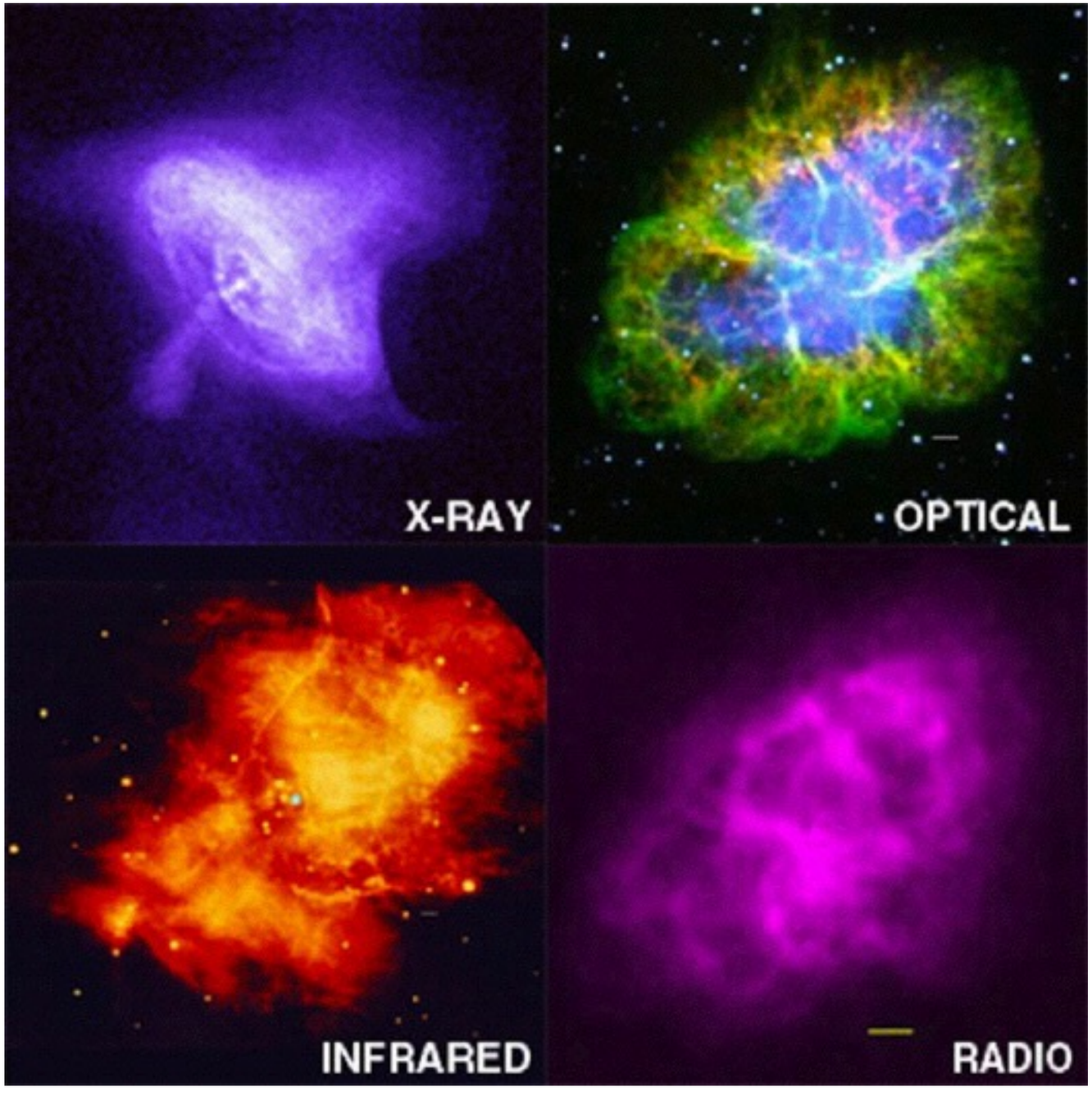


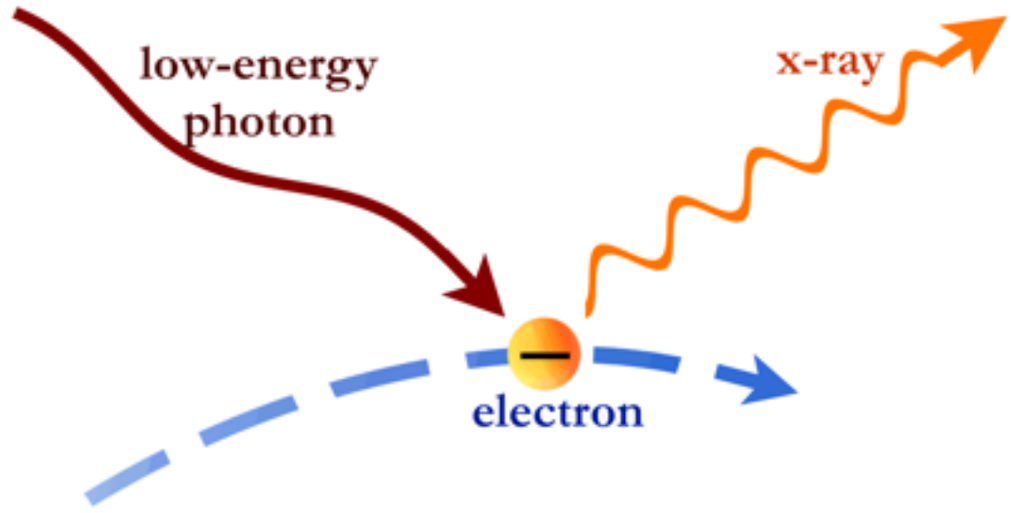
X-ray emission



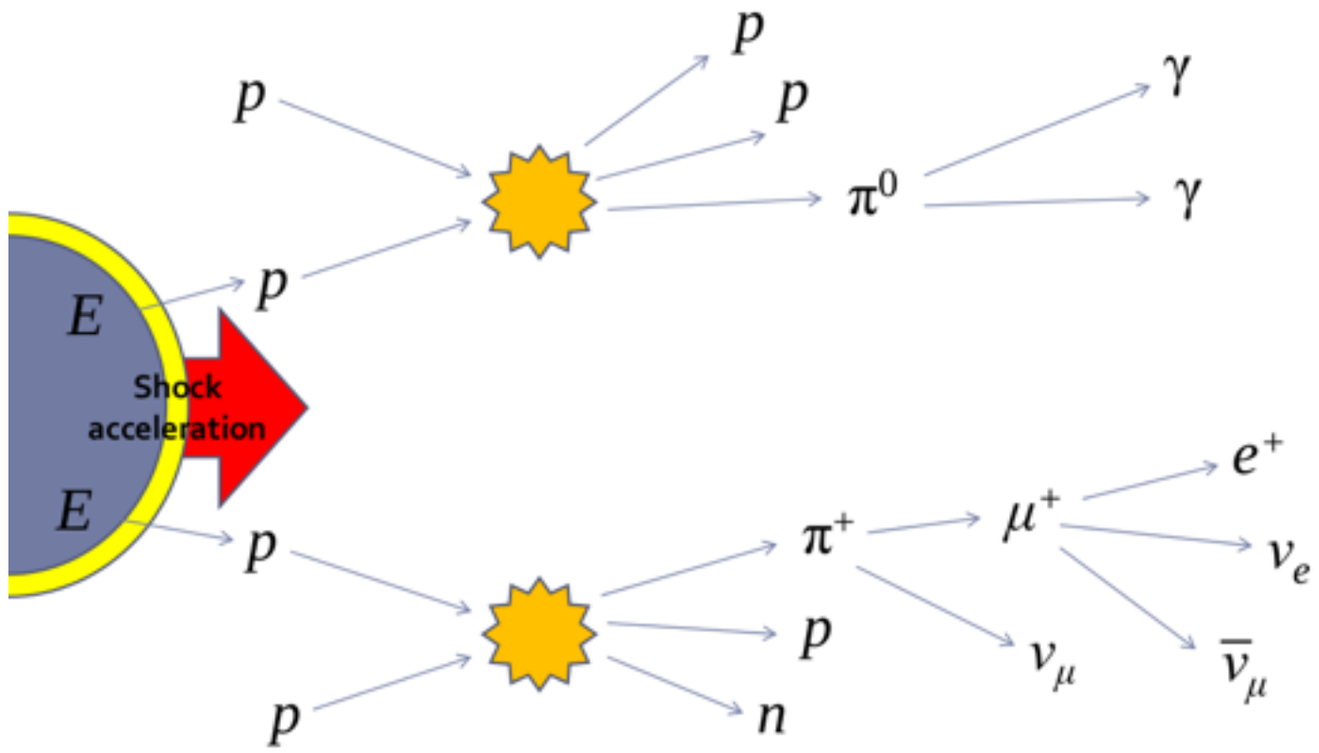


gamma-ray emission

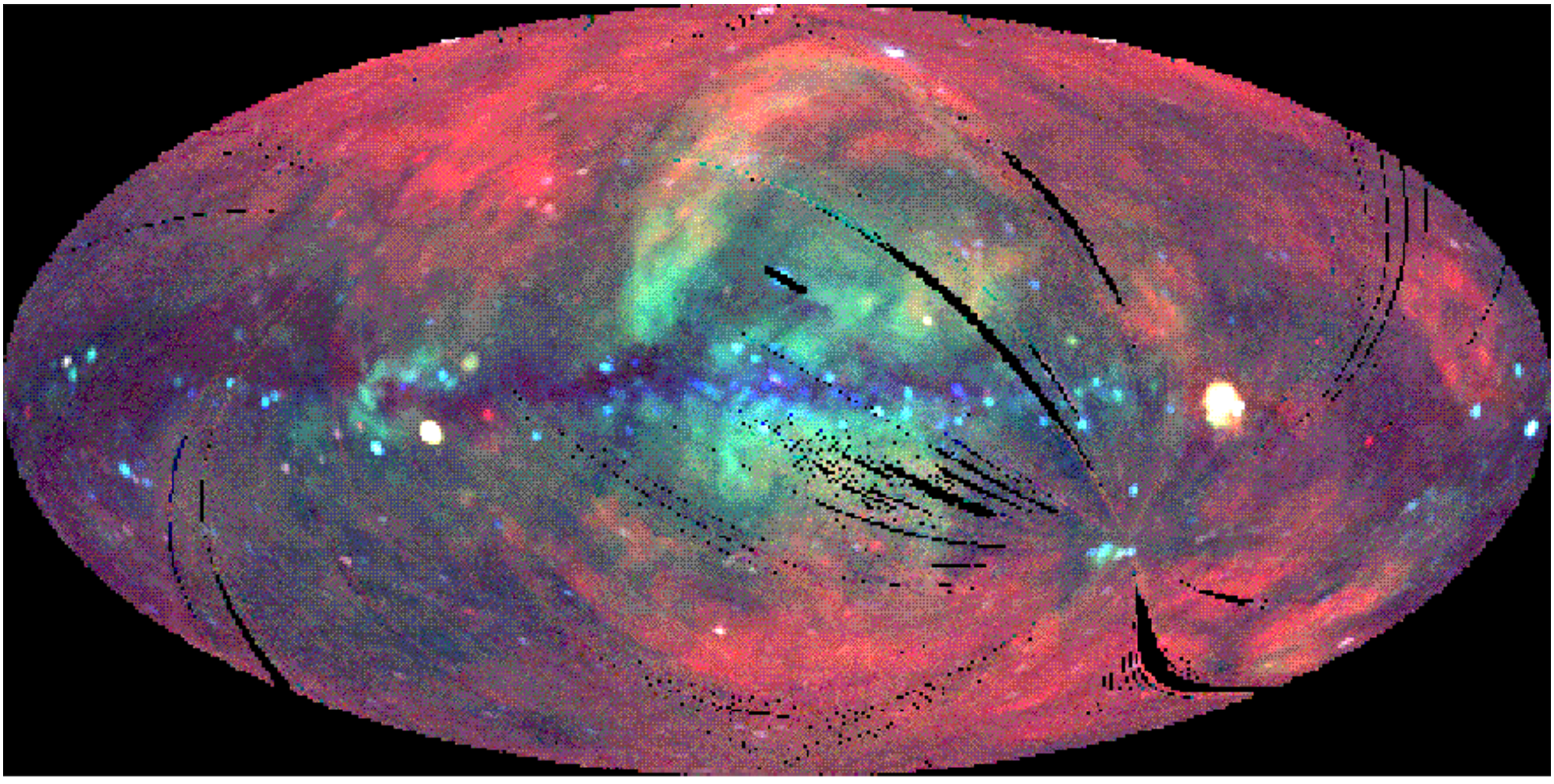
Inverse Compton scattering



Pion decay

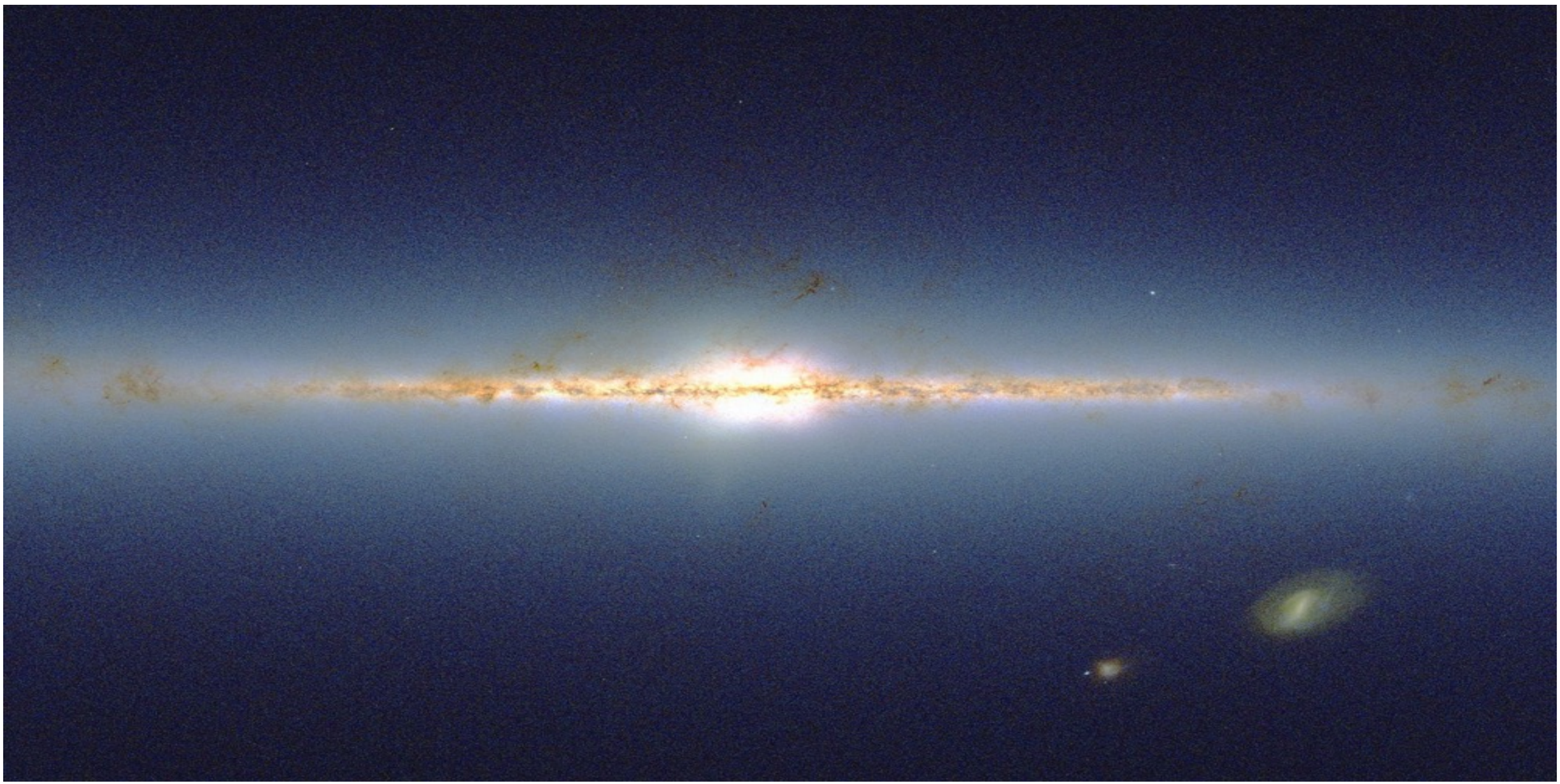


Milky Way: X-ray



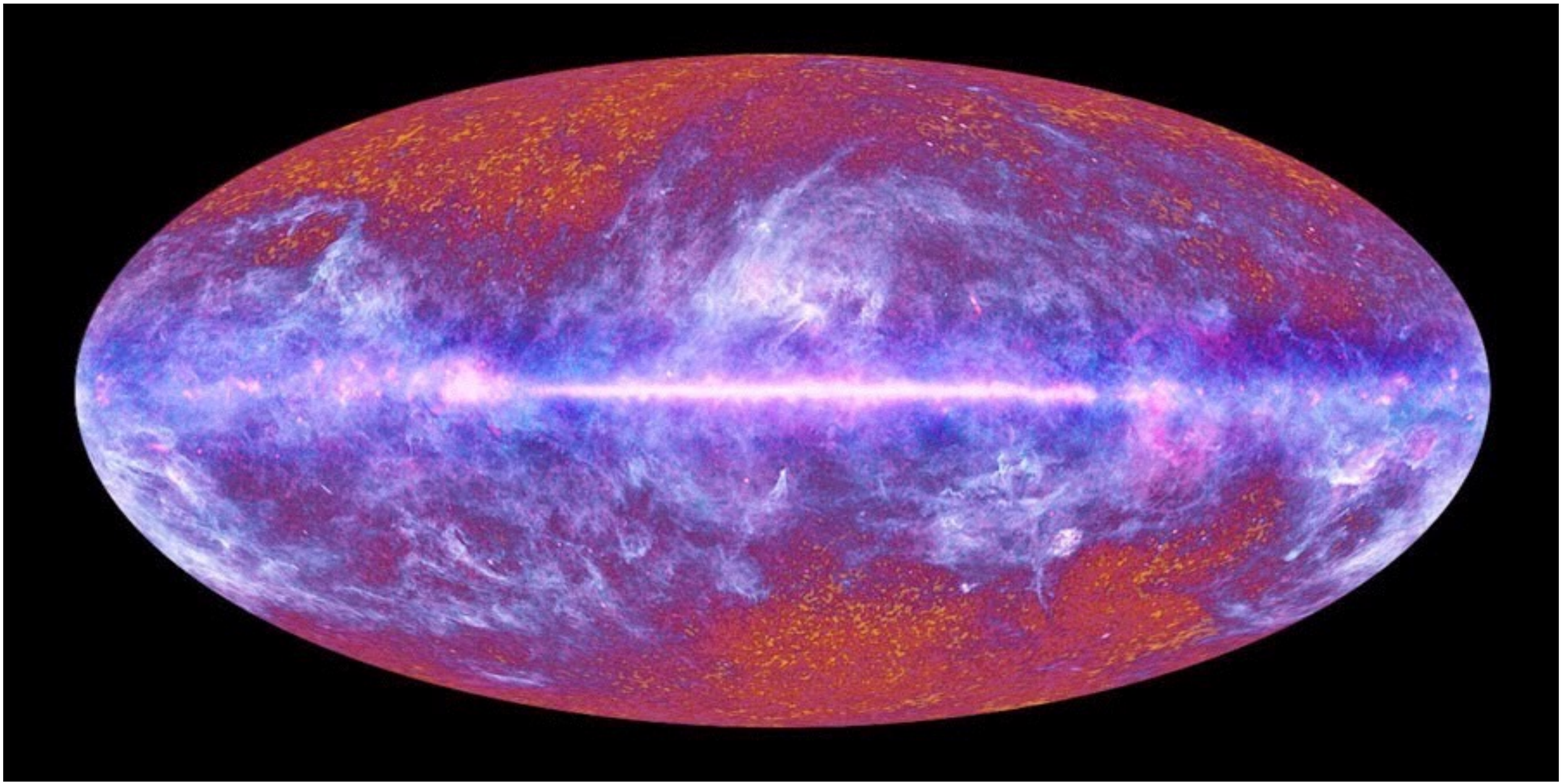
S. Digel and S. Snowden (GSFC), ROSAT Project, MPE, NASA

Milky Way: Infrared



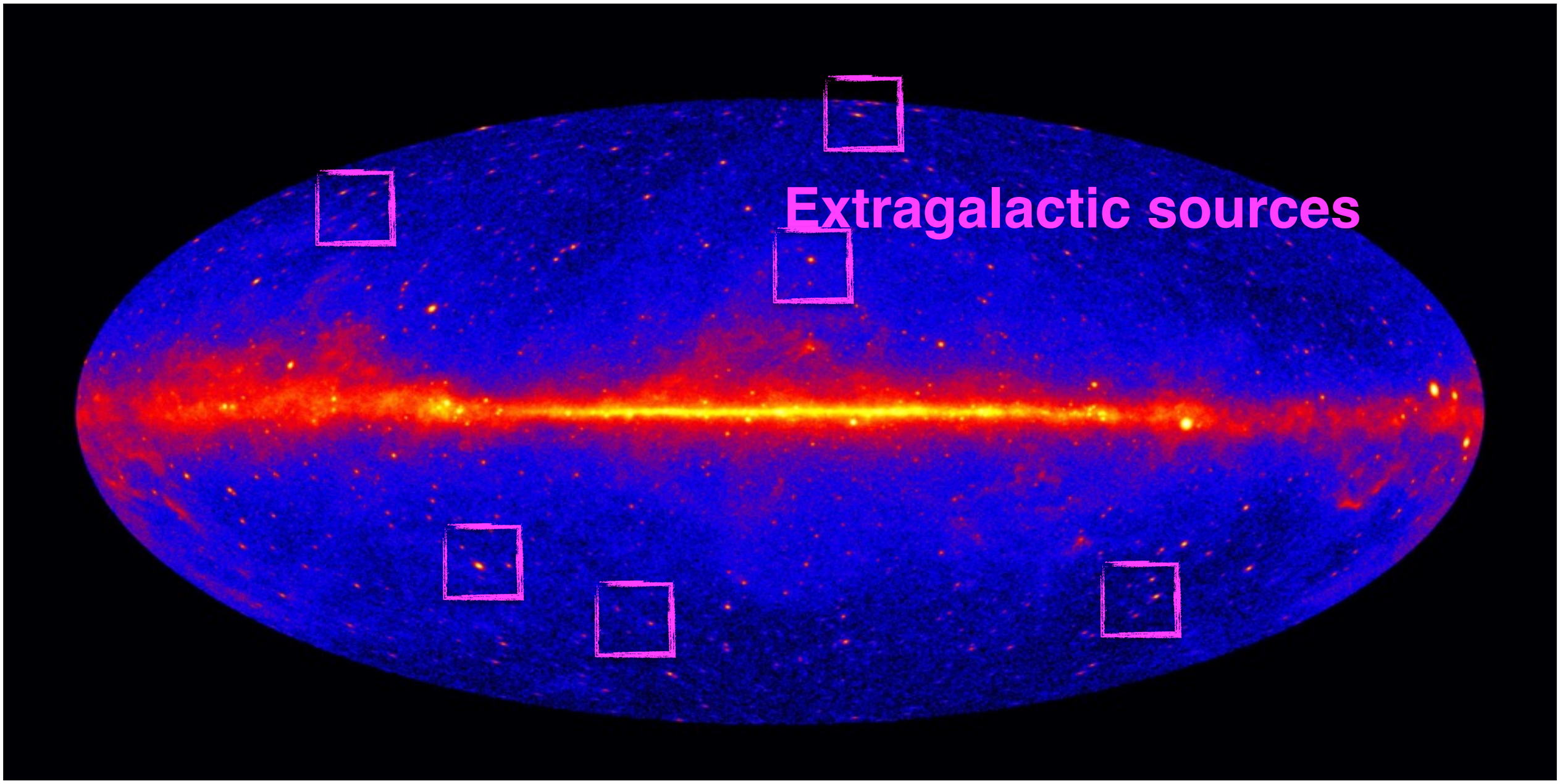
Milky Way: Optics

Milky Way: radio



European Space Agency, HFI and LFI consortia

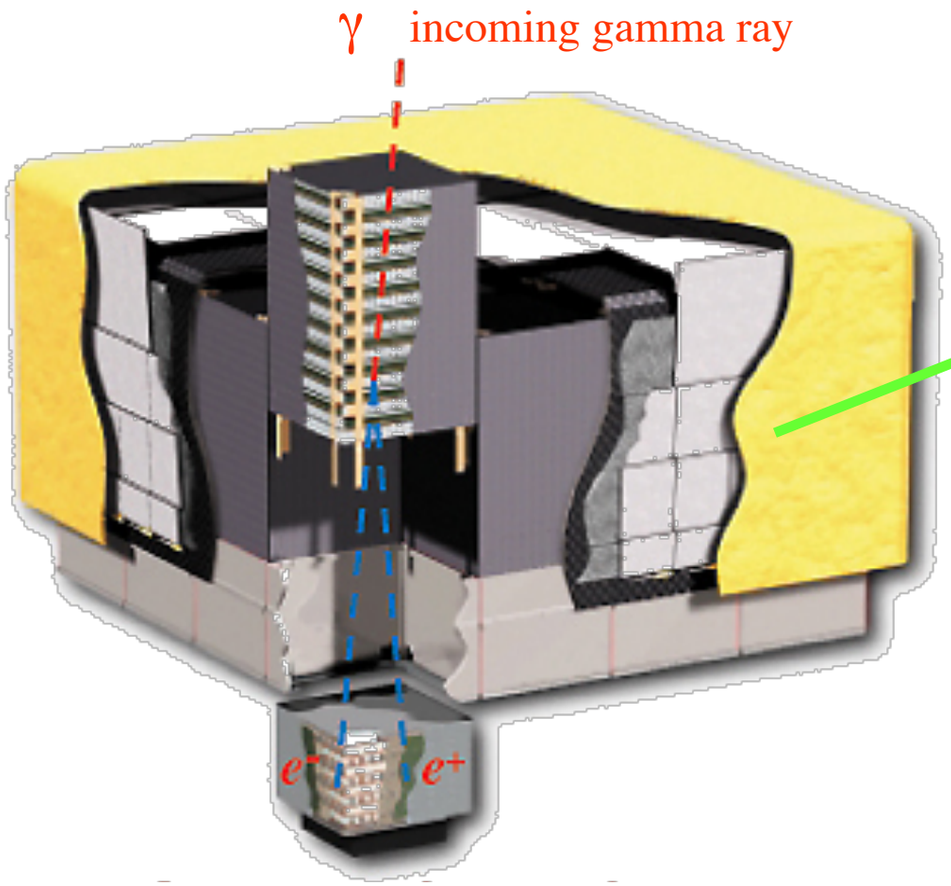
Milky Way: gamma rays

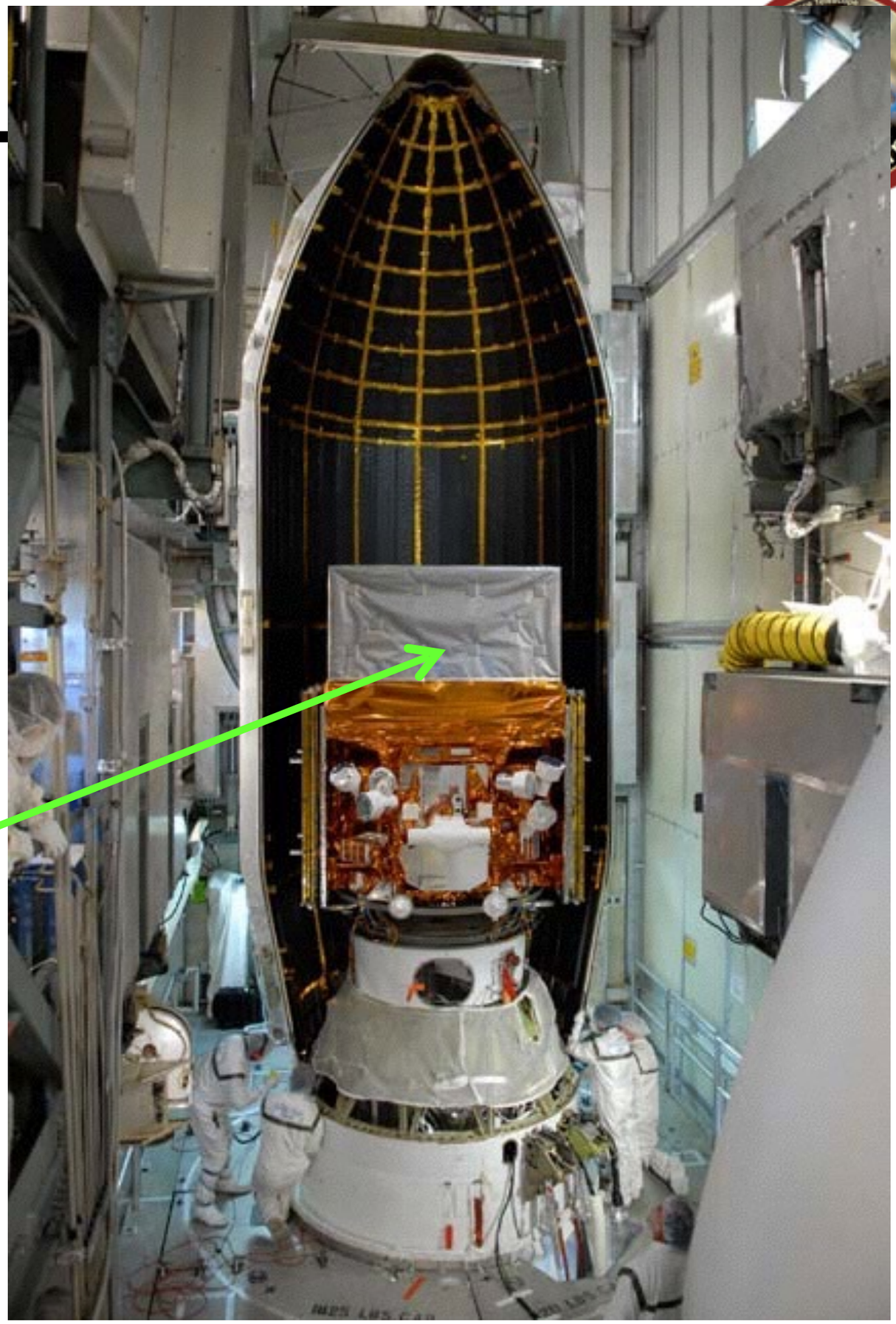


NASA/DOE/Fermi LAT Collaboration

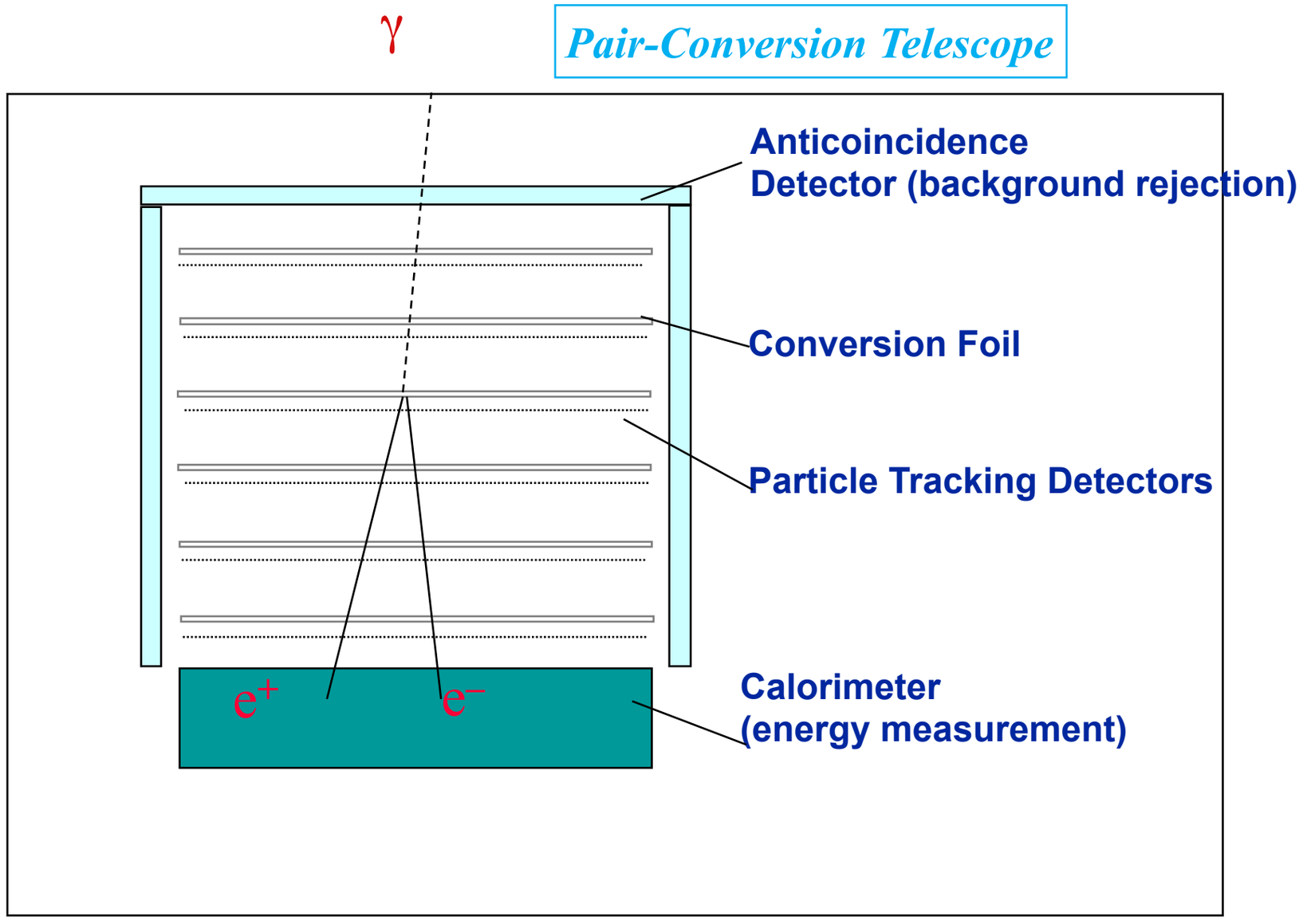
The Large Area Telescope on board the Fermi satellite

(launch: June 11, 2008)



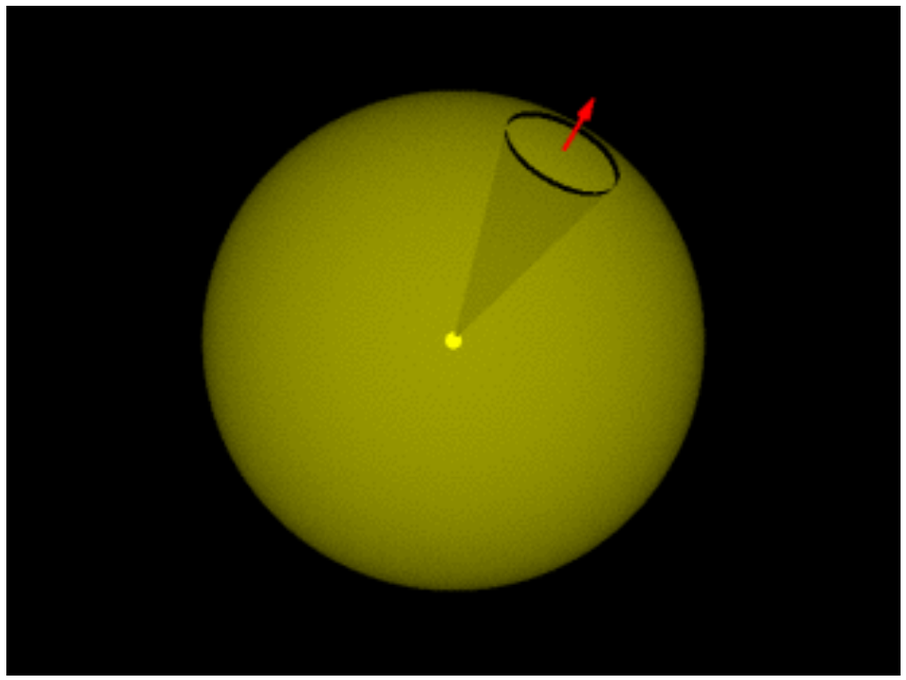


The Fermi Large Area Telescope (LAT)



The gamma-ray photons interact with matter and produce an electron-positron pair photons ("$E=mc^2$"). The LAT is a detector similar to those used in particle physics at CERN.

Flux and luminosity



- *The number of photons emitted in a cone per second remains constant and thus is independent of the distance to the source.*
- *At a given distance, the area of a sphere intercepting the cone scales as the square of the distance.*
- *So the number of photons per square cm and second (= the flux) is inversely proportional to the distance squared ("inverse-square law").*

Flux $F_p = N / S\,T$

F_p= Flux (ph cm^{-2} s^{-1})

N = Number of collected photons

S = Collecting area (cm^2)

T = Collecting time (s)

Energy flux $F_E = F_p\,E$

F_E= Energy flux (W cm^{-2})

E = Mean photon energy (MeV)

1 MeV= 1.6 10^{-13} J

Fluence $F = N\,E / S$

F= Fluence (J cm^{-2})

N = Number of collected photons

S = Collecting area (cm^2)

Luminosity $L = 4\,\pi\,d^2\,F_E$

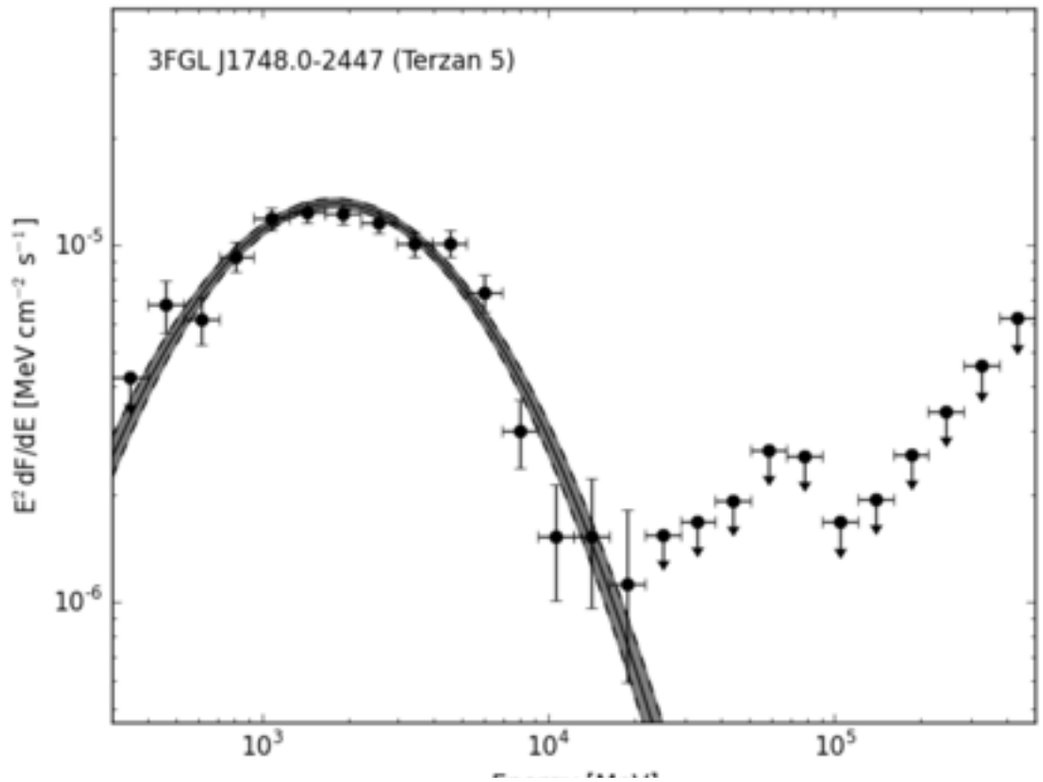
L = Luminosity (W)

d = distance (cm)

Luminosity of the Sun: 4 10^{26} W

Luminosity of the Milky Way: 5 10^{36} W

Flux and luminosity



$$\mathrm{dN/dE\ [1/(cm^2\,s\,MeV)]} = \mathrm{N/\Delta E}$$

$$F_{100} = \int_{100\,\mathrm{MeV}}^{100\,\mathrm{GeV}} \frac{\mathrm{d}N}{\mathrm{d}E}\mathrm{d}E, \qquad G_{100} = \int_{100\,\mathrm{MeV}}^{100\,\mathrm{GeV}} E\frac{\mathrm{d}N}{\mathrm{d}E}\mathrm{d}E.$$

[ph/(cm^2 s)] [MeV/(cm^2 s)]

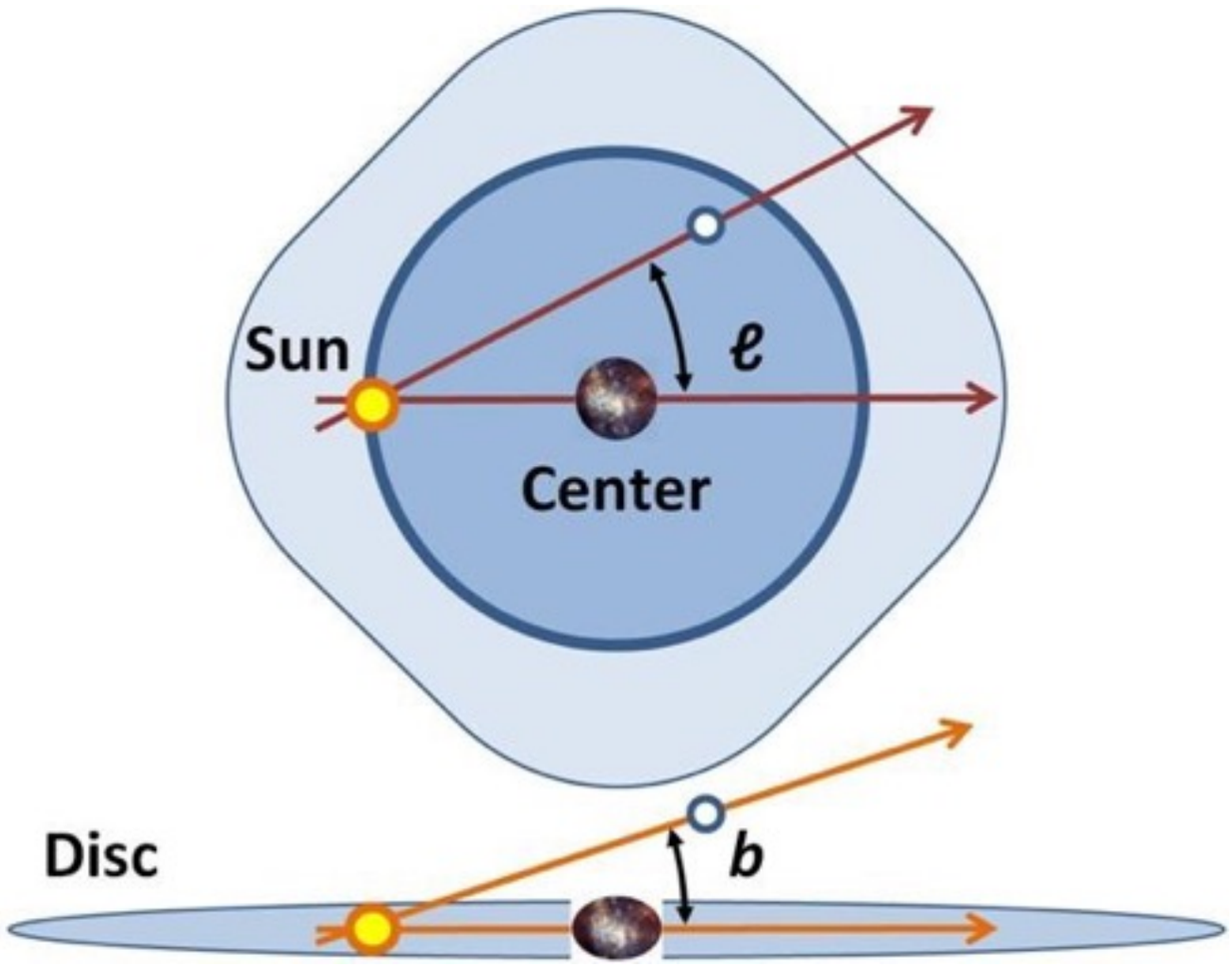
$$L = 4\pi d^2\, G$$

[MeV/(s) or erg/s where 1erg=6,242 10^8MeV]

Coordinate

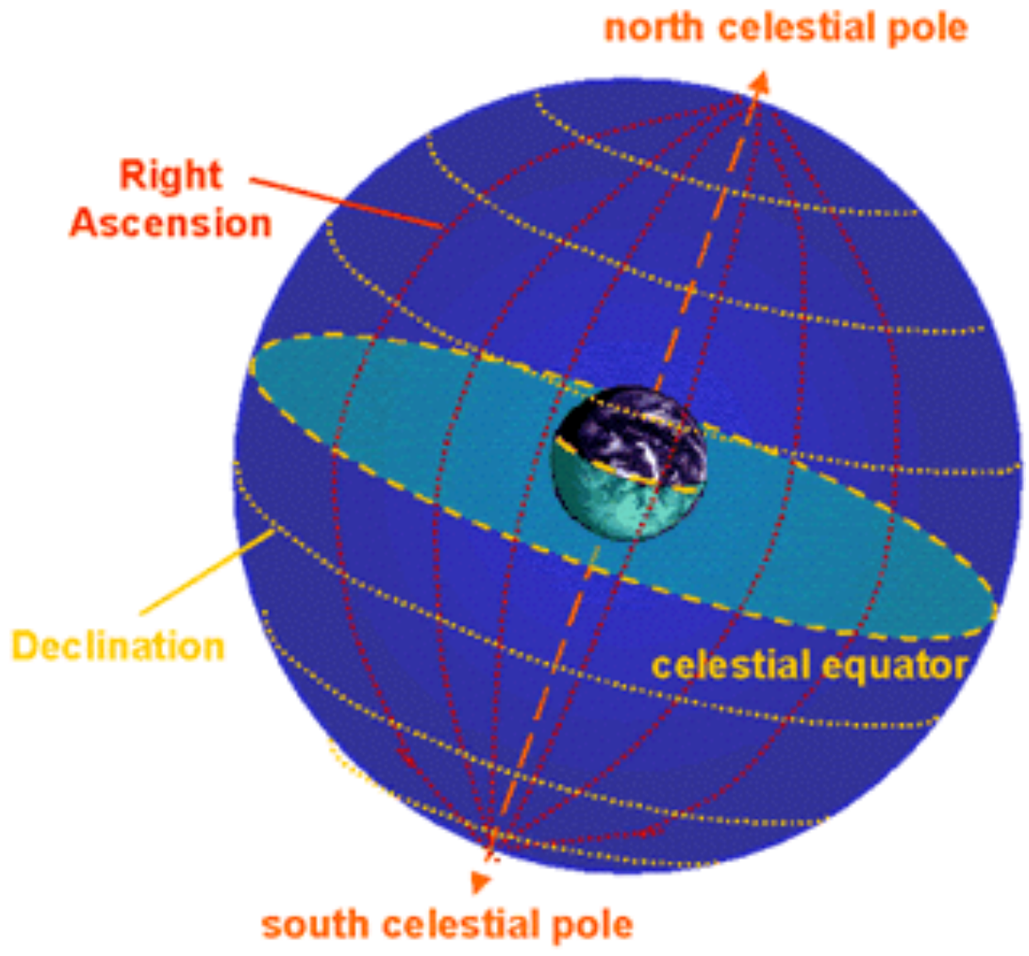
Coordinate Galattiche

Il sistema di coordinate galattiche è un sistema di coordinate celesti centrato sul Sole e allineato col centro della Via Lattea. L'"equatore galattico" è così allineato con il piano galattico.



Coordinate Equatoriali

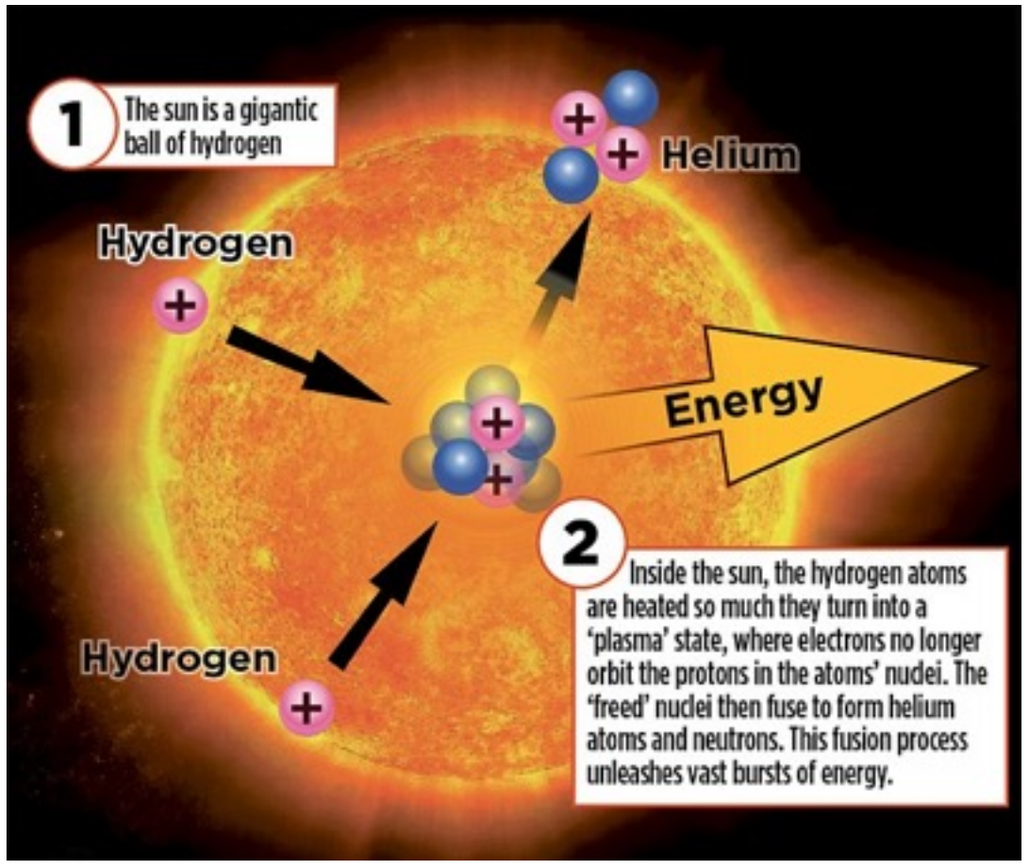
Il **sistema di coordinate equatoriali** è un metodo largamente impiegato per specificare le posizioni degli oggetti celesti dove l'origine è posta al centro della Terra, da un piano fondamentale, l'equatore celeste, formato dalla proiezione dell'equatore sulla sfera celeste, e da una direzione principale verso il punto vernale.



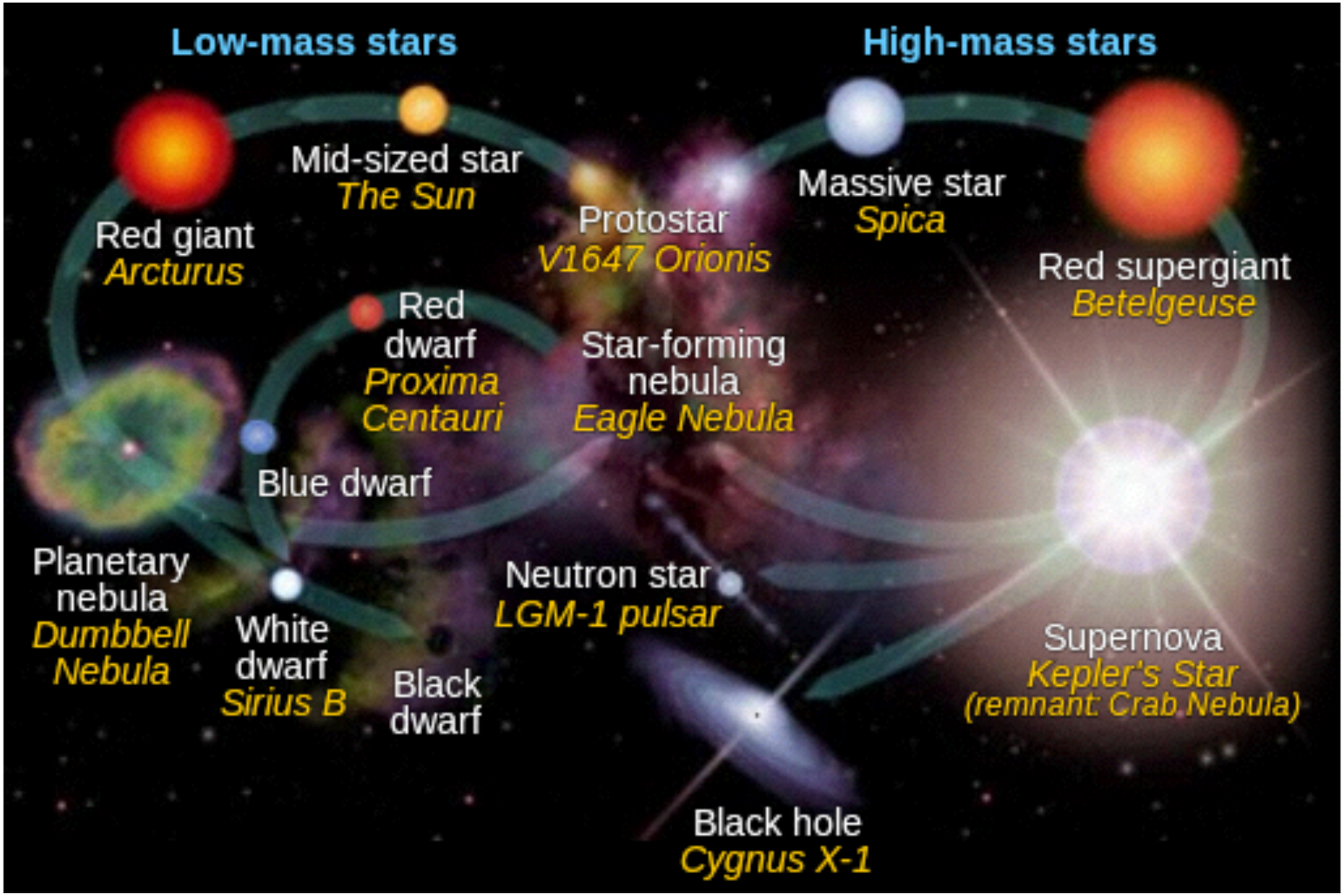
GC (0.0,0.0)deg (266.41,-28.94)deg

The Sun

- The **Sun** is the star at the center of the Solar System. It is a nearly perfect sphere of hot plasma.
- It is by far the most important source of energy for life on Earth. Its **diameter is about 109 times that of Earth**, and its **mass is about 330,000 times that of Earth**, accounting for about **99.86% of the total mass of the Solar System.**
- **About three quarters of the Sun's mass consists of hydrogen (~73%); the rest is mostly helium (~25%).**
- The central mass became so hot and dense that it eventually initiated **nuclear fusion** in its core. It is thought that almost all stars form by this process.
- The Sun is roughly middle-aged: it has not changed dramatically for more than four billion years, and will remain fairly stable for more than another five billion years. After hydrogen fusion in its core has stopped, the Sun will undergo severe changes and become a red giant. It is calculated that the Sun will become sufficiently large to engulf the current orbits of Mercury, Venus, and possibly Earth.



Life star cycle



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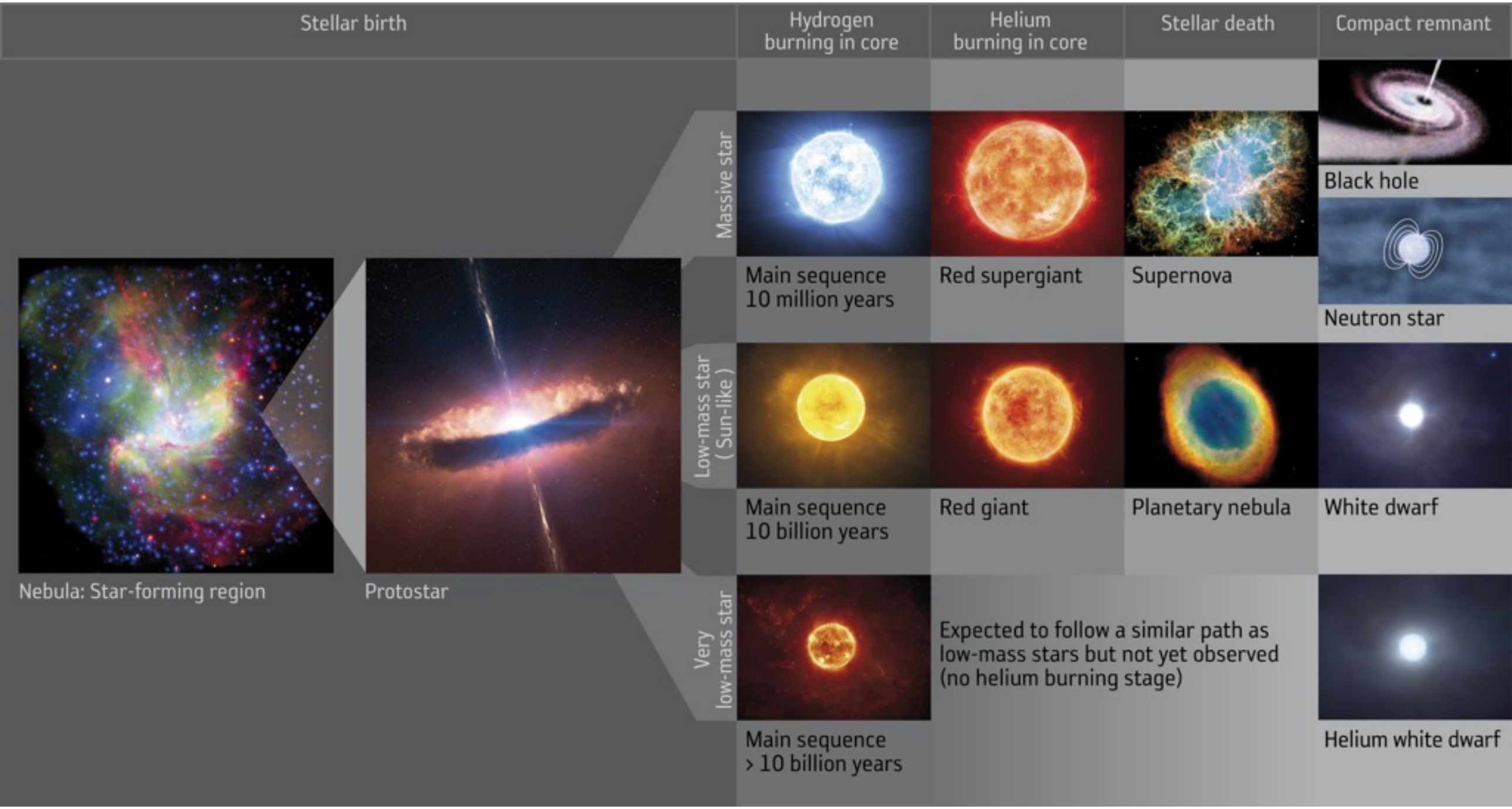
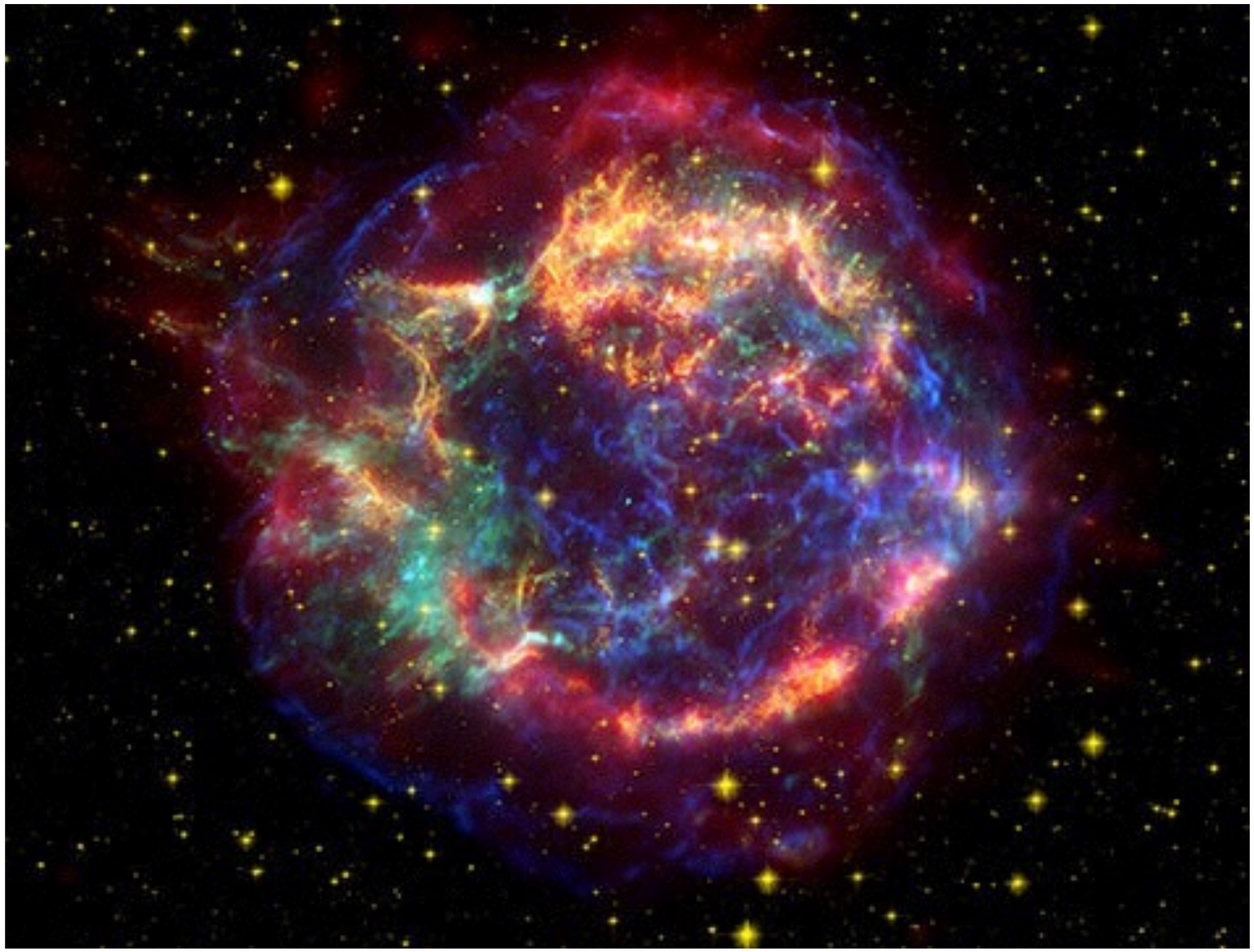


Supernova first

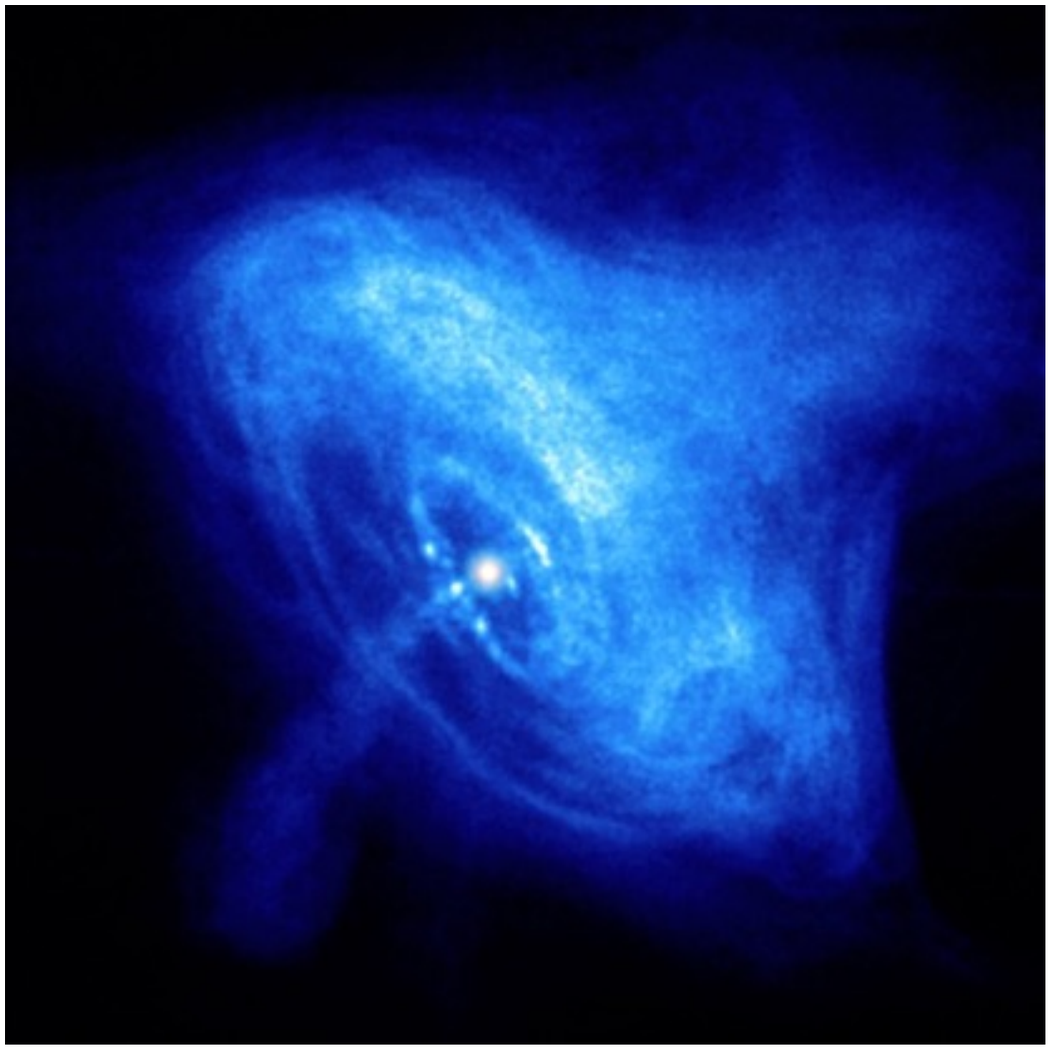


Cas A

https://www.youtube.com/watch?v=C3ue7cEocvI

Neutron star

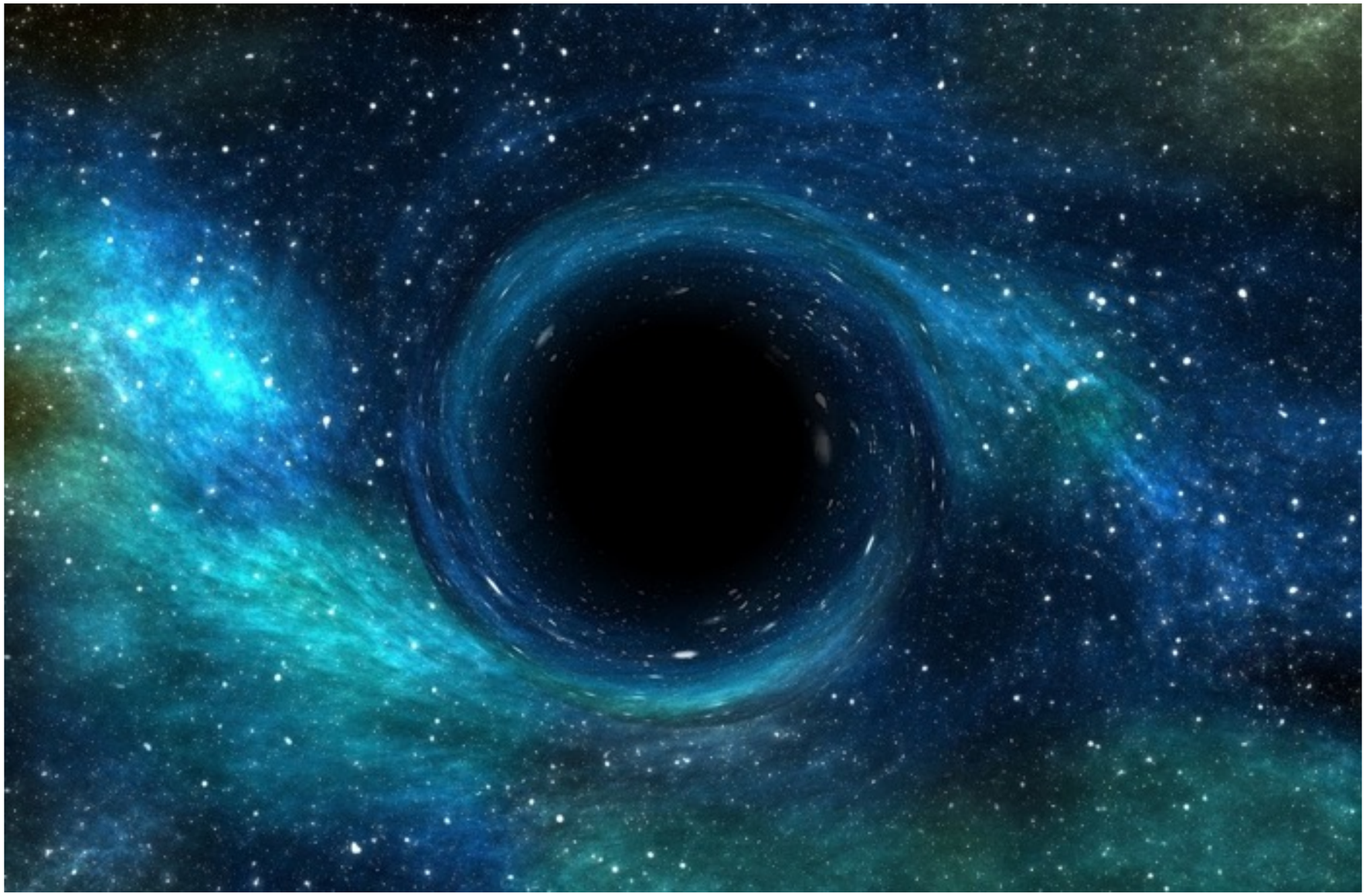
A **neutron star** is about 20 km in diameter and has the mass of about 1.4 times that of our Sun. This means that a **neutron star** is so dense that on Earth, one spoon would weigh a billion tons!



Crab Nebula

Black hole

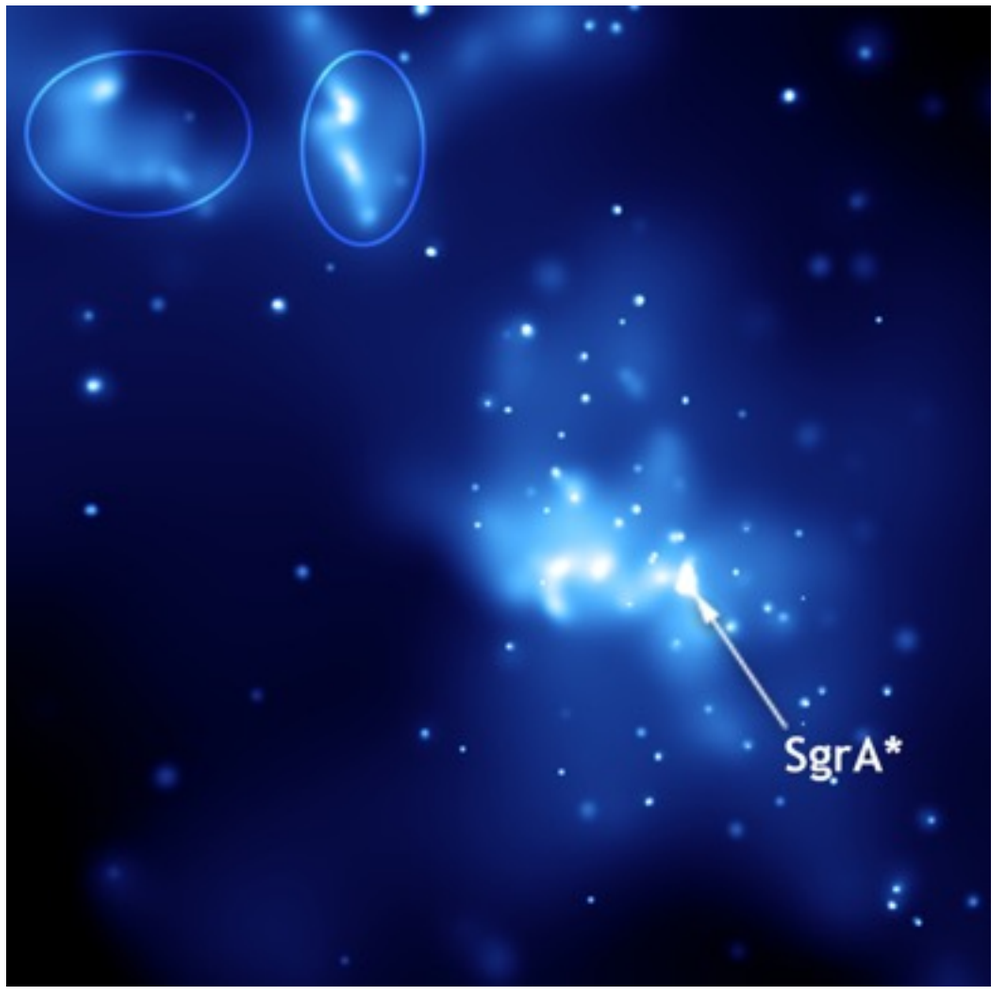
A **black hole** is a region of spacetime exhibiting such strong gravitational effects that nothing—not even particles and electromagnetic radiation such as light—can escape from inside it.



The Galactic Center: Observation of the black hole

- **Sagittarius A*** is thought to be the location of a supermassive black hole, like those that are now generally accepted to be at the centers of most spiral and elliptical galaxies.
- Observations of the star S2 in orbit around Sagittarius A* have been used to show the presence of, and produce data about, the Milky Way's central supermassive black hole, and have led to the conclusion that Sagittarius A* is the site of that black hole.
- Its mass is estimated in $(\mathbf{1 \pm 0.5}) \times \mathbf{10^6}\ \boldsymbol{M_\odot}$.

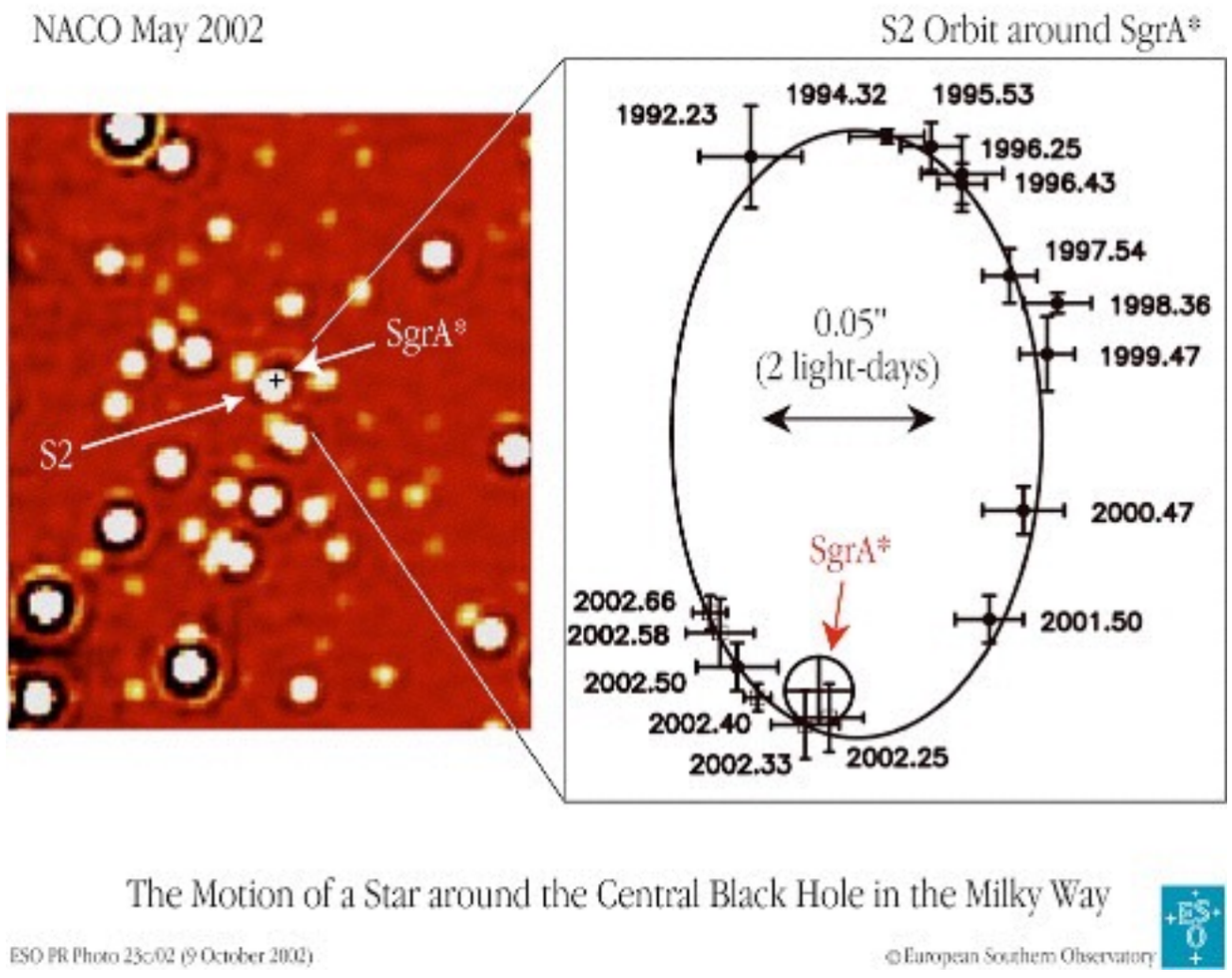
https://www.youtube.com/watch?v=W6e3hoa_2i0



Sgr A* (center) and two light echoes from a recent explosion (circled)

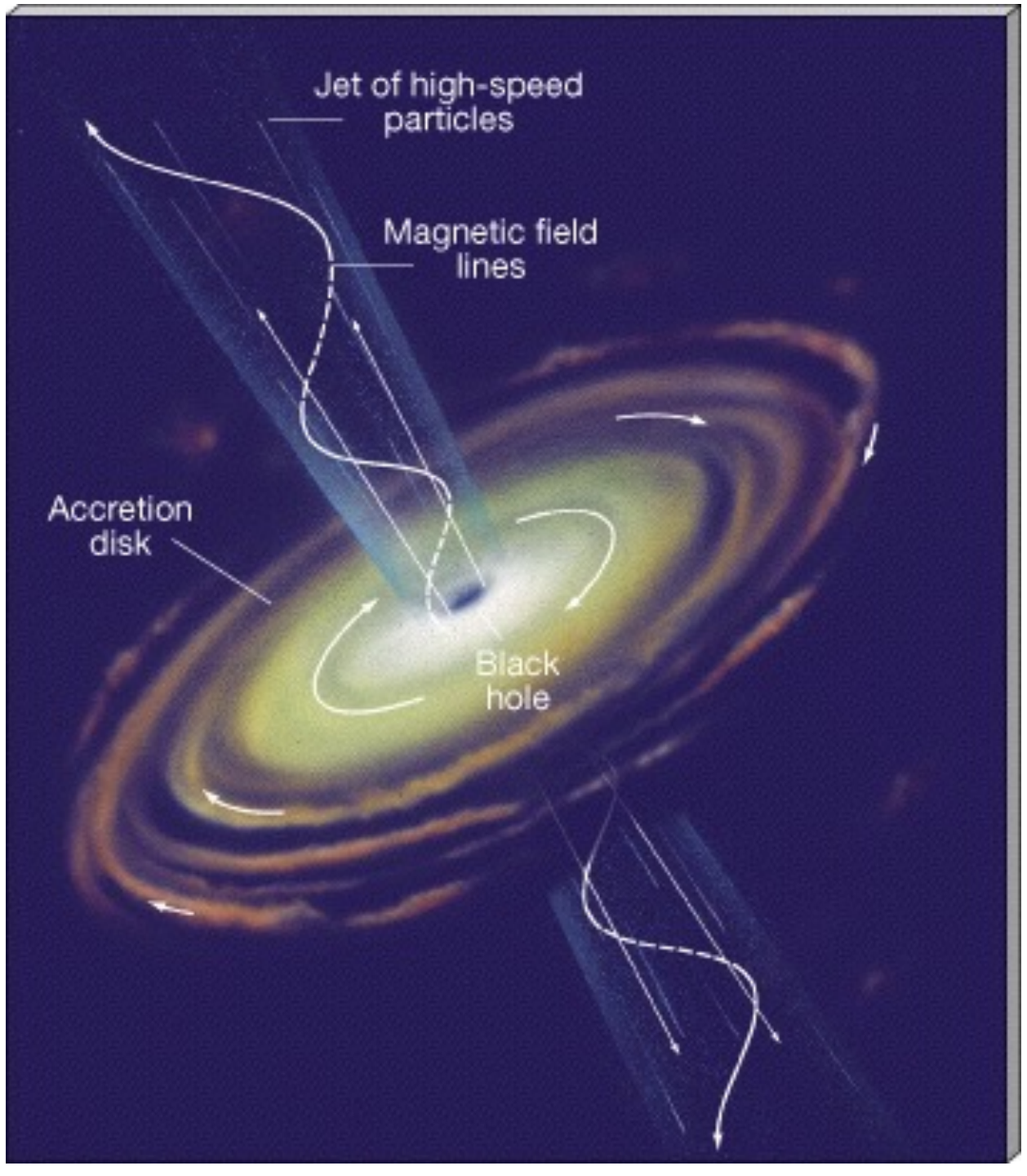
The Galactic Center: Observation of the black hole

- **The star orbits the galaxy's central black hole at an average distance of 5.5 light-days that takes about 15.2 years to complete**, at "an inclination of 46 degrees with respect to the plane of the sky". Its highly elliptical orbit is fairly stable, as S2 would have to come 70 times closer to the hole (16 light-minutes) to be at risk of being destroyed by tidal forces from the hole's gravity.
- Early in 2002, S2 came very close to the black hole, coming within 17 light-hours or around three times the orbital distance of Pluto from the sun (or 39 AUs). At its nearest approach, it zooms around the black hole at speeds exceeding 11 million mph (5,000 km per second).
- Because of its extremely high eccentricity (e= 0.87) of orbit, however, S2 also moves as far away from the hole as 10 light-days.

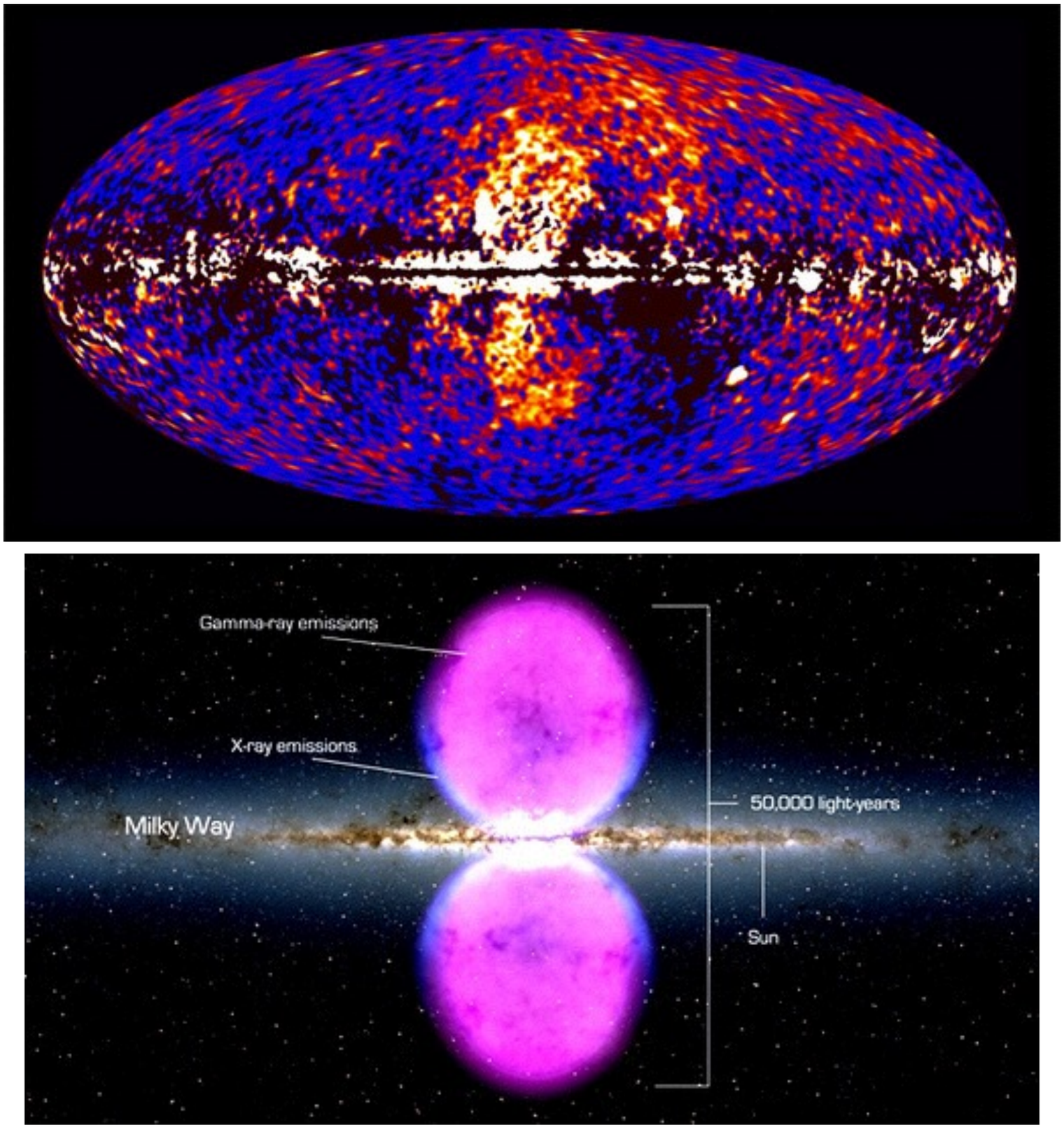


https://www.youtube.com/watch?v=u_gggKHvfGw

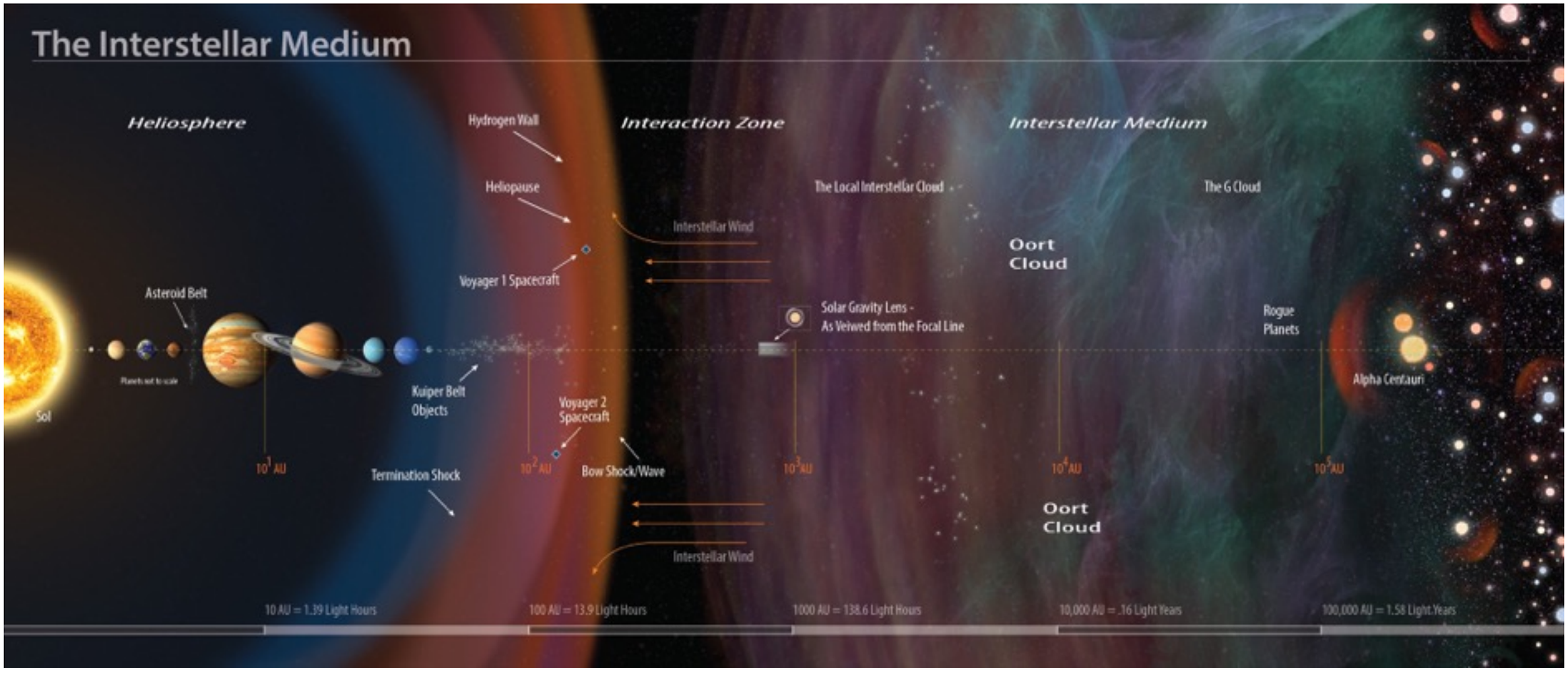
Active Galactic Nuclei



Fermi-Bubbles



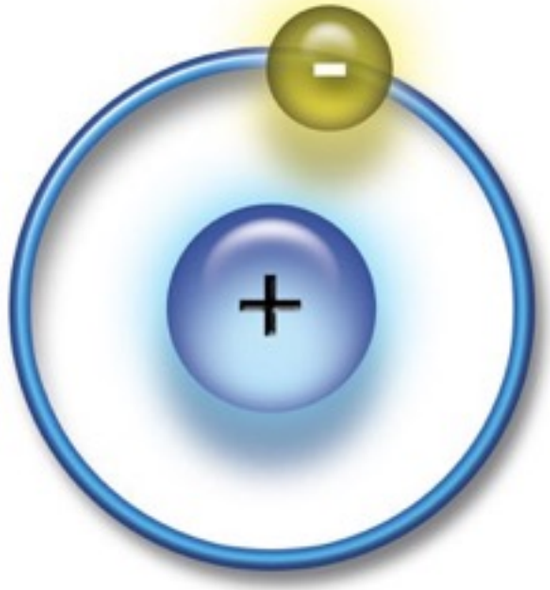
Interstellar medium



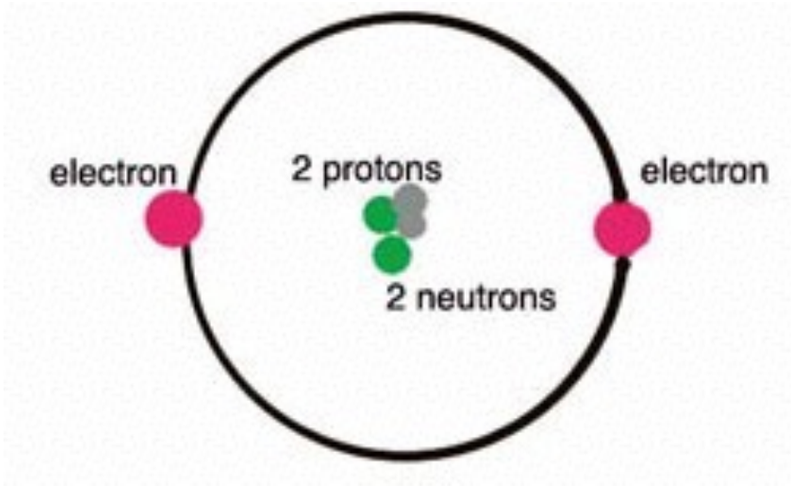
- The **interstellar medium** (**ISM**) is the matter that exists in the space between the star systems in a galaxy. This matter includes gas in ionic, atomic, and molecular form, as well as dust and cosmic rays.
- **It is composed by 90% if made of hydrogen atoms, 9% of helium atoms and a 1% of heavier nuclei.**
- The energy that occupies the same volume, in the form of electromagnetic radiation, is the **interstellar radiation field**.
- In the ISM there is a magnetic field with a strength of a few μG far from the Galactic Center and a few tens of μG in the GC.

Hydrogen, Helium and Photons

Hydrogen



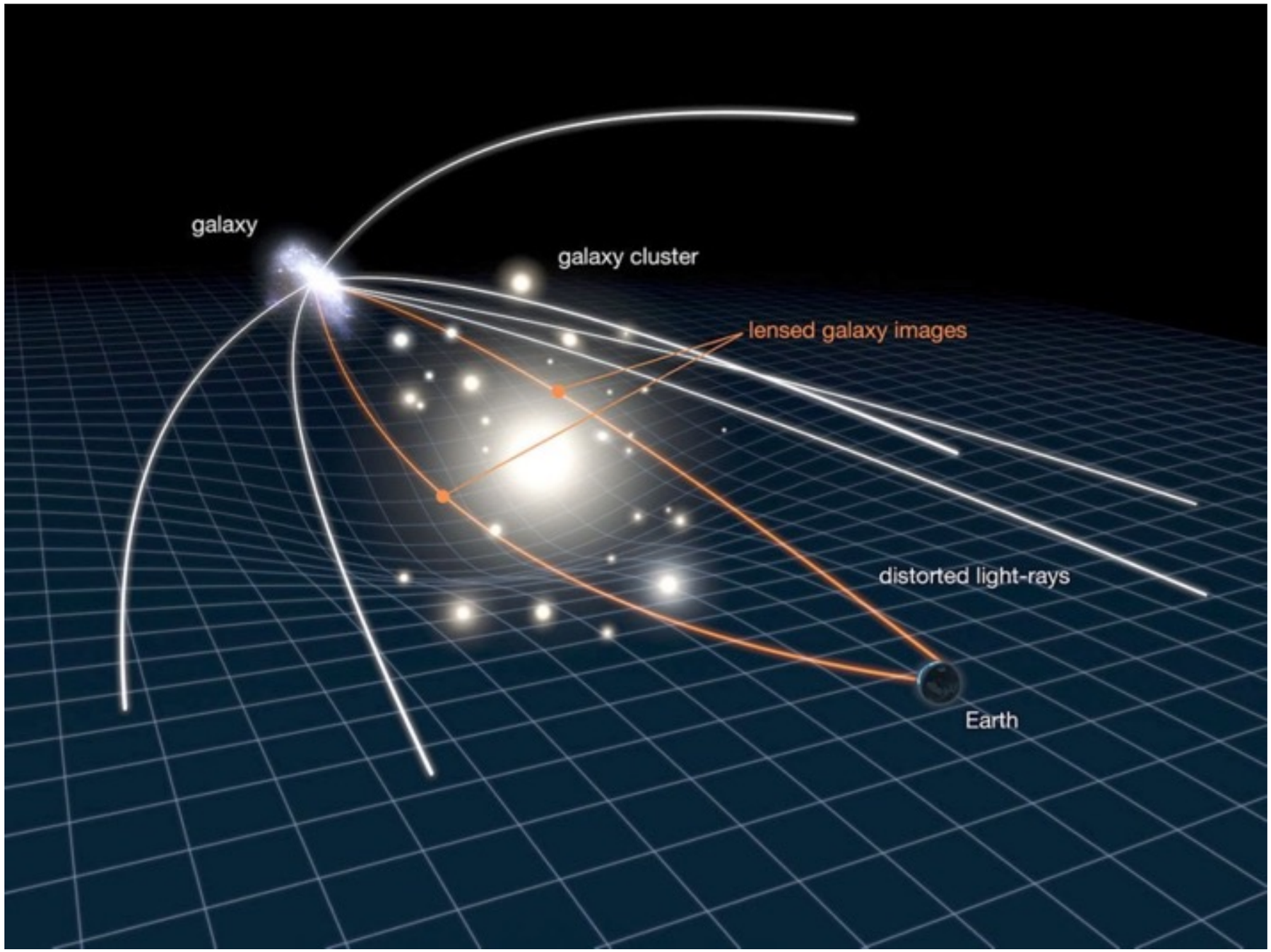
Helium



Photon

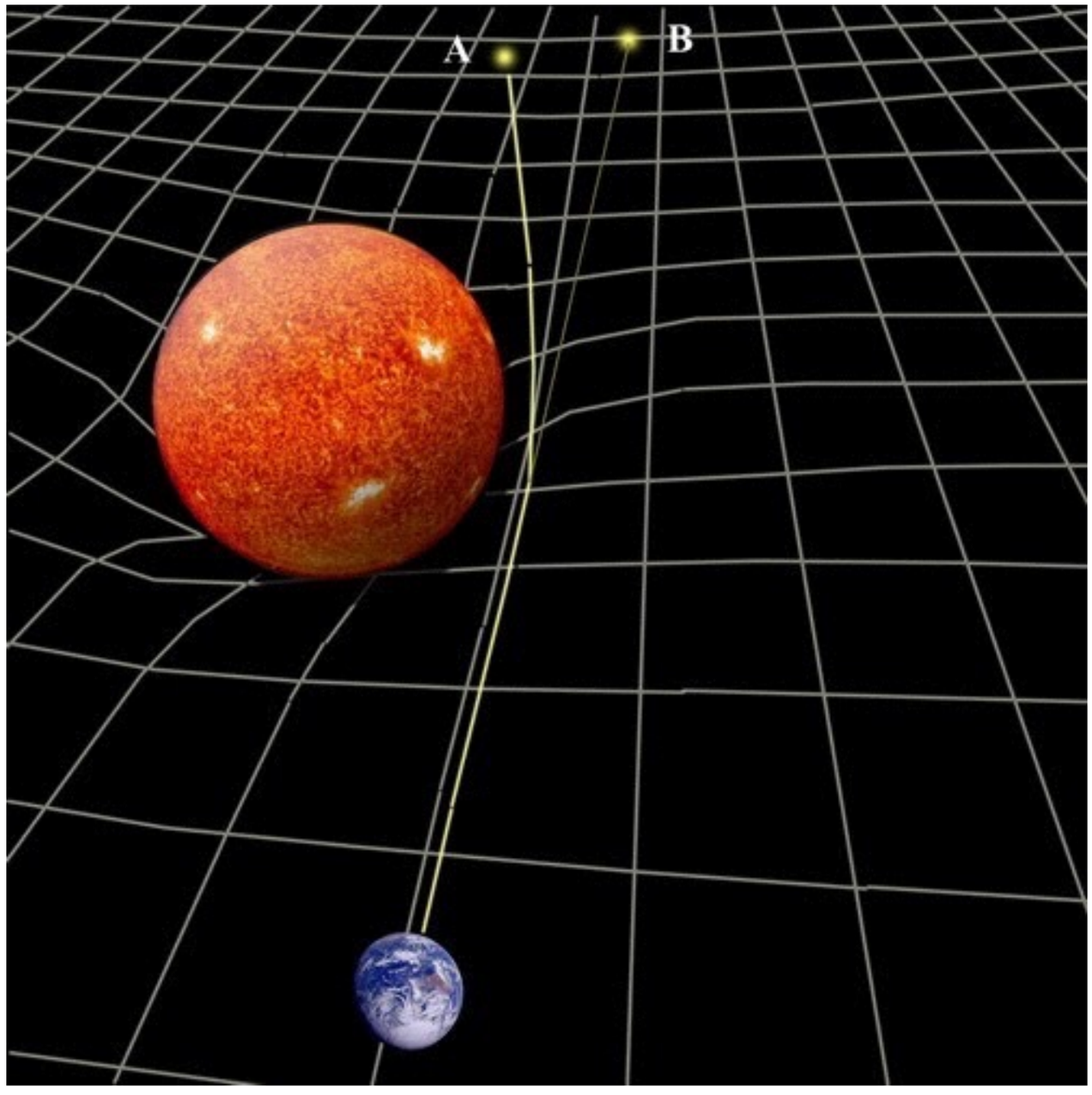
Gravitational lensing

Gravitational lensing

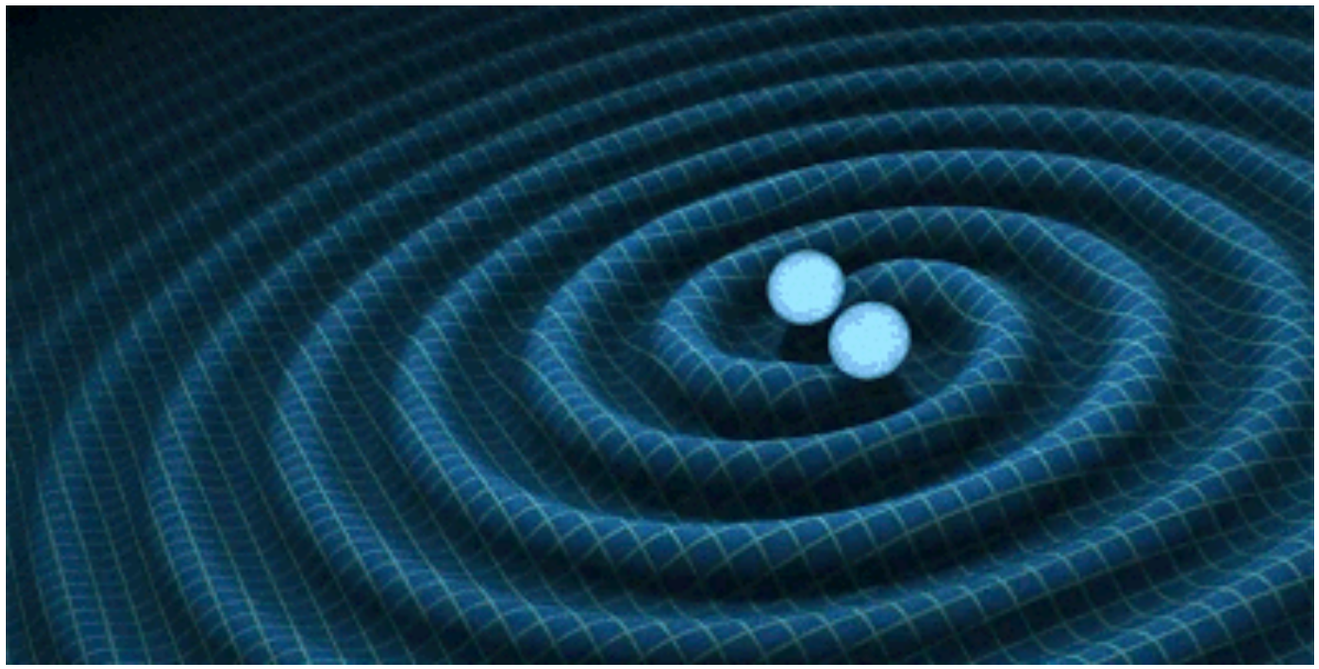


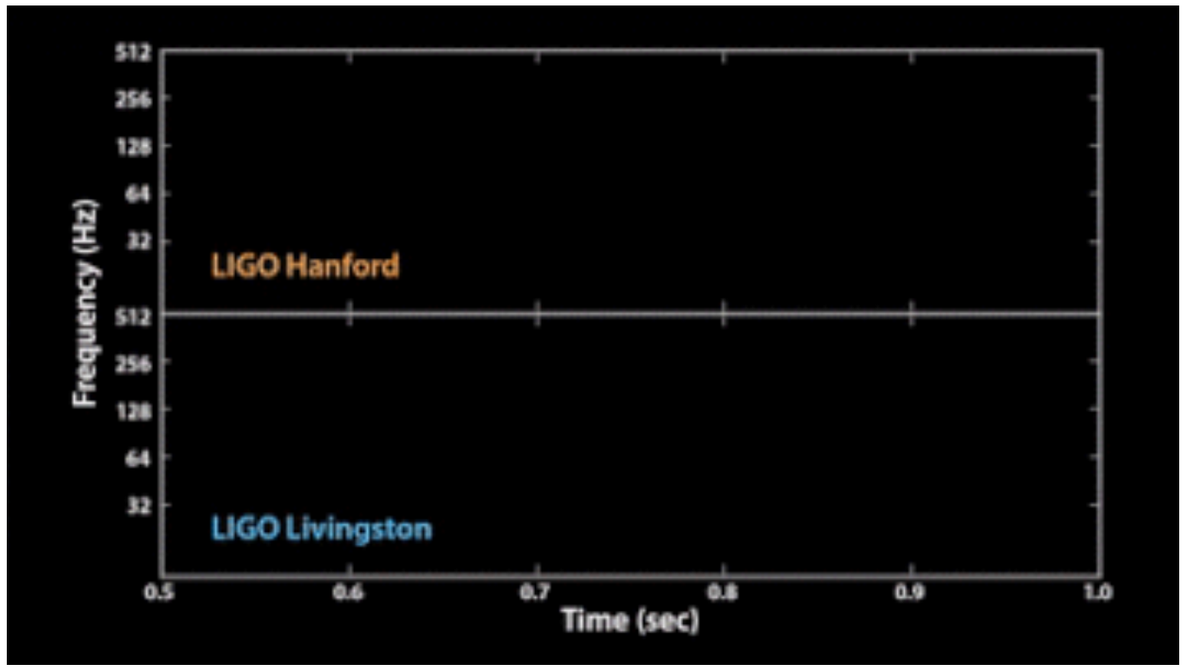
Gravitational waves

Gravitational waves are ripples in the curvature of spacetime that propagate as waves at the speed of light, generated in certain gravitational interactions that propagate outward from their source.



Gravitational waves





The end