# Tour of the Universe

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# Part 1: The invisible universe

Part 2:: An orientation tour of the multicolor Universe

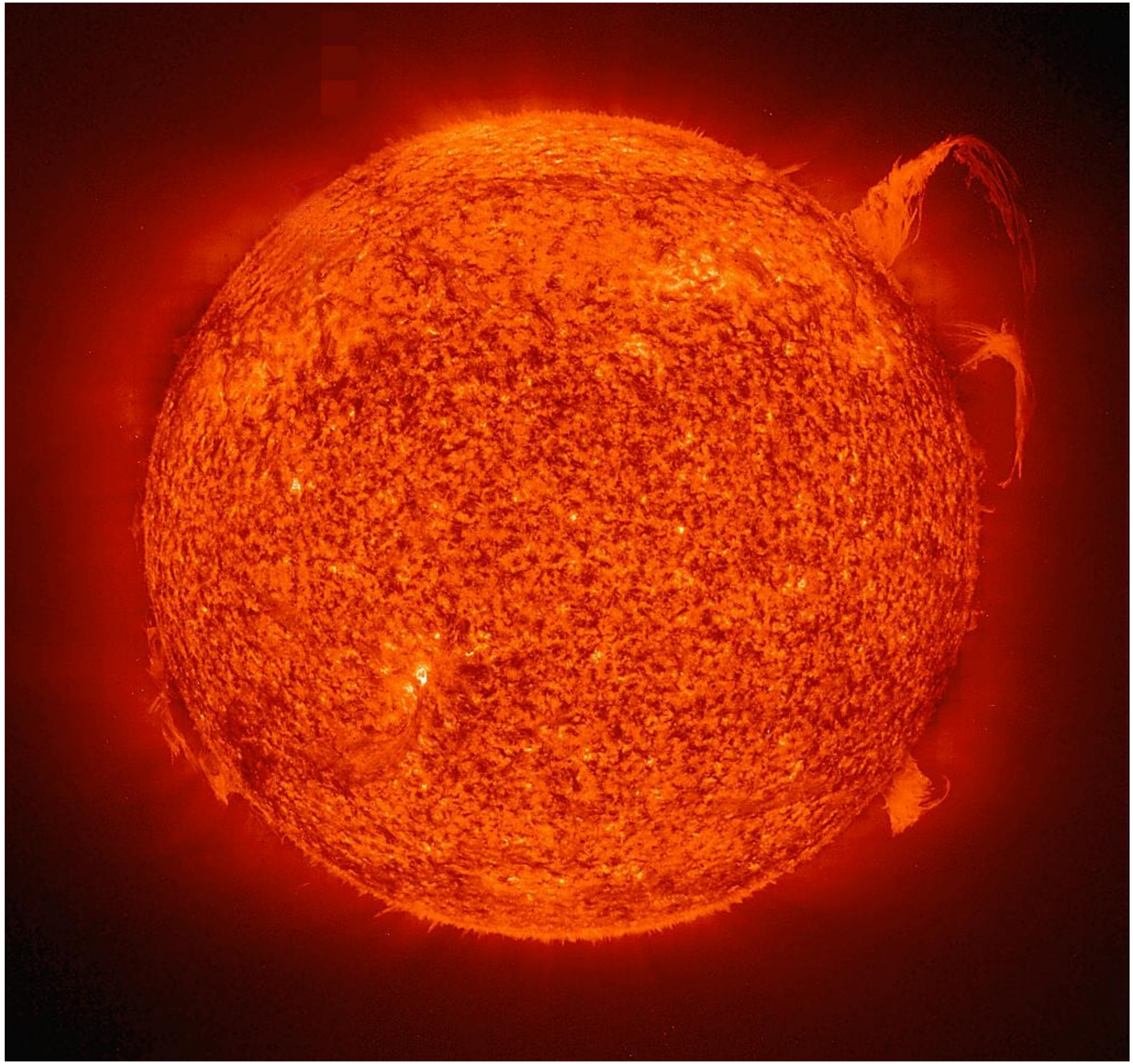
From the Earth to distant galaxies

Our Solar System: The Earth-Moon system

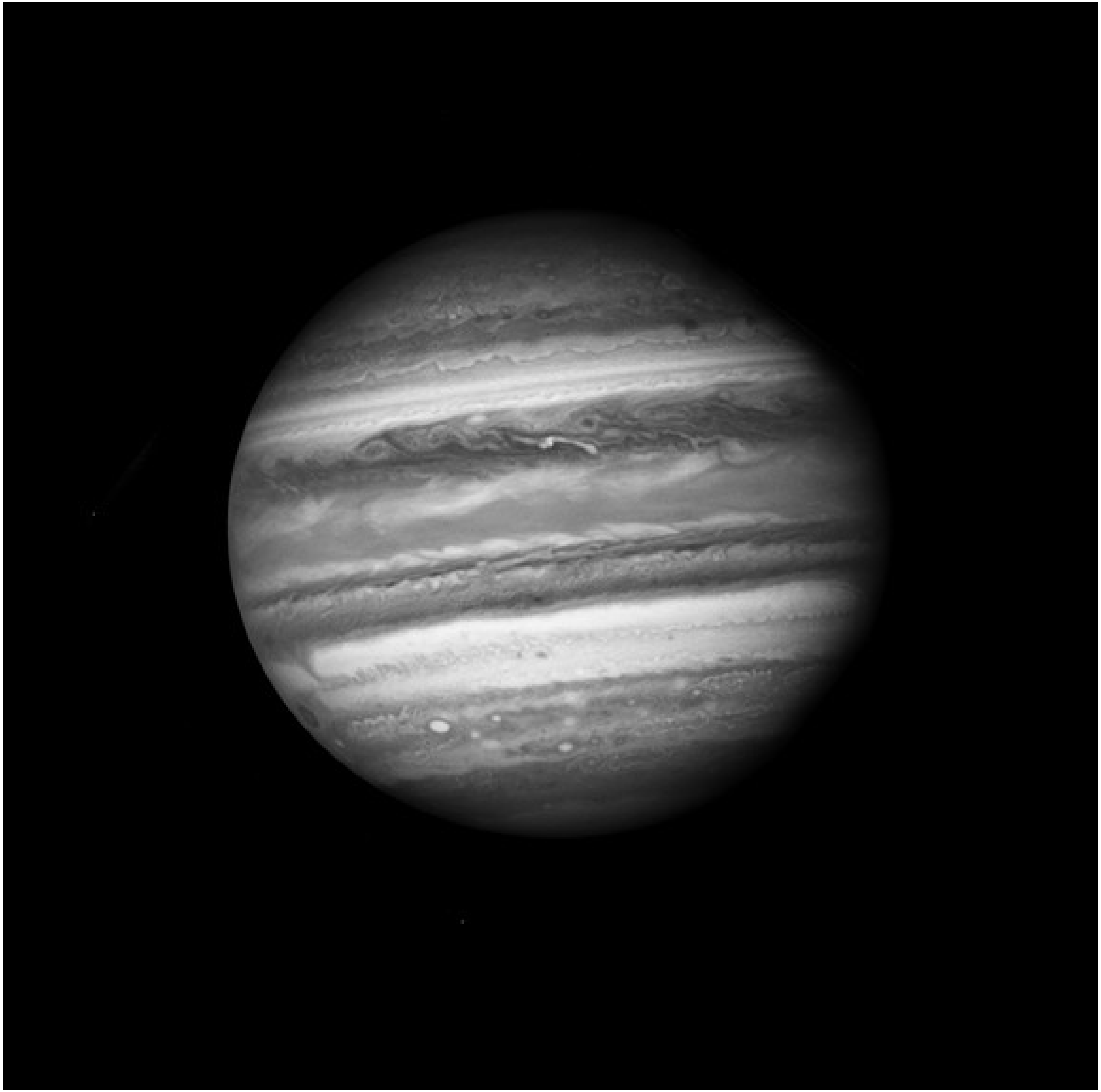
Earthrise over the Moon: 1969

1.3 seconds away at the speed of light

Our Solar System: The Sun



The Sun: 8 minutes away

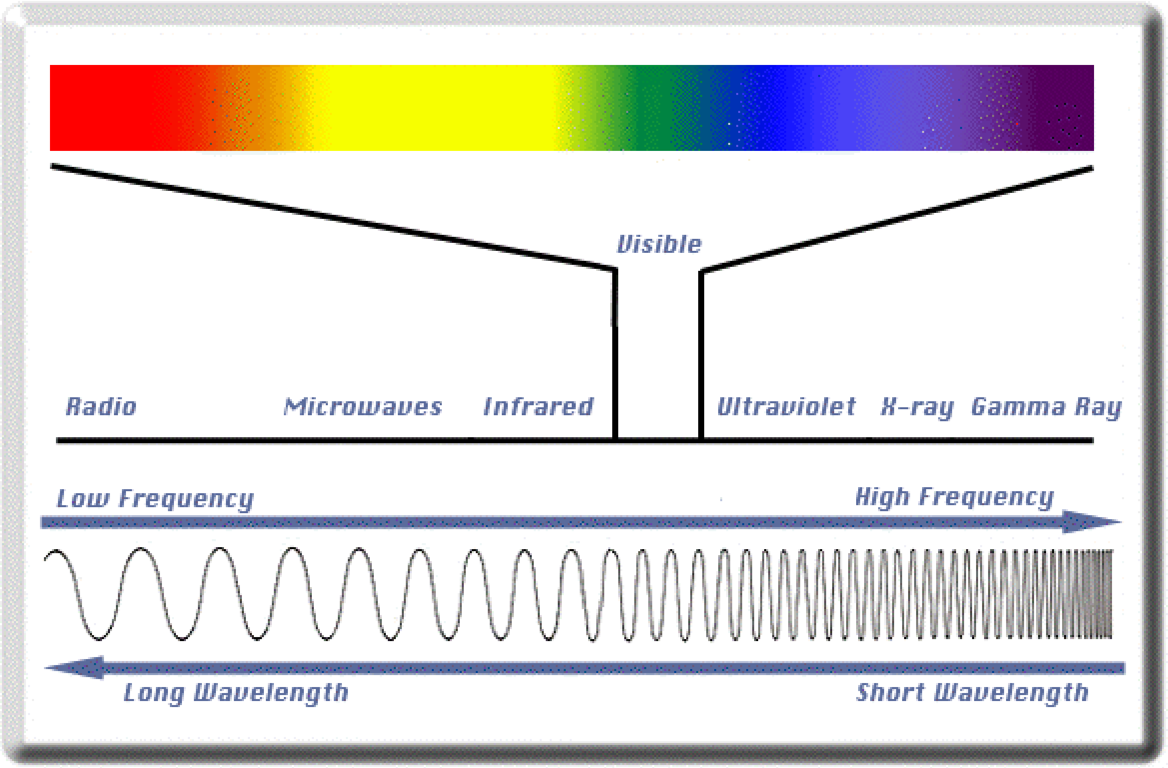


Our solar system:
Jupiter
(visible light,
Hubble)

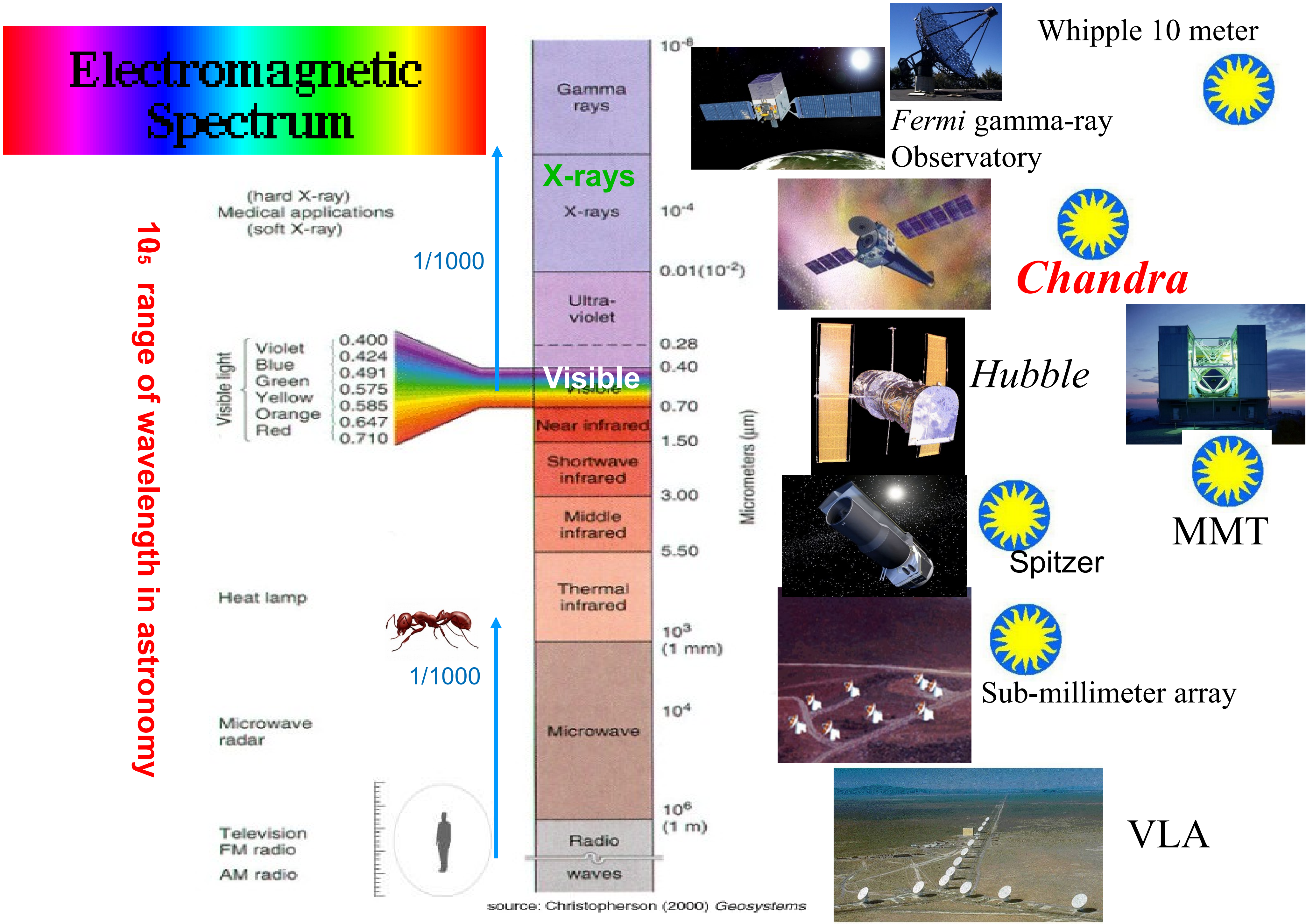
What's happing in the Universe these days?

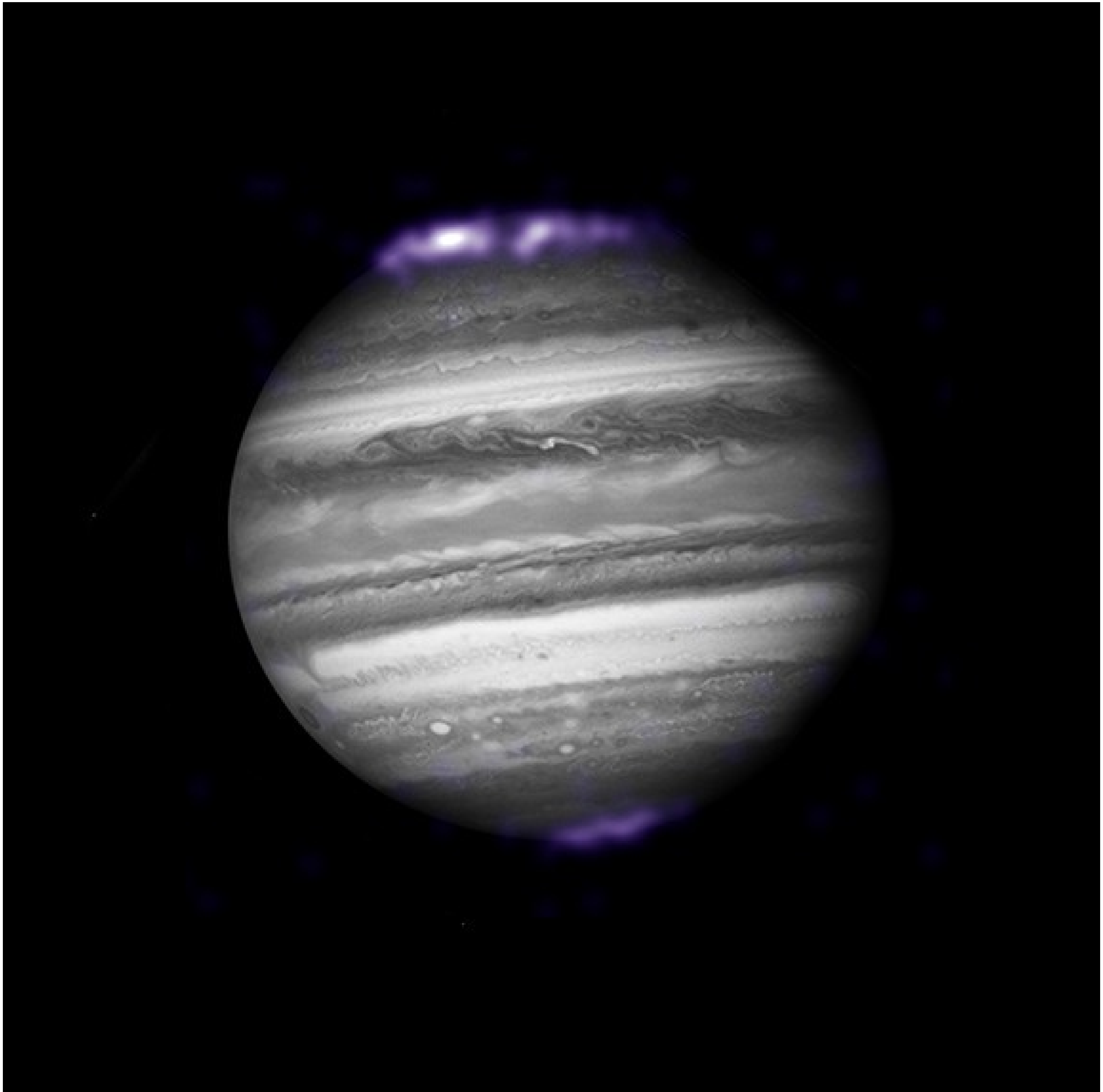
We often divide up astronomy by the different WAYS WE LOOK AT THE SKY...

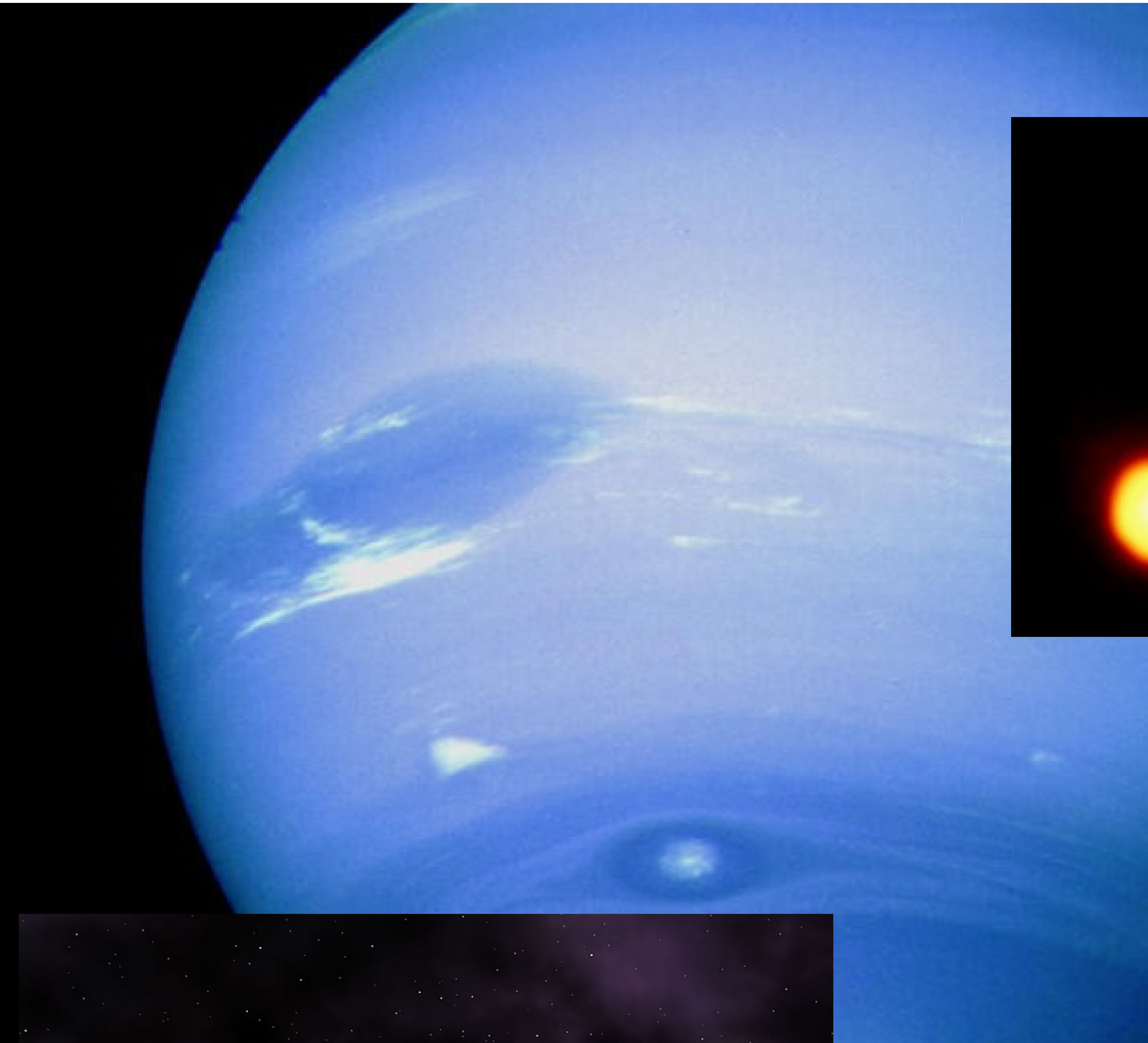
- RADIO telescopes which mostly see 'nonthermal' radiation
- INFRARED telescopes see cold (10-1000K) matter – star formation
- OPTICAL telescopes see warm (1000-100000K) matter – ordinary stars and gas
- X-RAY telescopes see hot (1 to 10 million K) matter – black hole accretion, supernovae and other drastic events



# We are now in the era of multiwaveband astronomy

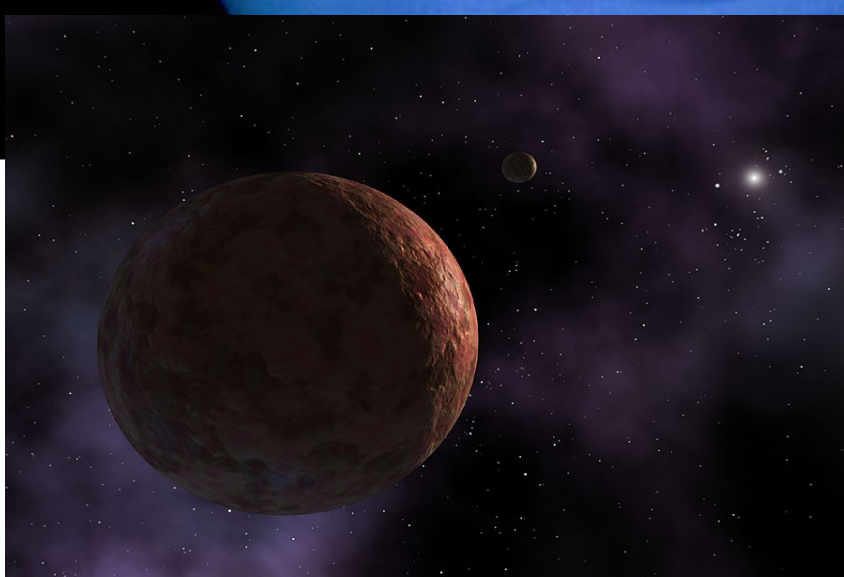


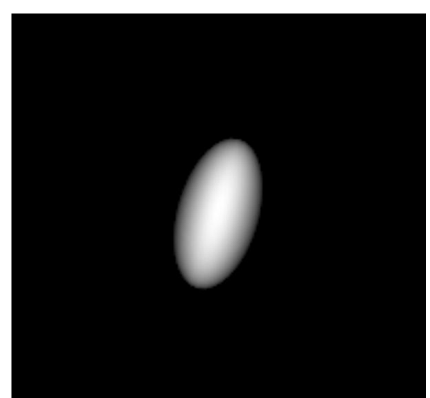


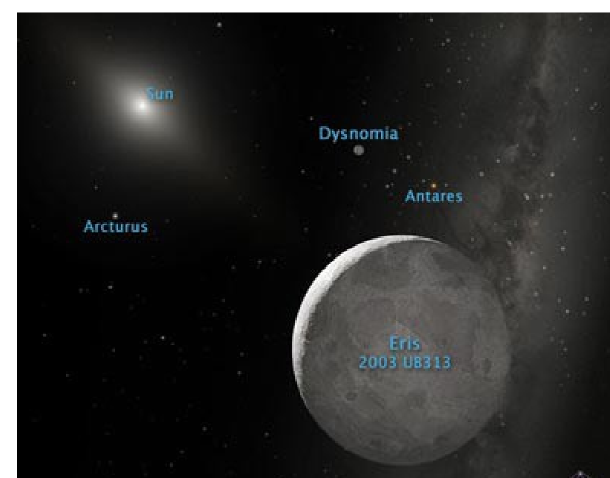


# Our Solar System: Neptune and Beyond

| | | |
|---|---|---|
| VIII Neptune: | 4 hours | 50000 km |
| 134340 Pluto: | 4h 24min | 2300 km |
| 136108 Haumea: | 7h 4 min | 1960 x 1000 |
| 136472 Makemake: | 7h 13 min | 1500 km? |
| 136199 Eris: | 13h 23 min | 2600 km |



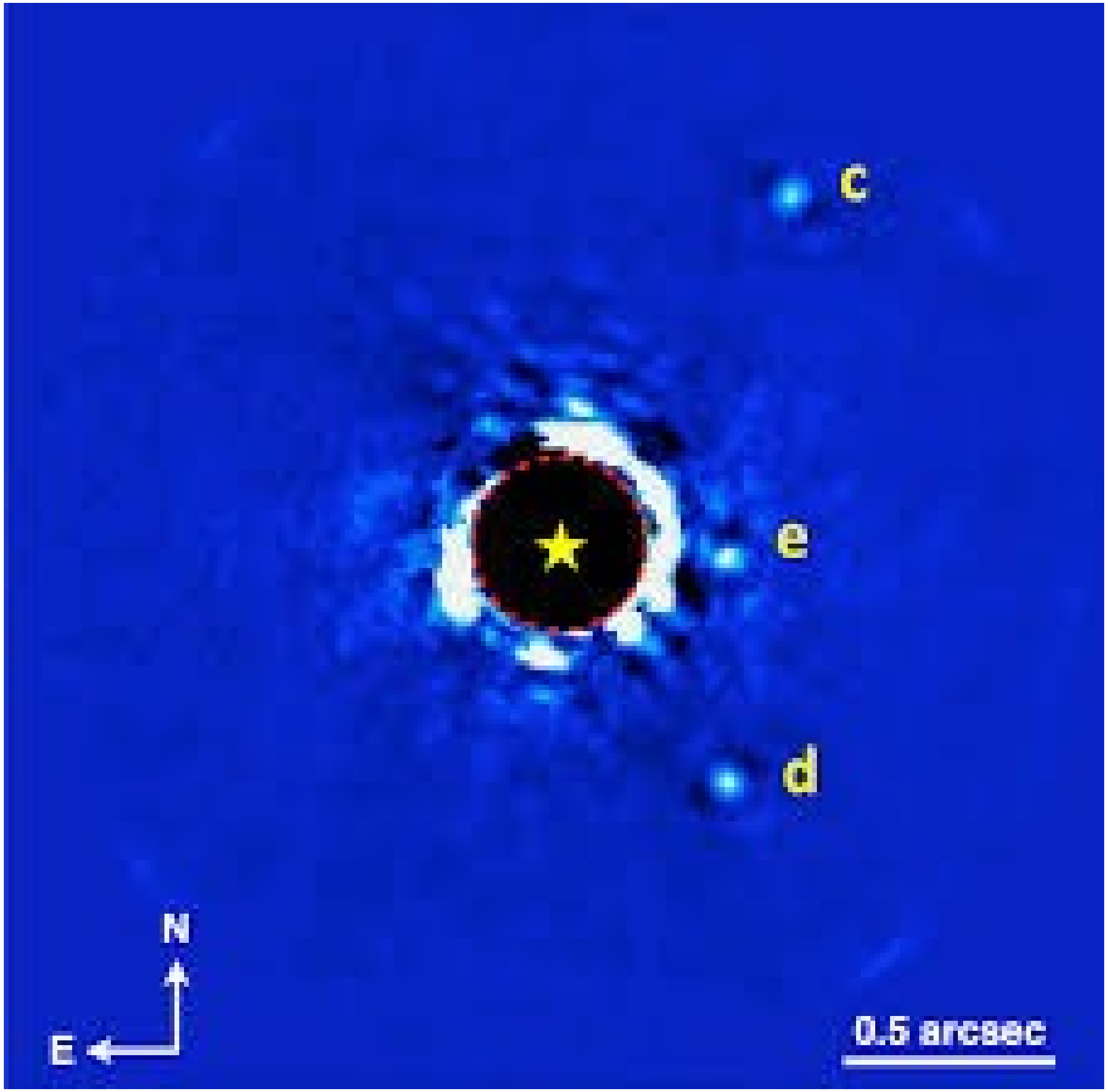




# The Milky Way Galaxy: star clusters


Pleiades Star Cluster in Taurus:  440 years away

Seen as it was when Shakespeare was a child




Planets around the star HR8799
129 light years away
(central star blocked)

(Gemini Planet Imager)

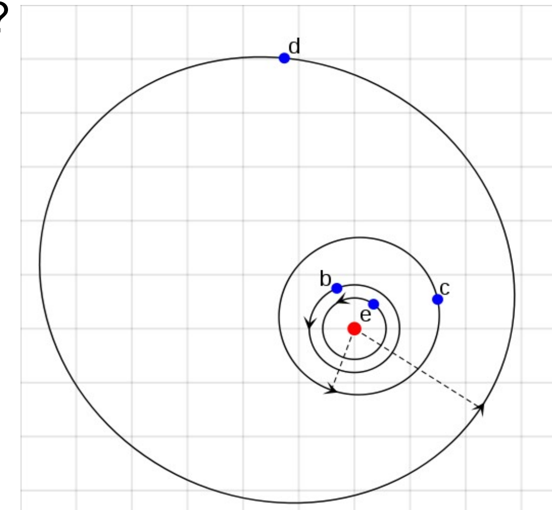
# EXOPLANETS

1989: Dave Latham finds object around HD114762 – planet or brown dwarf?

1995: Discovery of 51 Pegasi b (Mayor and Queloz, Geneva)
a “Hot Jupiter”, only 5 million mi (8 million km) from its parent star

2007-2009: Gliese 581 system
Gliese 581d, mass of 6-10 Earths
A “super-Earth” in the habitable zone

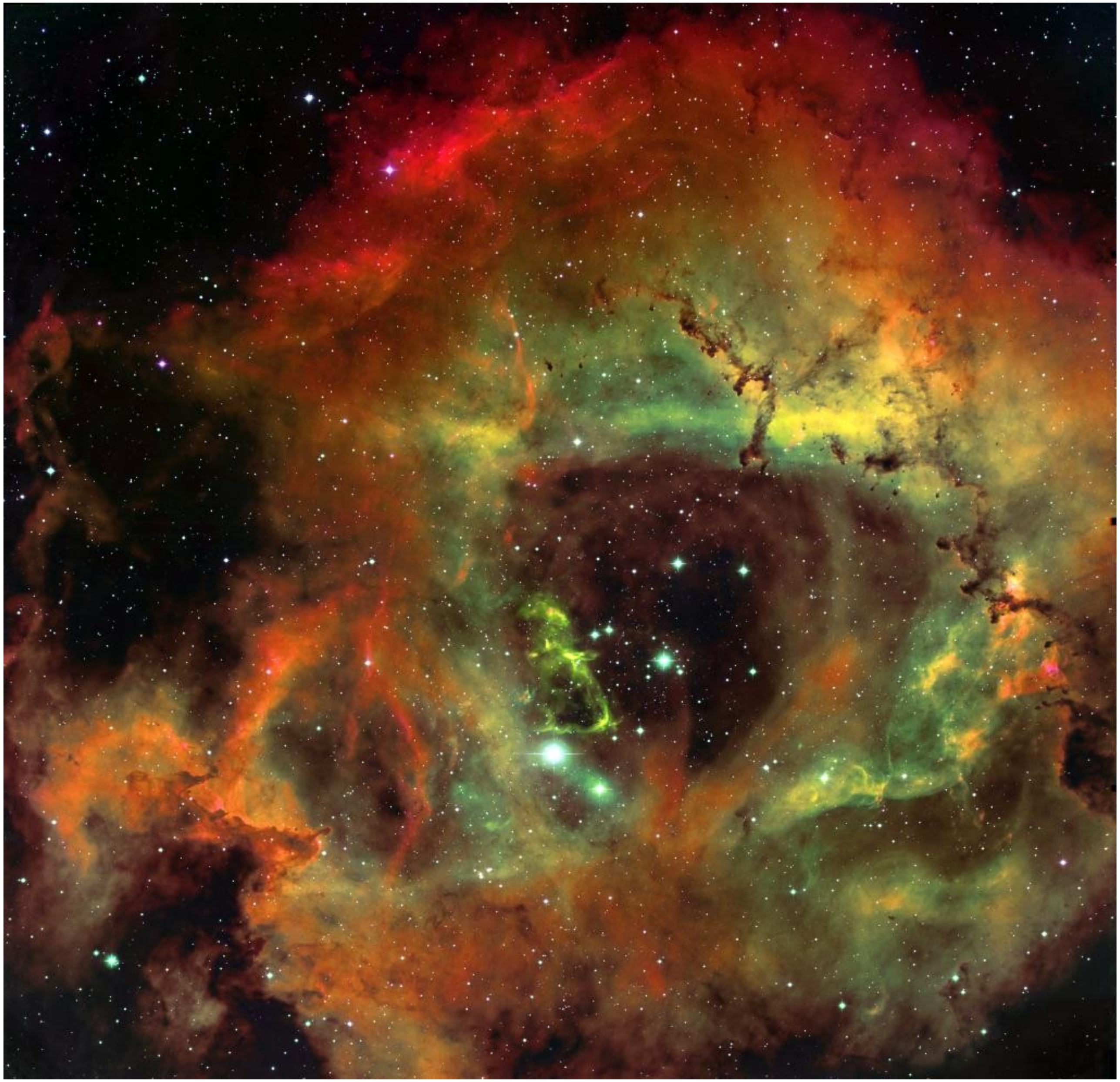
2012: 760 exoplanets now known
Kepler mission finding many new ones, including multiple-planet solar systems and **Earth-sized planets**



JD 2453152.0 (26 May 2004CE, 12:00:00.0 UT)
Each grid square 0.05 AU × 0.05 AU
Planets and star not to scale

Blue: our solar system. Red: Pre-2012 Kepler planets, Green: new Kepler planets

The Milky Way Galaxy:  Nebula



Rosette Nebula in Monoceros
4900 years away

Seen as it was when the first pyramids were built in Egypt

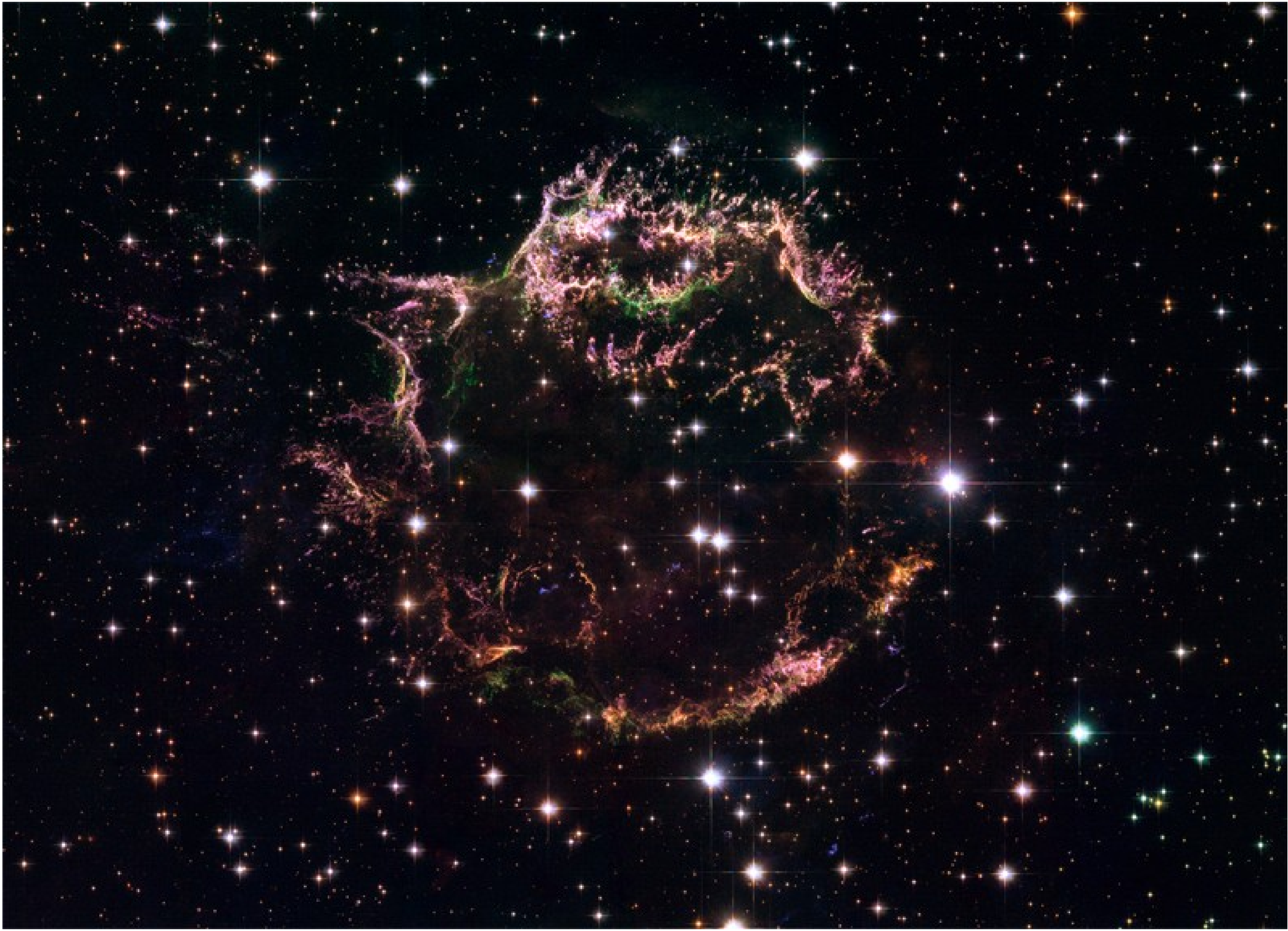
Milky Way galaxy: star cluster (infrared)

NGC 281 star cluster – infrared
10000 light years away

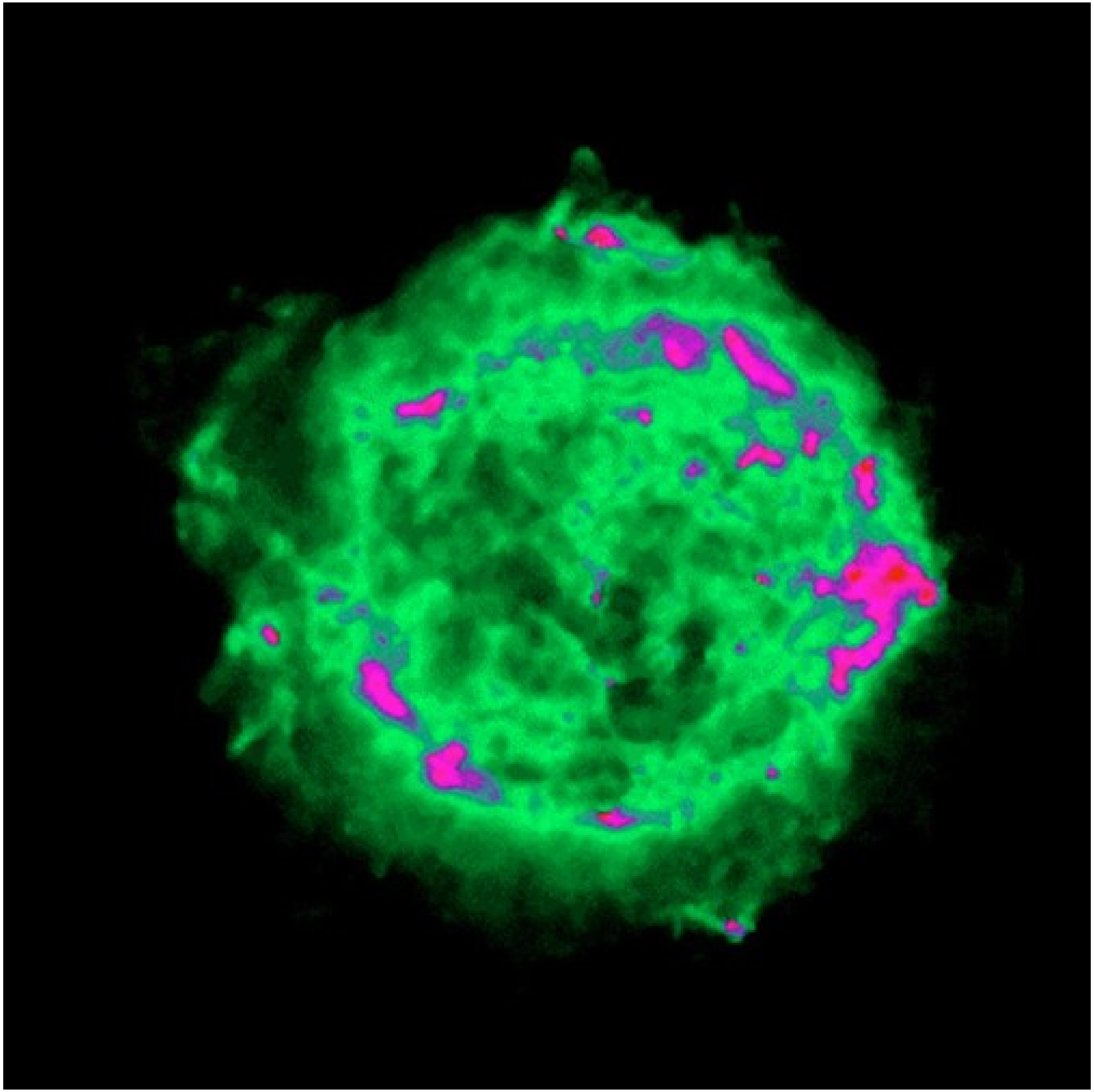
Milky Way galaxy: Star cluster NGC 281

Milky Way galaxy: star cluster (infrared +X-ray)

NGC 281 (Scott Wolk, SAO)



Milky Way galaxy: Supernova remmant (radio)

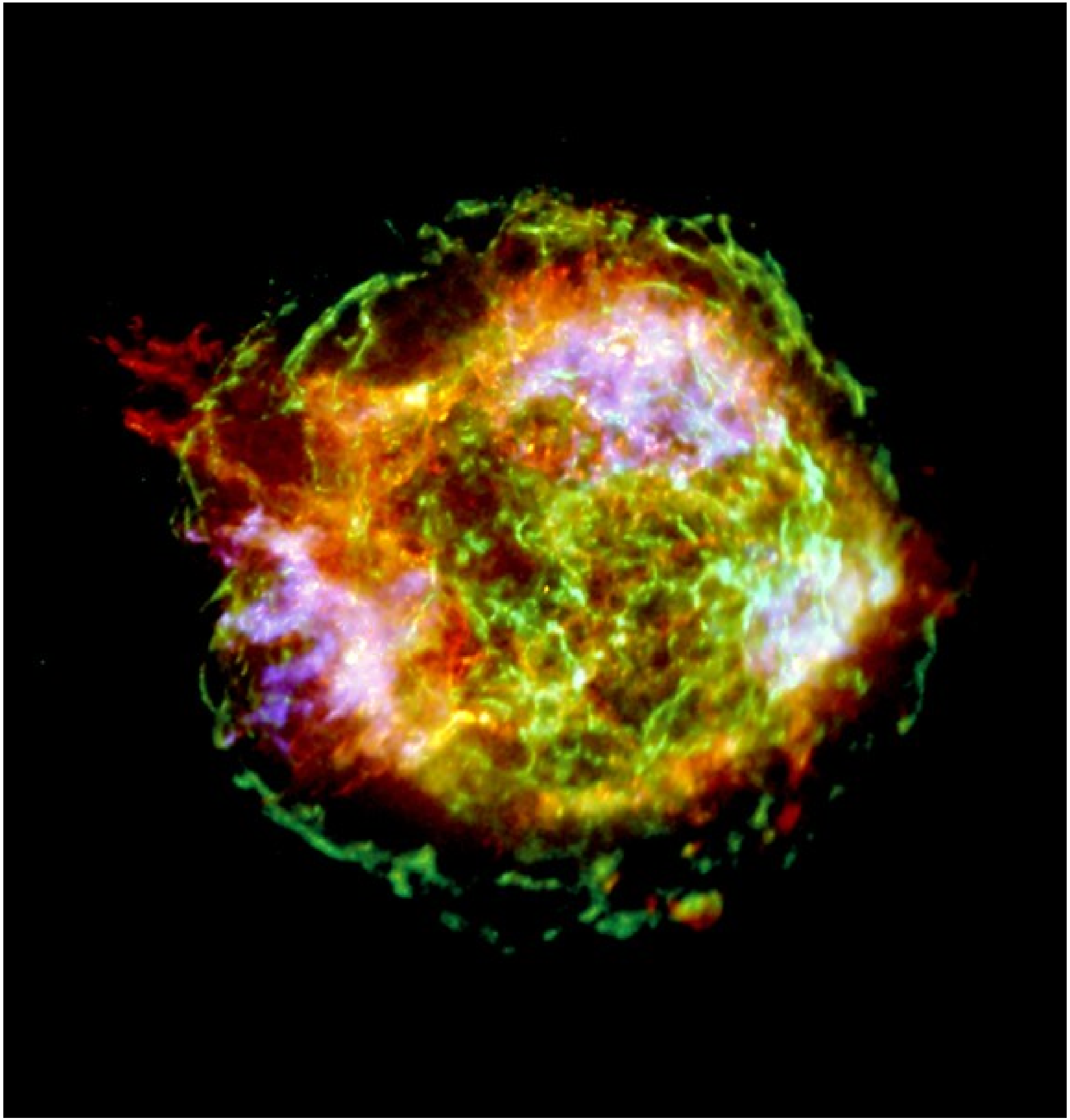


Cas A as seen by a radio telescope

## Milky Way galaxy: Supernova remmant (X-ray)

- 1 megasecond (11 days)
- Blue: Iron
- Red: Silicon
- Green: outer shock wave

# Cas A with Chandra (Una Hwang)

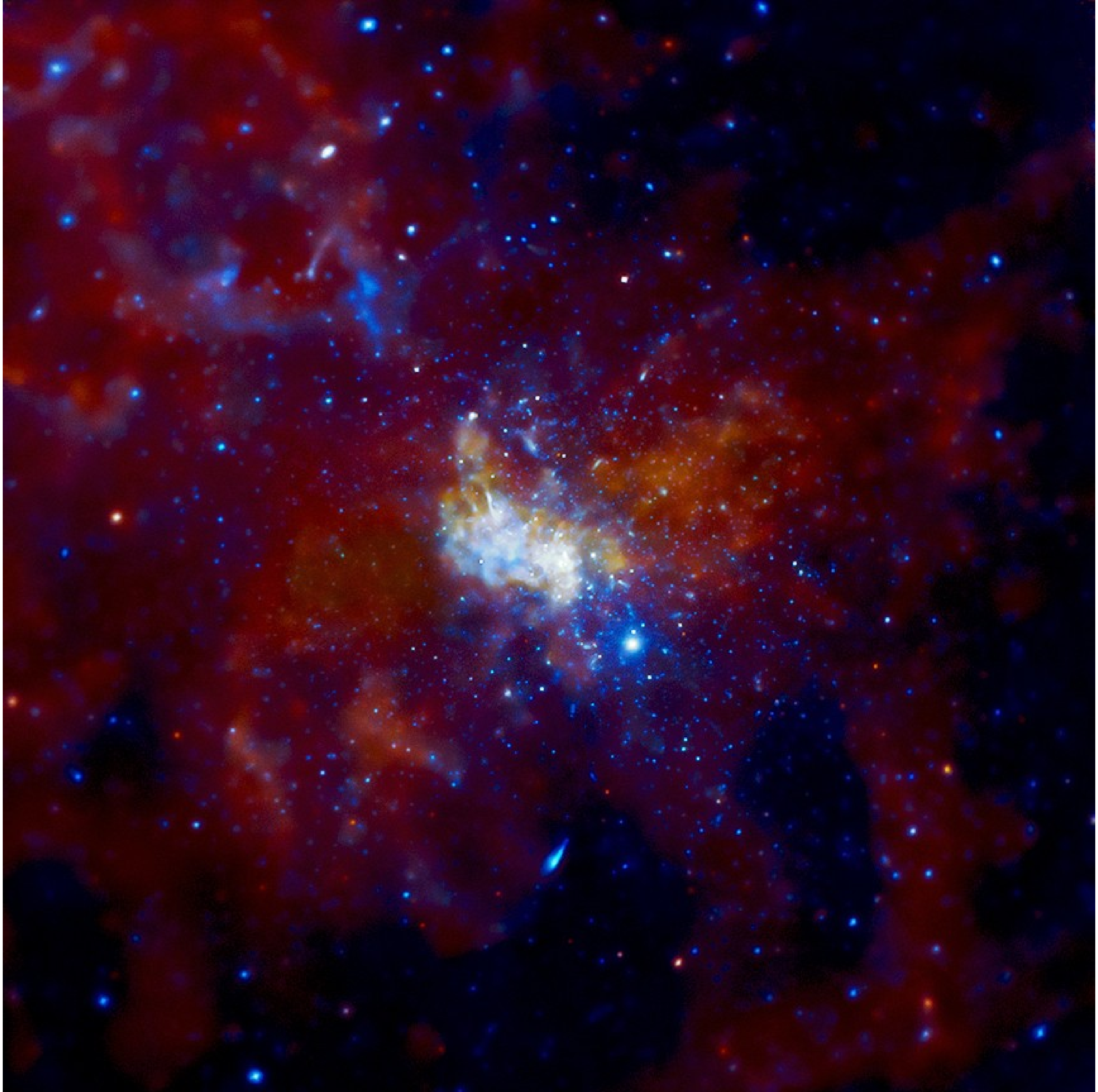


11000 light years away

16 light years across

# The Milky Way Galaxy: Galactic Center

Milky Way in Sagittarius: 30000 Years Away
Seen as it was when modern humans had just evolved



The Extragalactic Universe:  Spiral Galaxy

Great Galaxy in Andromeda (M31):  Our Next Door Neighbour - 2 Million Years Away

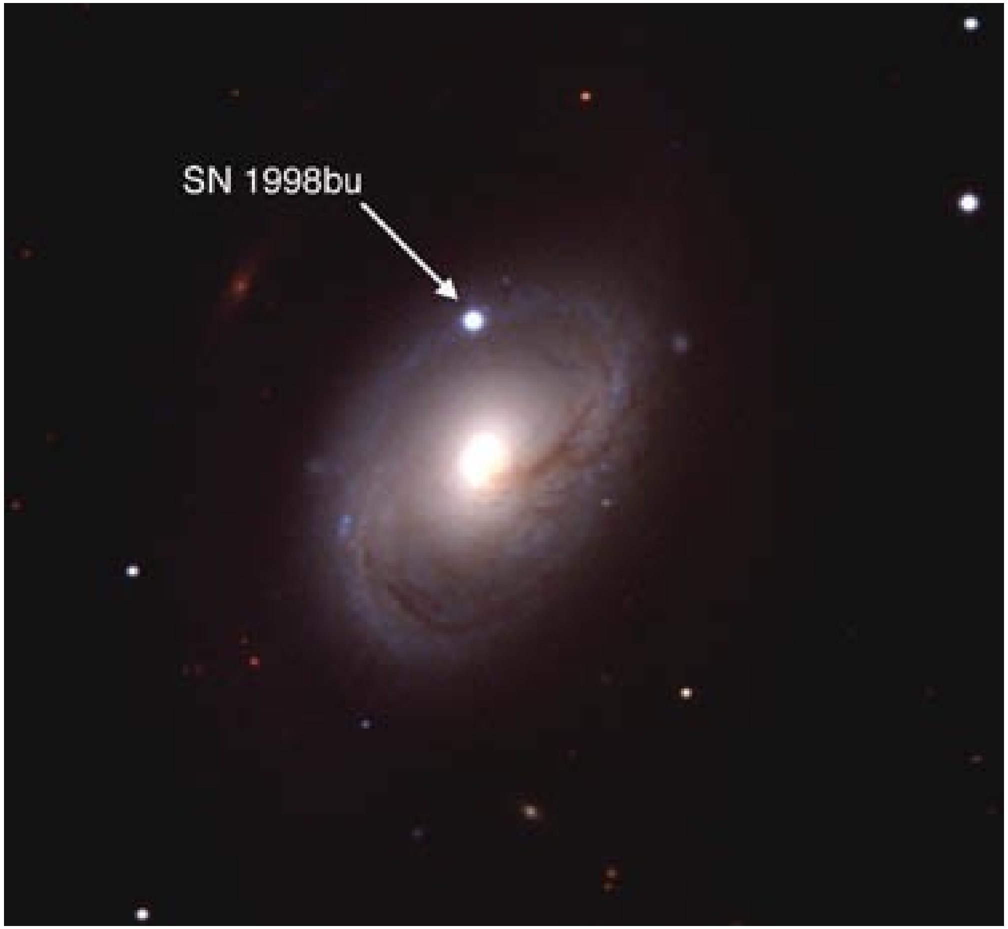
Seen as it was in the Pleistocene

Extragalactic Universe:   Spiral Galaxy

Galaxy NGC 3982 in Ursa Major – 60 Million Years Away

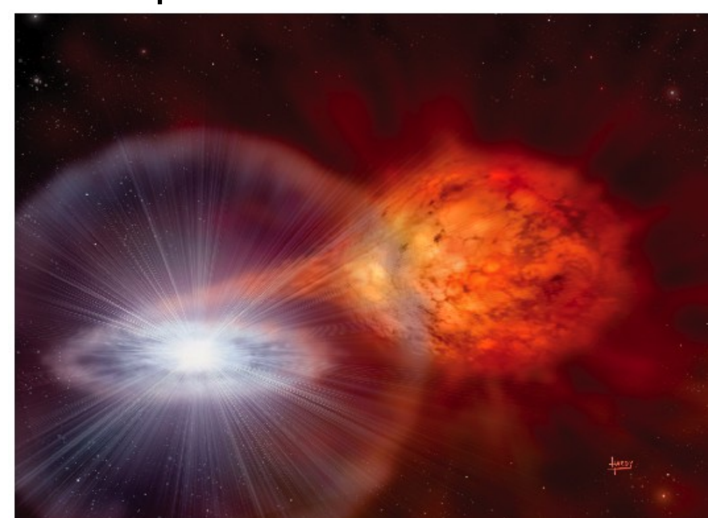
Tertiary  (K-T boundary)

# SUPERNOVAE



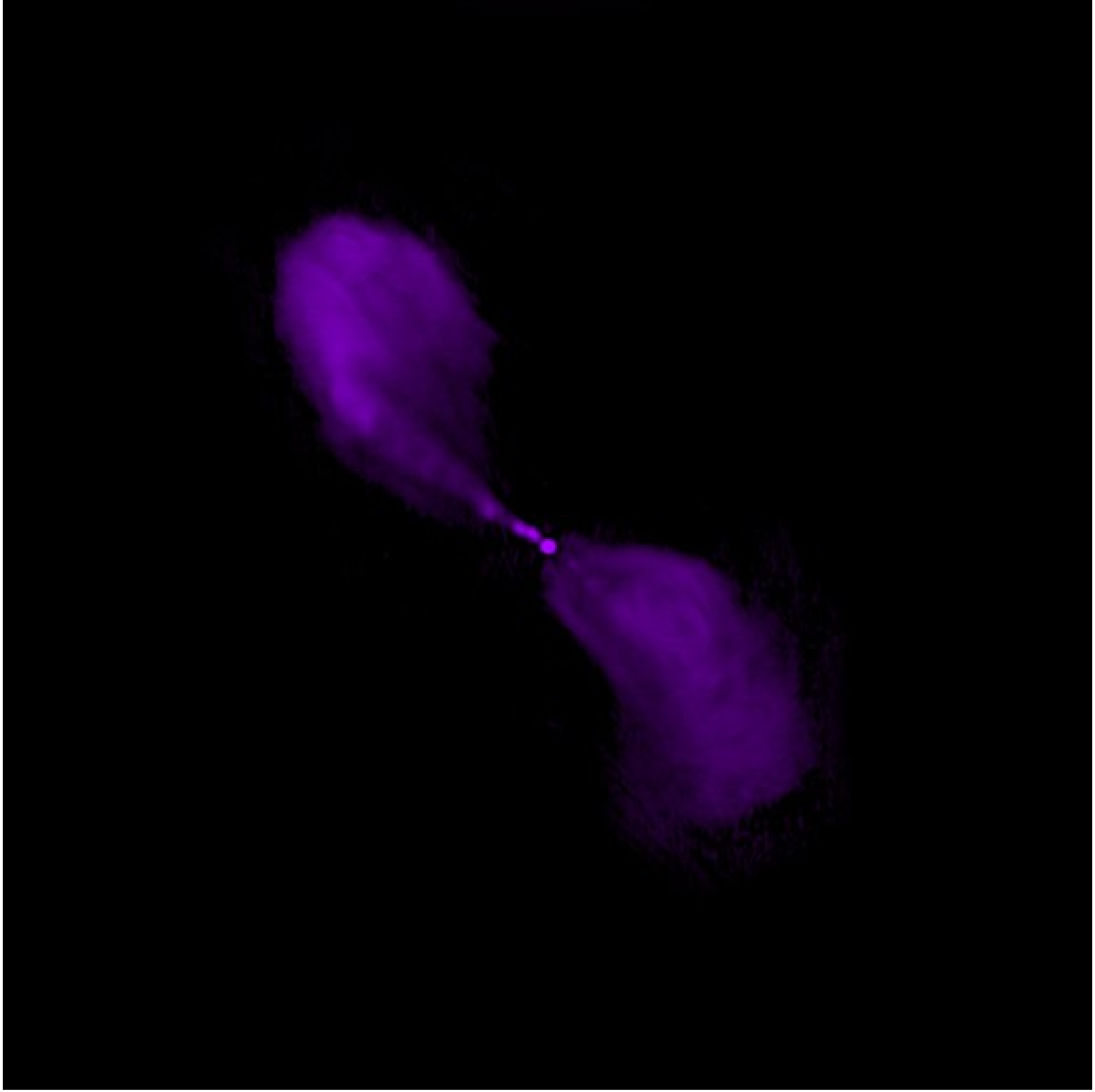

Type 1a SN:

- White dwarf star in binary system
- Steals extra mass from companion
- Reaches critical mass
- Runaway fusion converts part of the star to energy within a few seconds
- Star flies apart
- Radioactive decay of newly made elements releases energy over months
- Can tell how much energy it's putting out from how long it takes to fade, so can tell how far away it is!
- Use them to map out the scale of the universe

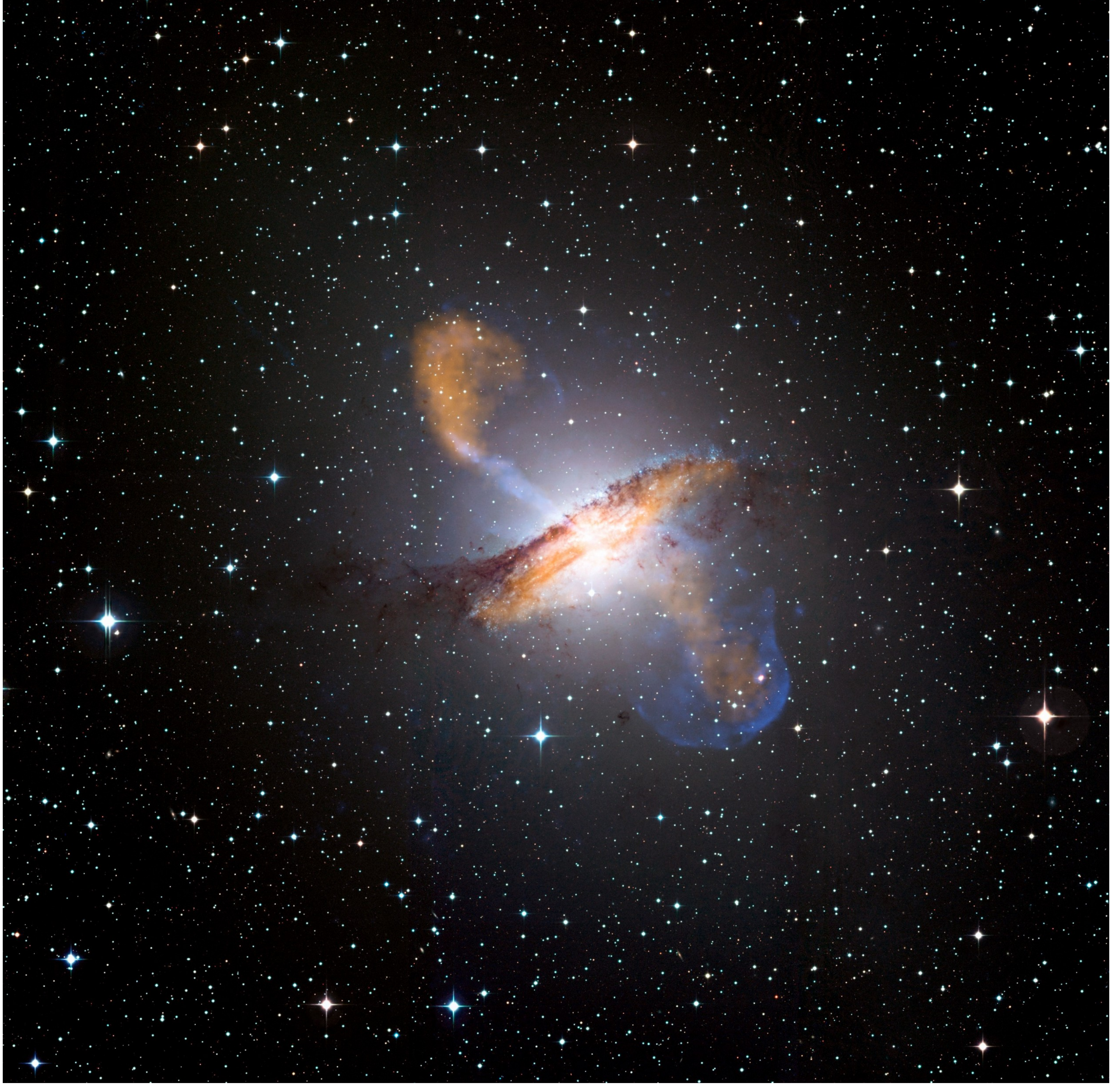


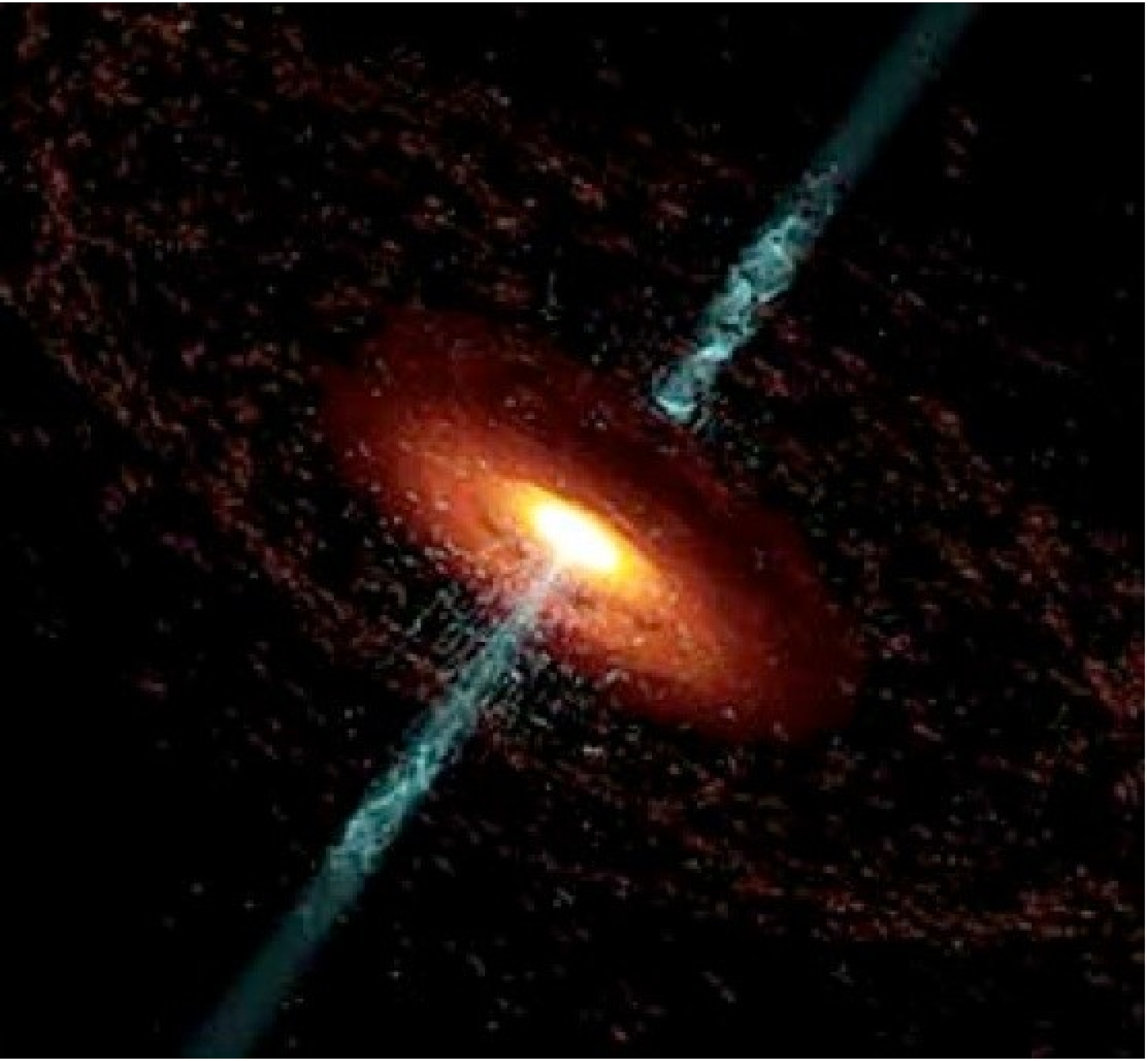
Artist's rendition of a white dwarf accumulating mass from a nearby companion star. This type of progenitor system would be considered singly-degenerate.

Galaxy Centaurus A  (NGC 5128) -  12 million light years away



# Extragalactic Universe:  Active Galaxy (X-ray)





Artist's impression of a quasar

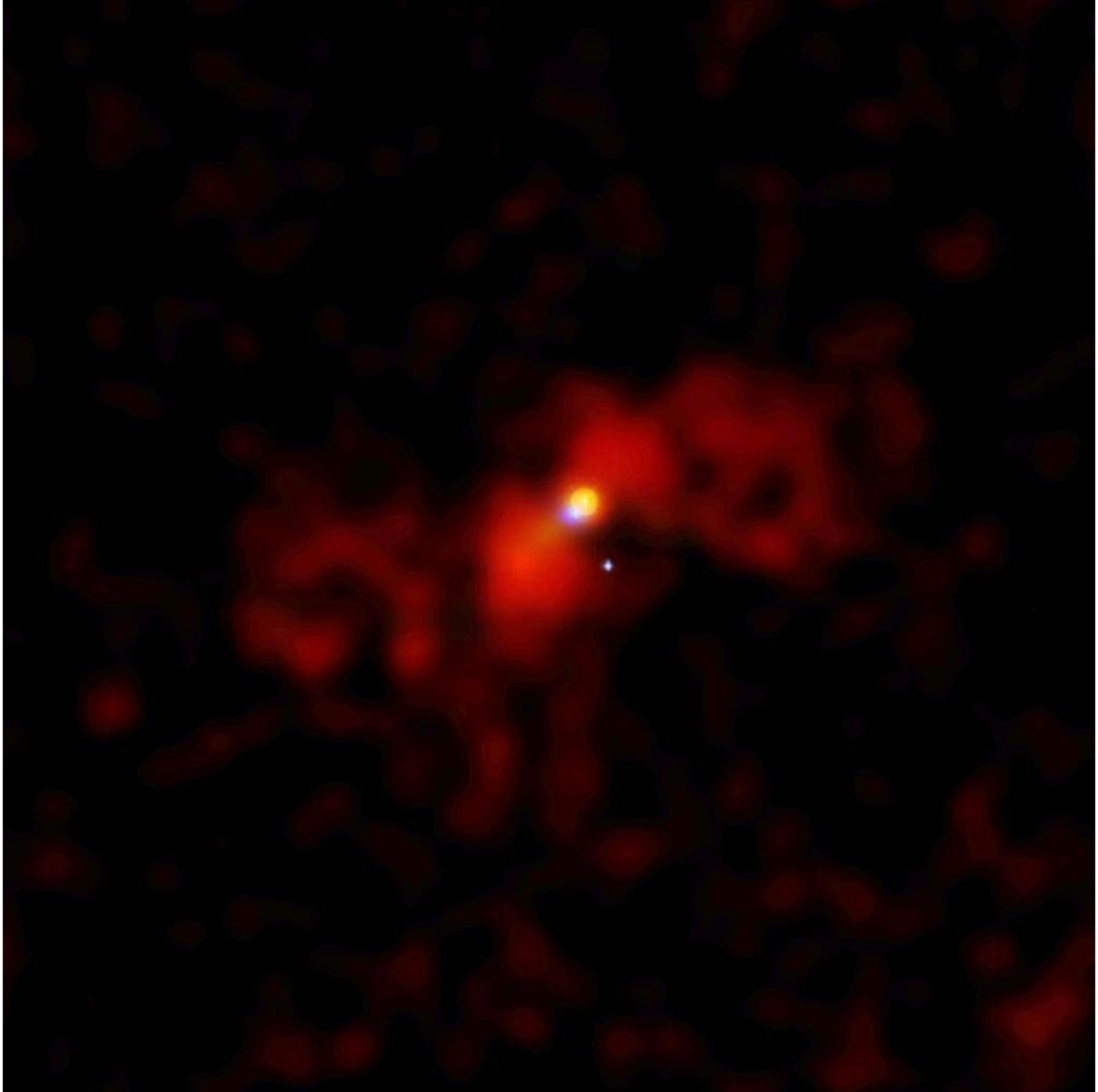
In the middle is a spinning supermassive black hole (SMBH)

Matter orbiting the hole slowly spirals down into it

As the matter trickles downhill it gains energy from the black hole's gravity – the matter is squeezed and gets hot, and releases energy

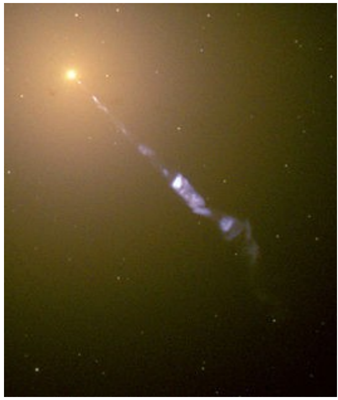
LOTS of energy – more efficient than nuclear fusion

Some of the matter misses the hole and gets shot out the north and south poles at almost lightspeed - “jets”



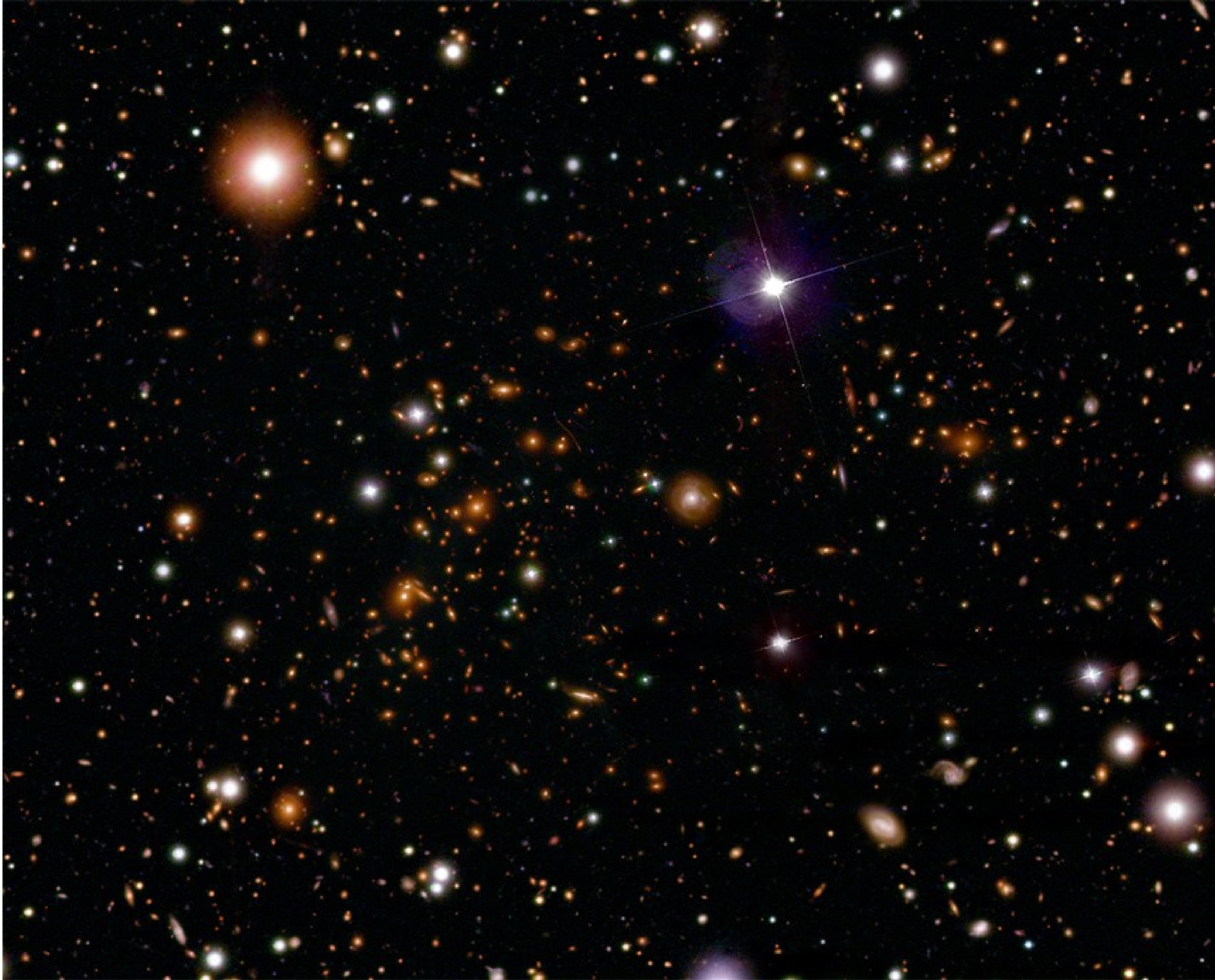
Virgo cluster
55 million
light years awa

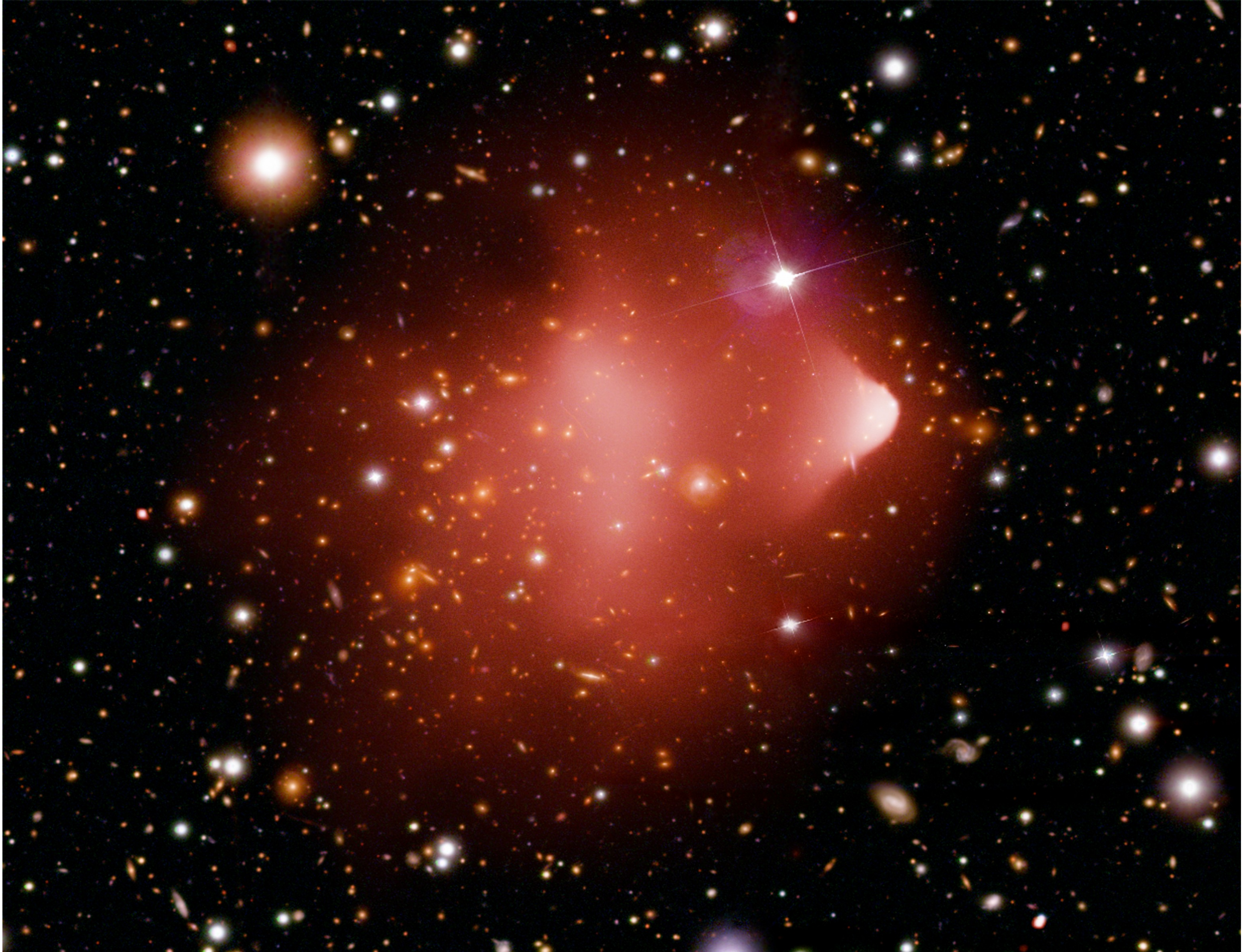
Extragalactic
universe:
Active galaxy
in cluster of
galaxies
(visible light)



The Extragalactic Universe: Cluster of Galaxies

Abell 2744 - 3.5 billion light years away





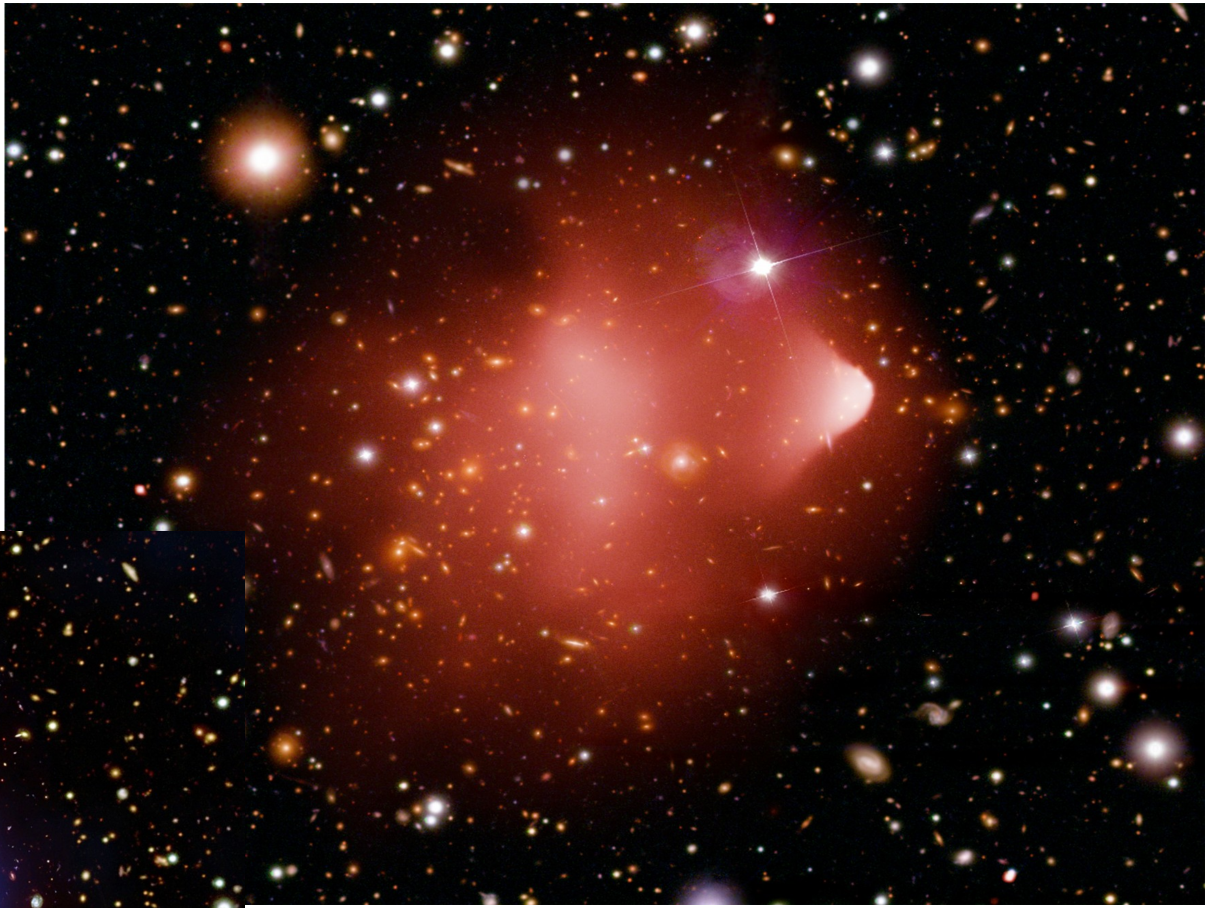
The Bullet Cluster, 1E0657-56

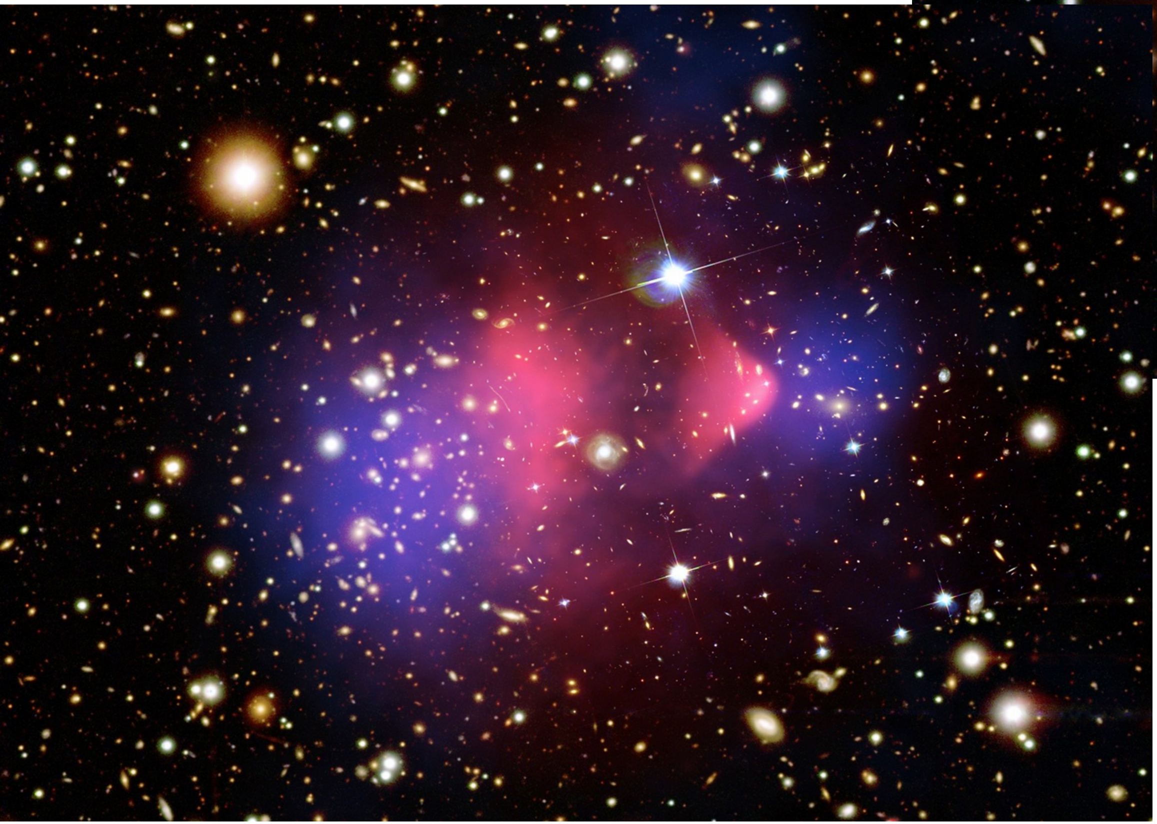
Extragalactic universe:
Cluster of galaxies (X-ray, visible and dark-matter model)

Two clusters in collision: studying this object let us measure the dark matter

Right: what we see directly in X-rays (red) and optical

Below: blue shows the matter distribution we infer

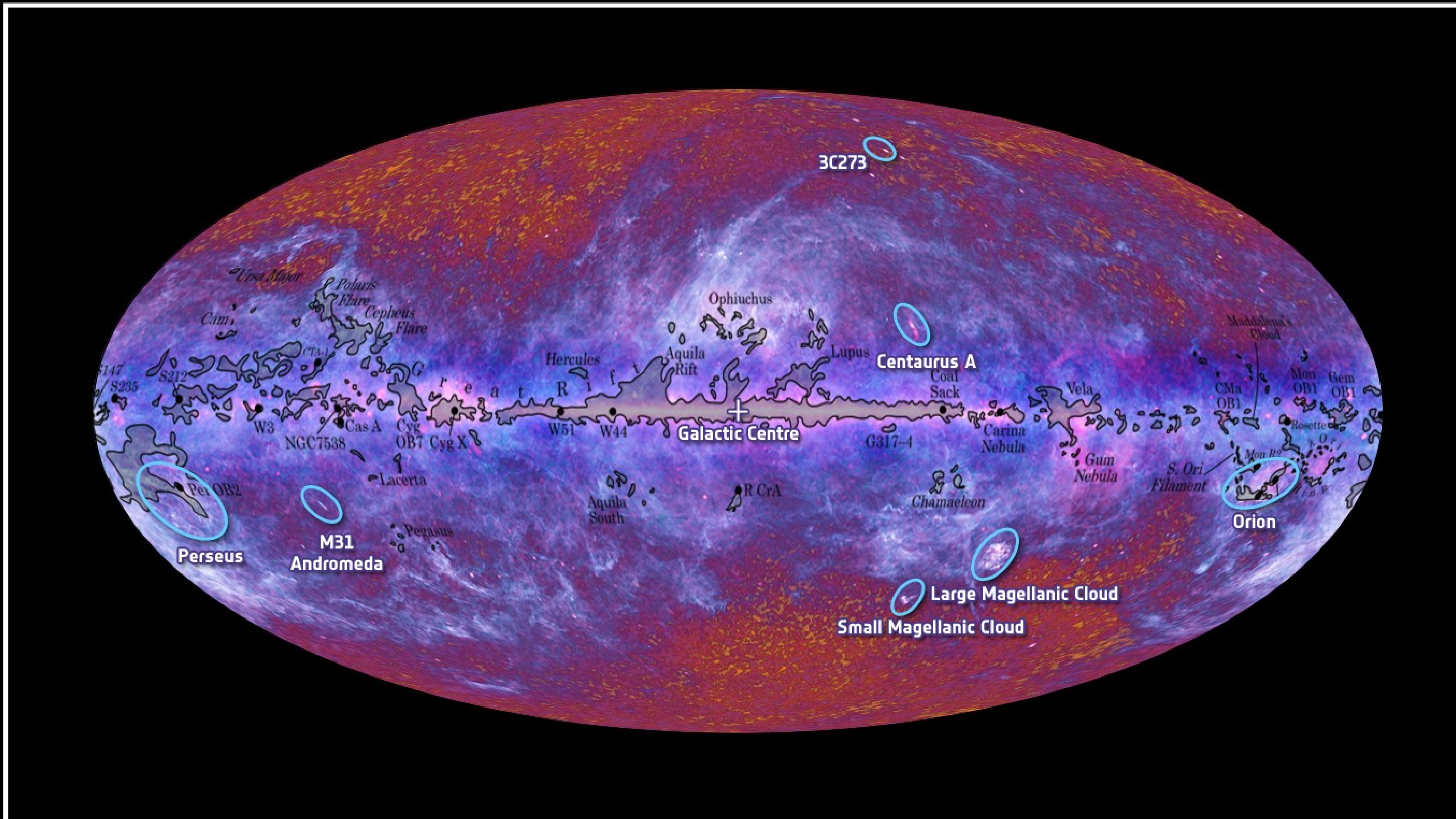




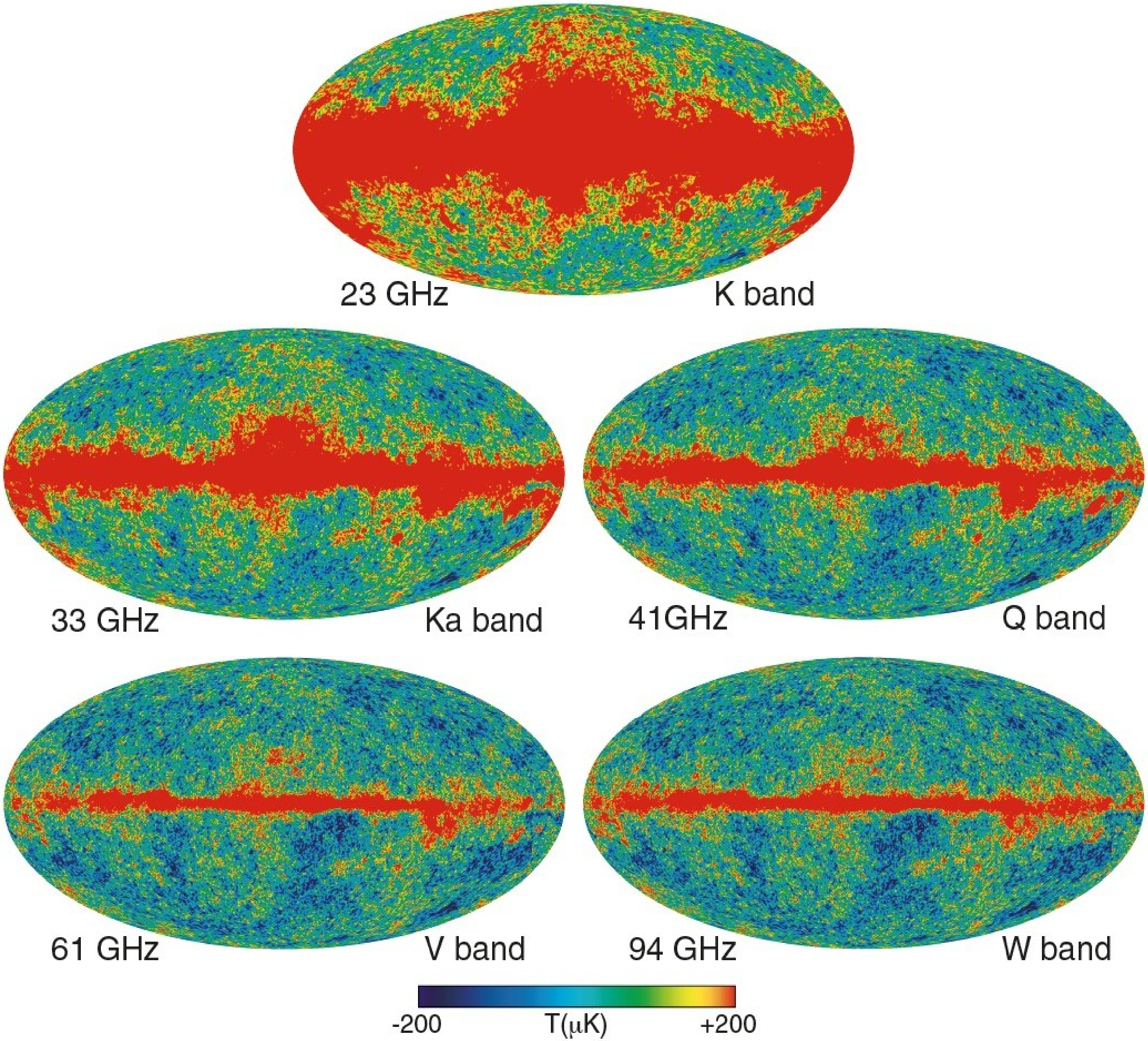
Distance: 3.3 billion light years

Size: 3 million l.y.

Data: Maxim Markevitch et al.



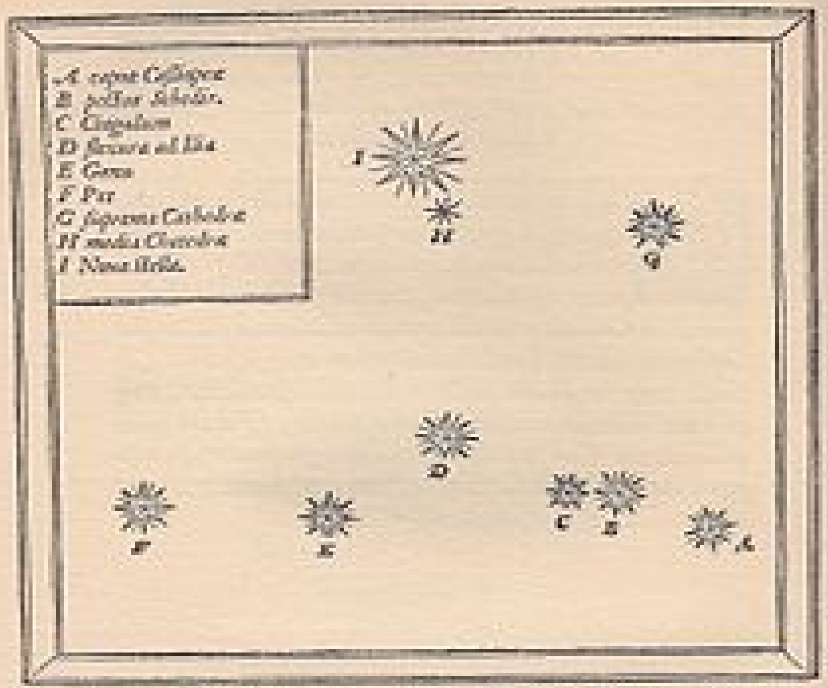

The Planck one-year all-sky survey




WMAP
Science Team

In 1572, Danish astronomer Tycho Brahe recorded a 'new star' in the constellation Cassiopeia

It was visible to the naked eye until 1574, slowly fading from view..



Distantiam verò huius stellæ à fixis aliquibus in hac Cassiopeiæ constellatione, exquisito instrumento, & omnium minutorum capaci, aliquoties obseruaui. Inueni autem eam distare ab ea, quæ est in pectore, Schedir appellata B, 7. partibus & 55. minutis: à superiori verò

Digression: What's an X-ray?

A lot of people are familiar with, but confused by, medical X-rays

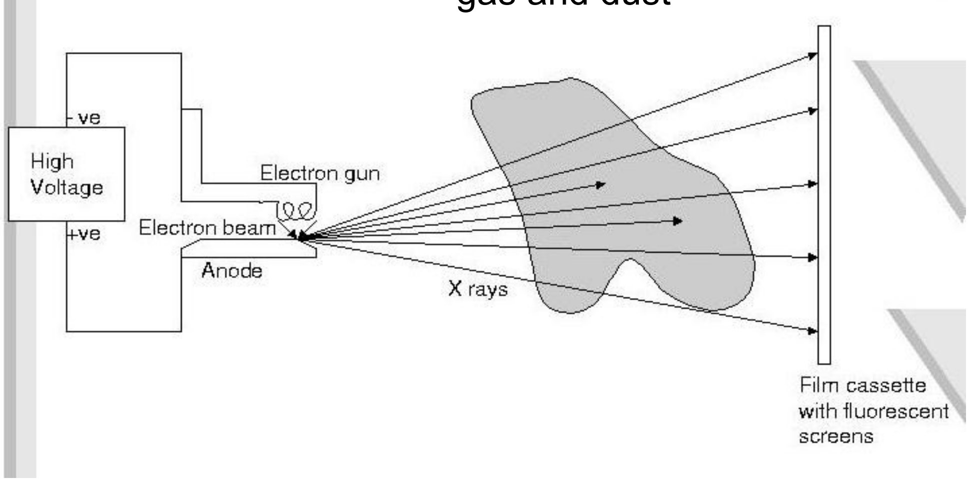
The photo at left is a picture of an X-ray light bulb, photobombed by someone's hand

The X-rays are the light bit. The dark areas are where there aren't any X-rays because the hand has blocked them.

X-ray bulb
= star,galaxy

Hand
= interstellar gas and dust

X-ray camera



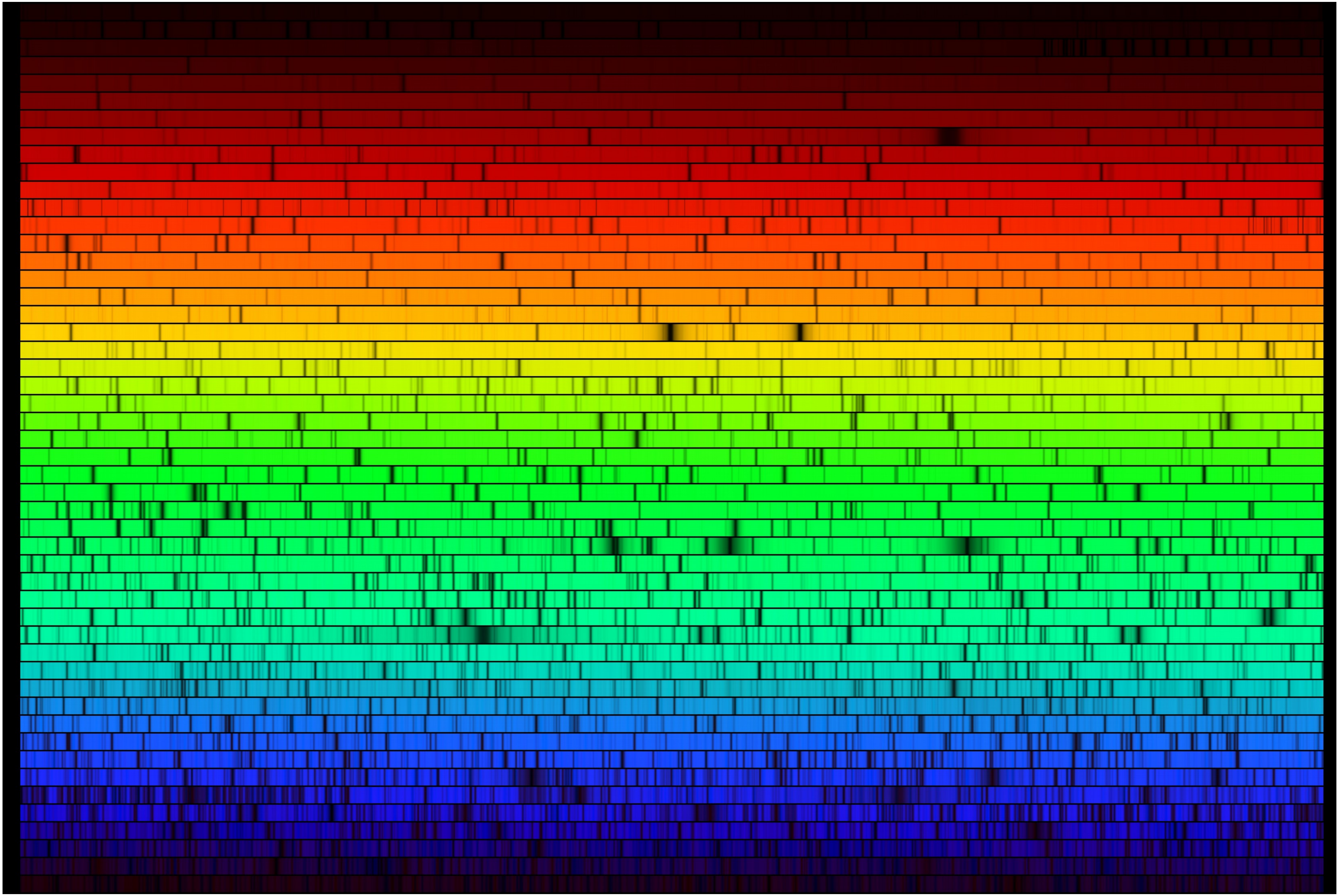

In X-ray astronomy we are usually taking a picture of the “light bulb” (the star making the X-rays) and not interested in the “hand” (stuff blocking the X-rays between the star and us)

Visible-light photons are like raindrops
- each one is 'small' (has a small amount of energy)
- there are lots of them, but don't do any damage

X-ray photons are like hailstones
- each one is 'big' – lots of energy
- there are many fewer of them
- but each one packs a wallop

If you up the INTENSITY (number of photons) in a beam of light you increase the total energy you get but not the energy per 'packet'
If you want to get a tan (or worse) you have to increase the energy per photon, not just the number of photons.
We have a word for the energy of a photon: “COLOR”
(well, “COLOUR” but I'll defer to the local sensibility)

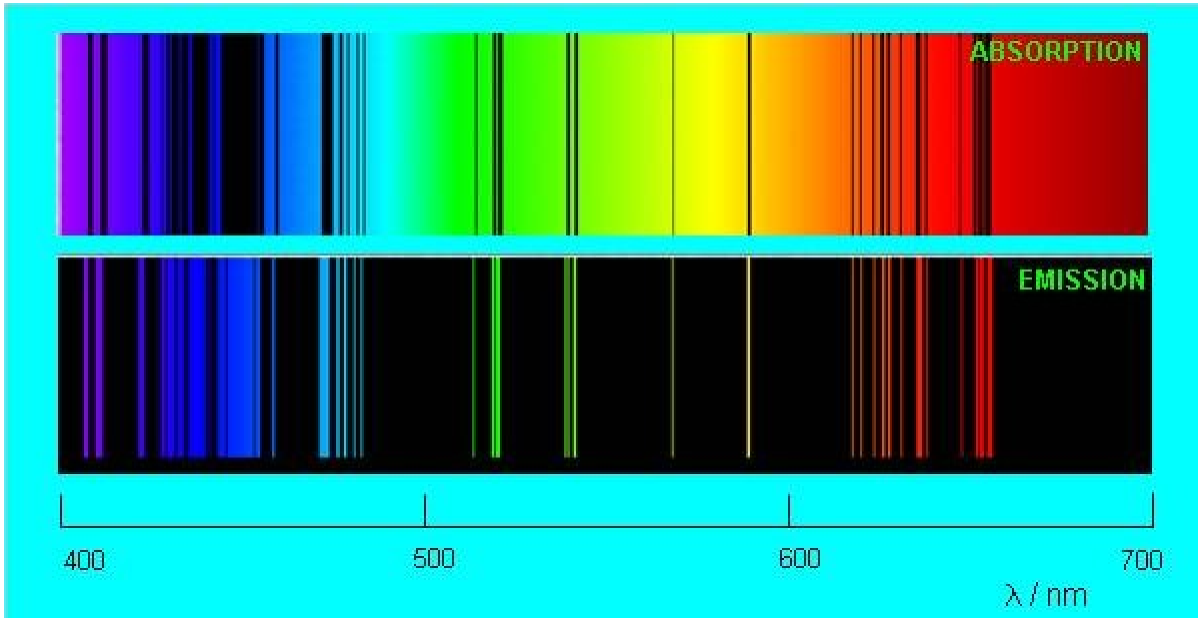
# Part 3: Space Telescopes Galore



Data: Bob Kurucz et al (SAO); Image: Nigel Sharp. NOAO; Telescope: KPNO-McMath

Solar spectrum, 2960-13000 Angstroms

What we can learn from a spectrum:



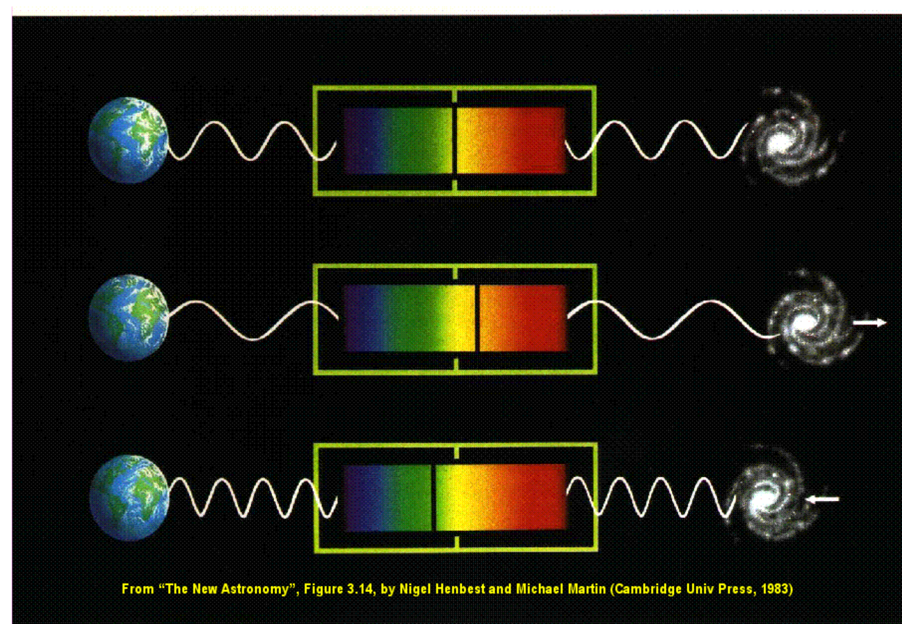

What is the light source made of?

- this is the “fingerprint' of sodium

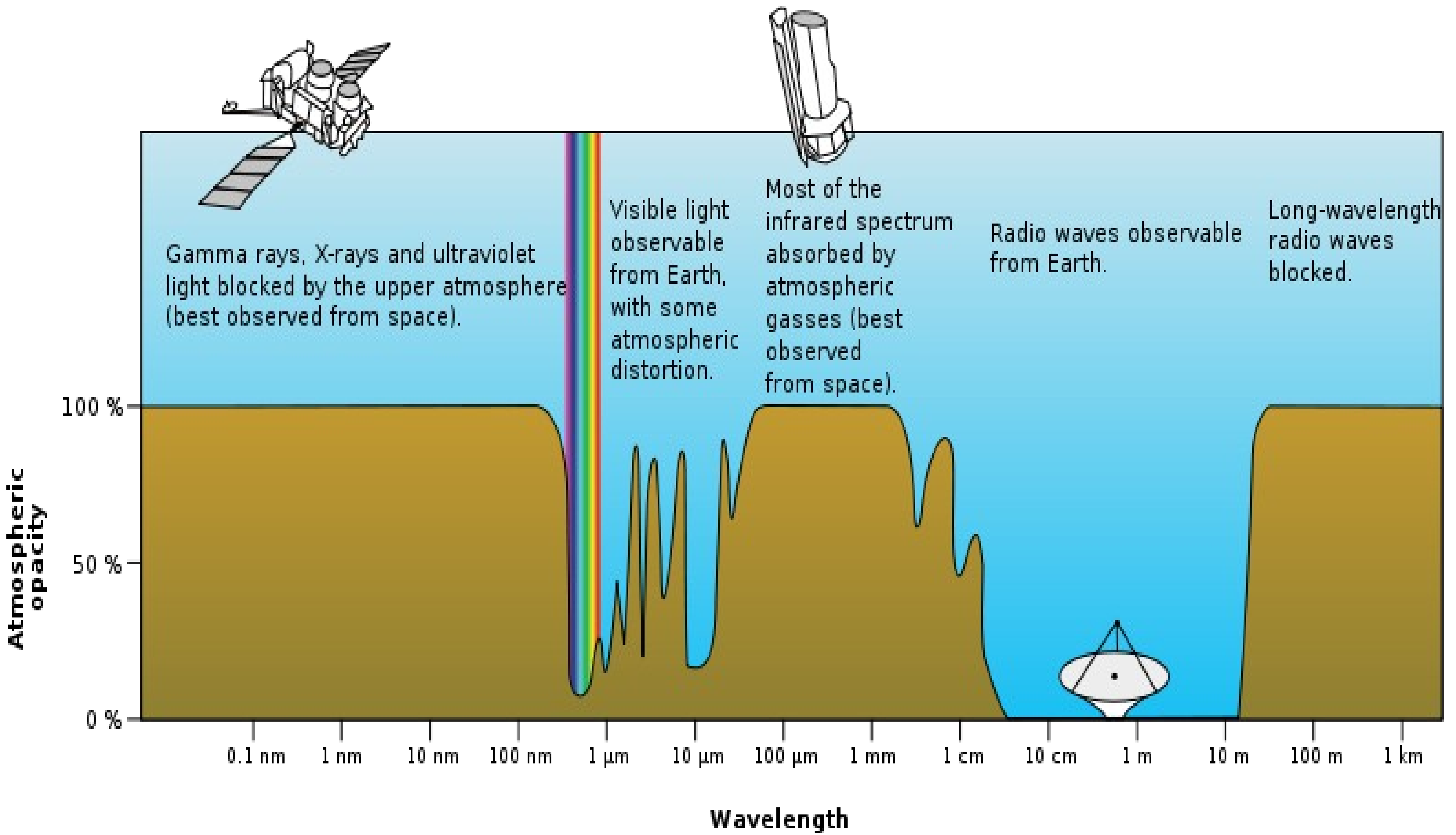
What are the physical conditions like?

- relative brightness and thickness of different lines indicates temperature and density

How fast is it moving?
“Doppler Shift” stretches or squeezes the spectrum: read off the speed

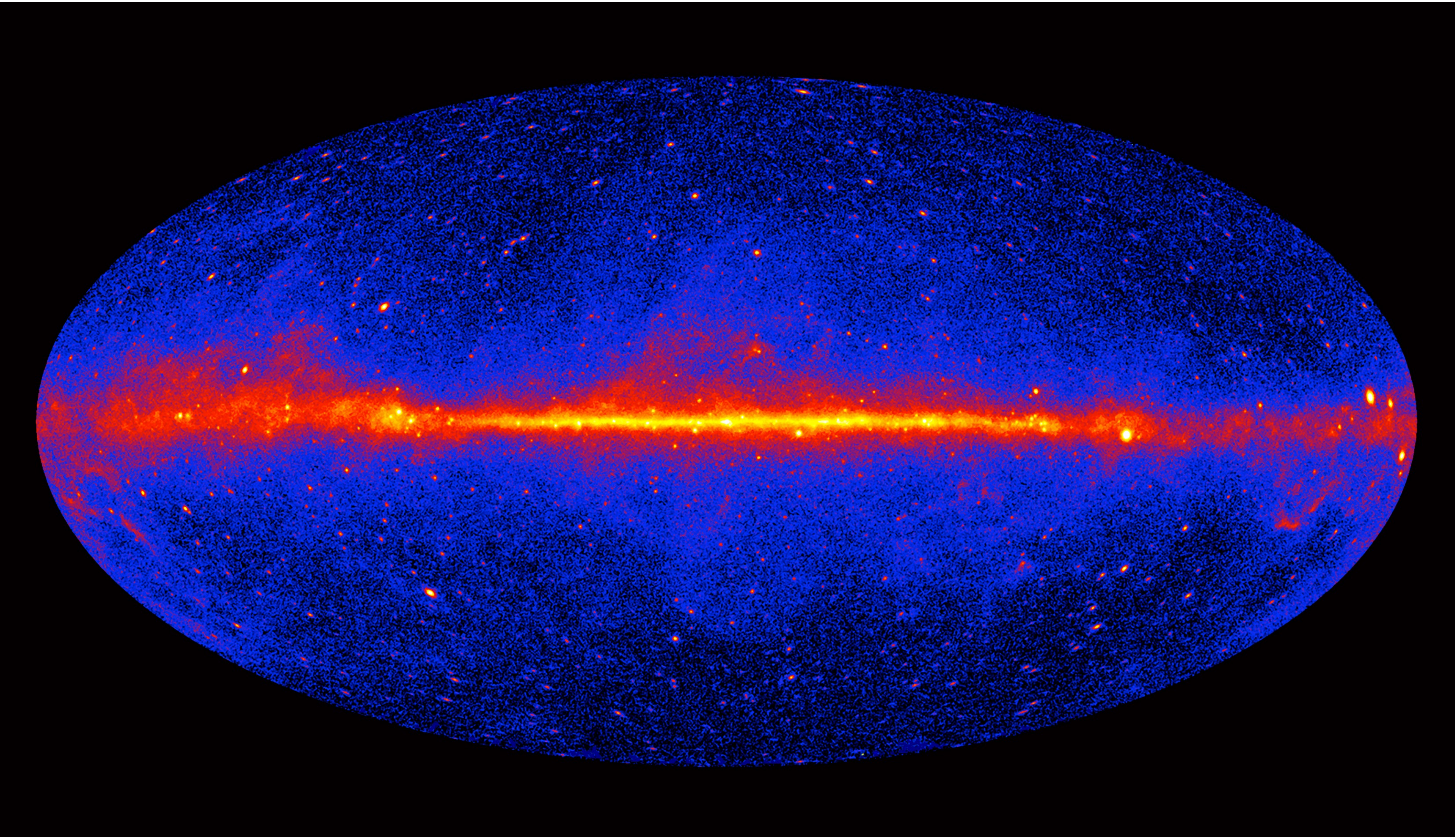


From “The New Astronomy”, Figure 3.14, by Nigel Henbest and Michael Martin (Cambridge Univ Press, 1983)



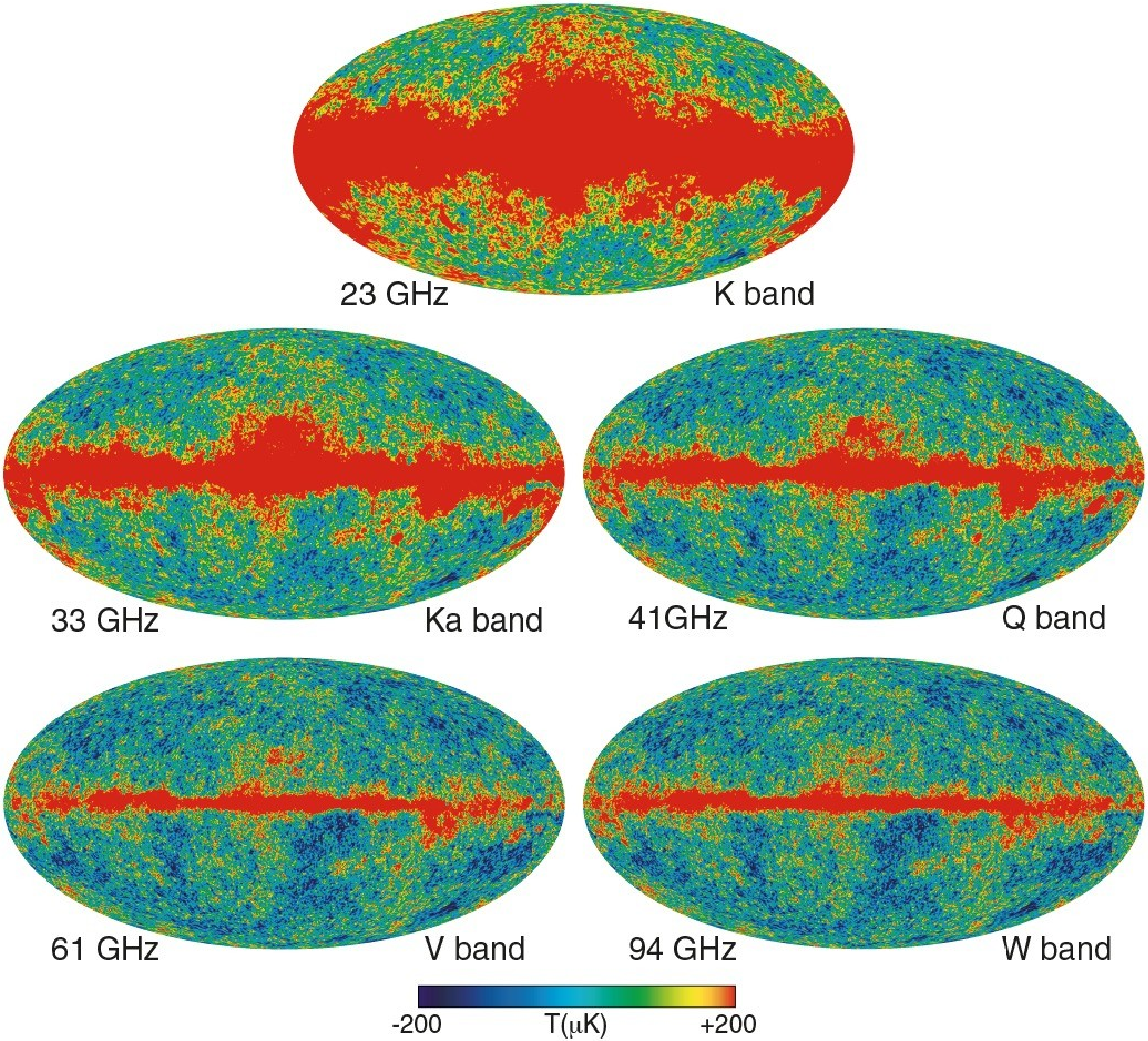
Gamma rays, X-rays and ultraviolet light blocked by the upper atmosphere (best observed from space).
Visible light observable from Earth, with some atmospheric distortion.
Most of the infrared spectrum absorbed by atmospheric gasses (best observed from space).
Radio waves observable from Earth.
Long-wavelength radio waves blocked.
100 %
50 %
0 %
Atmospheric opacity
0.1 nm
1 nm
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength

## Whole sky view (Milky Way and extragalactic) [Gamma ray, Fermi satellite]



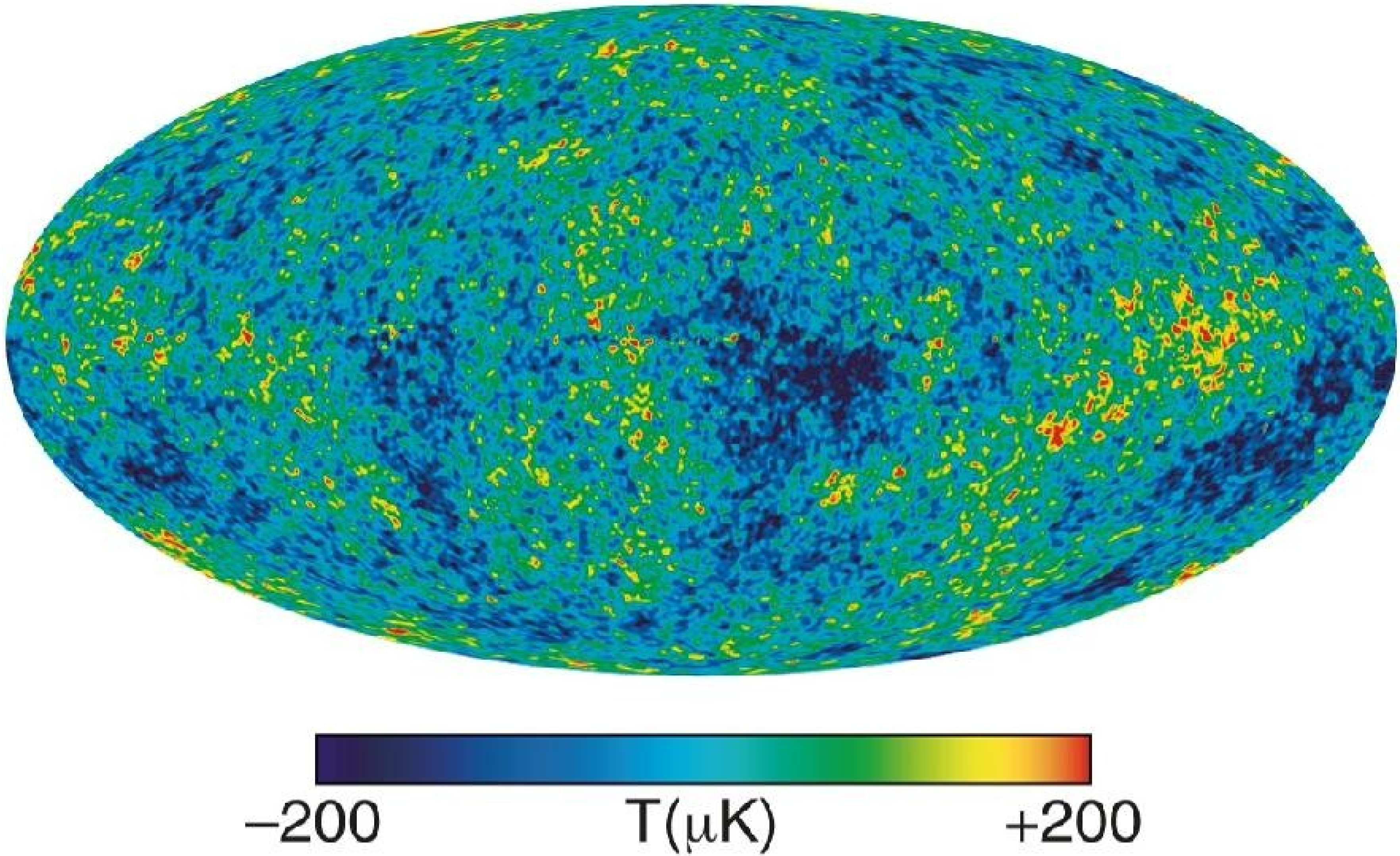
Gamma ray sky seen by Fermi
Gas in the Milky Way and a sprinkling of distant black holes

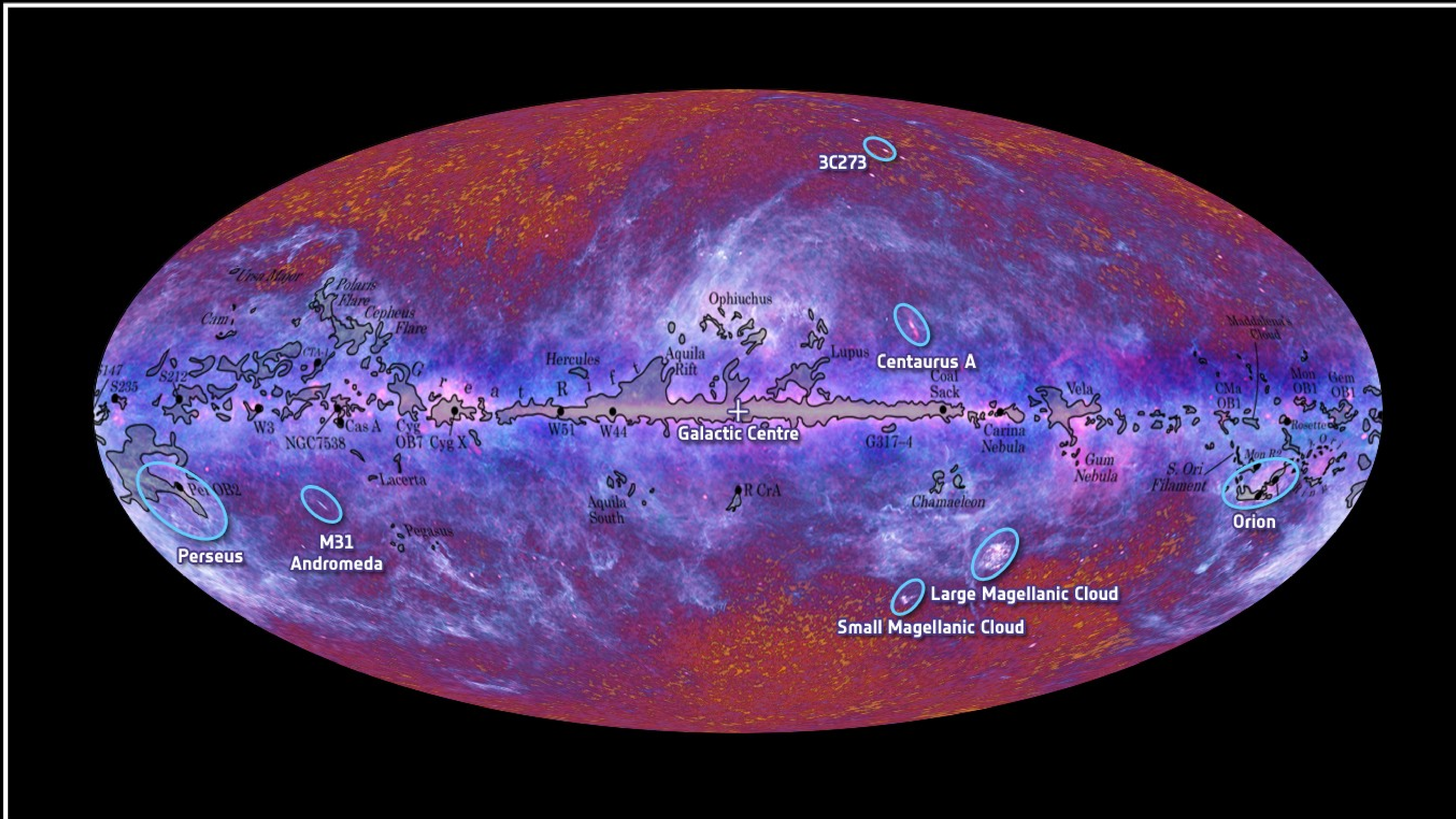
WMAP
Science Team



Whole sky view (Milky Way subtracted out) [Microwave, WMAP]

WMAP: Imaging the universe as it was 13.7 billion years ago
The specks are the seeds from which galaxy clusters will form
From their size we can work out the age of the universe






The Planck one-year all-sky survey

Data released earlier this year!