An Introduction to

IR Telescopes

The Electromagnetic Spectrum

The colours of light

The electromagnetic spectrum is a spectrum of light, encompassing all light that we know of. Depending on its specific characteristics such as energy or wavelength can be classified into different types as seen here. With the visible light spectrum that we see only taking up such a small portion of the EM spectrum, Imagine how much more we could learn about the universe if we could see all the light within it.

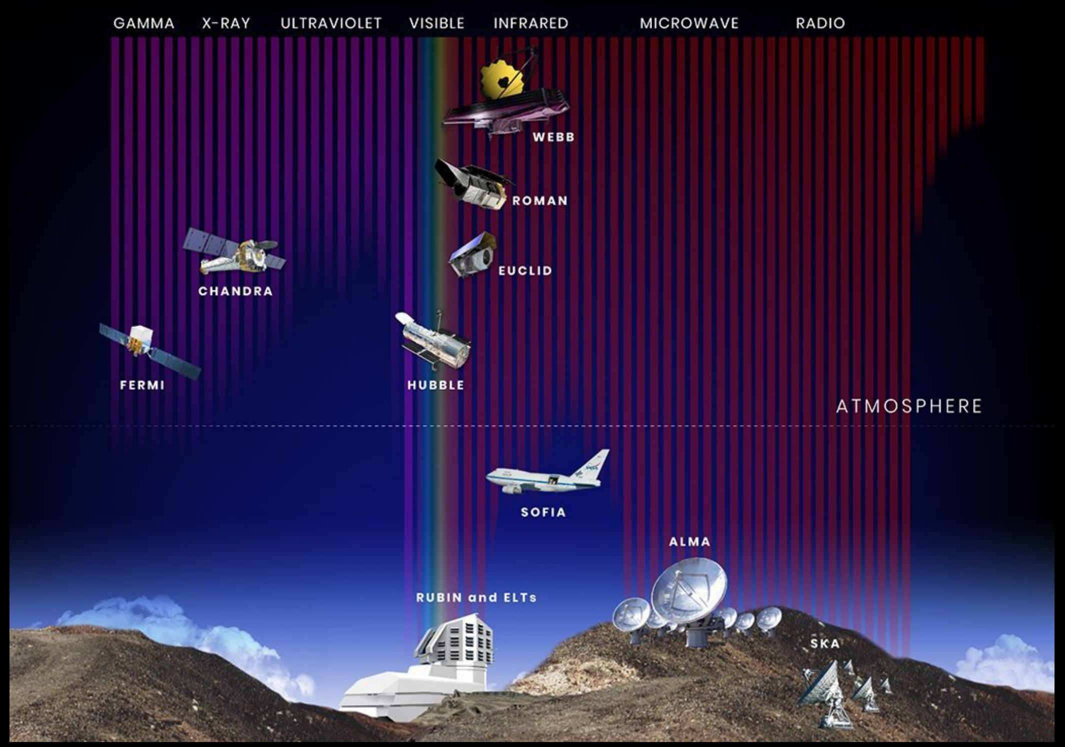


Figure 1: Diagram depicting location of telescopes in terms of altitude and electromagnetic spectrum

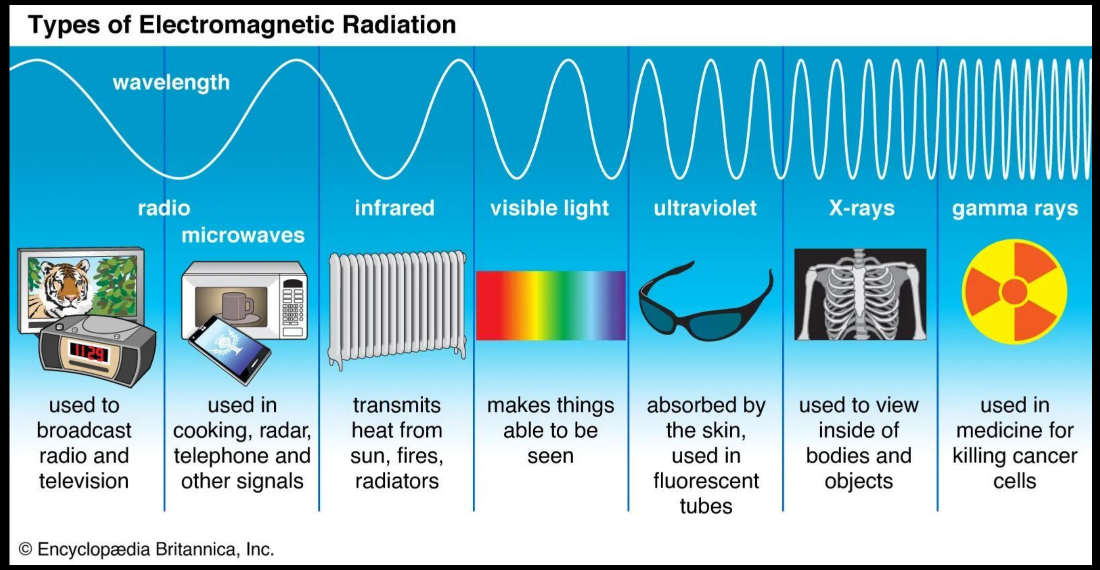


Figure 2: Electromagnetic Spectrum with super cool real-life applications. Also shows qualitative wavelength comparisons.

Fantastic Telescopes

And Where to Find Them

Visual Telescopes

- See what we see
- includes famous telescopes like Hubble and most telescopes we talked about in class (Galileo, Newton)

Ultraviolet (UV) Telescopes

- looks at the energy responsible for sunburns
- Used for looking at Hot, young, stars and for looking at supernovae as well as these objects since they release a bunch of UV radiation[1]

X-Ray Telescopes

- same x-rays as the bone showing machine
- mirrors aligned to be in-line with the incoming x-ray light, leading to a minimal change in light-path. Mirrors arranged like this act more like a refracting telescope to focus the light to act as a light bucket.[2]
- Evidence of neutron stars and black holes have been found using x-ray telescopes. The x-ray telescopes looked at the hot gasses found around and near the dense objects.[1,2]

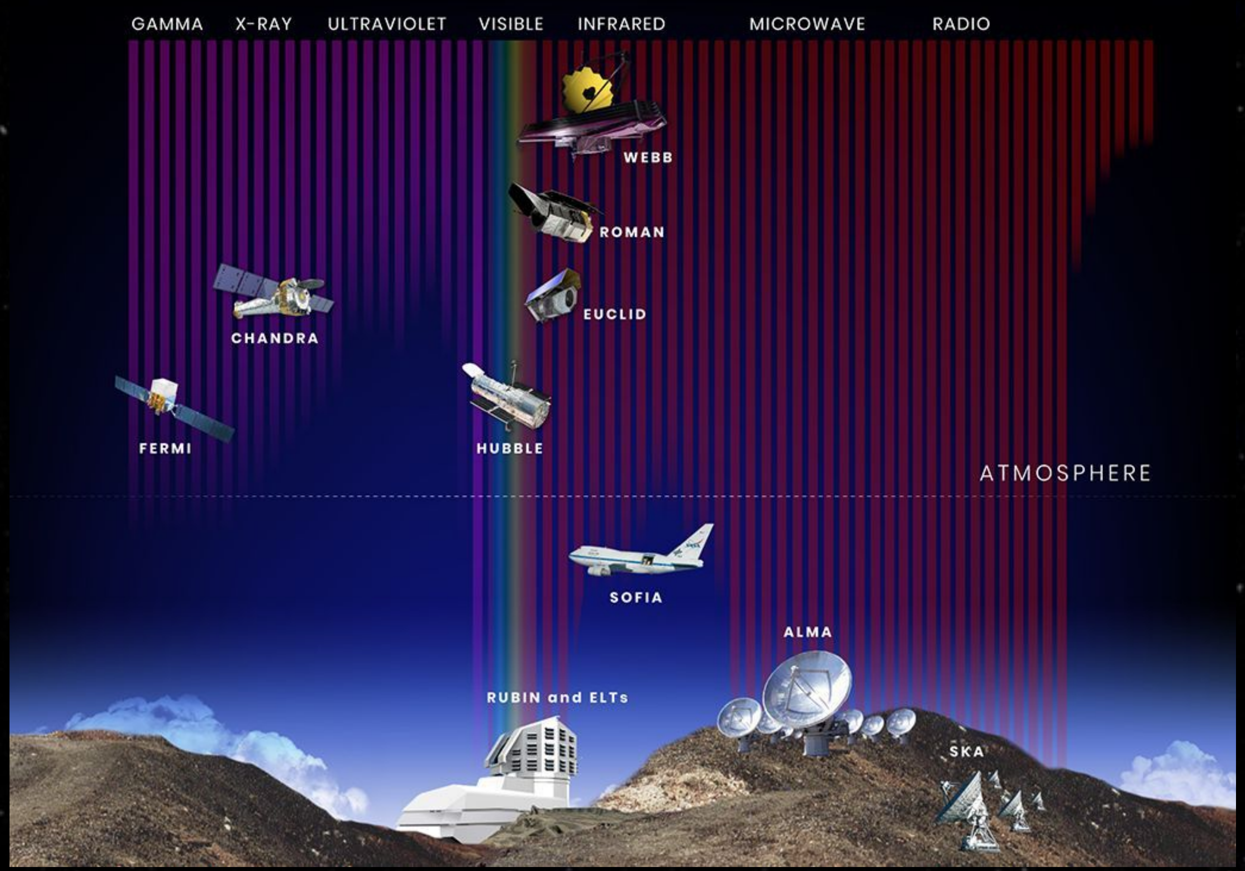


Figure 1: Diagram depicting location of telescopes in terms of altitude and electromagnetic spectrum

Fantastic Telescopes

And Where to Find Them

Gamma-ray Telescopes

- *Gamma-ray telescopes look at gamma rays in space.[3] Occasionally a big burst of gamma rays will appear, and are called gamma ray bursts.[3] Scientists are unsure of where they come from, they speculate that gamma-ray bursts may come from the birth of a black hole.[3]*

Microwave Telescopes

- *can look inside your microwave oven and see the energy/ light used to cook your food*
- *Used to see remnants of the big bang[1]*

Radio Telescopes

- *Big and don't need mirrors or lenses[1]*
- *10 radio telescopes across the world worked together to get the first image of a black hole[1]*

INFRARED Telescopes!

- *not very good on the ground since gasses in the atmosphere like water vapor absorb IR radiation.[1] (works on a plane)*
- *See heat from far away*
- *IR telescopes can look past dust clouds in space[1]*

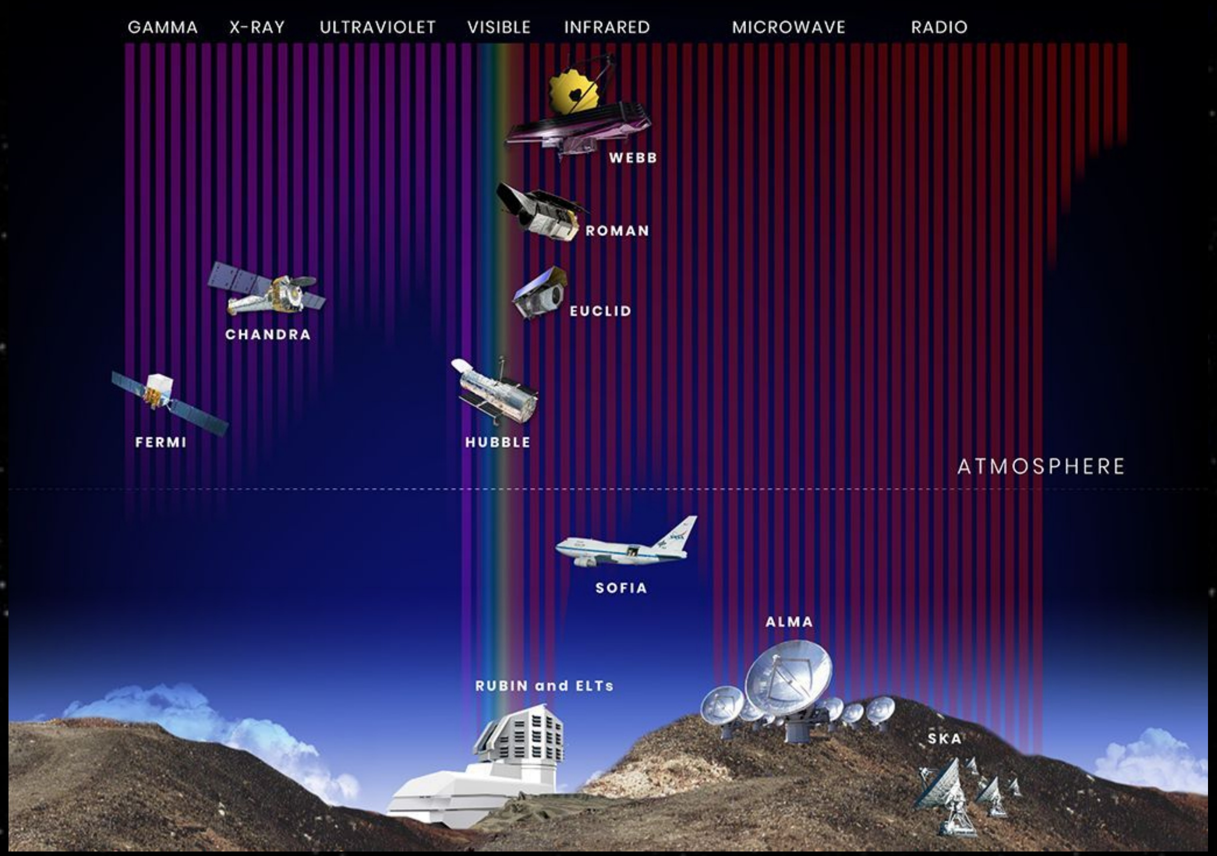


Figure 1: Diagram depicting location of telescopes in terms of altitude and electromagnetic spectrum

What is IR (Infrared)?

Infrared Radiation on EM Spectrum

- **IR is higher wavelength than visible light[4]**
  - Lower energy

- **IR is also what radiating heat is[4]**
  - Thermal cameras pick up infrared light

- **It's just a type of invisible light[4]**
  - Comes in different "colours" just like visible light

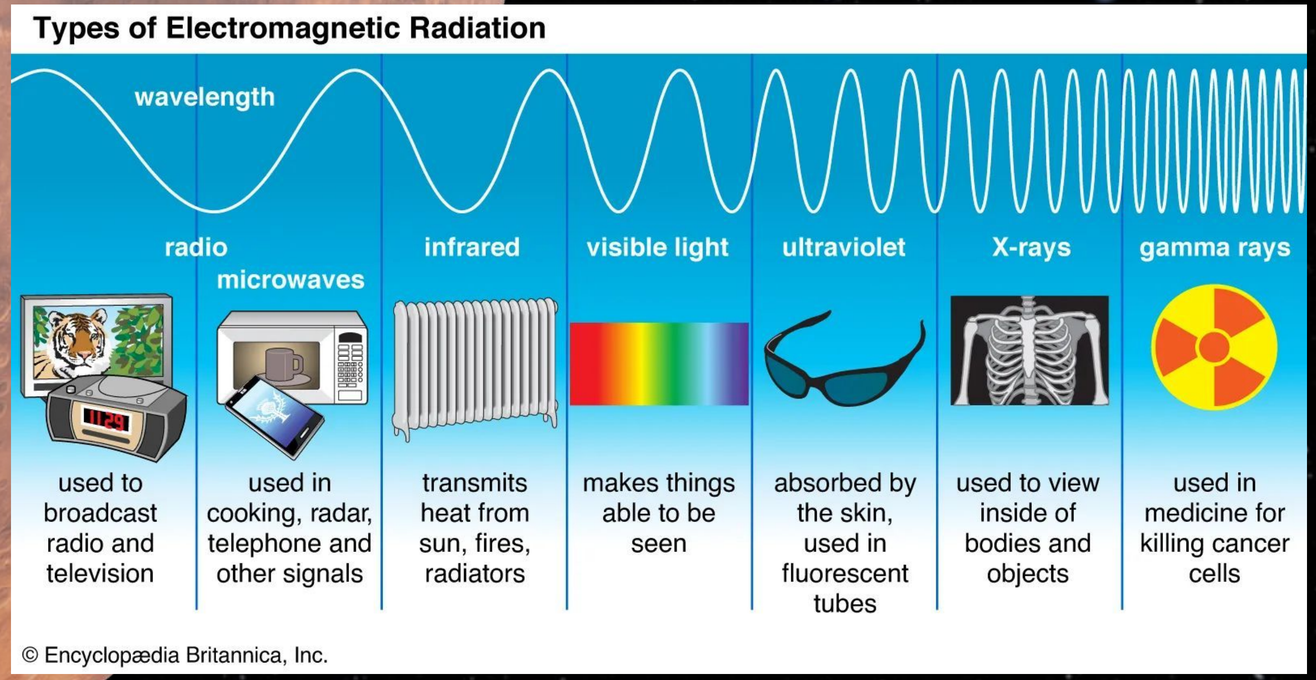
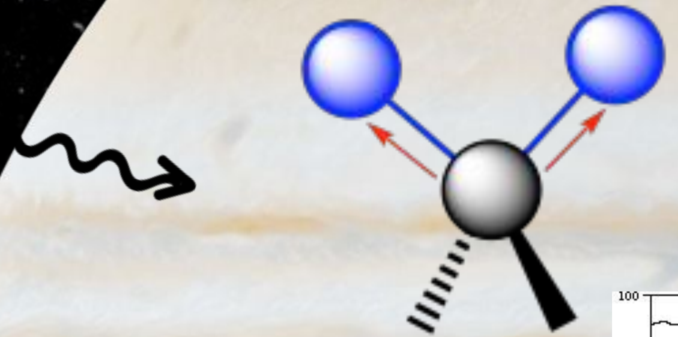


Figure 2: Electromagnetic Spectrum with super cool real-life applications. Also shows qualitative wavelength comparisons.

What does IR tell us?

- **Molecules absorb IR light specifically so we use for spectroscopy[4]**
- They vibrate (heat) when they absorb the light
- Frequency ("colour") of absorbed light & vibration depends on bond type.[4]
- **Absorbed frequencies tell you molecule info (spectroscopy)[4]**
  - Position, shape, and size of spectra absorbance peaks tells you the types of bonds in a molecule.
  - Can find identities of simple molecules and mixtures with just a spectra (Fig. 3)
- **Or you can just take a photo**
  - Use normal camera lenses and CCDs and select a wavelength(s) to capture a photograph



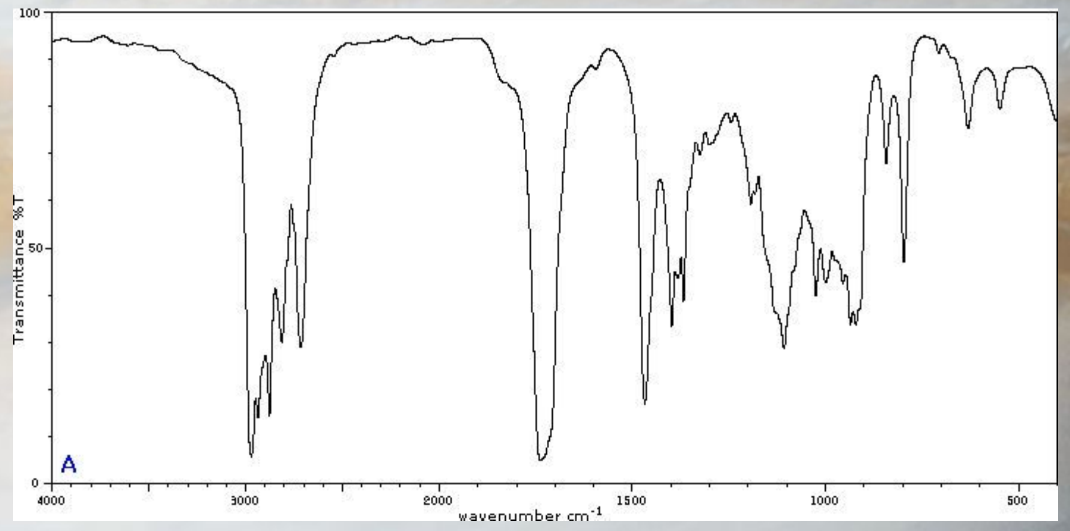


Figure 3. IR spectrum of 2-methylpropanal

Figure 4. IR view of the sky

How do IR telescopes work?

- **Need infrared light source - use the sun[5]**
  - Planets in our solar system are close enough to reflect enough sunlight for us to directly measure the IR light bounced off.[5]
- **For exoplanets, use their star and wait for a transit[5]**
  - Look at silhouette of planet and use its host star light as a backlight.
  - Atmosphere of a planet comparable to apple skin on apple.
- **Telescopes observe the IR light before and during the transit, the difference is the atmosphere spectrum, it tells you what it's made of.[5]**
  - The atmosphere cross section area makes up a tiny fraction of the star area, so it's incredible that it's detectable.
- **Telluric absorption and lens heating are hurdles[5]**
  - Telluric absorption is the absorption of the incoming light by our atmosphere. Reduces light intensity and adds peaks that must be subtracted. Also the atmosphere has heat which adds to baseline.
  - Optics are heated so they must be cooled in some way.
  - Because of this space telescopes > ground telescopes

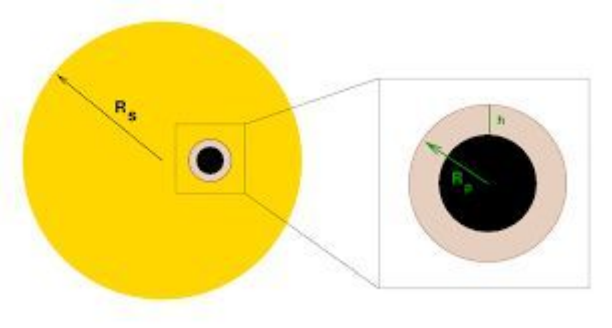


Figure 5. Transit of planet across star

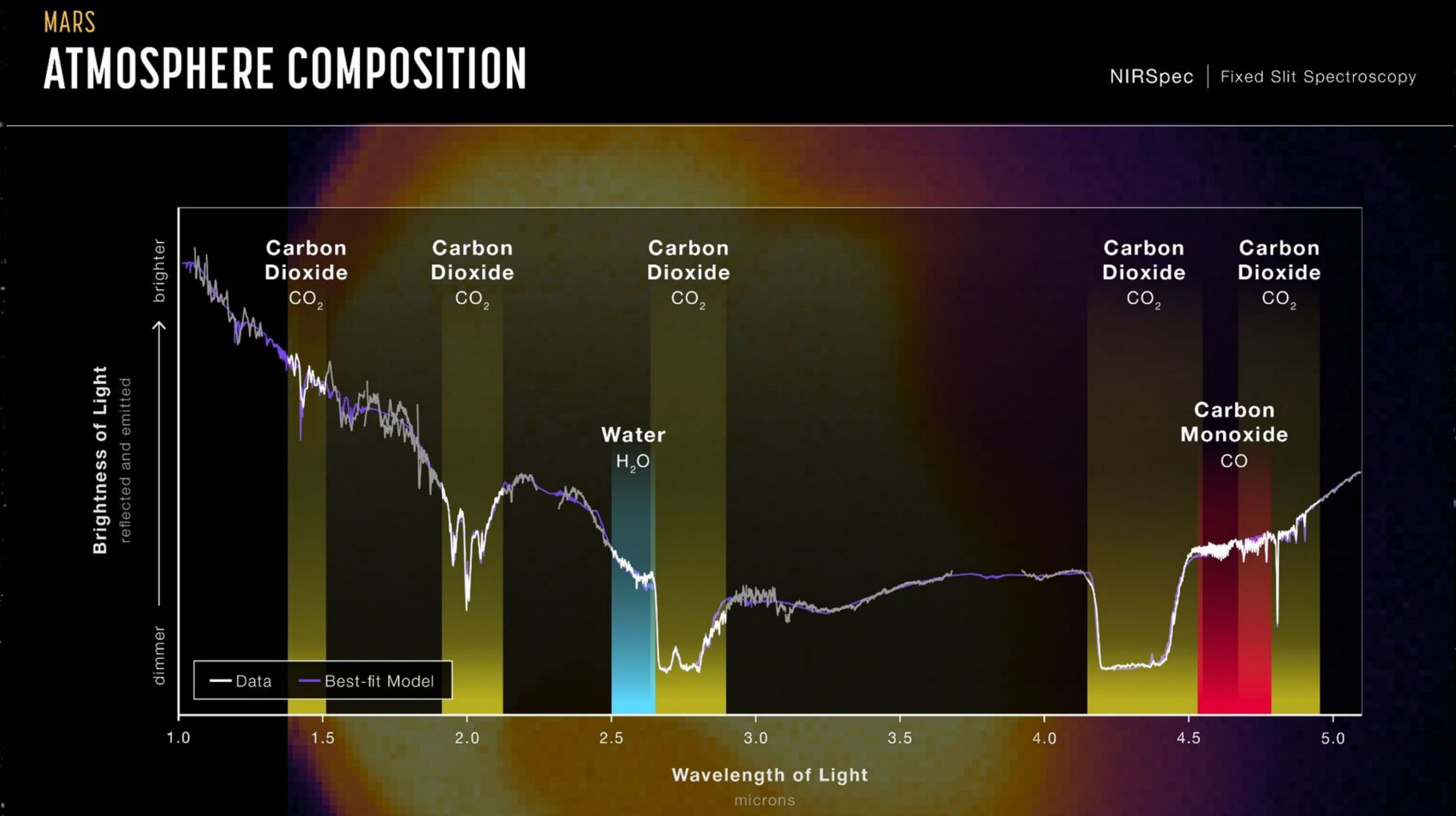


Figure 6. JWST Infrared spectrum of Mars' atmosphere

Figure 7a: Pillars of Creation in the Visible Spectrum

Figure 7b: Pillars of Creation in the Infrared Spectrum

Why use IR Telescopes?[6]

They're BETTER

- See through some clouds/interference
- See things that are invisible in visible spectrum
- Take a spectrum of planets/stars for molecule composition

Clicker Question

Which of the below options is the best telescope?

a) Visual Telescope

b) Radio Telescope

c) IR TELESCOPE

d) UV Telescope

How did we get here?

- 1800 Herschel discovered Infrared Light[7]
- Early 1960s: Frank Low invens the Germanium Bolometer. Cooled by liquid Helium, with germanium and gallium, this bolometer was able to detect tiny changes in heat (super sensitive) therefore we can detect IR BETTER since IR radiation is just heat.[8]
- Early 1960s: IR telescopes were put on high-altitude balloons and planes to reduce atmospheric interference and maximize the amount of IR radiation [9]

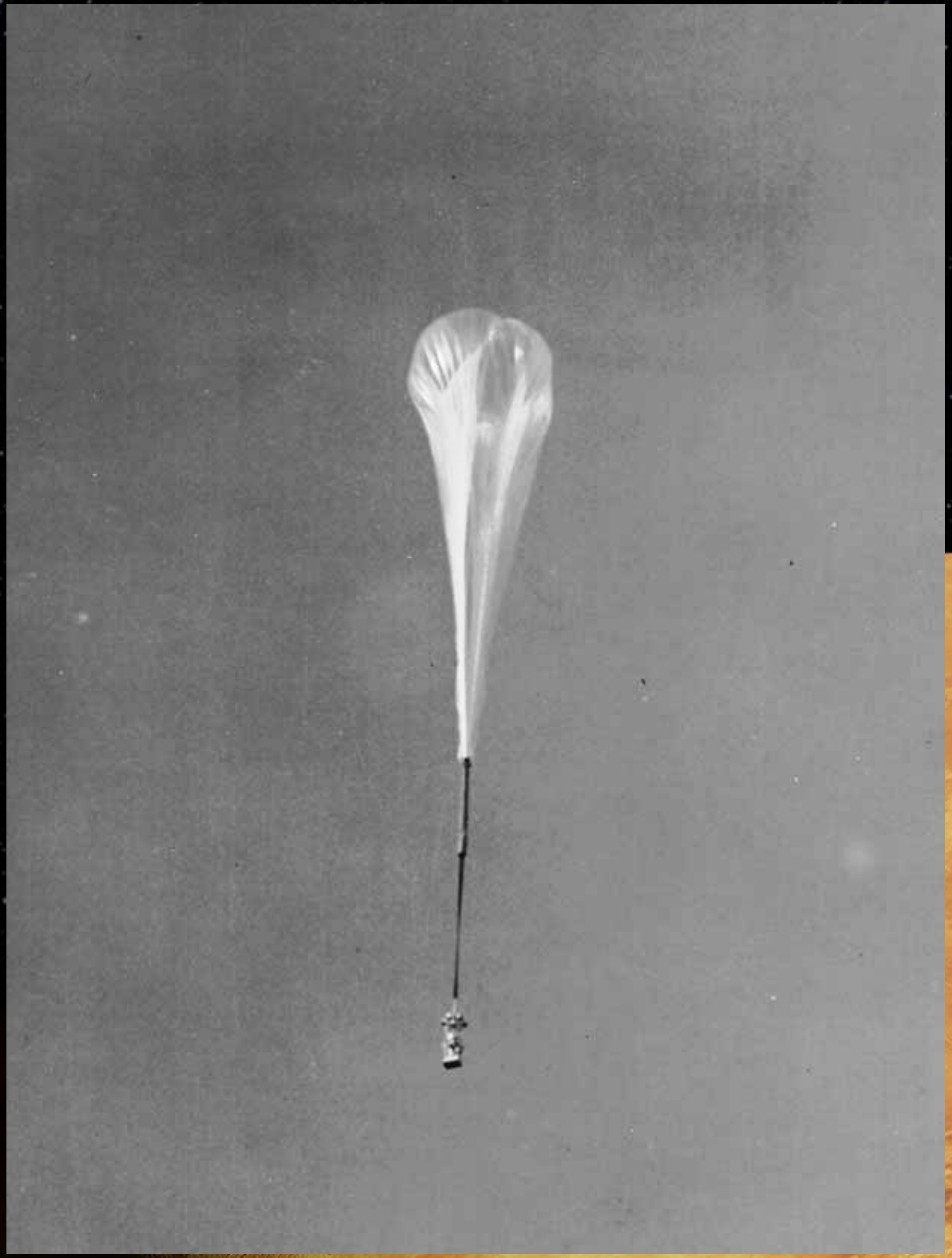
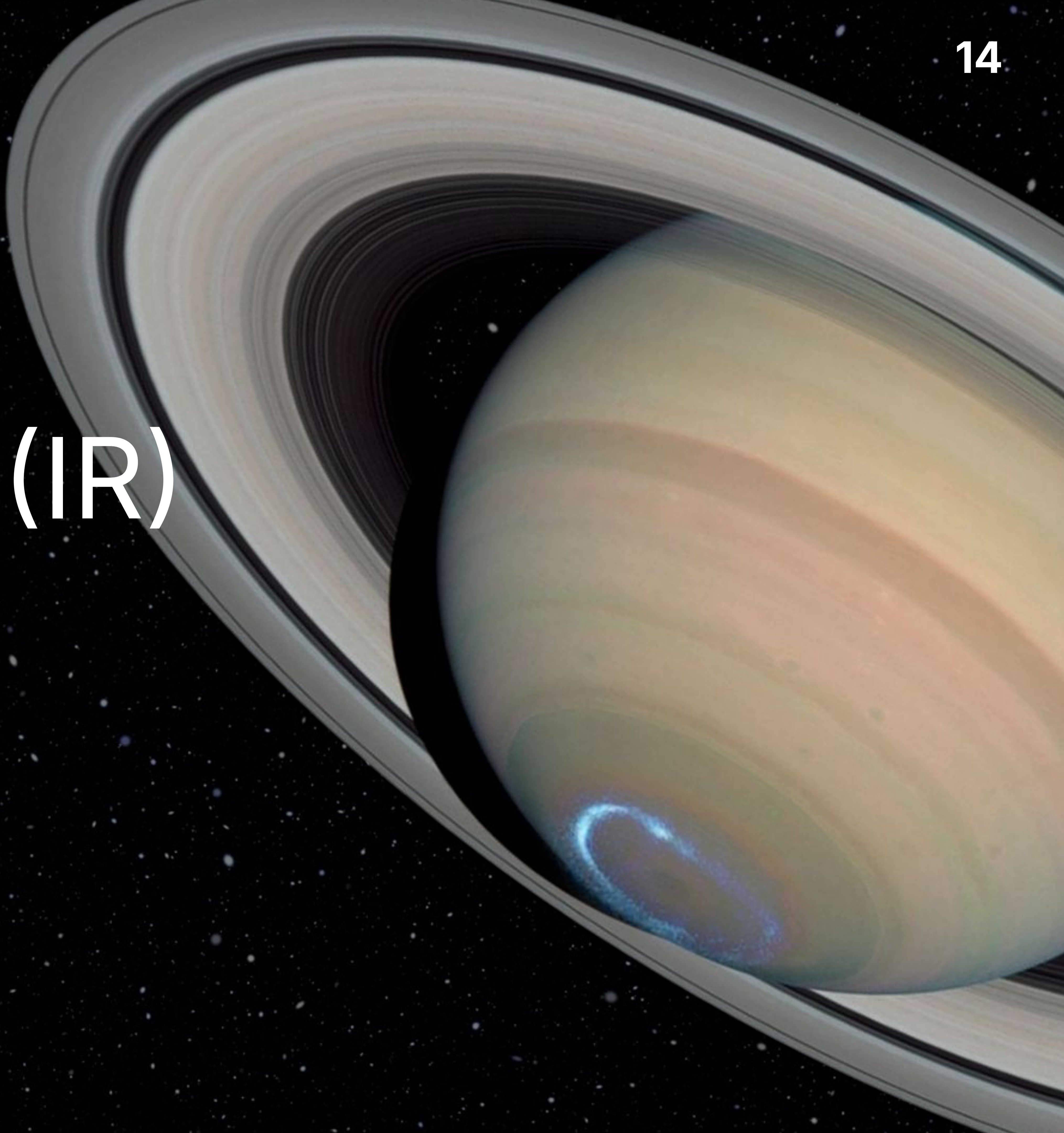


Figure 8: Picture taken of Telescope attached to a high-altitude balloon for better imaging with less atmospheric inference

<u>Higher in the sky=less atmosphere in the way</u>

Modern Infrared (IR) Telescopes



Infrared Astronomical Satellite (IRAS)

- Launched in 1983[10]
- First IR telescope in space.[10]
- Objective: Full sky scan in IR.[10]

- ***350,000*** new IR Features Found! (previous catalogue increased by ***70%***)[10,11]

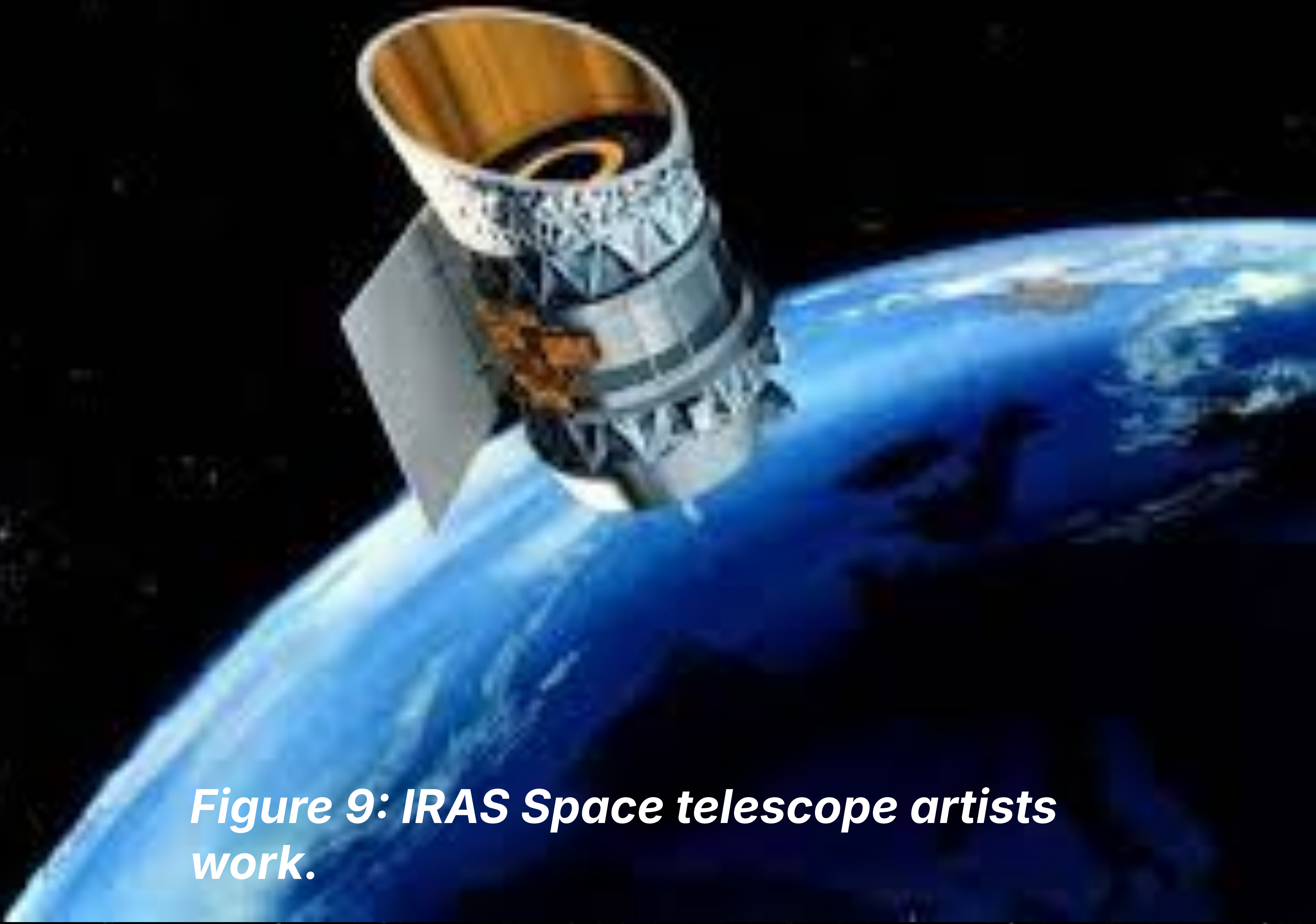


Figure 9: IRAS Space telescope artists work.

The Innards of IRAS

The IRAS uses 62 total detectors for IR radiation.[12] Some detectors were made of different materials to detect IR radiation better at different wavelengths.[12] the Germanium Bolometers invented by Frank Low used Germanium and Gallium.[12] Other detectors used different elements like silicon, arsenic, and antimony.[12]

Some of the instruments used in the IRAS include: A low resolution spectrometer (LRS) was used to determine the wavelength of IR radiation detected.[12]

A chopped photometric channel (CPC) was used to determine the intensity of light.[12]

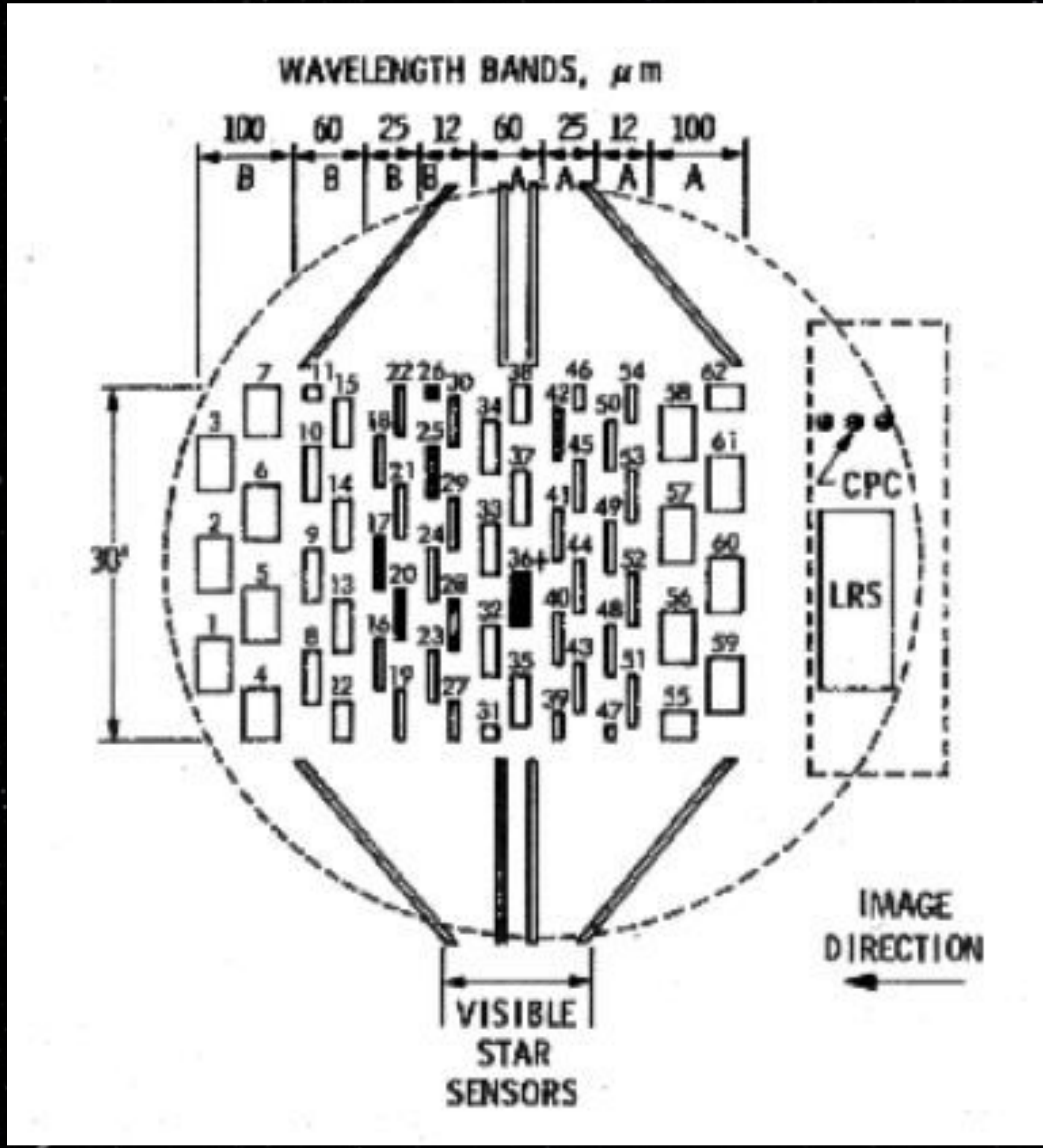


Figure 10: Diagram of IRAS's 62 detector set-up

The Innards of IRAS

- IRAS took multiple images of the milky way each at different wavelength ranges.[13]
- 8.5-15 um, 19-30 um, 40-80 um, and 83-120 um centered around a wavelength used to denote the range. (12um, 25 um, 60 um, and 100 um respectively)[13]. These wavelengths are called the center wavelengths.[13]
- They can be interpreted individually, or combined to make a composite and colorized infrared image.[13]

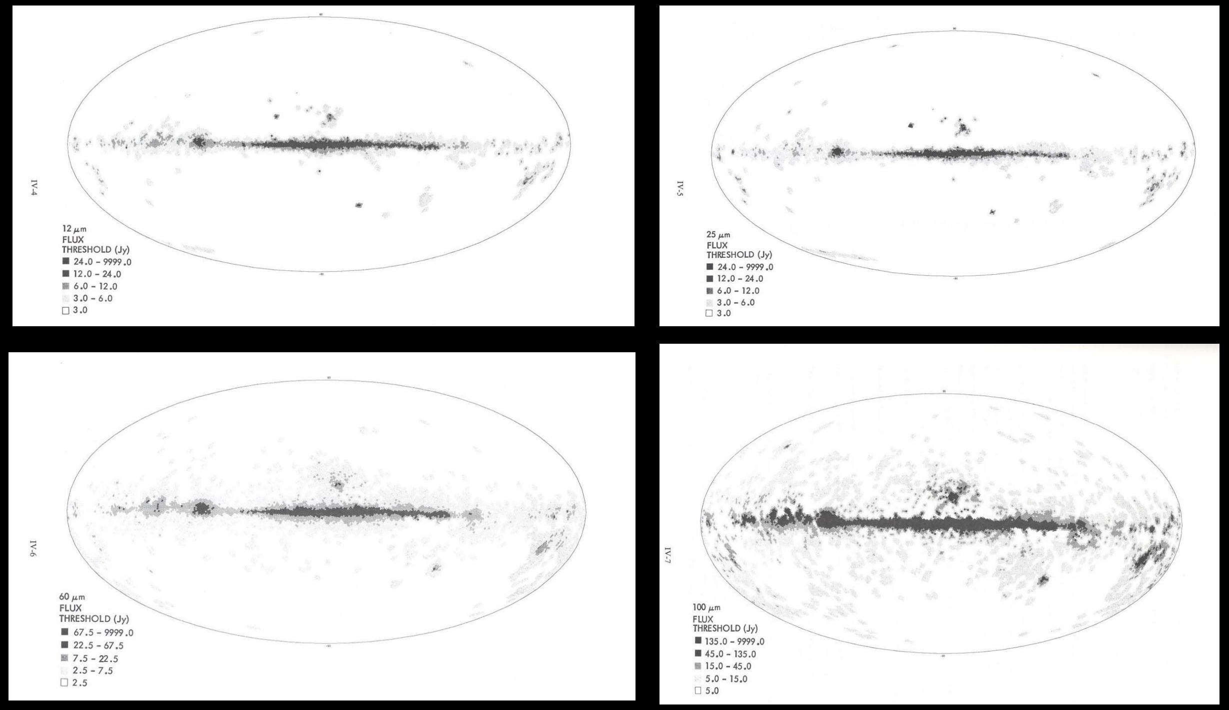


Figure 11: IRAS Milky Way IR image at Four different wavelengths

IRAS -Milky Way

- Figure 12 is made up of a layered and coloured view of 12 um, 60 um, and 100 um images take by IRAS to show the full sky scan that IRAS took over 6 months.[14]
  - Bright yellowish orangish line in the middle is the Milky Way[14]
- Red arrow points to Ophiuchus[14]
- Yellow arrow points to Orion[14]
- Black segments swooping around are areas that the IRAS did not image[14]

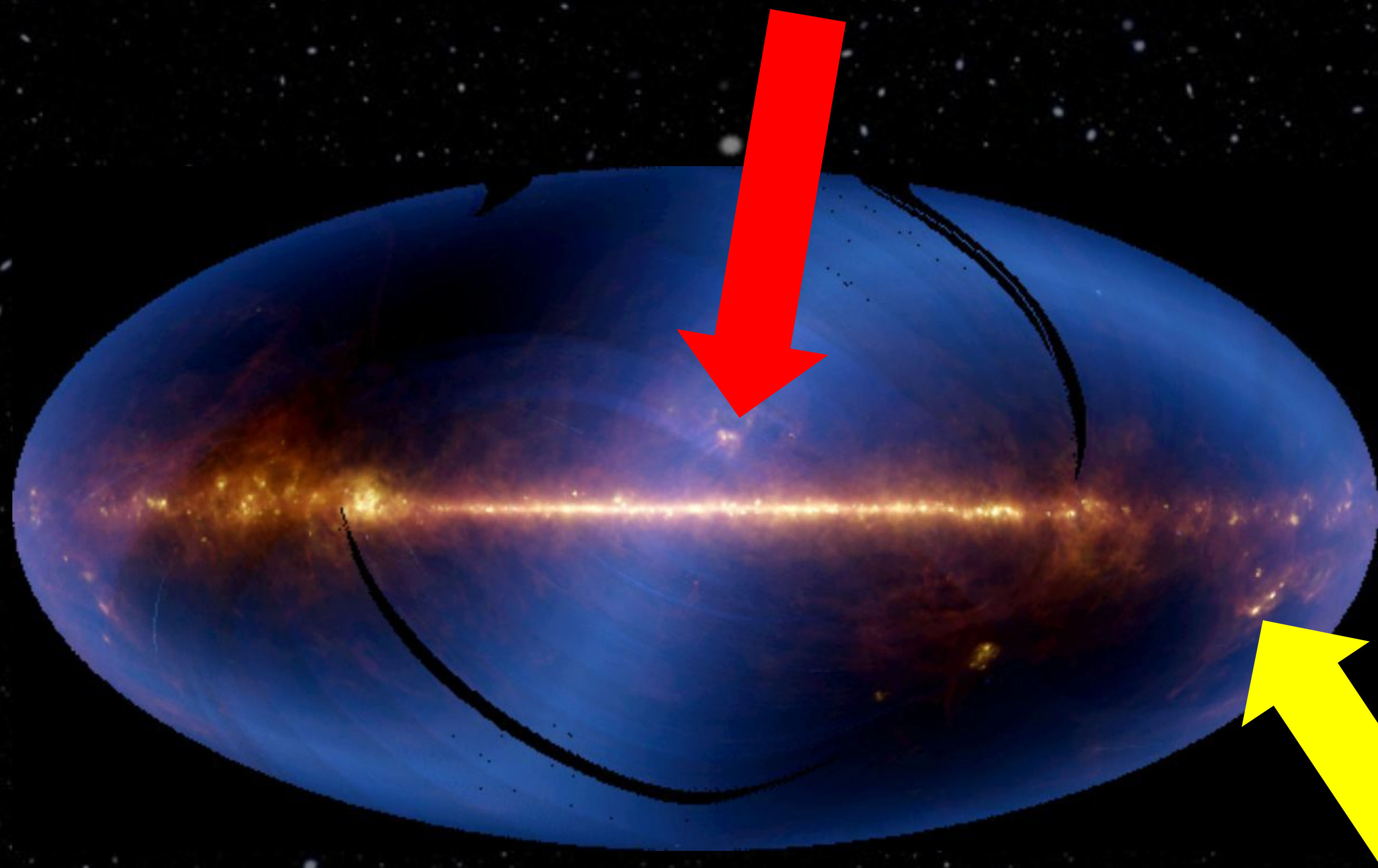


Figure 12: Composite of 6 months of IR data captured by IRAS.

Clicker Question

Why did scientists put IR telescopes higher and higher?

a) For style points since it would look extra cool

b) To minimize interference from the atmosphere

c) To be closer to space to get bigger pictures

d) because William Herschel asked them to

Spitzer Space Telescope

To go deeper NASA launched the Spitzer Space Telescope two decades later.

The telescope was launched in 2003 and was planned to only be a 2 and a half year mission.[15,16]

But, it actually lasted for 17 years, finally being decommissioned in 2020 due to operational costs (got too far away to communicate with it).[15,16]

Main objective: Look at specific celestial objects and other targets in more detail.[15]

During its long deployment, it did achieve some amazing things with some of its most distinguished being:

-Was the first to detect light from an exoplanet (a planet not within our own solar system).[15]

-in 2009 it found Saturn's largest ring that is 300x the diameter of the planet (moon phoebe orbits within it).[15]

- Spitzer was zooming in on specific targets — planets, exoplanets, galaxies, star-forming regions — another mission took a broader approach.

Figure 13: Artists rendition of the Spitzer Space Telescope.

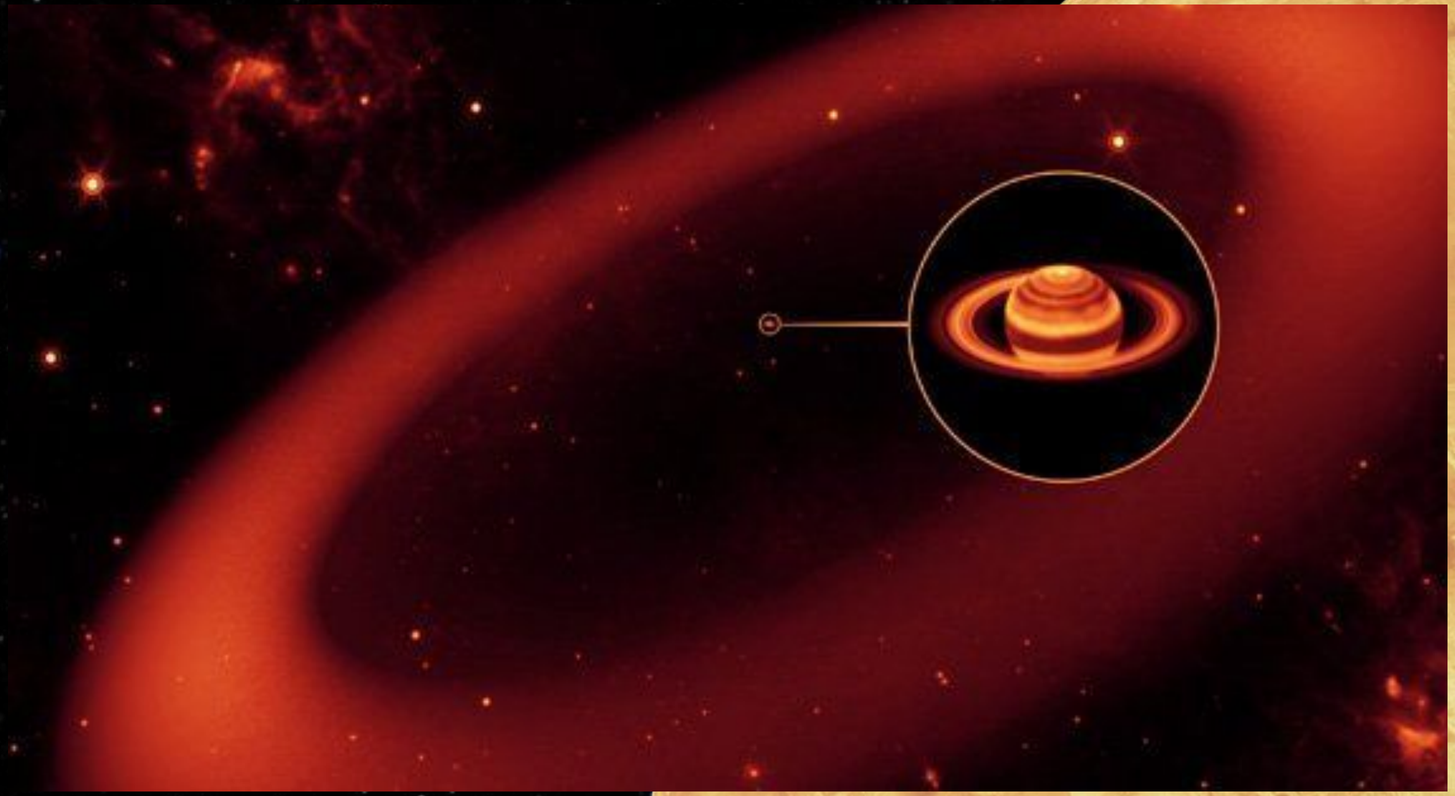


Figure 14: Artist's conception of largest ring around Saturn

Spitzer Calendar

To celebrate 12 years of operation, NASA created a 12 image calendar for the Spitzer Space telescope.[17]

This calendar highlights the amazingly detailed IR images that Spitzer was able to capture giving us a deeper understanding of our Universe.

This telescopes pleasantly surprising long career was prolonged due to the fact that scientists at NASA were prepared for the coolant to run out, and prepared a "warm mission" once that happened.[15] A shift to a lower IR frequency allowed for the telescope to stay in operation while minimizing thermal noise to continue its data gathering journey.[15,16]

- Spitzer was zooming in on specific targets — planets, exoplanets, galaxies, star-forming regions — another mission took a broader approach.

Figure 15: 12 Images taken by Spitzer over its first 12 years of deployment.

Wide-Field **I**nfrared **S**urvey **E**xplorer

The Wide-field Infrared Survey Explorer, or WISE, was launched to map the entire sky again in infrared, continuing the work that IRAS began, but with far better resolution.[18-21]

Launched in 2009, ran till 2011.[18-21]

0.4 m telescope. Why smaller than IRAS? With the surge of technological advancements after the time of IRAS, WISE had detectors that were much more sensitive than that of IRAS over two decades prior.[18]

750 million objects were catalogued.[19]

Ranging from: bright brilliant galaxies, millions of black holes, even identified many brown dwarfs (dark, failed stars that are hard to find!) some of which have a temperature similar to the human body.[19]

Again, ran out of coolant.

So it was put into hibernation in 2011 until two years later...[19-21]

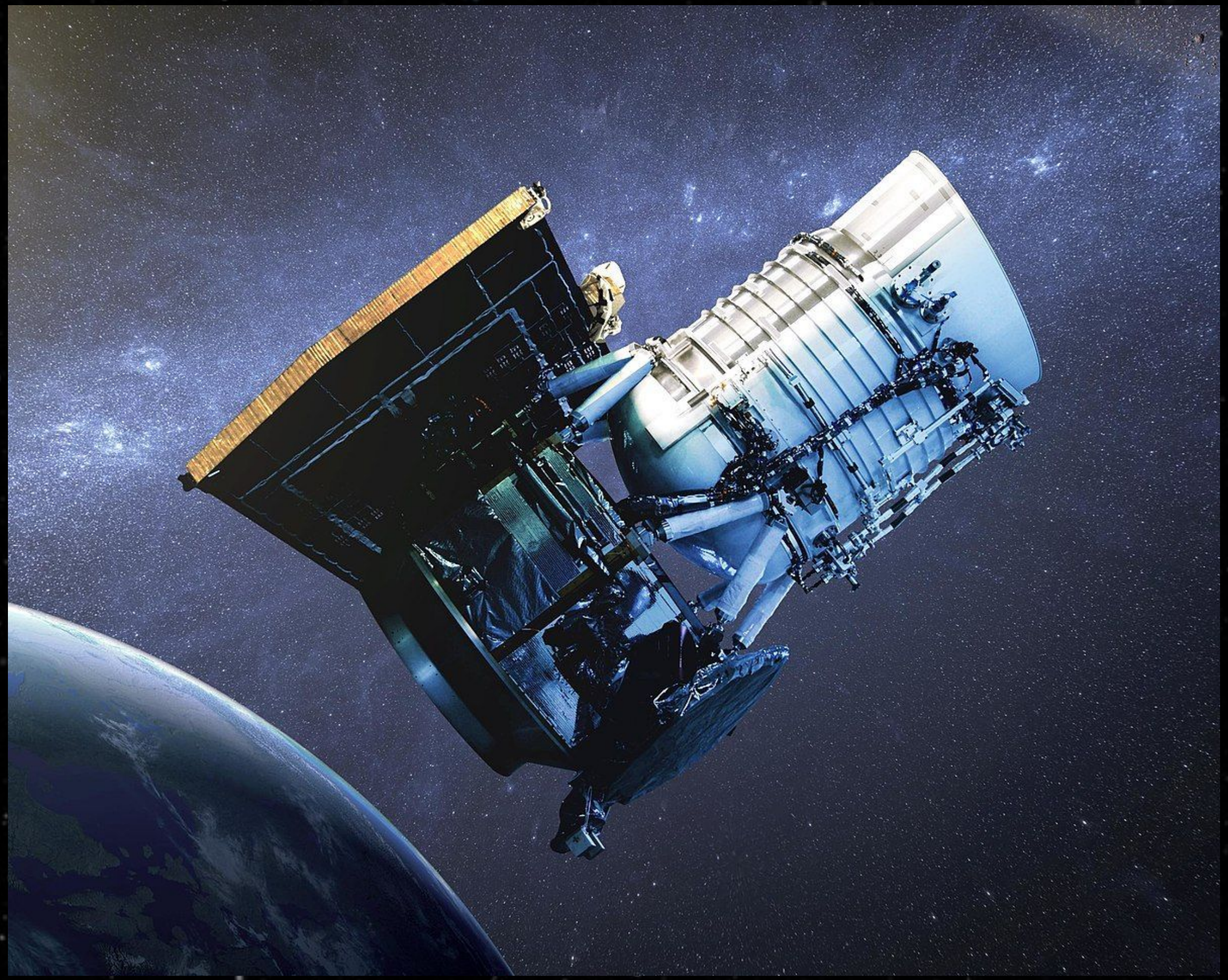


Figure 16: Artist's conception of the WISE/NEOWISE space telescope.

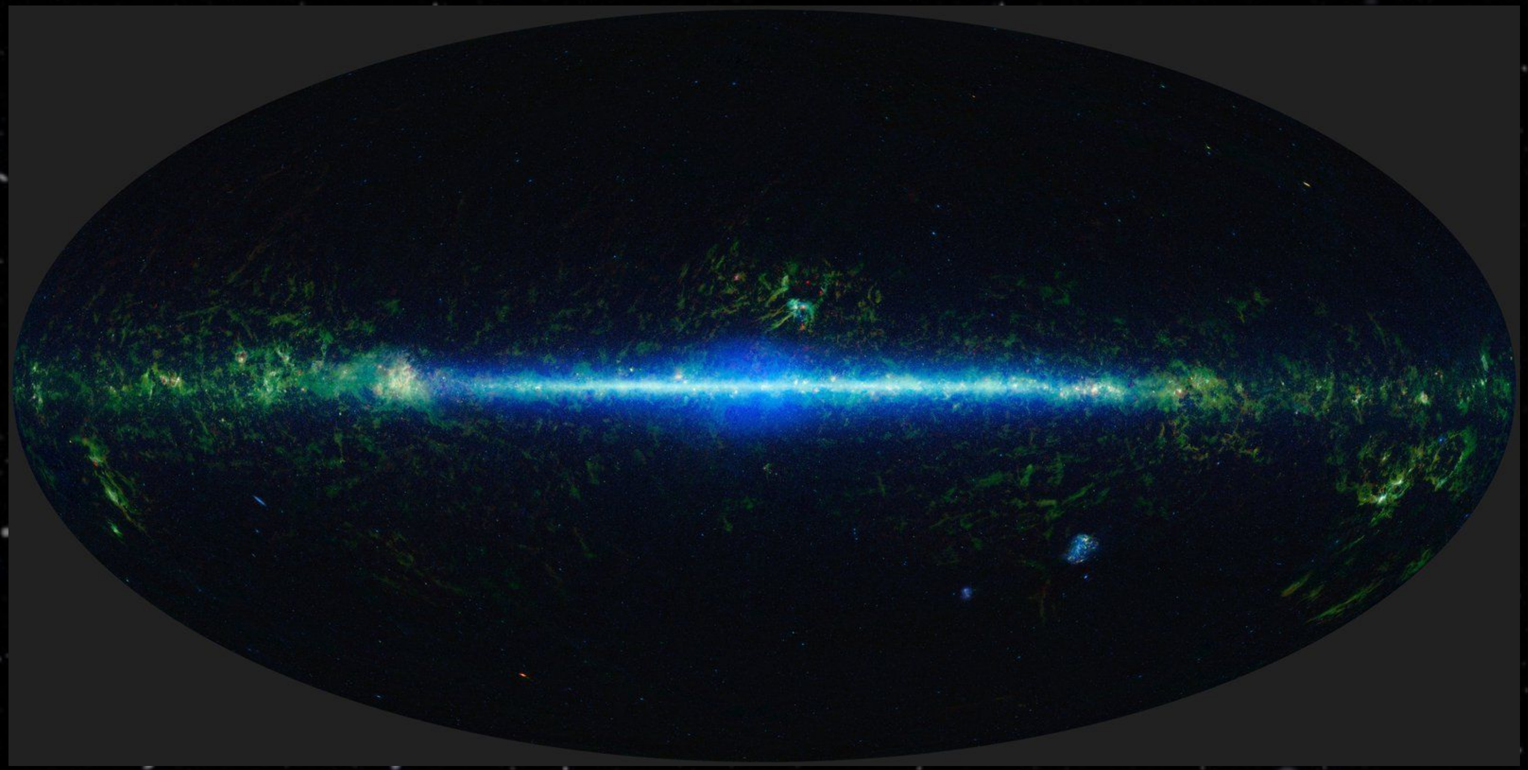


Figure 17: Mosaic of images taken from full-sky survey of WISE in 3 out of the 4 wavelengths used.

Near-Earth Object Wide-Field Infrared Survey Explorer

NEOWISE = WISE REVIVED!
Came out of hibernation in 2013, burned up in Earth's atmosphere in 2024.[20]

Same detectors but shifting to a shorter wavelength avoids thermal noise similar to Spitzer's strategy.[20,21]

It's new mission now was to essentially act as Earth's watchdog by learning more about the population of NEO's that could pose a possible threat to Earth.[20,21]

IR telescopes are particularly useful for detecting comets, because where a visual light telescope would have a hard time identifying a dark, rocky object that doesn't reflect much sunlight, IR telescopes can pick up the heat radiating off of it.[20-22]

NEOWISE observed the orbits, sizes, and probable compositions of 3000 NEO's throughout our solar system, giving us a better understanding of potential hazards around us.[21]

Building on NEOWISE's legacy, NEO surveyor set to launch in 2028, specifically designed to detect asteroids and comets that may be hazardous.[22]

- As remarkable as IRAS, Spitzer, and WISE were, they were stepping stones, revealing more of the hidden universe, and pushing the boundaries of what infrared astronomy could do. But then came a telescope unlike any before: the James Webb Space Telescope.

Figure 18: Artist's conception of a massive meteor approaching Earth.

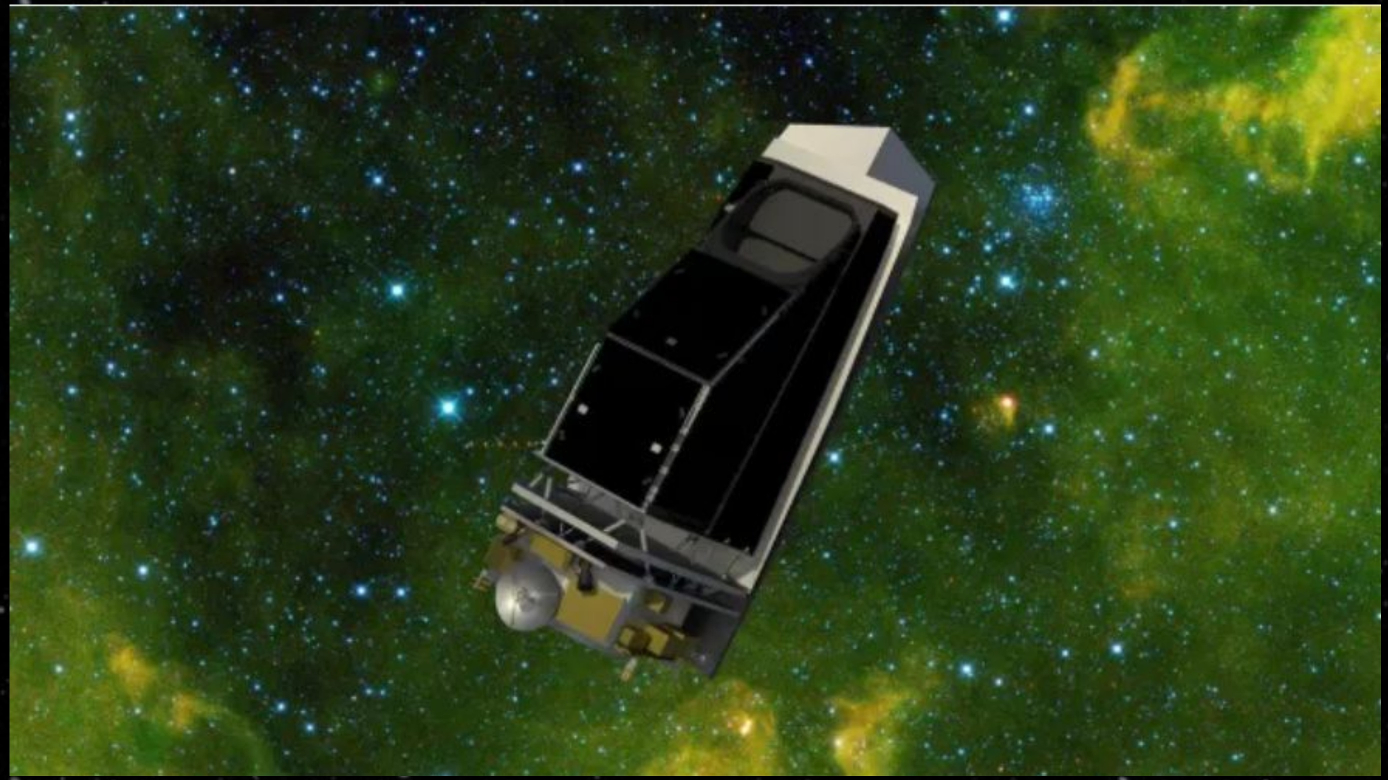


Figure 19: Artist's conception of the proposed NEO surveyor.

James Webb Space Telescope

The JWST was launched in 2021 after nearly 18 years and 9 billion dollars in production (with the end cost reaching nearly $11 billion).[23]

Just the mirror is 21 ft in diameter and 705 kg, and the scale of this telescope is visualized in Figure 20 where it is shown beside proud NASA employees.[24]

Now this is a HUGE COST but it is well worth it, giving as insane resolution down to 0.1 arcsec. Reminder: A fingernail at arms length is equivalent to 1 arcsec.[24]

It is expected to be functioning for 5 to 10 years (hopefully longer like the other ones at that cost!).[24]

The overall missions JWST is hoping to achieve not unlike the others previously described, is to give a greater understanding of the universe.

JWST is essentially a time machine, able to look back at every phase of the history of our universe by detecting light from billions of light years away.[23,25]

Another goal of JWST is to look for signatures of life, to answer that lifelong question – Are we alone? Are we unique?[23,25]

We as humans are innately curious, and have always and will always be explorers!

After sending $10 bill into space, I can imagine it would be scary! What if something goes wrong, or it doesn't work as well as they might have thought?

But James Webb has and continues to exceed expectations.

Figure 20: NASA employees standing beside the JWST.

JWST IR images

Figure 21: Tarantula nebula captured by IR detectors of the JWST. Uncovering never before seen cluster of stars in the center.

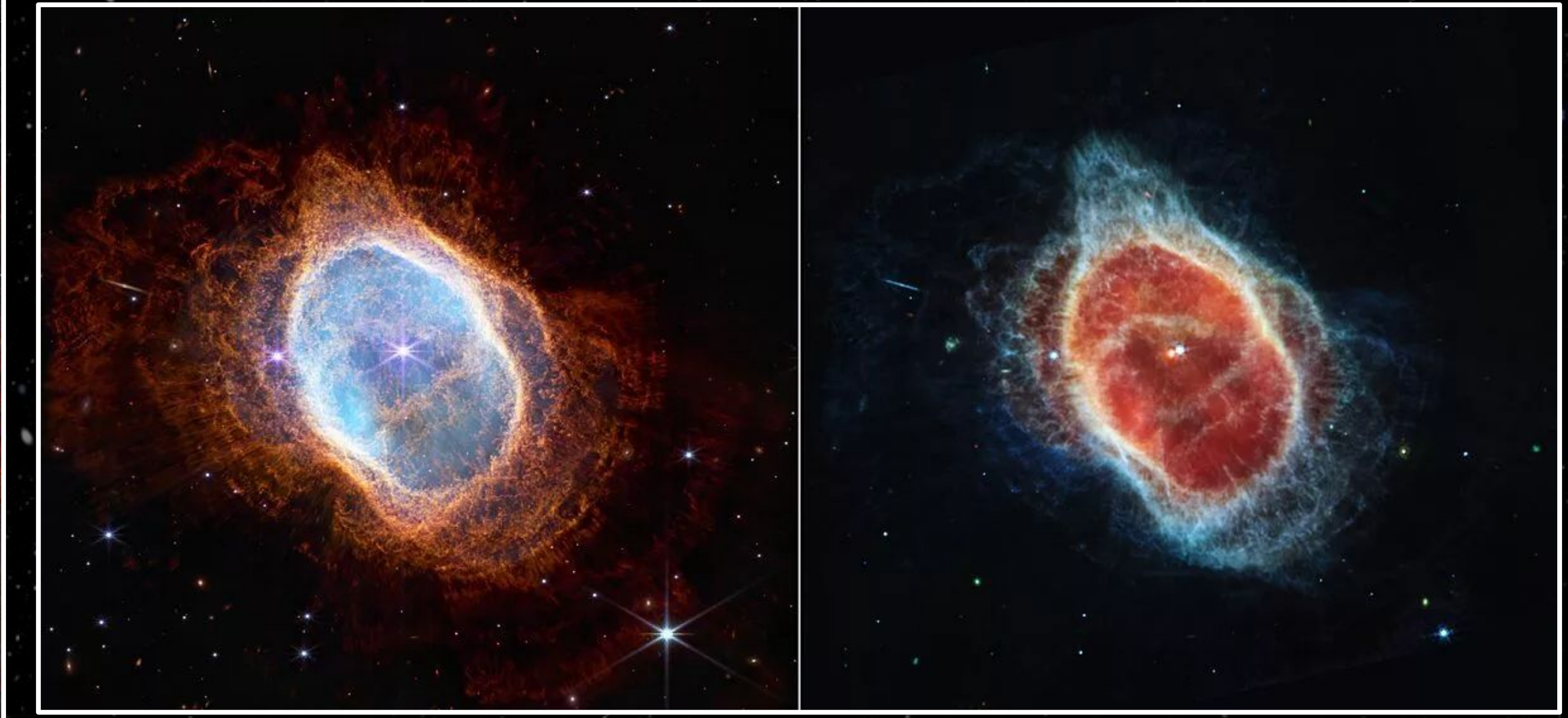


Figure 22: The Southern Ring nebula captured by JWST in NIR (left) and MIR (right). Valuable ability to be able to scan many wavelengths of IR to reveal new signatures.

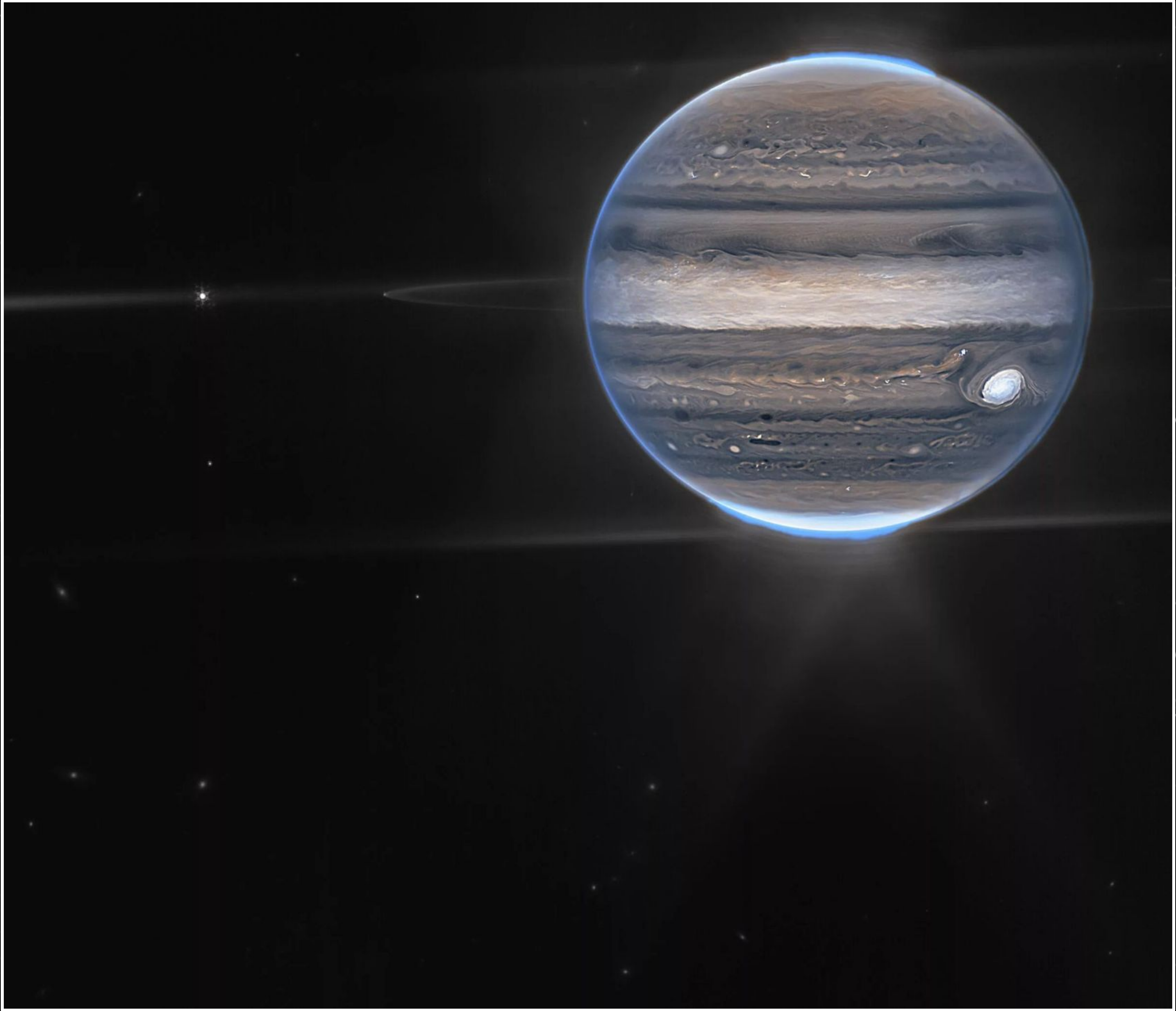


Figure 23: Jupiter and its rings, moons and aurora captured by the NIRcam of JWST. The detail that James Webb provides sheds an entirely new light on celestial objects, giving incredible new information.

Guess that celestial object:

a) Saturn
b) Planet X
c) Venus
d) Neptune

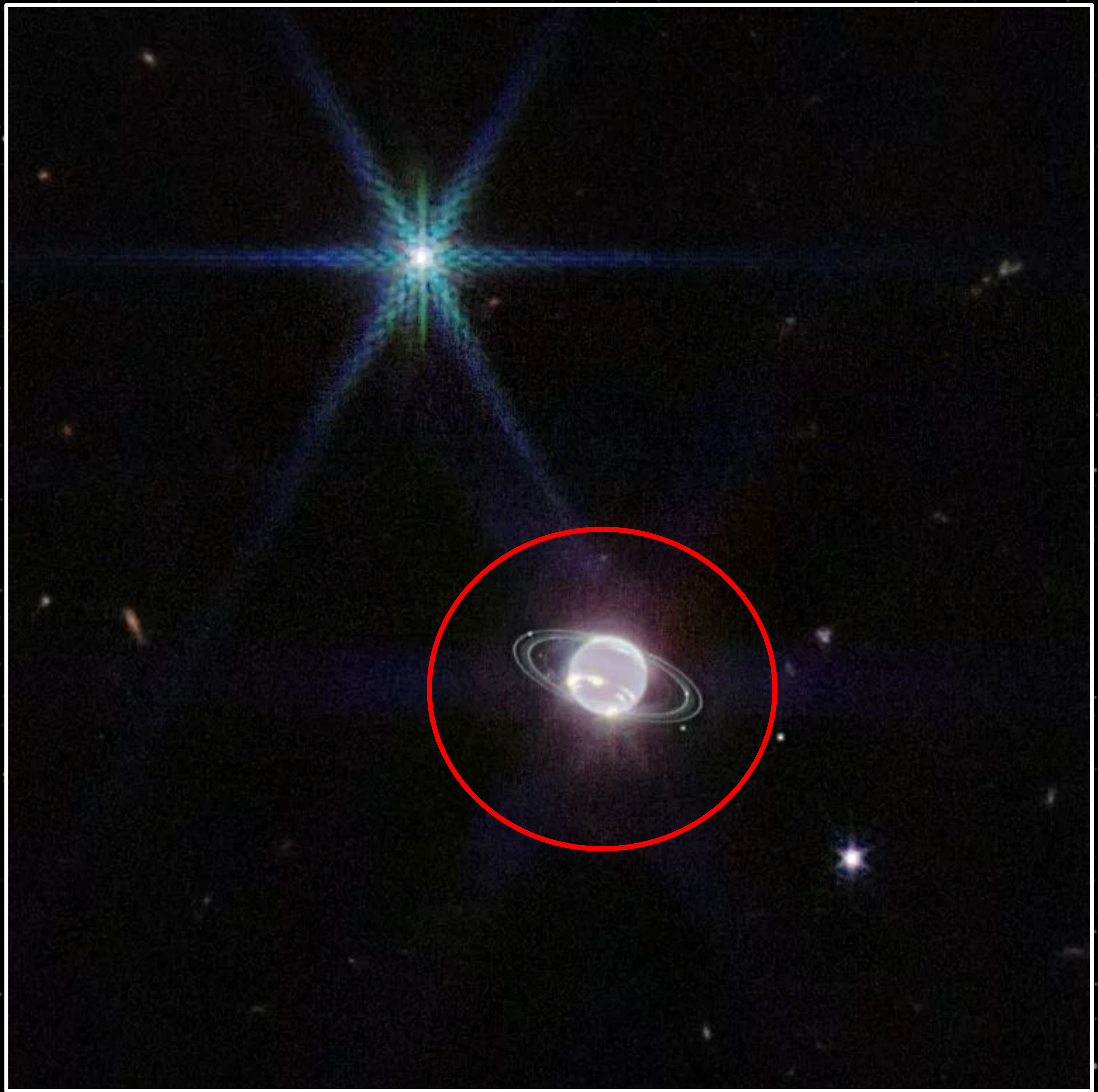


Figure 24: Neptune alongside the star Triton captured by the JWST.

End on this amazing picture taken by JWST. It is the deepest IR image we have available. Shows just a tiny sliver of the sky, but unveils thousands of galaxies.

Just shows how there is so much to discover, explore, mysteries to solve, and I hope we've shown how IR telescopes have played a crucial role in how we understand our Universe and our insignificant yet special place within it.

Figure 25: JWST first deep-field IR image uncovering thousands of galaxies.

Figure 26: JWST image of the Carina Nebula captured with the NIRcam.