JWST: A Many-Level Inspiration

George Rieke, Regents Professor of Astronomy and Planetary Sciences, The University of Arizona
To NY Creates, April 21, 2022

1st Inspiration: that human beings can create something on this scale just for indulging their curiosity

Building the great pyramid took 7060 men for 23 years and would have cost about 8 billion dollars at the time JWST was built. (estimate by Stuart Wier, *Cambridge Archaeological Journal*, 1996, 6, 150)

This is a perfect match to the effort to build JWST!

Photo by Nina Aldin Thune

There is enthusiasm around the world for JWST!!

Nojum, monthly astronomy magazine of Iran

SCIENCE & TECHNOLOGY

James Webb Space Telescope: How our launch of world's most complex observatory will rest on a nail-biting knife edge

If all goes well, humanity will have a new eye on the cosmos, with capabilities that far surpass anything that has gone before

NEXT BLOG >

Down-to-Earth (Indian)

By Leigh Fletcher, John Pye, Piyal Samara-Ratna
Published: Monday 20 December 2021

2nd inspiration: that we are bold enough to try something so ambitious

JWST is a high-wire act for NASA!

“The greatest danger is not that our aim is too high and we miss it, but that it is too low and we reach it,”-- Michelangelo.

Thomas Zurbuchen, NASA Associate Administrator for Space Sciences, points out: “It will take about three weeks to deploy Webb, and scientists will be on edge the entire time. Those who are not worried or even terrified about this are not understanding what we are trying to do.”

Building James Webb: the biggest, boldest, riskiest space telescope

The pressure is on the builders of the James Webb Space Telescope to ensure that NASA’s $8 billion gamble pays off

Science, 18 Feb. 2016

James Webb Space Telescope: The engineering behind a 'first light machine' that is not allowed to fail

Space.com

By Tereza Pultarova published December 21, 2021

The most complex and expensive space observatory ever built, has pushed engineers and technologies to their limits.

SPACENEWS

JWST launch marks only the start of a risky deployment process

by **Jeff Foust** — December 23, 2021

ASTROPHYSICS

The Webb Space Telescope Will Rewrite Cosmic History. If It Works.

47

The James Webb Space Telescope has been designed to answer many of the core questions that have animated astronomers over the past half-century. With a $10 billion price tag, it is one of the most ambitious engineering initiatives ever attempted. But for it to achieve its potential — nothing less than to rewrite the history of the cosmos and reshape humanity's position within it — a lot of things have to work just right.

Quanta magazine

3rd Inspiration: that it works!!!

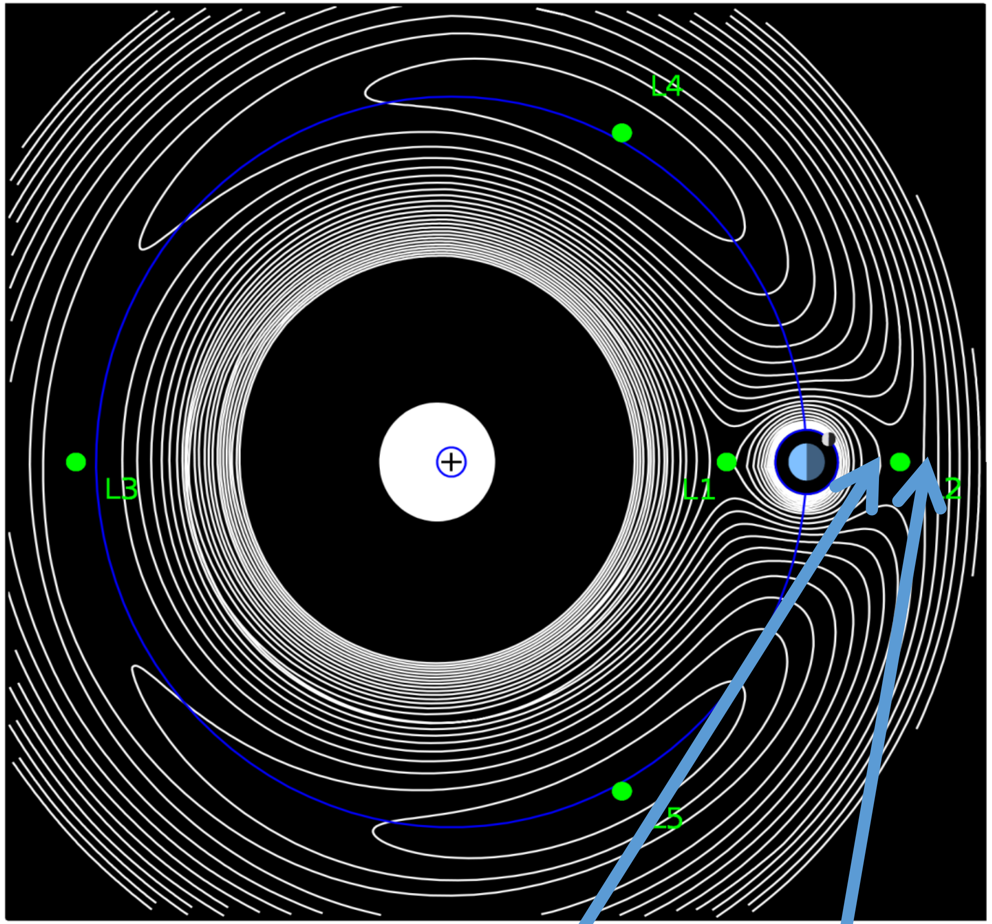
- Development of advanced new technologies
- Building them to be reliable
- Great engineering
- Fantastic management

JWST had a beautiful launch Christmas morning

Over the next month JWST cruised to the L2 Lagrangian point. It will stay there for the life of the mission.*

On a standard Keplerian orbit, the velocity is strict function of the radius. A Lagrangian point is where the centrifugal force on a small body cancels the combined gravitational forces of two large ones. They are good places to park observatories because they are far from the earth but track it in its orbit of the sun.

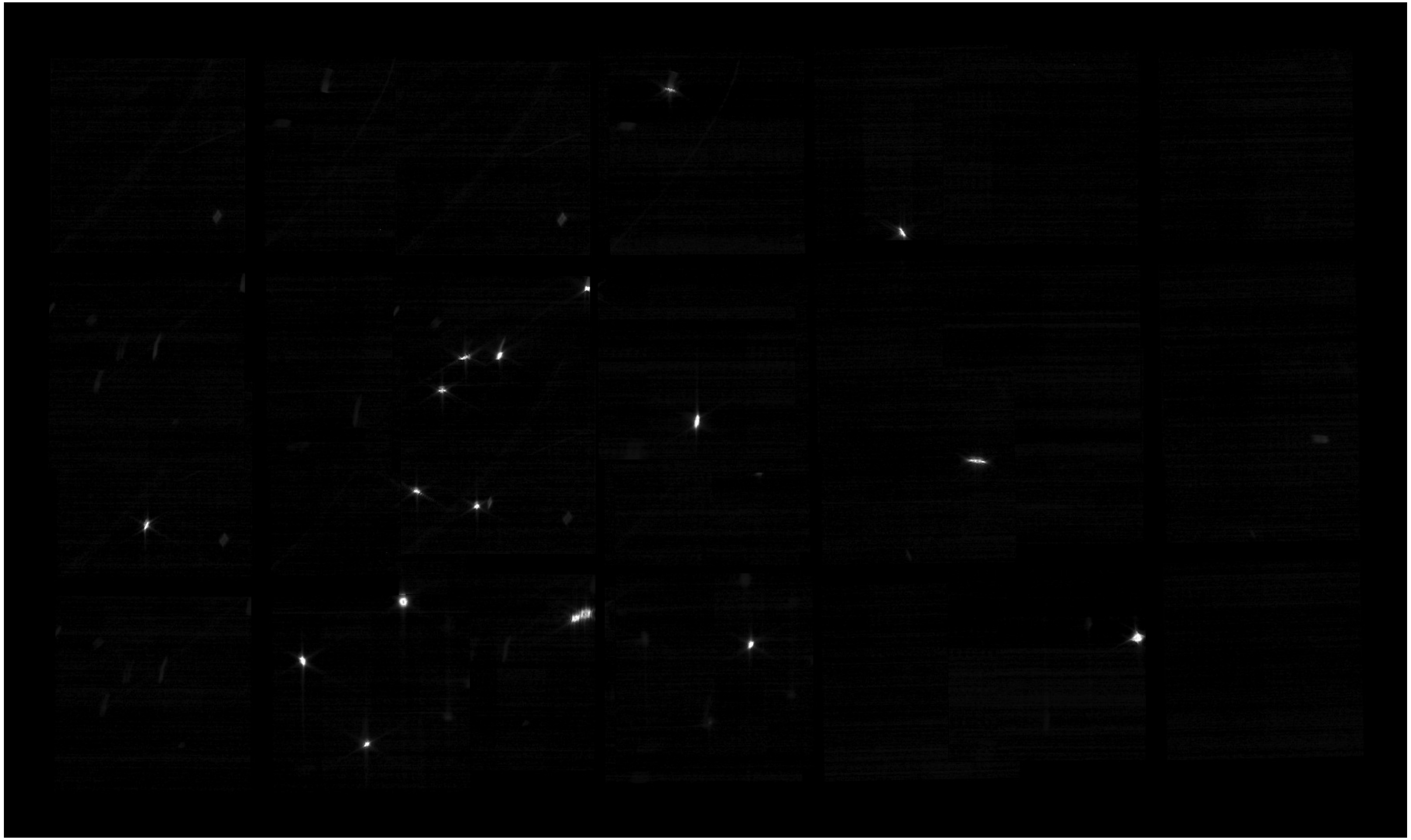
*could be 10 – 20 years



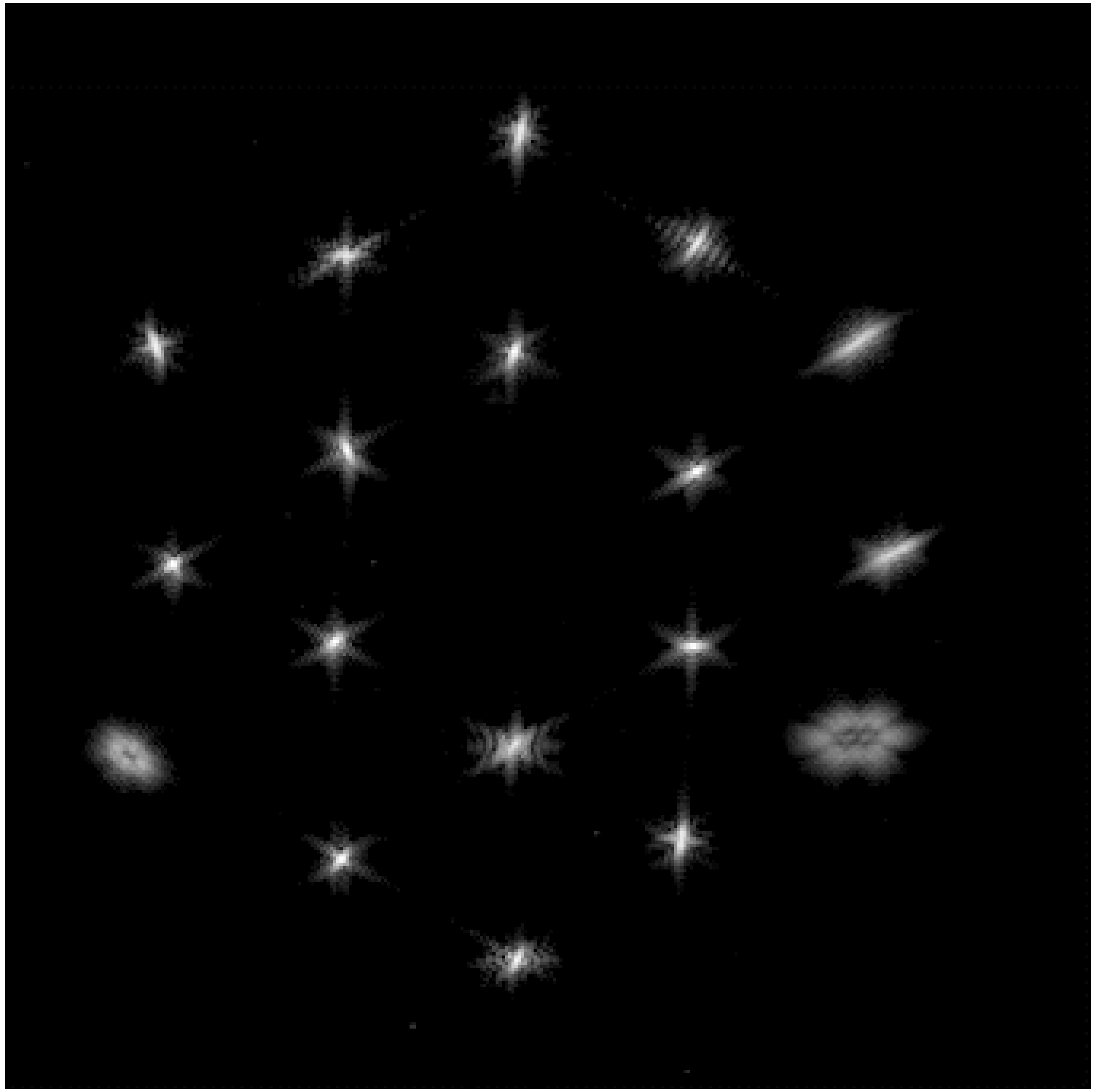
object orbits Earth

object orbits Sun

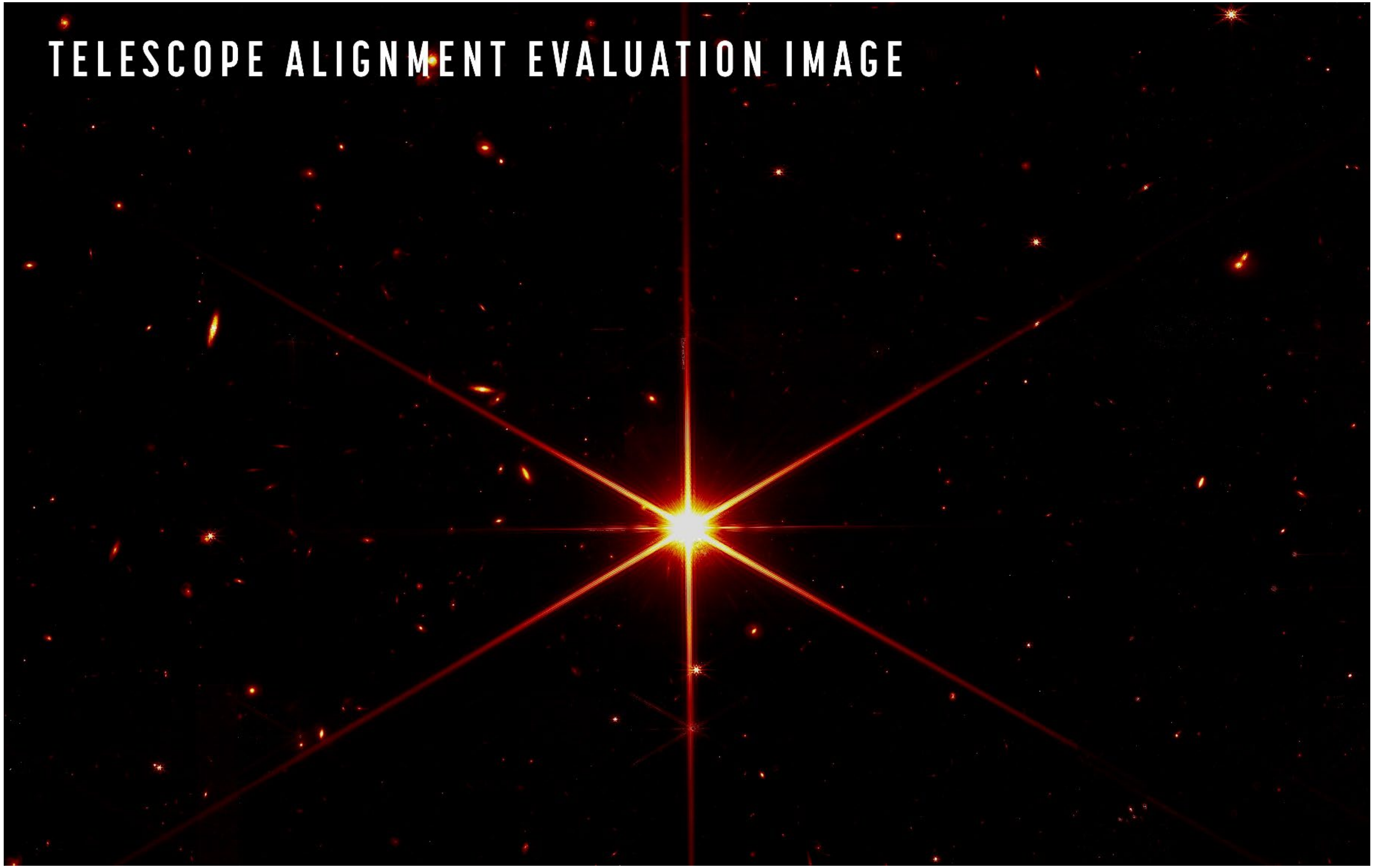
Here is the start to lining up the 18 mirror segments – here are 18 images of a single star, one for each segment, as they were found.



Now they are all gathered – but with various optical issues not fixed; the segments were next moved (and for two, bent) to fix things.



And here is the incredible, diffraction limited image obtained with NIRCam



Doing this wasn't easy. The whole JWST observatory (telescope plus spacecraft) weighs about 1/3 the weight of the *tube* of our 90-Inch.

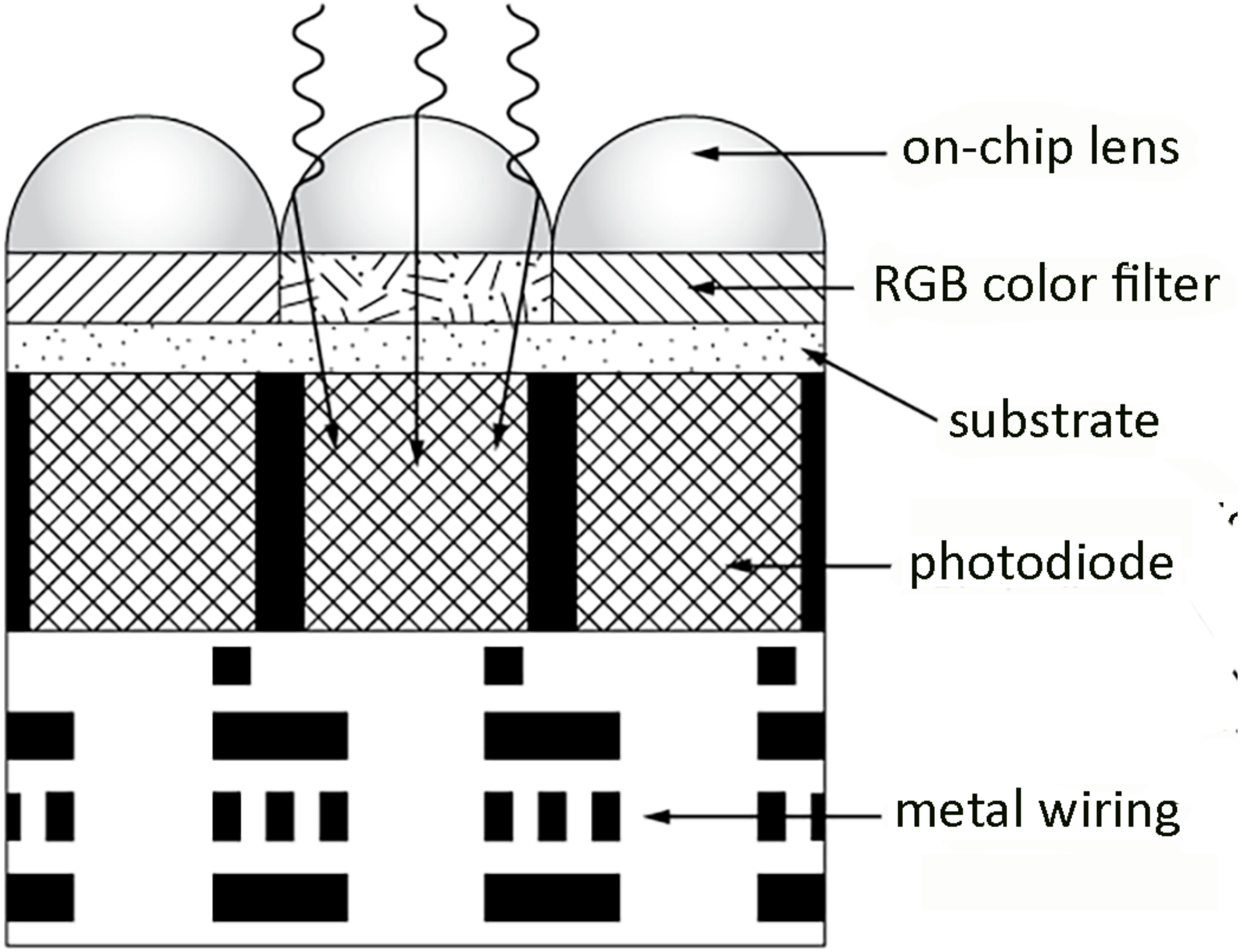
The 90-Inch is a standard old-style telescope, mirror area 1/6 that of JWST.

So JWST is doing 6 times the mirror area at much less than 1/3 the mass.

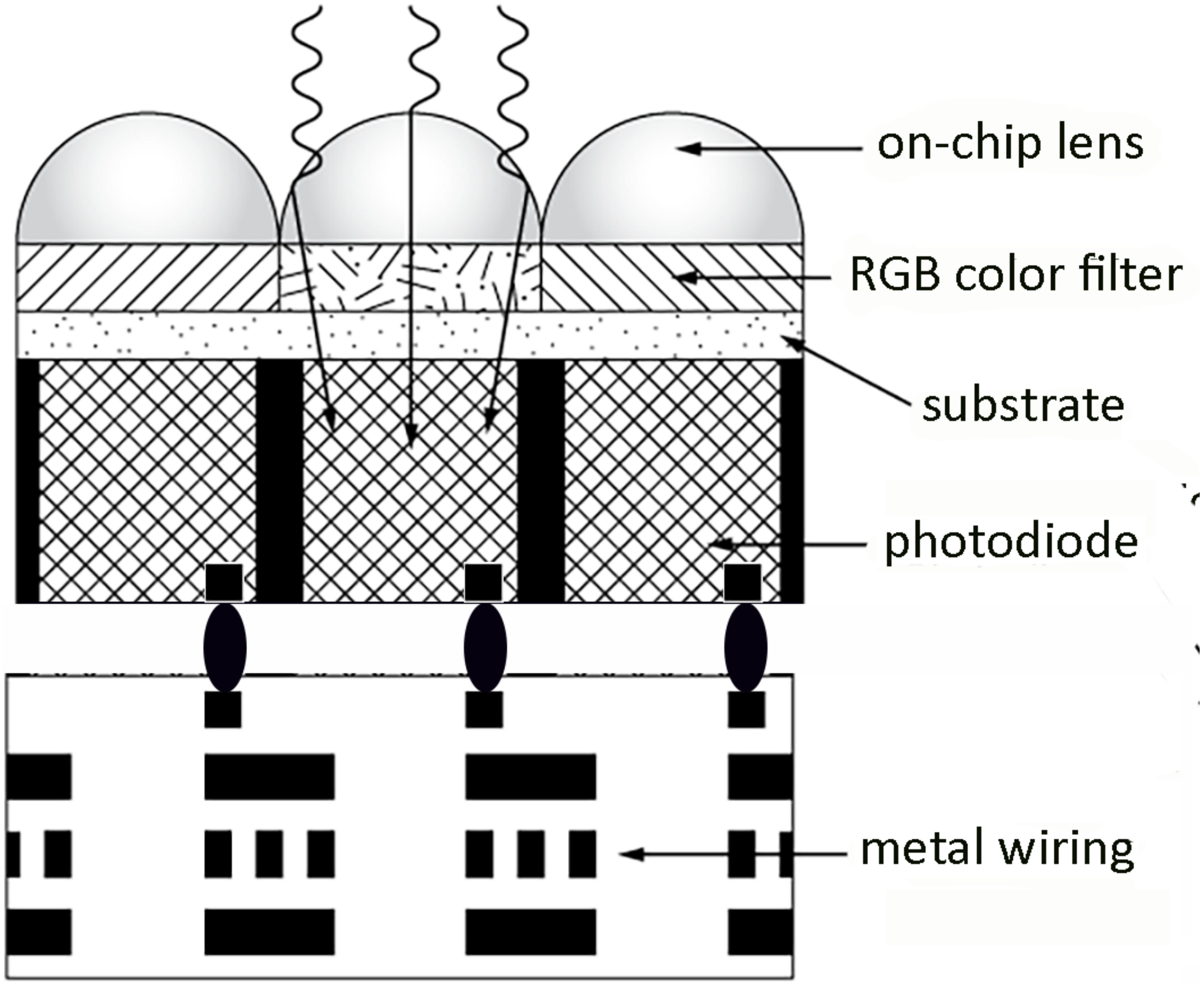
We equipped this telescope with high performance infrared detector arrays

Here is a cross-section of a CMOS detector array that you might find in a high-end digital camera.

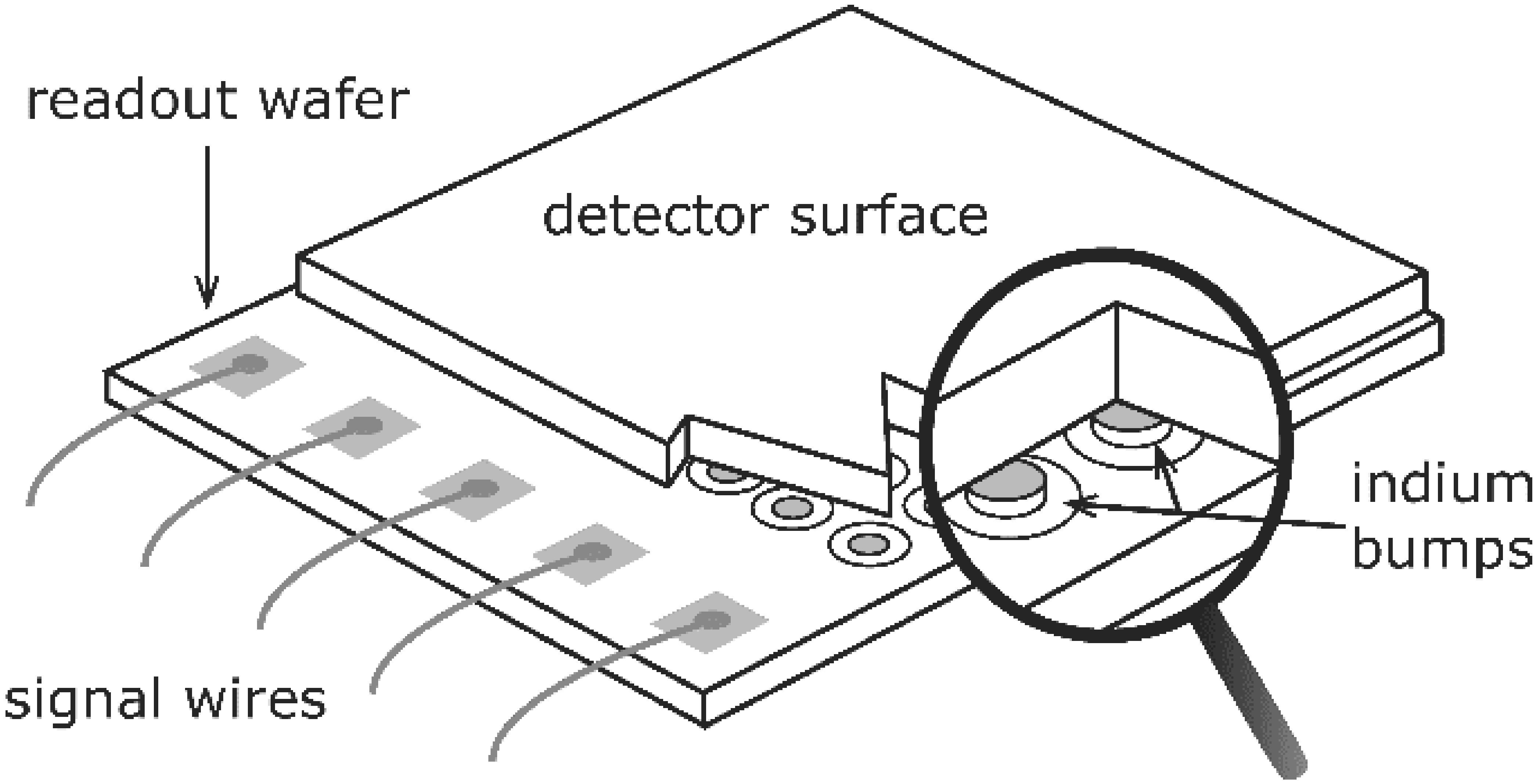
The "metal wiring" includes the output amplifiers for the signals generated by the photodiodes, one amplifier per diode.



CMOS detector arrays are build entirely of silicon. Infrared detectors are of different materials, so the detectors are separate and attached to the silicon readouts with indium bumps.



Here is how it actually looks



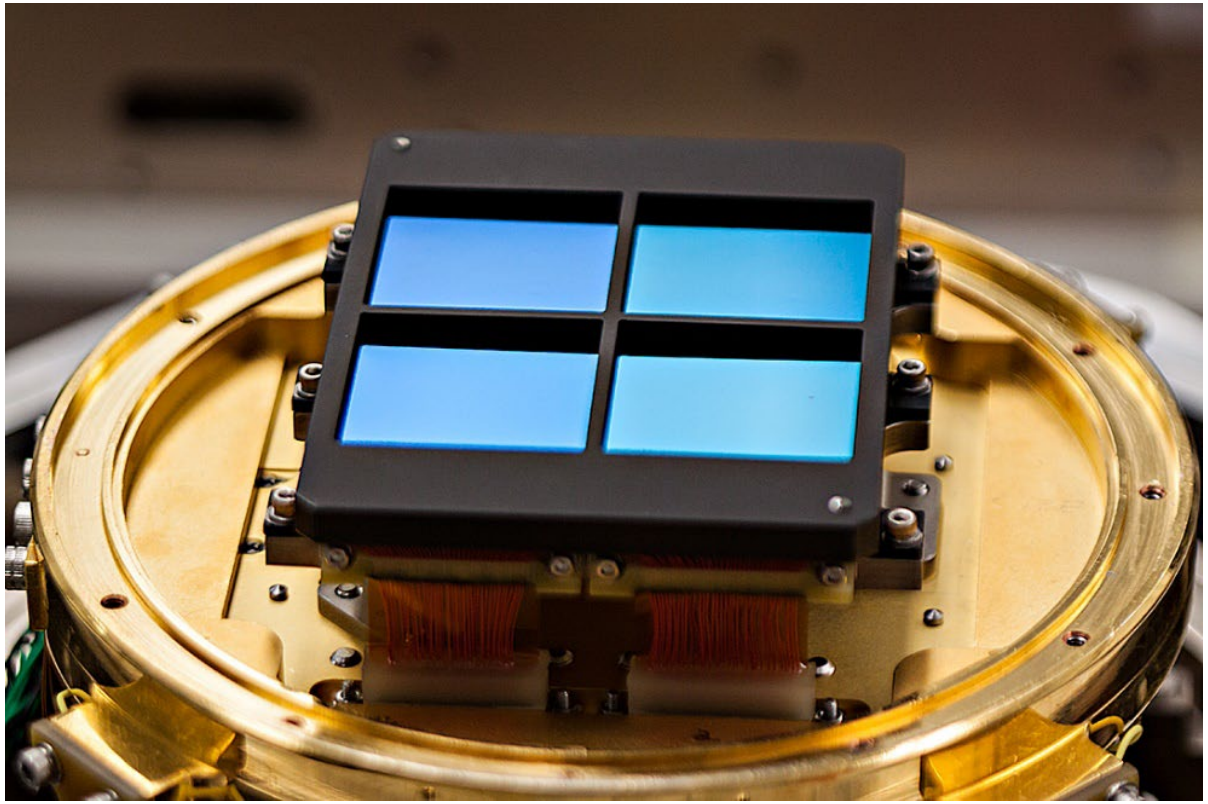


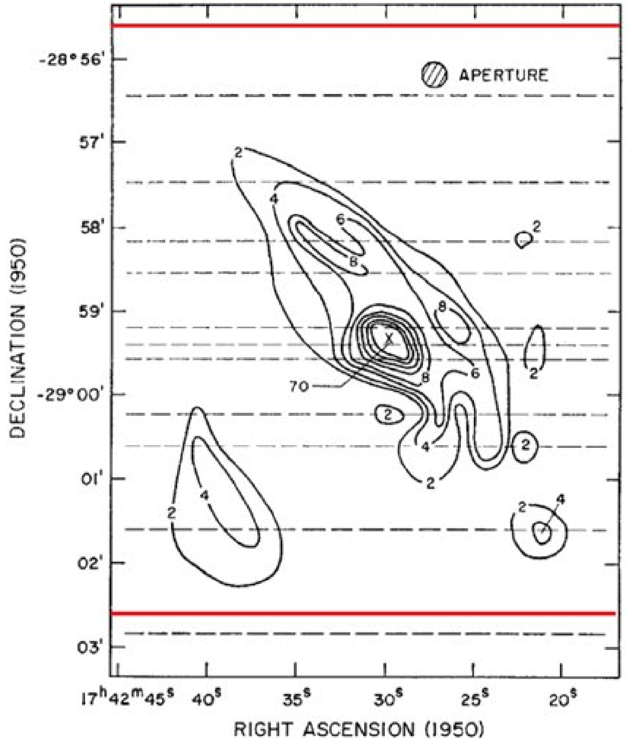
Photo of one of NIRCam's short wavelength detector assemblies

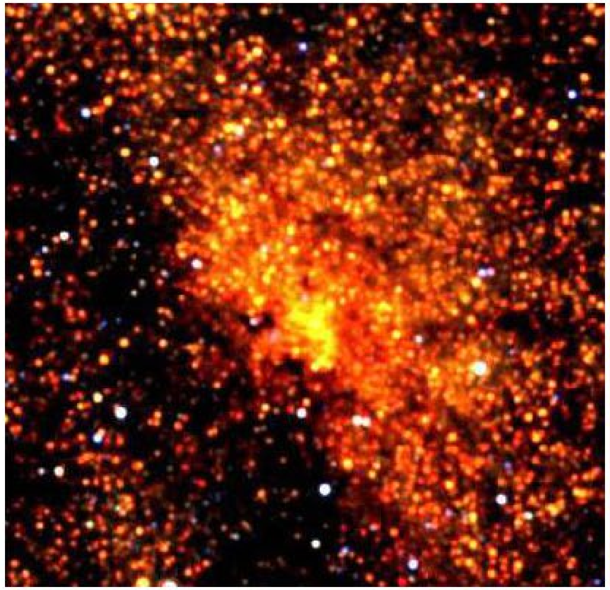
This package has 16 Megapixels with the total NIRCam complement being 40 Megapixels.

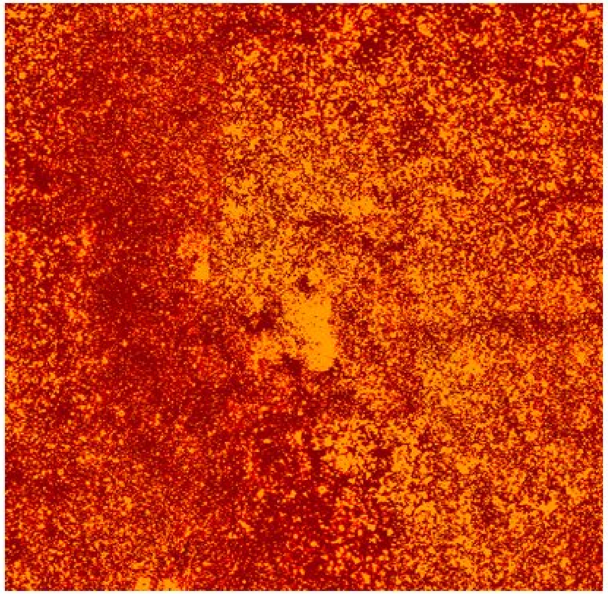
Each pixel has far better performance than the single detectors we used when I started in infrared astronomy (1970)

Here is a sample of what these arrays have meant

Left, map of Galactic Center, 5-m telescope, 15 arcsec aperture, three nights (1968)
Center, same, 1.3-m telescope, 256 X 256 array, 8 seconds per point,
resolution ~ 2 arcsec
Right, same, 6.5-m telescope, 1K X 1K array, one hour, resolution 0.5 arcsec (2005)







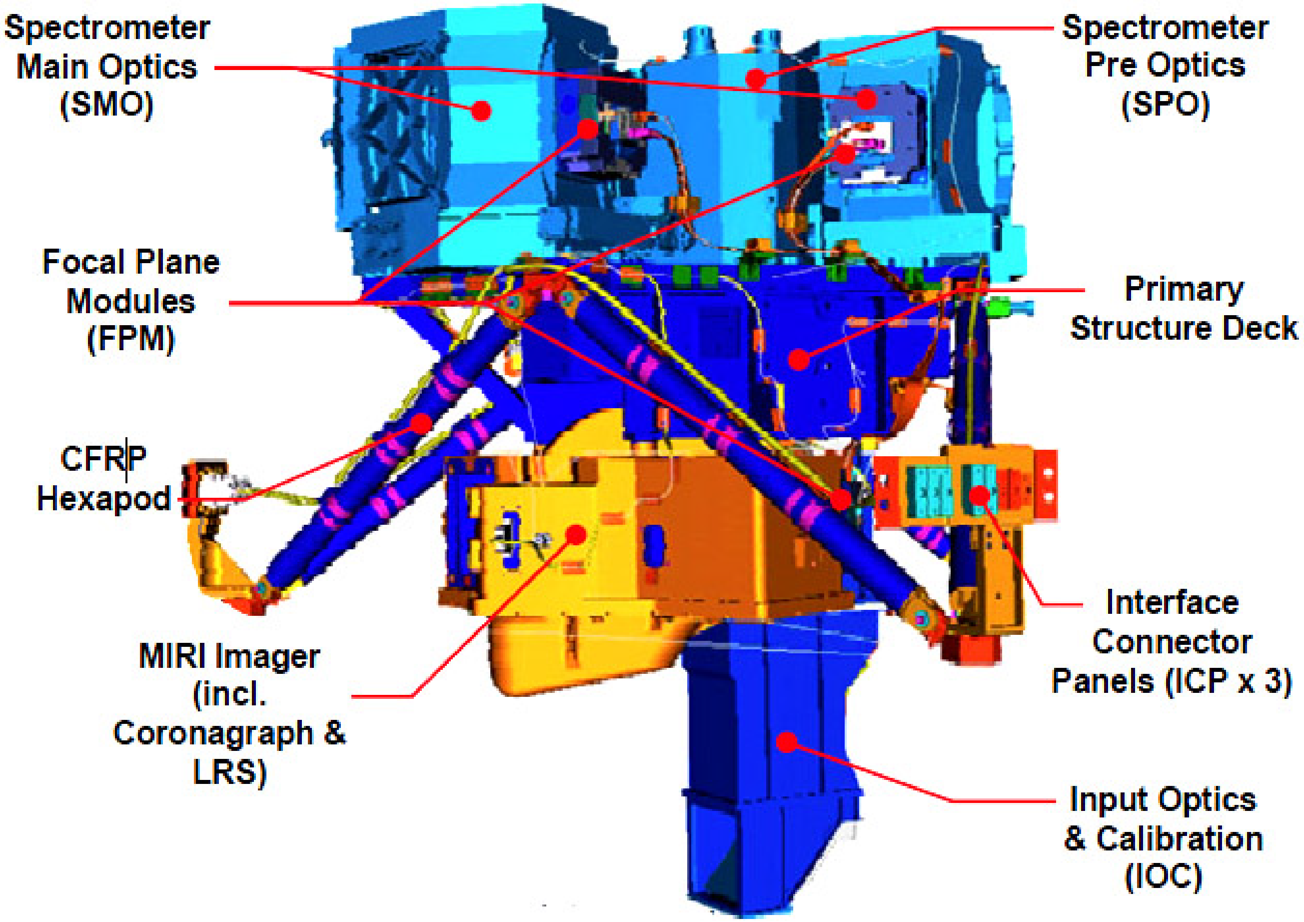
Many management challenges needed to be solved

The Mid-Infrared Instrument, built in multiple European countries, led by the UK Advanced Technology Center for astronomy.

MIRI: Designed and *built* by committee! And all done successfully.

Contributions from:
26 research organizations
2 space agencies
11 countries
GSFC, JPL, & STScI
Northrop Grumman,
EADS – Astrium,
& Raytheon

Led by Gillian Wright and George Rieke (and Alistair Glasse and Mike Ressler)



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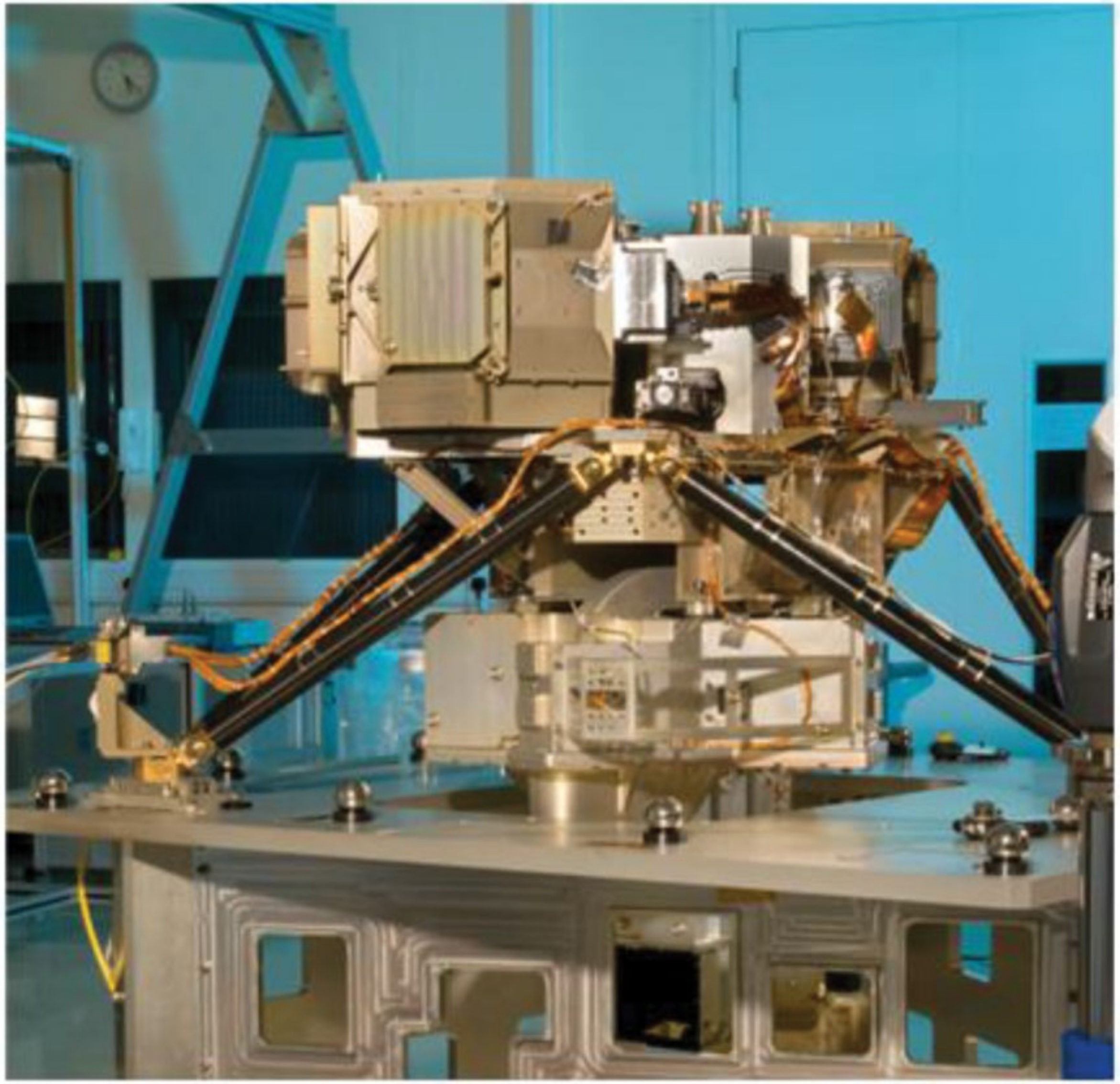
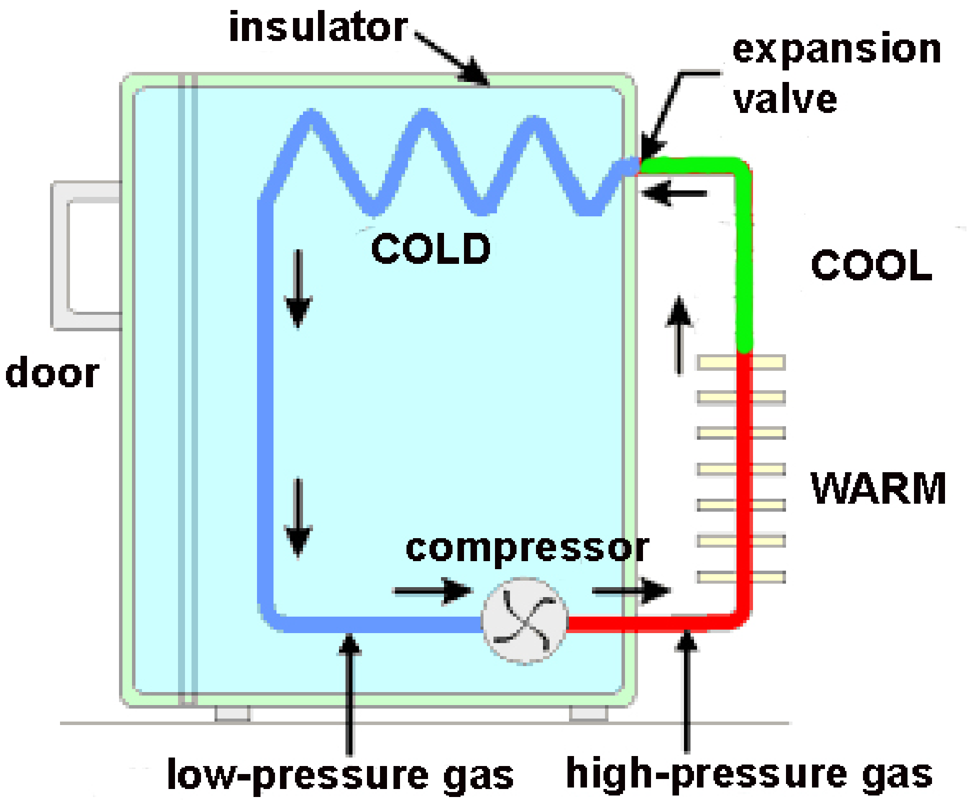


The MIRI cooler proved to be at least as big a challenge to build as the instrument.

The operation of the cooler is similar to that of your refrigerator.

But much more complicated because of the low temperatures, integration with JWST, etc.



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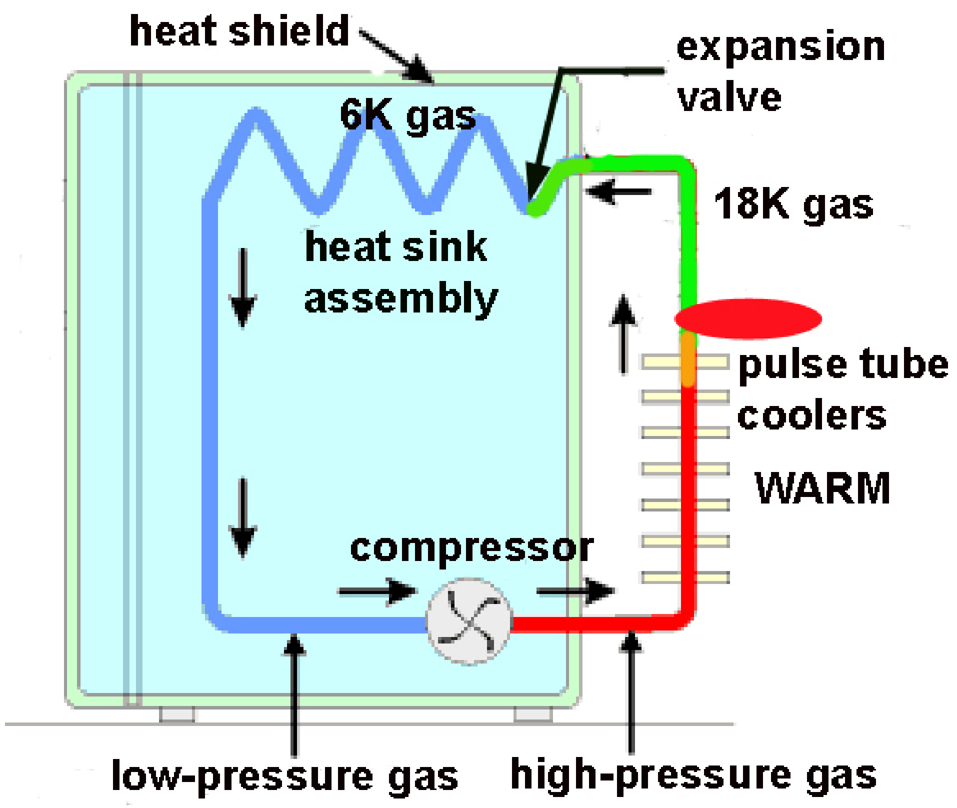
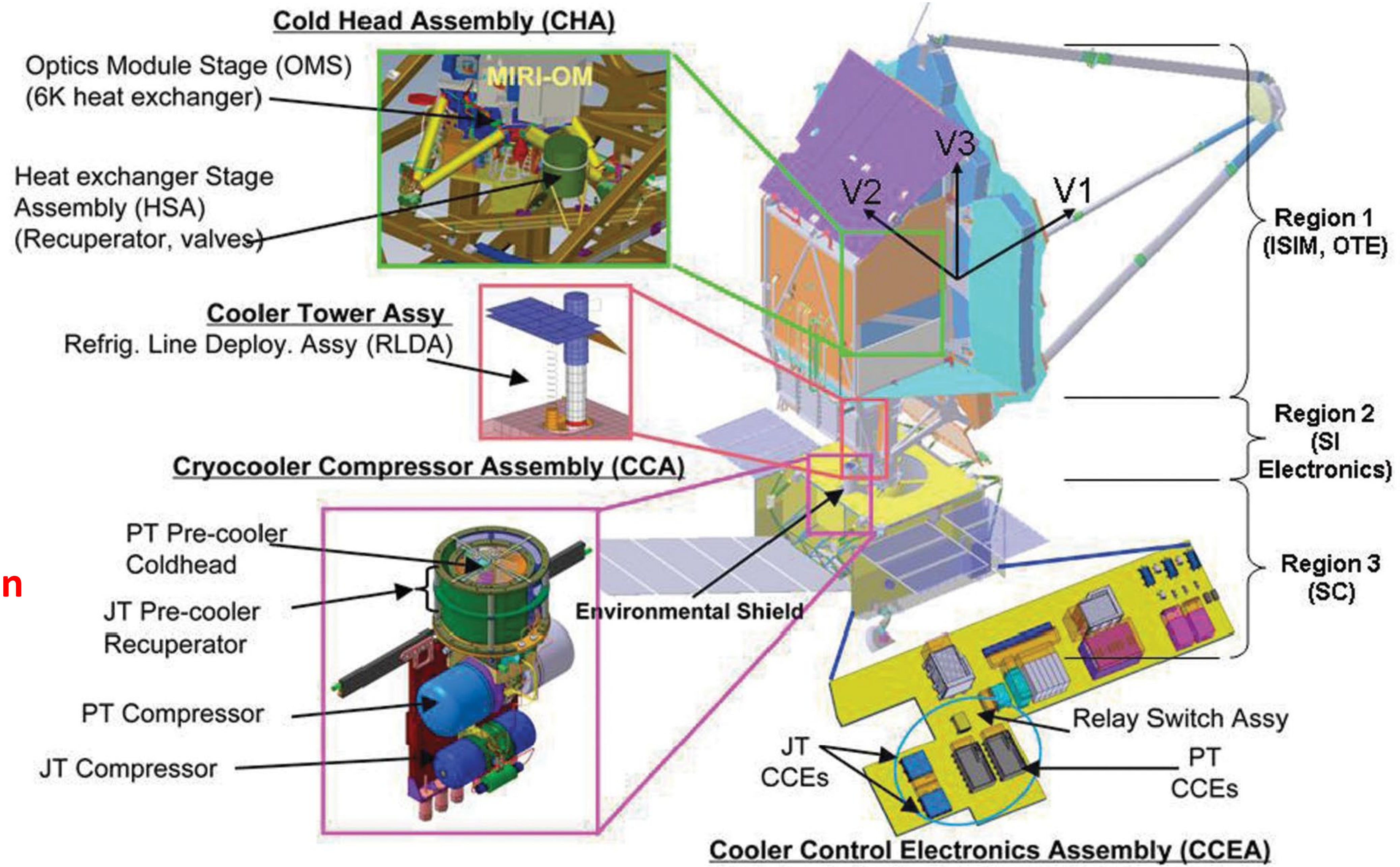


But for MIRI, it is a bit like a refrigerator with the compressor in your garage and the icebox in the kitchen.



This poses an immense engineering challenge!

The cooler took the instrument down to 6 Kelvin perfectly, just like they said it would!!

4^{th} Inspiration: enabling incredible science

- Why a large, cold telescope in space is such an advance
- What infrared astronomers look at
- An example: the composition of the atmospheres of earth-like exoplanets

Getting into space is critical for the infrared. Groundbased thermal infrared astronomy is like finding a match in a blast furnace.

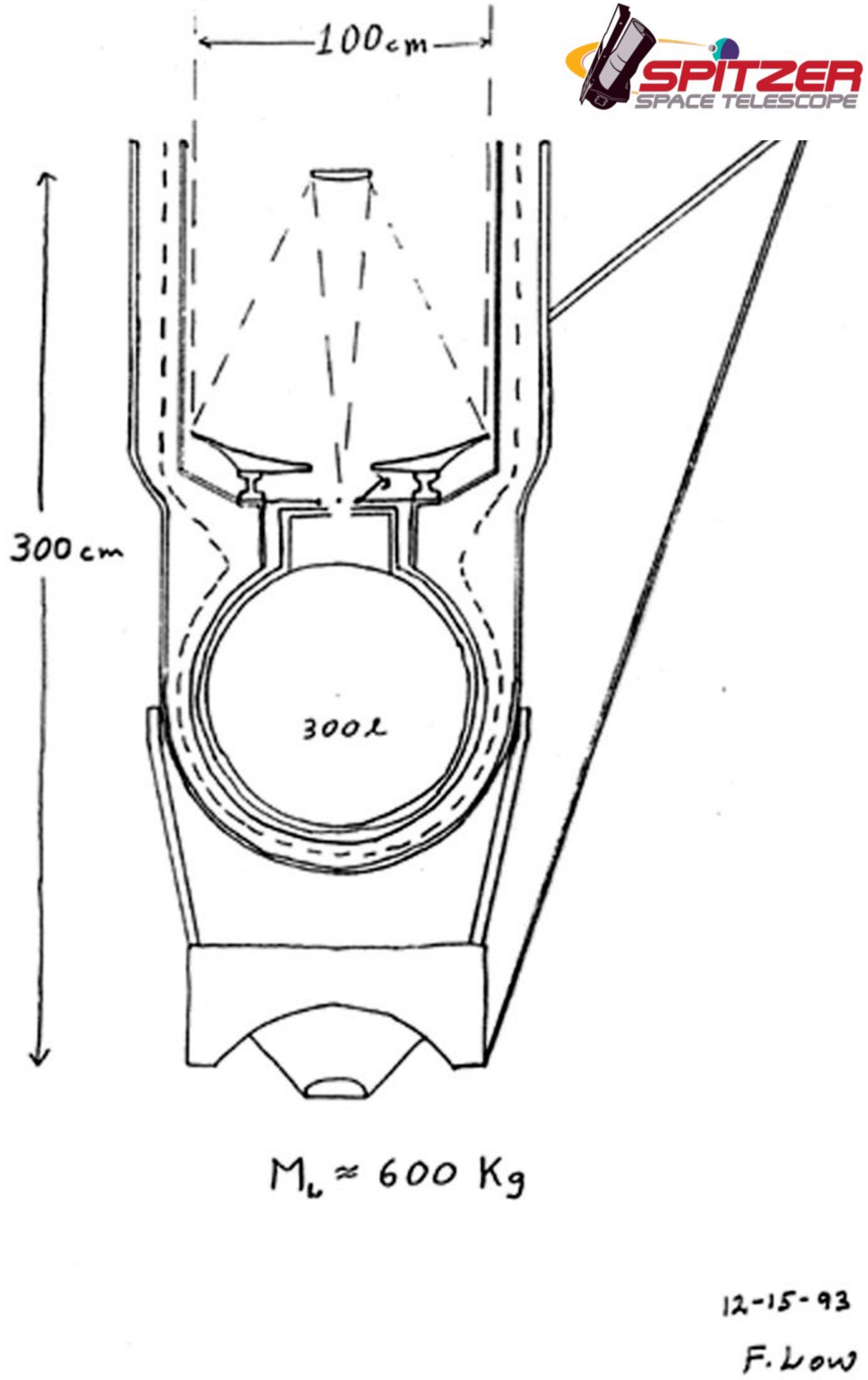
Space is the solution!

Gaining in the mid-infrared requires a cold telescope in space.

> The 10μm background in space is ~10,000,000 times lower than from the ground.

The "safe" way to proceed is to put the telescope inside a dewar so it can be completely checked out in its operating condition just before launch, but this limits the size of the telescope severely.

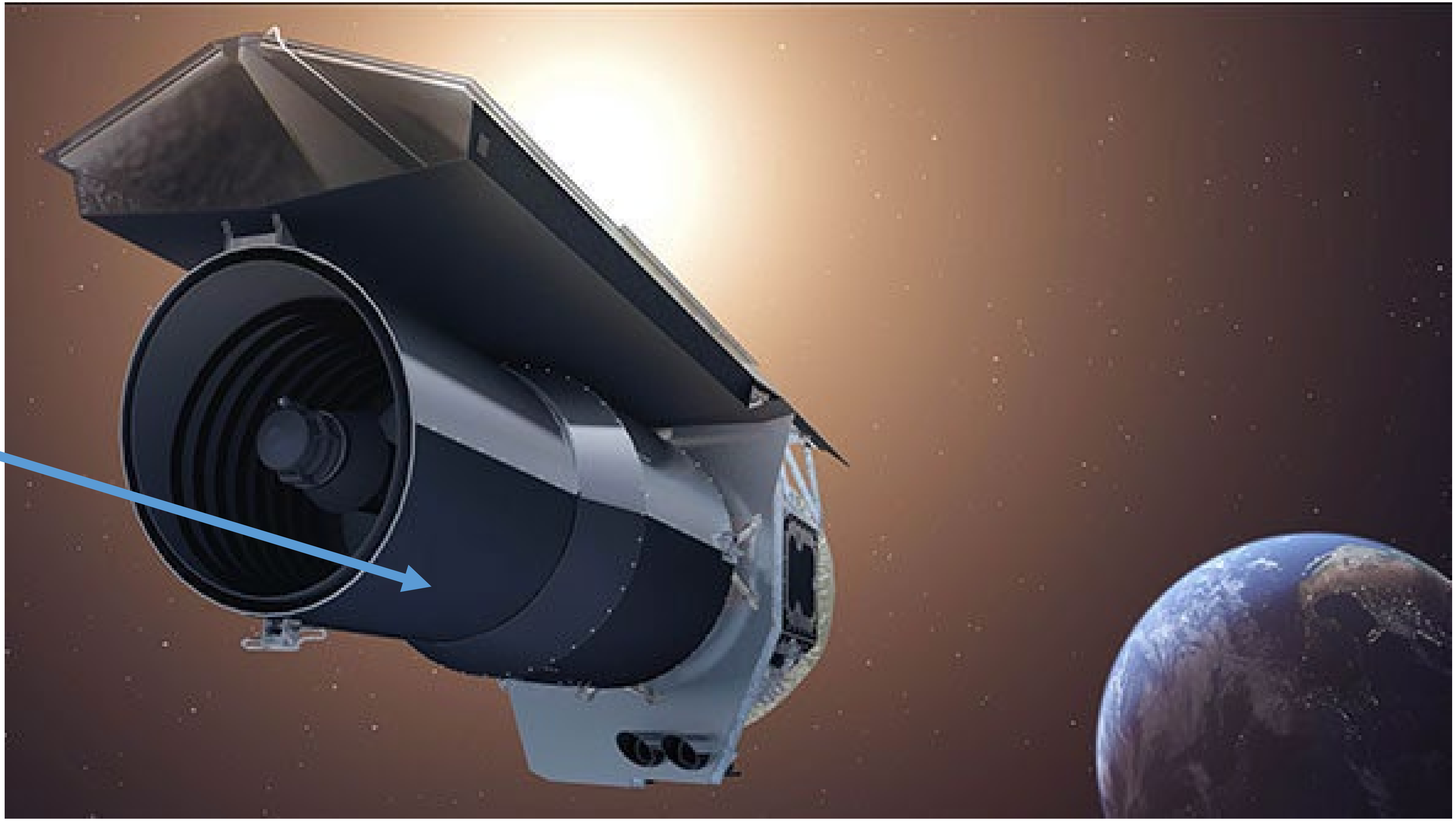
Tim Hawarden, and independently (and later) Frank Low, promoted a warm launch concept, where the telescope radiates its energy and cools after launch and in space.



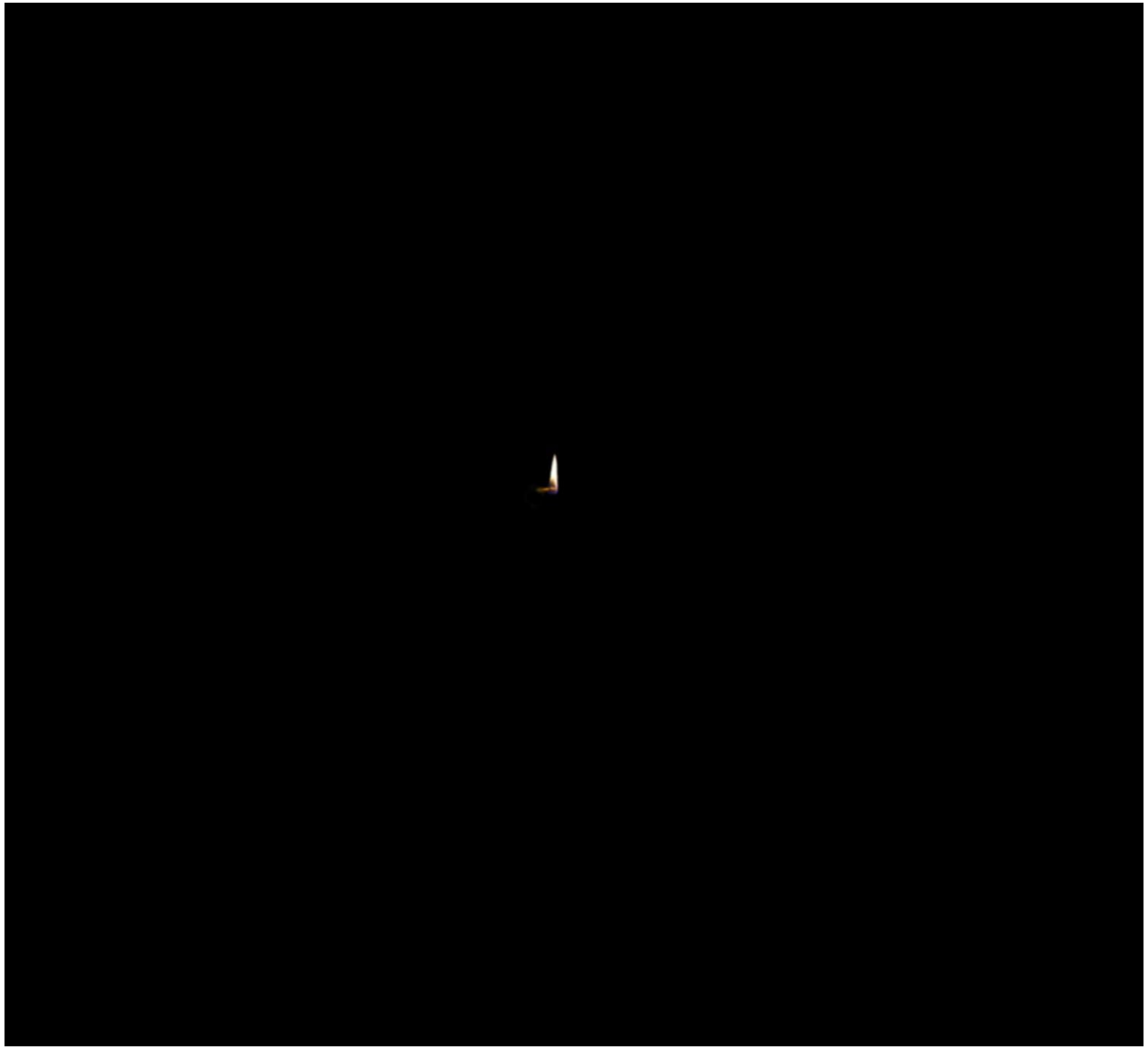
Radiative cooling was central for the Spitzer Space Telescope.

Launched in 2003, de-commissioned in 2020

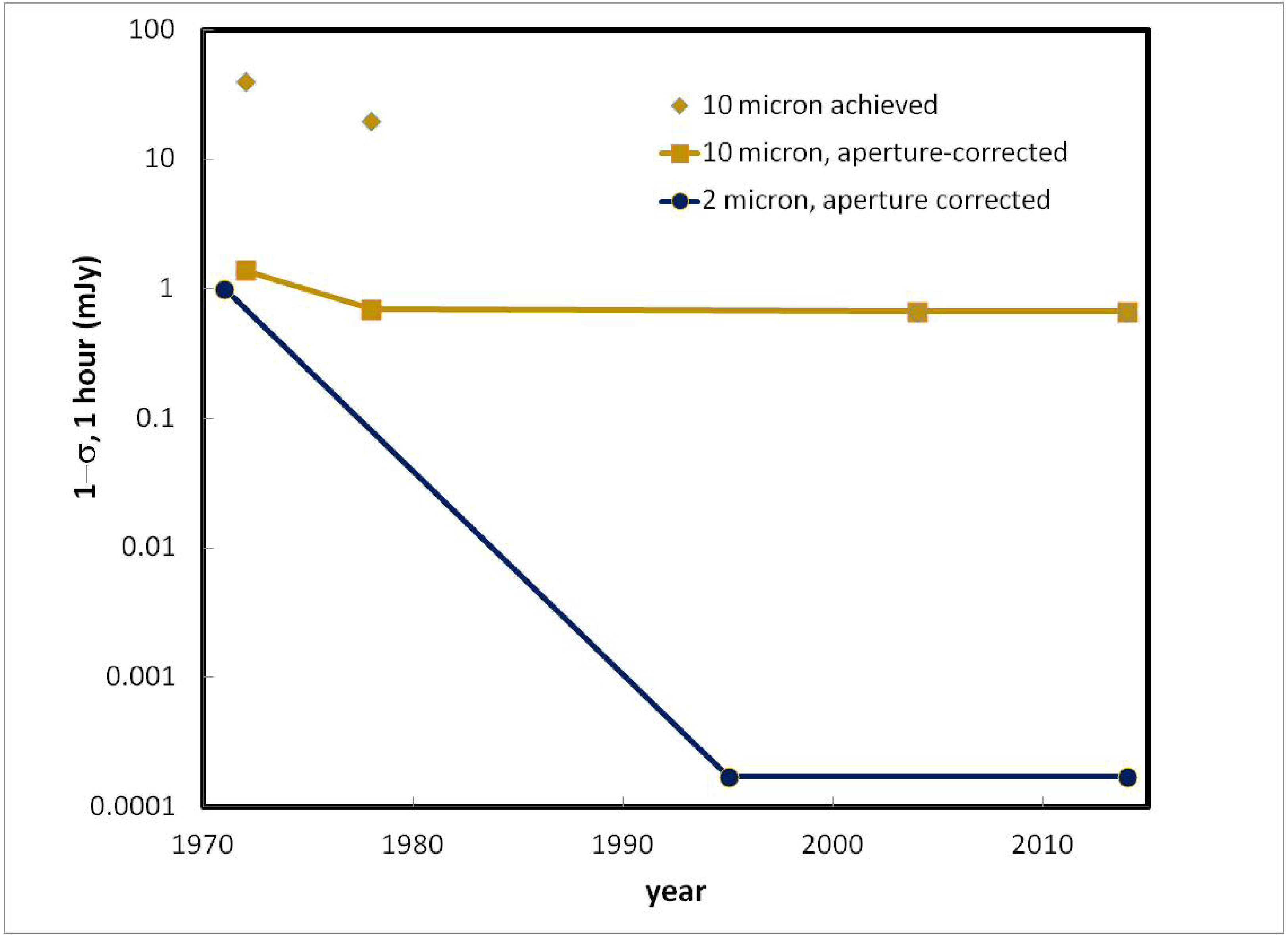
This black surface radiated into space and did all of the cooling down to 40 Kelvin



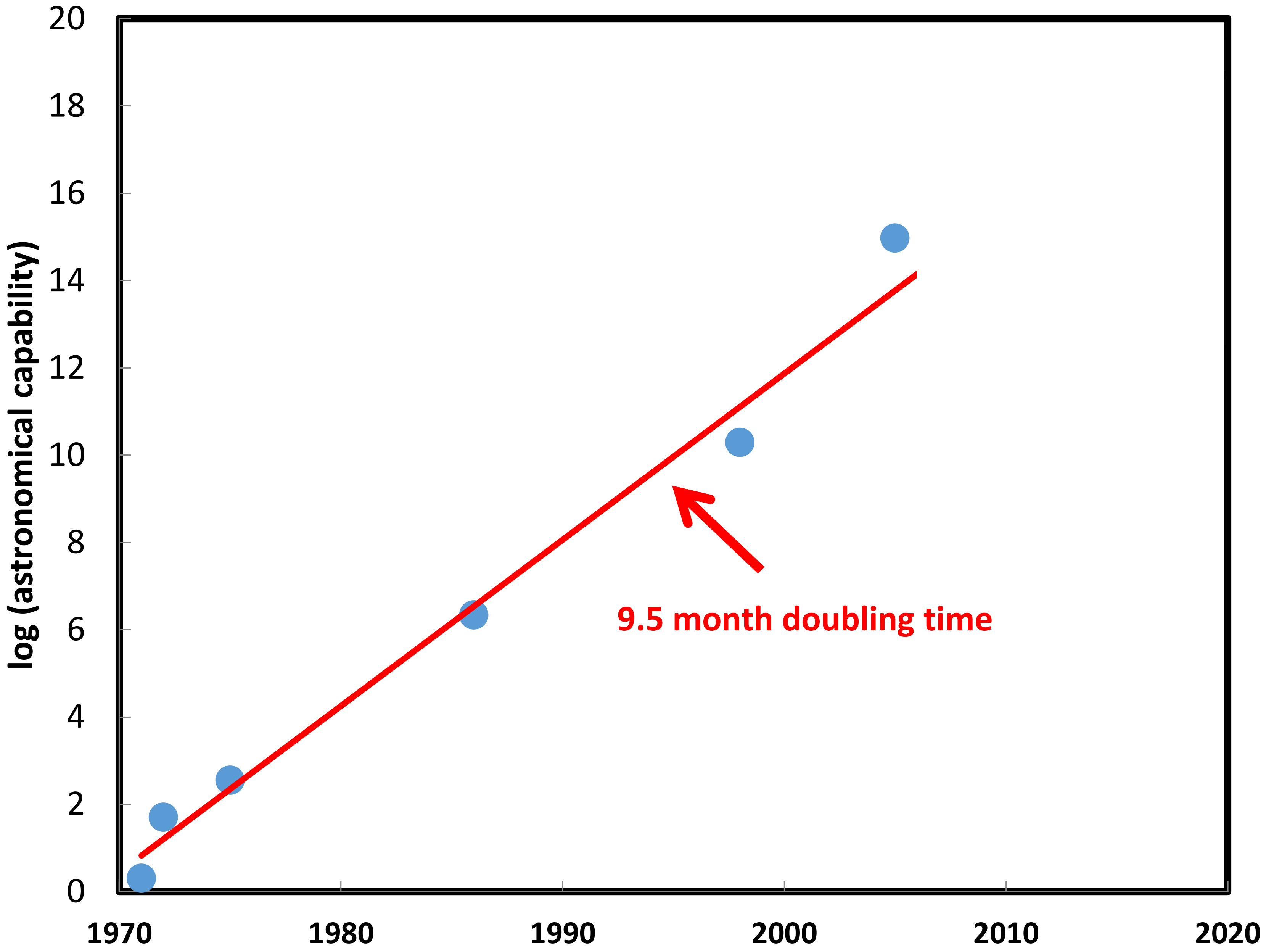
Aaahhh! That's much better.



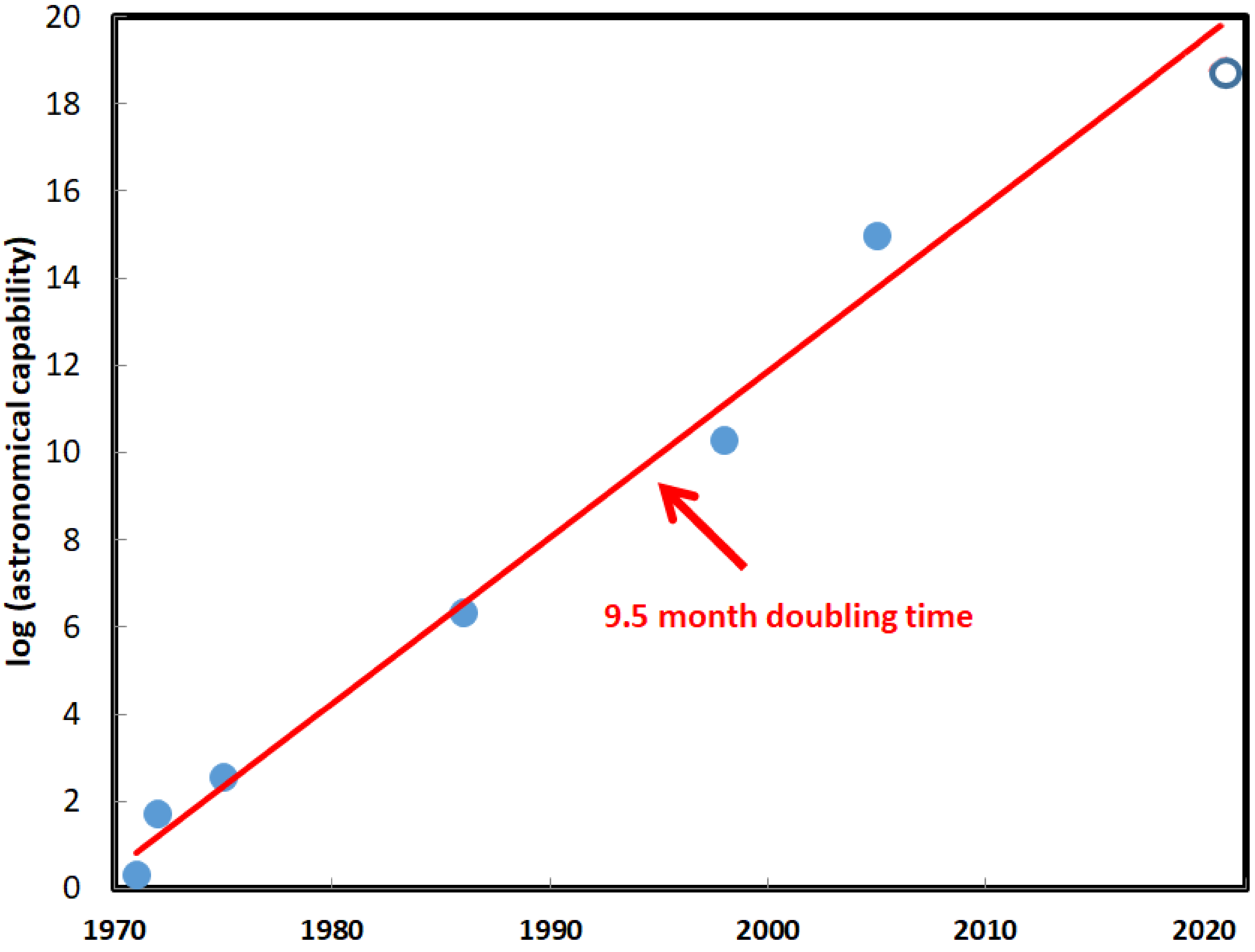
Progress from the ground in the near infrared has been phenomenal; However, 10 microns is another story.



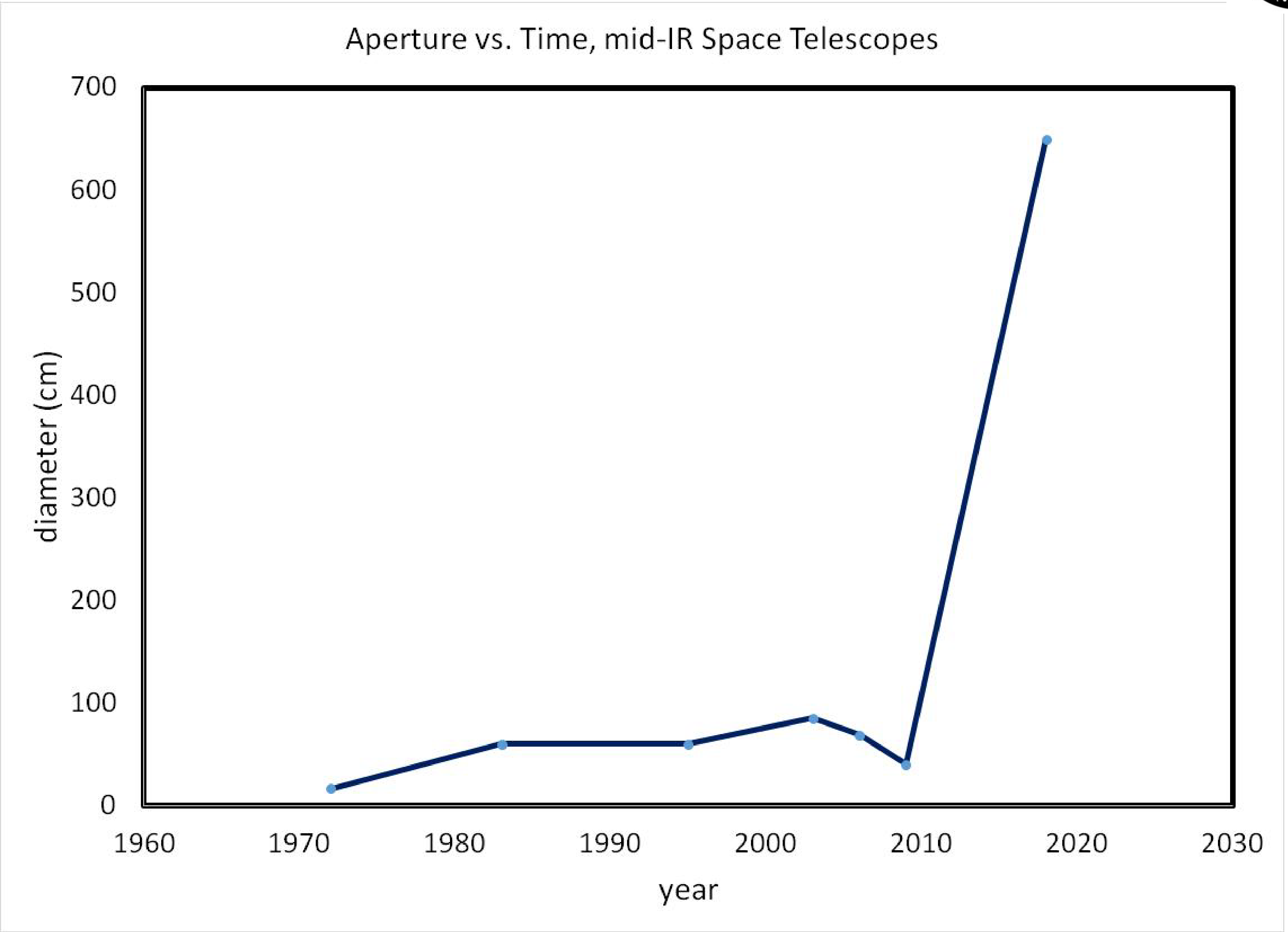
Going to space has produced phenomenal growth in 10μm capability.
First 3 points are ground, then IRAS, ISO, and Spitzer.



JWST with its Mid-IR Instrument (MIRI) continues the steep Moore's-Law-like growth in capability.



JWST uses the warm launch concept to provide a much bigger telescope. It will be the first LARGE cold infrared telescope in space.



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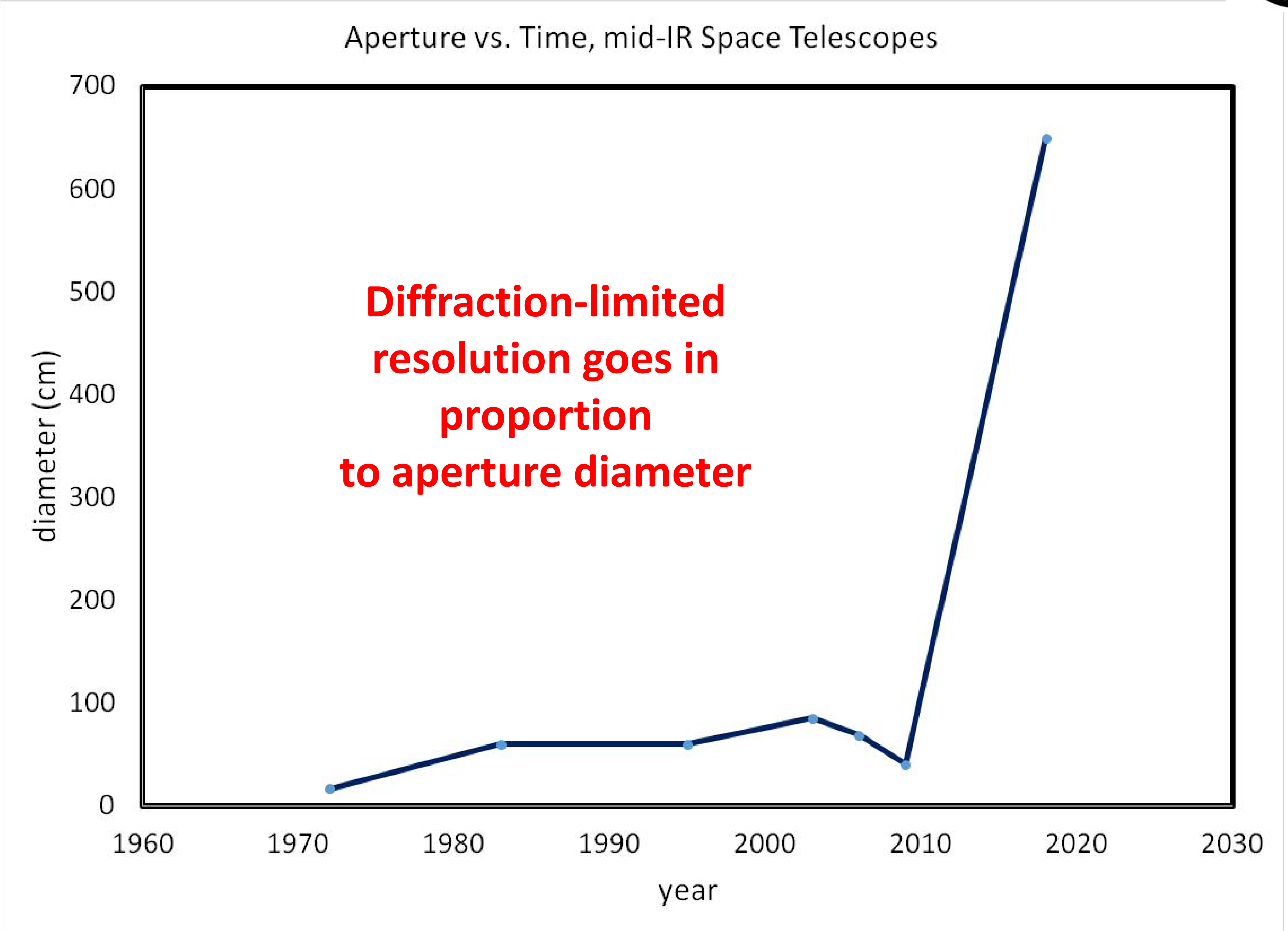


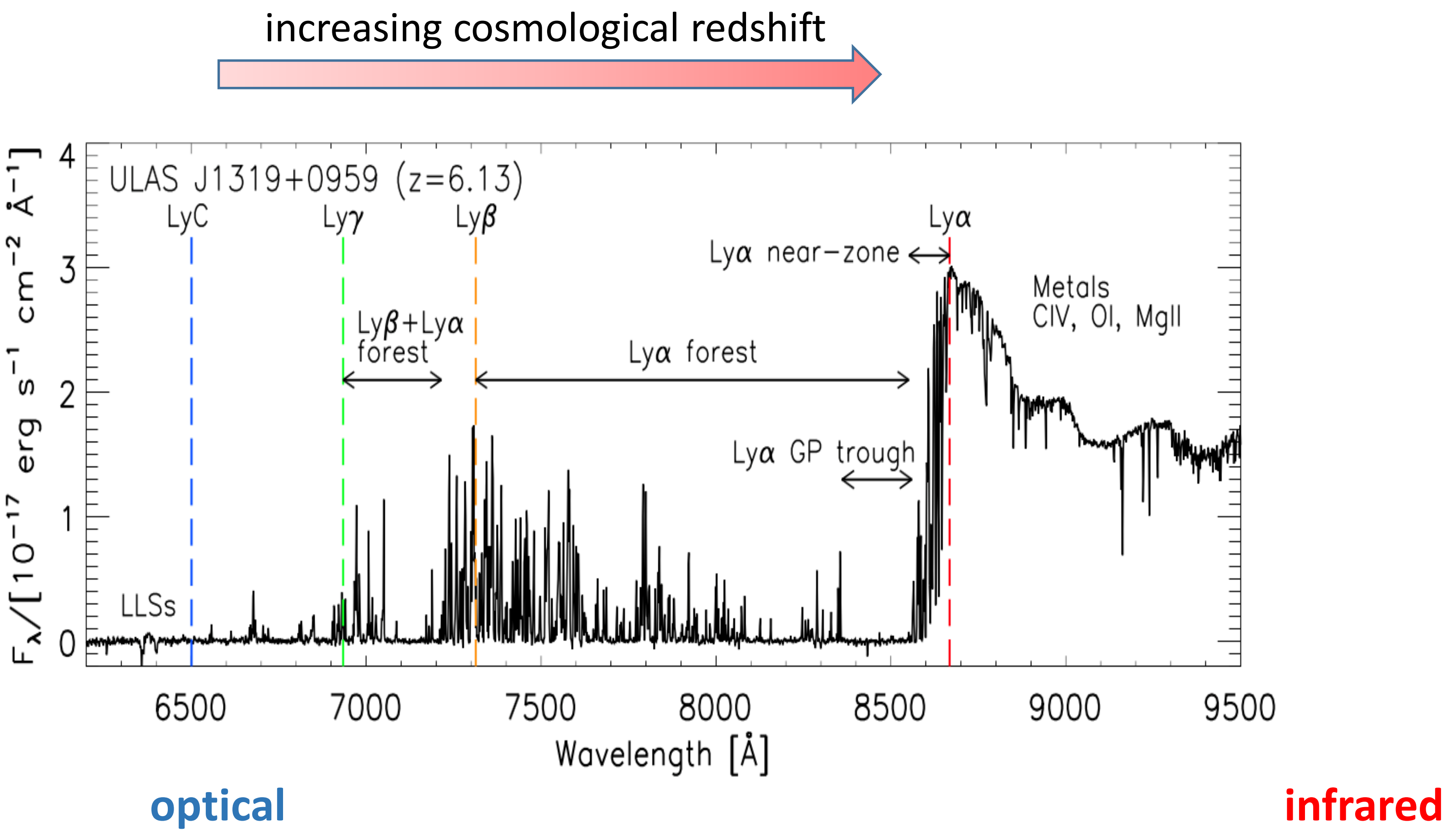
What we “see” with infrared astronomy

Infrared shows astronomical sources in a *really* different light

On the left is the famous HST picture of the "pillars of creation." The interstellar dust (similar to smoke) makes them beautiful in the visible (left) but also hides what is going on inside. The near infrared (middle) sees through the dust. The mid-infrared (right) shows where the dust is warmed by young stars.

Pillars of Creation in visible, near infrared, and mid-infrared.

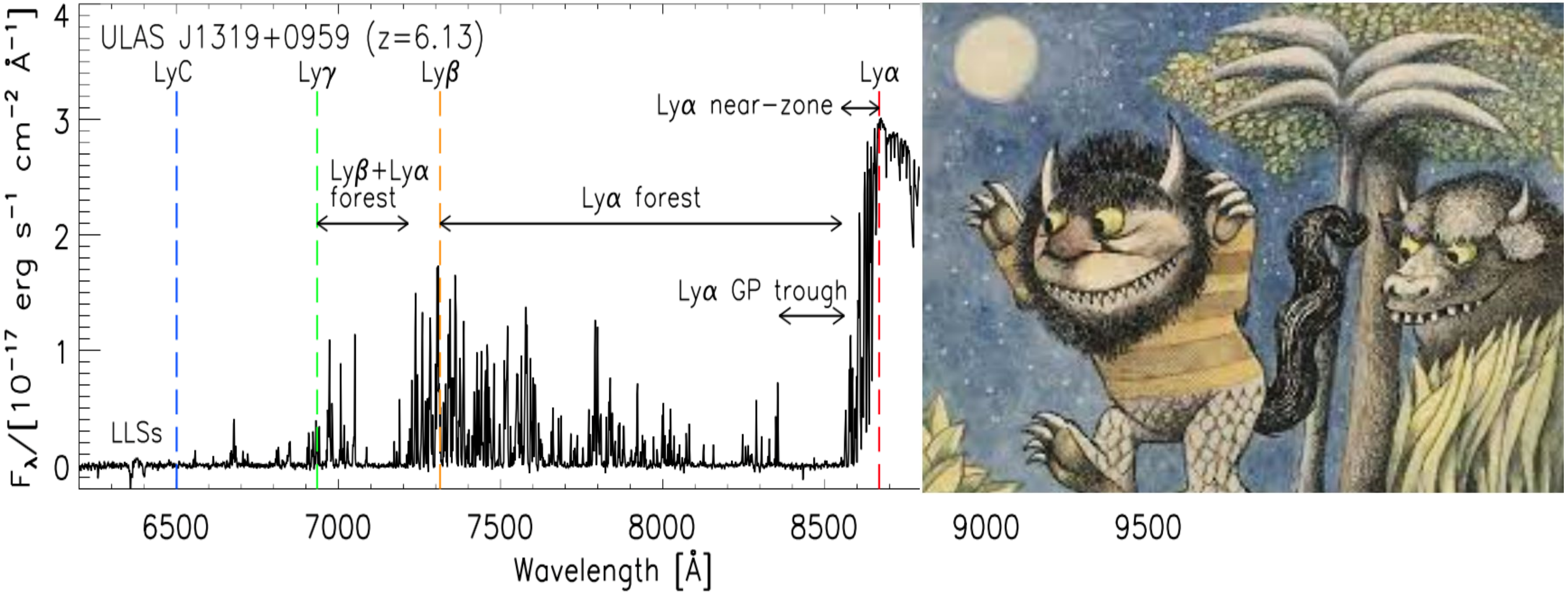
The cosmological redshift shifts the light of distant galaxies into the infrared.



In distant galaxies, almost everything at wavelengths shorter than about 1000 Angstroms is removed through absorption by foreground material – the "Gunn Peterson trough." Studying very high redshifts demands observing in the infrared.

The cosmological redshift shifts the light of distant galaxies into the infrared.

increasing cosmological redshift



optical

infrared

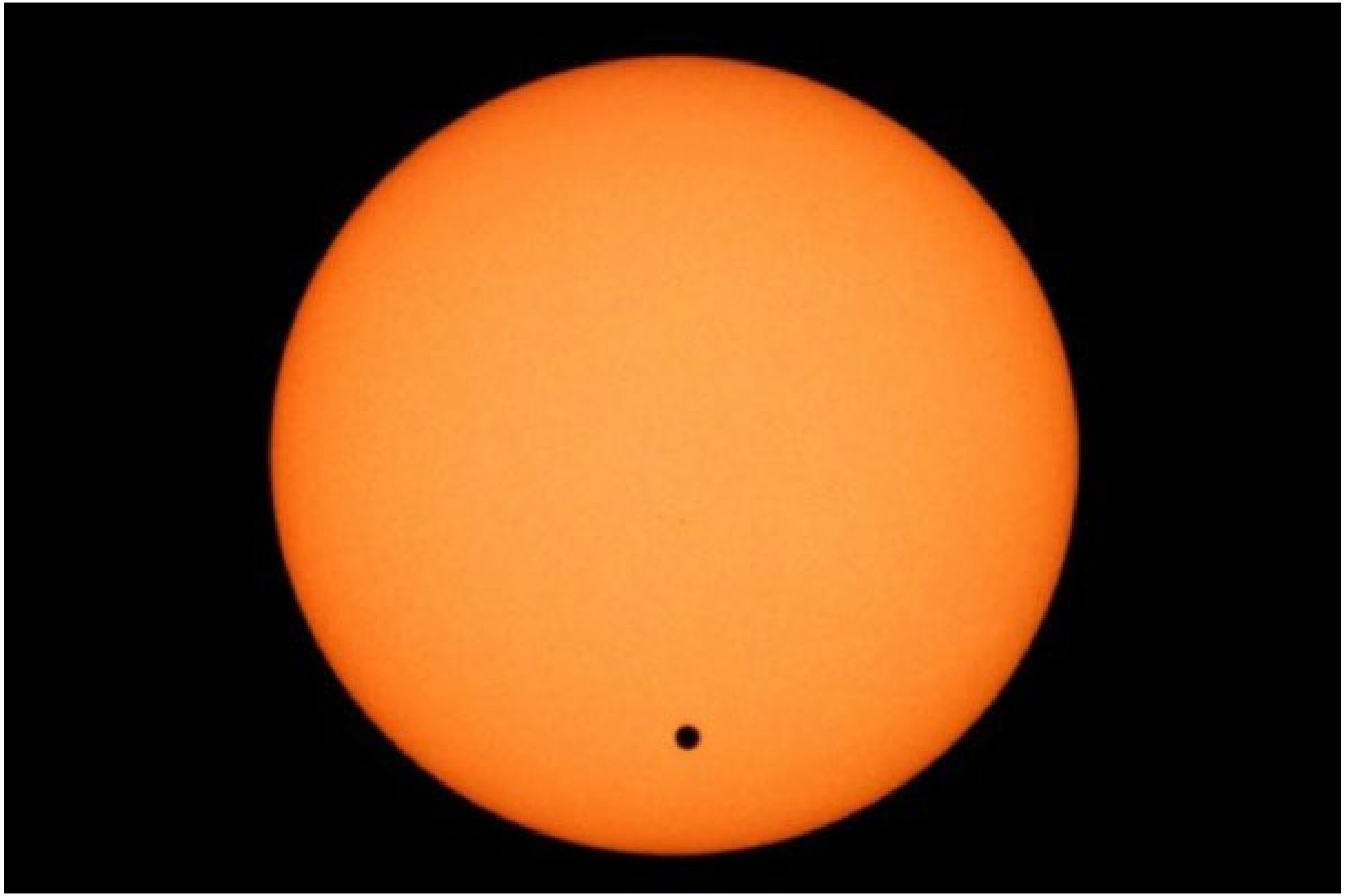
But until about 25 years ago, most astronomers viewed infrared as the realm of beasts and dragons. As more and more distant objects have been discovered, the necessity of sensitive infrared observations has become apparent.

A more detailed example: We are going to use JWST to study the atmospheres of earth-like exoplanets in the Habitable Zones of other stars.

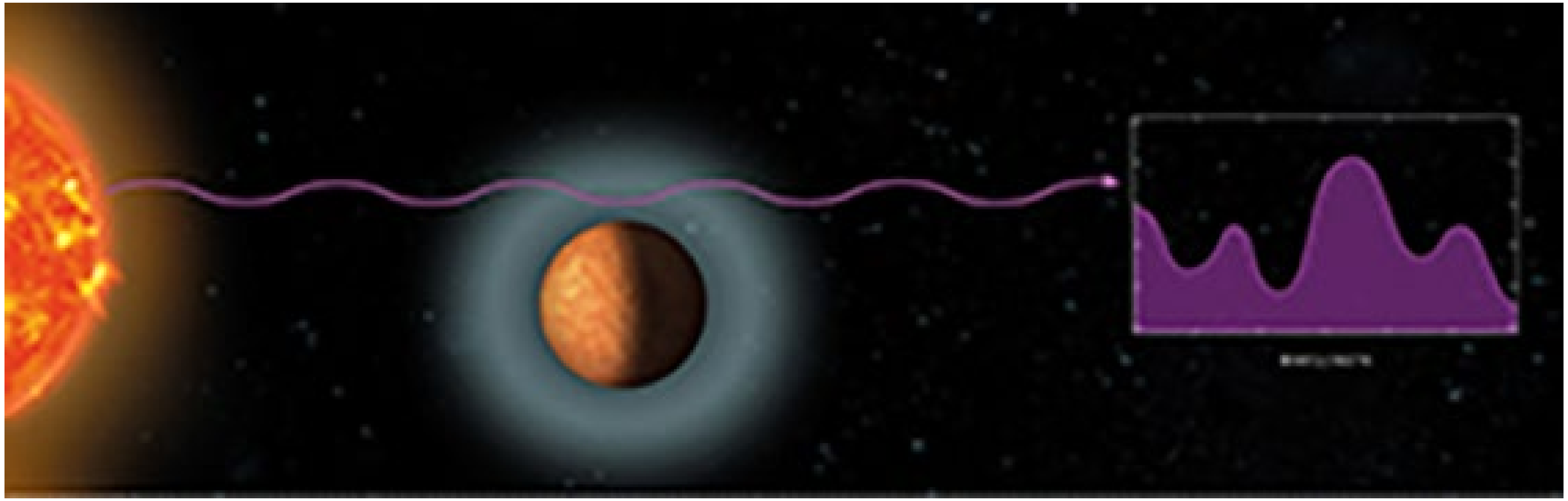
We will determine the atmospheric composition and weather on planets outside the Solar System.

"Here I am out at the 2012 Transit of Venus event run by the Cornell Astronomy Department. I made a little card to show visitors the difference between the sunspots and Venus as the planet crossed in front of the sun. This was a nearby version of the exoplanet transits I research." – Everett Schlawin

Here is the transit Everett is talking about.

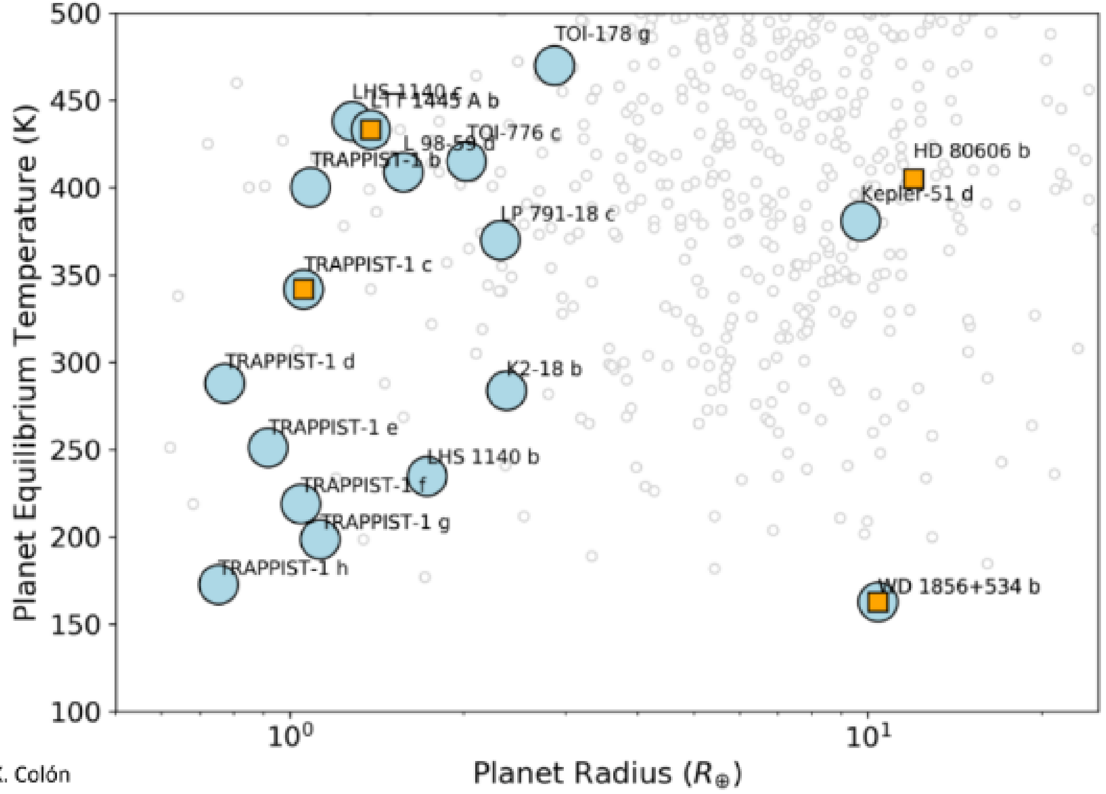


When there is a transit, a little of the light from the star is blocked completely, but some of the light passes through the atmosphere of the planet. If we can get a really good spectrum, we can see what gases there are in the atmosphere!

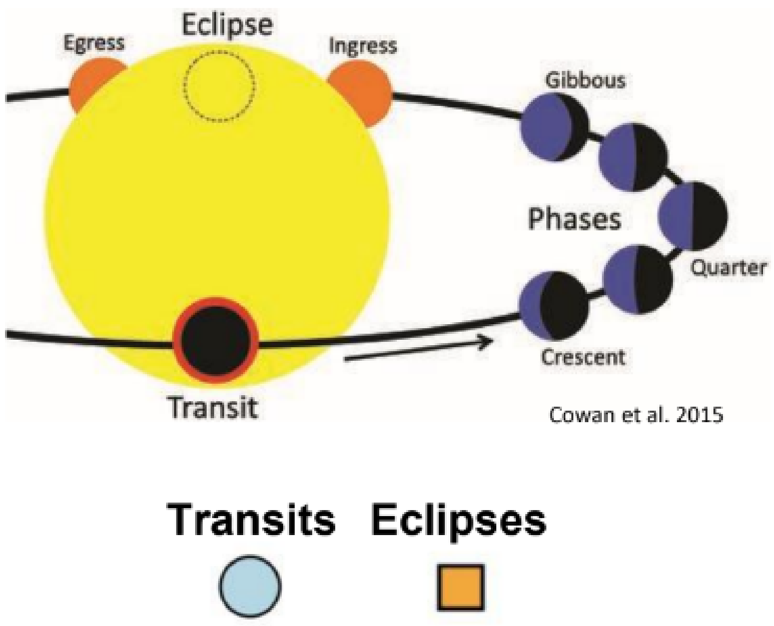


JWST will let us do this for earth-like planets.

A subset of JWST Cycle 1 transiting exoplanet targets is shown below, illustrating particularly the population of small, cool planets to be observed in either transit, or eclipse, or at both phases.



K. Colón



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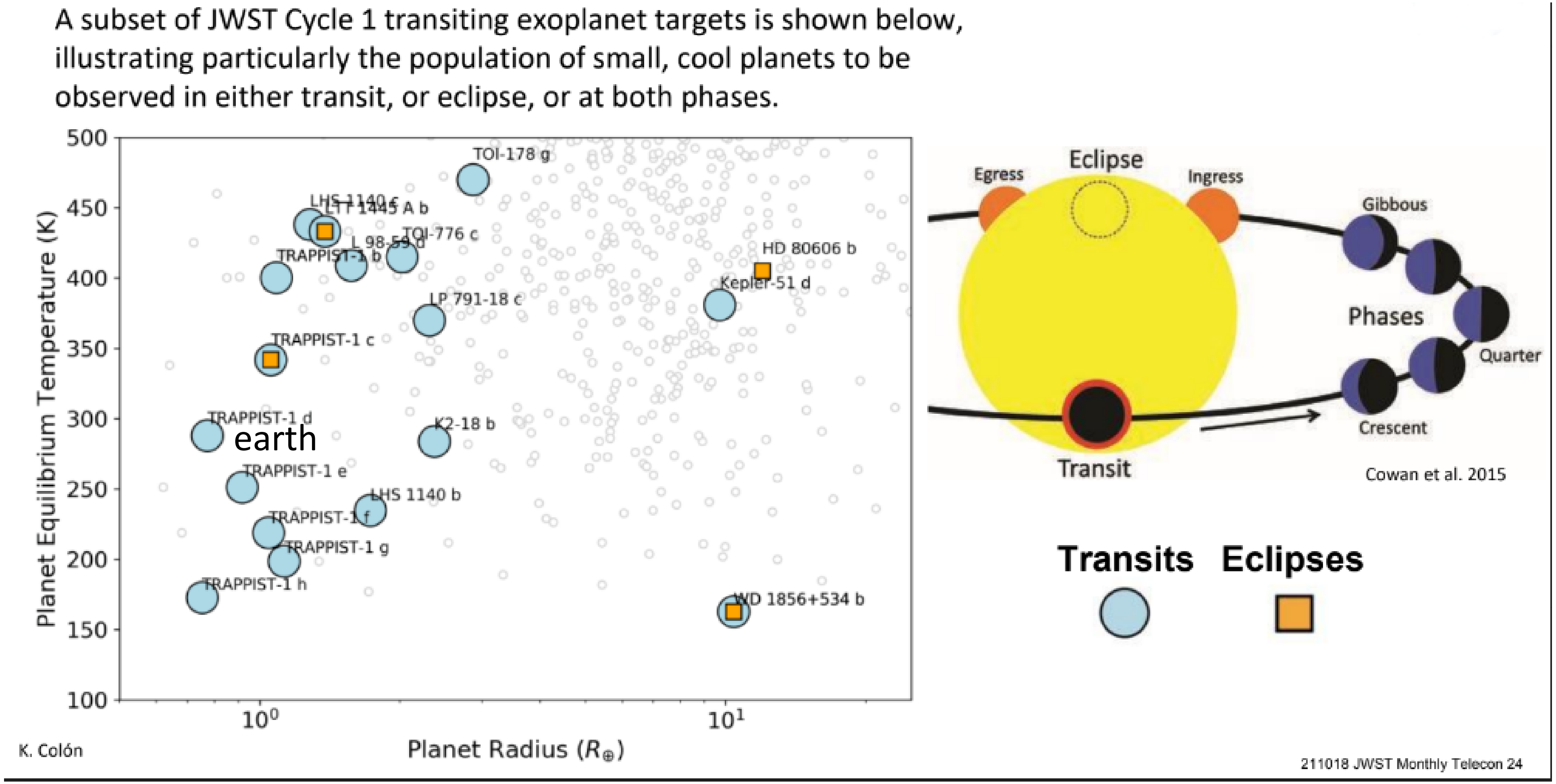
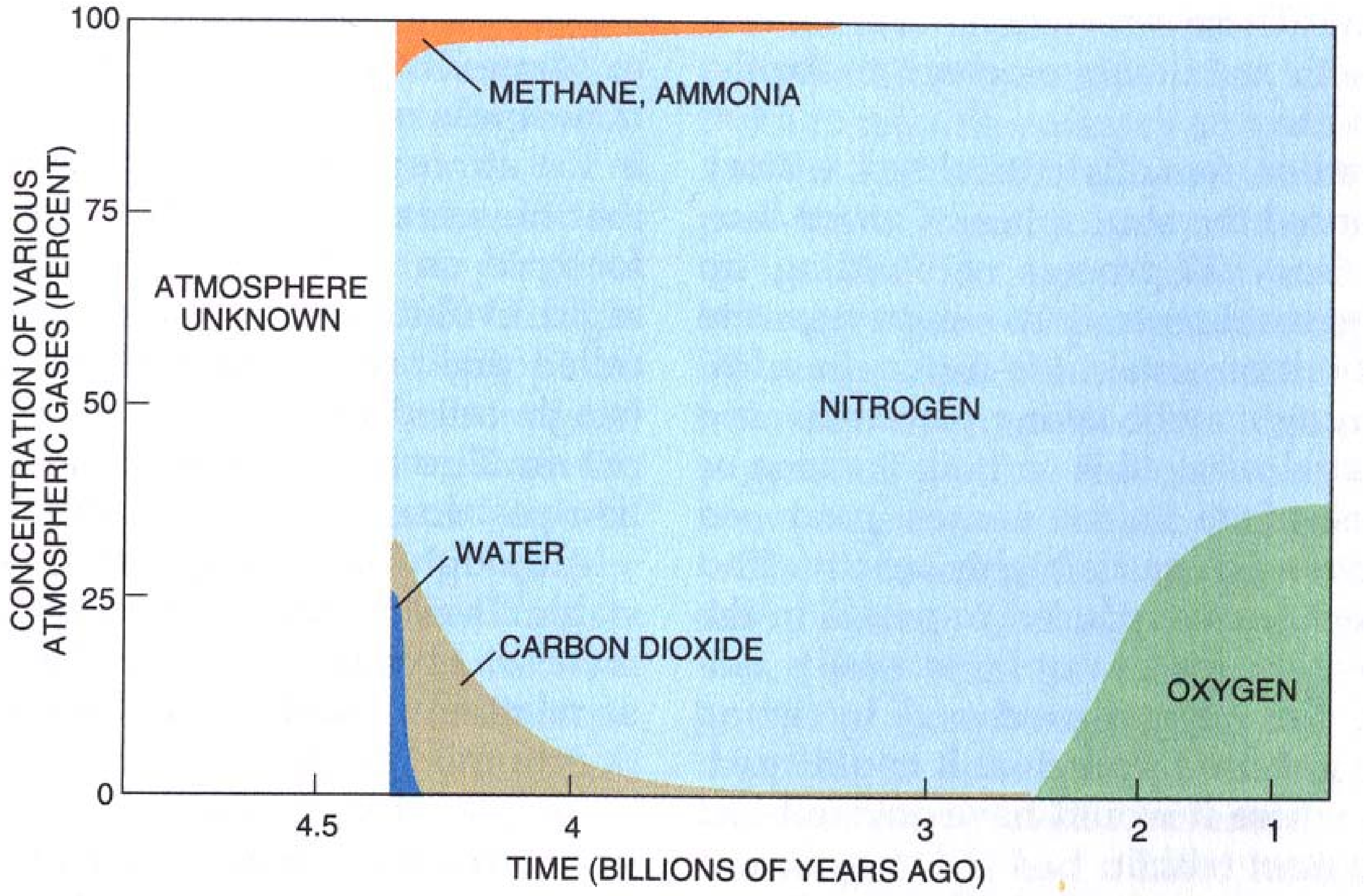
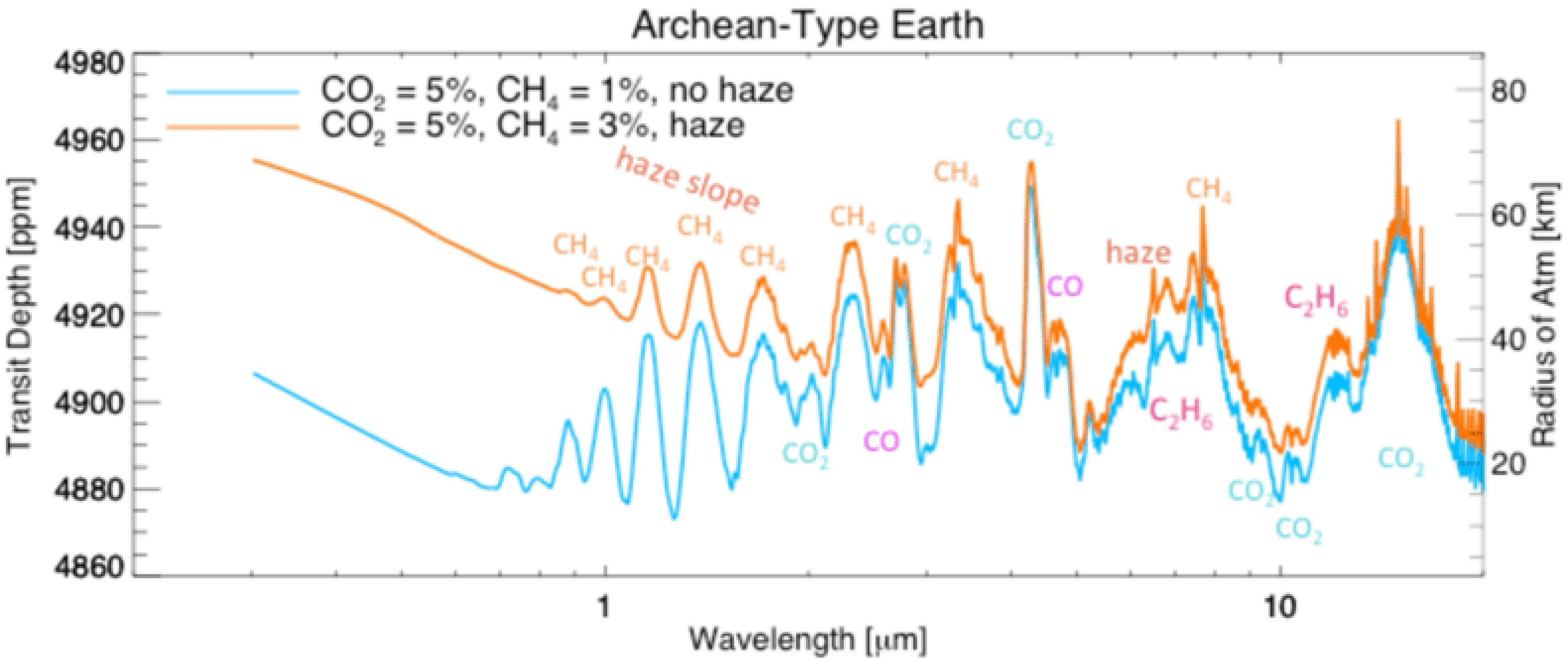


Let's look at what we might find:

Here is the sequence of gases in the atmosphere of the earth as it evolved.

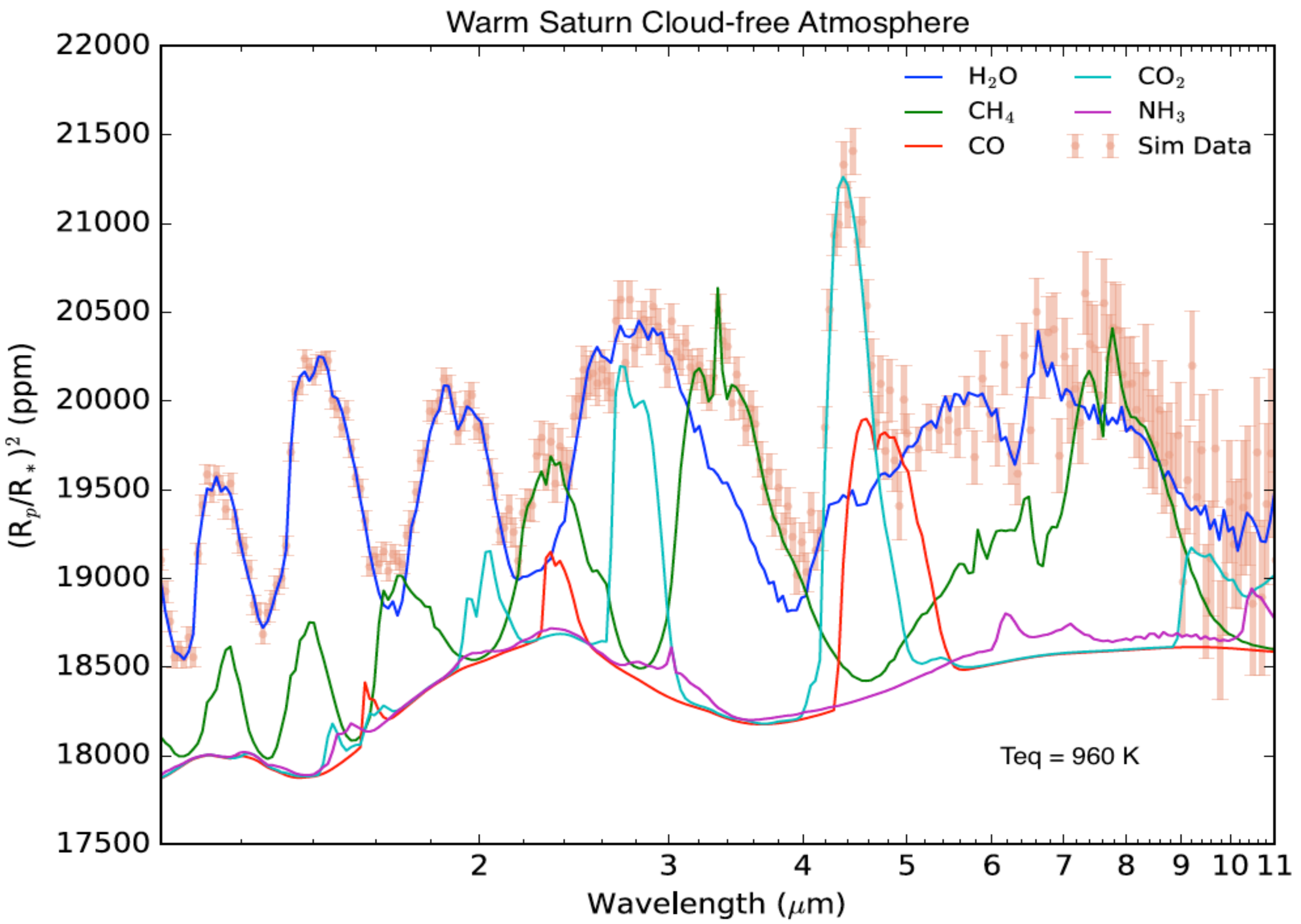


Here is what we might find for a planet in the early stages of developing an atmosphere:



There are lots of features of methane (CH_4) and of carbon dioxide (CO_2).

As a planet evolves, it might become covered with oceans and would have a water-rich atmosphere. We will see if that is the case (the blue line is the spectrum we would observe).



There is much, much more to come!!!

Follow JWST in the news!!

and here: https://blogs.nasa.gov/webb/

The hard work is (mostly) done and now we get to enjoy the results!