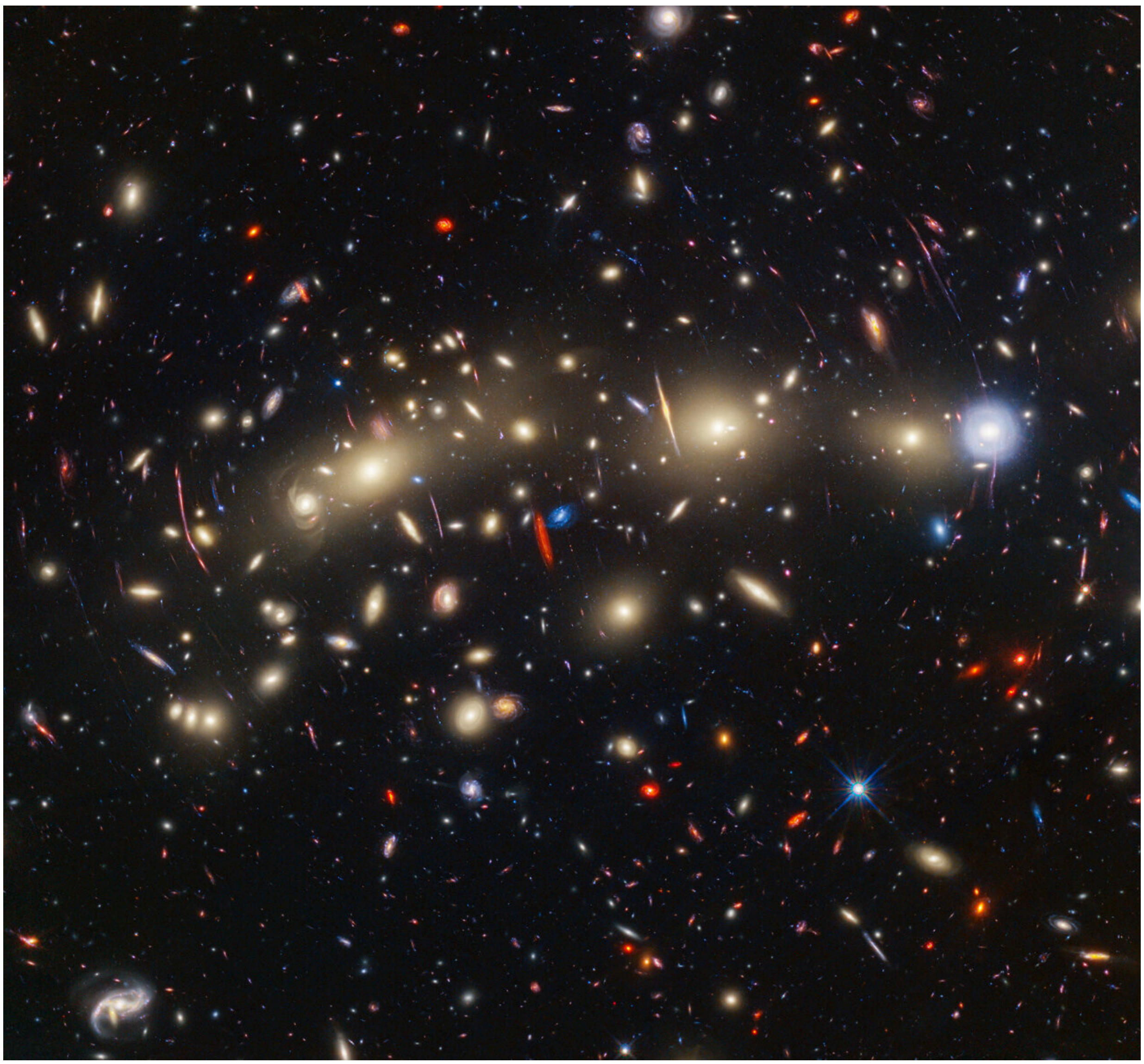
Webb and Hubble combine to create most colorful view of universe

November 9 2023



This panchromatic view of galaxy cluster MACS0416 was created by combining infrared observations from NASA's James Webb Space Telescope with visible-light data from NASA's Hubble Space Telescope. To make the image, in general, the shortest wavelengths of light were color-coded blue, the longest wavelengths red, and the intermediate wavelengths green. The resulting wavelength coverage, from 0.4 to 5 microns, reveals a vivid landscape of galaxies that could be described as one of the most colorful views of the universe ever created. MACS0416 is a galaxy cluster located about 4.3 billion light-years from Earth, meaning that the light we see now left the cluster shortly after the formation of our solar system. This cluster magnifies the light from more distant background galaxies through gravitational lensing. As a result, the research team has been able to identify magnified supernovae and even very highly magnified individual stars. Those colors give clues to galaxy distances: The bluest galaxies are relatively nearby and often show intense star formation, as best detected by Hubble, while the redder galaxies tend to be more distant, or else contain copious amounts of dust, as detected by Webb. The image reveals a wealth of details that are only possible to capture by combining the power of both space telescopes. In this image, blue represents data at wavelengths of 0.435 and 0.606 microns (Hubble filters F435W and F606W); cyan is 0.814, 0.9, and 1.05 microns (Hubble filters F814W, and F105W and Webb filter F090W); green is 1.15, 1.25, 1.4, 1.5, and 1.6 microns (Hubble filters F125W, F140W, and F160W, and Webb filters F115W and F150W); yellow is 2.00 and 2.77 microns (Webb filters F200W, and F277W); orange is 3.56 microns (Webb filter F356W); and red represents data at 4.1 and 4.44 microns (Webb filters F410M and F444W). Credit: Image: NASA, ESA, CSA, STScI, Jose M. Diego (IFCA), Jordan C. J. D'Silva (UWA), Anton M. Koekemoer (STScI), Jake Summers (ASU), Rogier Windhorst (ASU), Haojing Yan (University of Missouri)

NASA's James Webb Space Telescope and Hubble Space Telescope have united to study an expansive galaxy cluster known as MACS0416. The resulting panchromatic image combines visible and infrared light to assemble one of the most comprehensive views of the universe ever taken. Located about 4.3 billion light-years from Earth, MACS0416 is a pair of colliding galaxy clusters that will eventually combine to form an even bigger cluster.

The image reveals a wealth of details that are only possible by combining the power of both space telescopes. It includes a bounty of galaxies outside the cluster and a sprinkling of sources that vary over time, likely due to gravitational lensing—the distortion and amplification of light from distant background sources.

This cluster was the first of a set of unprecedented, super-deep views of the universe from an ambitious, collaborative Hubble program called the Frontier Fields, inaugurated in 2014. Hubble pioneered the search for some of the intrinsically faintest and youngest galaxies ever detected. Webb's infrared view significantly bolsters this deep look by going even farther into the early universe with its infrared vision.

"We are building on Hubble's legacy by pushing to greater distances and fainter objects," said Rogier Windhorst of Arizona State University, principal investigator of the PEARLS program (Prime Extragalactic Areas for Reionization and Lensing Science), which took the Webb observations.

What the colors mean

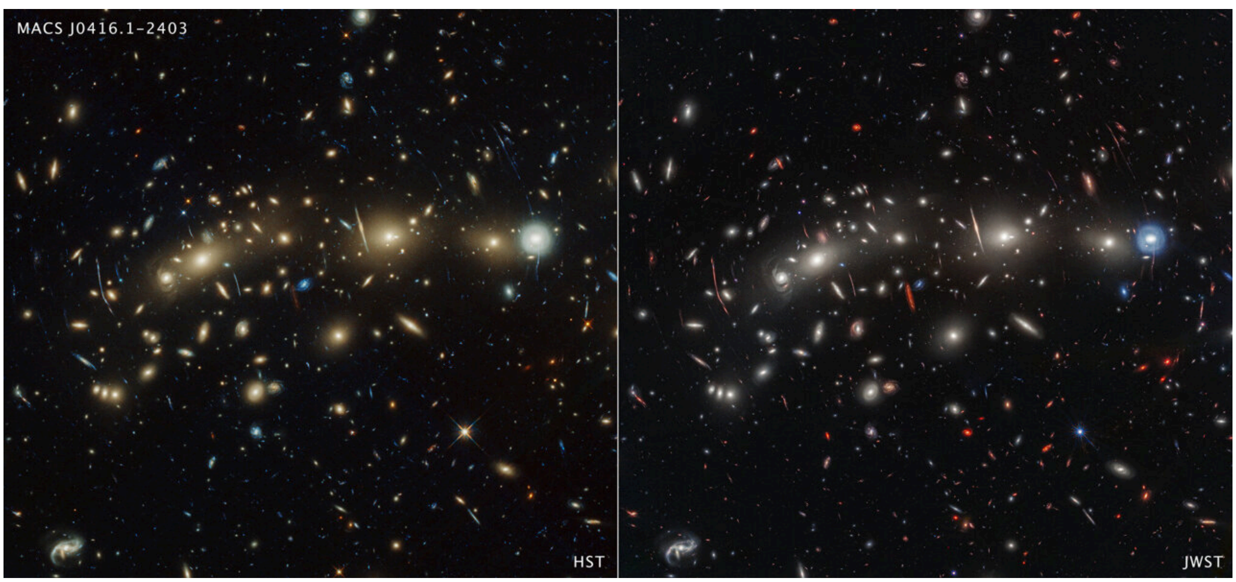
To make the image, in general, the shortest wavelengths of light were color-coded blue, the longest wavelengths red, and the intermediate wavelengths green. The broad range of wavelengths, from 0.4 to 5 microns, yields a particularly vivid landscape of galaxies.

Those colors give clues to galaxy distances: The bluest galaxies are relatively nearby and often show intense star formation, as best detected by Hubble, while the redder galaxies tend to be more distant as detected by Webb. Some galaxies also appear very red because they contain copious amounts of cosmic dust that tends to absorb bluer colors of starlight.

"The whole picture doesn't become clear until you combine Webb data with Hubble data," said Windhorst.

Christmas tree galaxy cluster

While the new Webb observations contribute to this aesthetic view, they were taken for a specific scientific purpose. The research team combined their three epochs of observations, each taken weeks apart, with a fourth epoch from the CANUCS (CAnadian NIRISS Unbiased Cluster Survey) research team. The goal was to search for objects varying in observed brightness over time, known as transients.



This side-by-side comparison of galaxy cluster MACS0416 as seen by the Hubble Space Telescope in optical light (left) and the James Webb Space Telescope in infrared light (right) reveals different details. Both images feature hundreds of galaxies, however the Webb image shows galaxies that are invisible or only barely visible in the Hubble image. This is because Webb's infrared vision can detect galaxies too distant or dusty for Hubble to see. (Light from distant galaxies is redshifted due to the expansion of the universe.) The total exposure time for Webb was about 22 hours, compared to 122 hours of exposure time for the Hubble image. Credit: Image: NASA, ESA, CSA, STScI

They identified 14 such transients across the field of view. Twelve of those transients were located in three galaxies that are highly magnified by gravitational lensing, and are likely to be individual stars or multiple-star systems that are briefly very highly magnified. The remaining two transients are within more moderately magnified background galaxies and are likely to be supernovae.

"We're calling MACS0416 the Christmas Tree Galaxy Cluster, both because it's so colorful and because of these flickering lights we find within it. We can see transients everywhere," said Haojing Yan of the University of Missouri in Columbia, lead author of one paper describing the scientific results.

Finding so many transients with observations spanning a relatively short time frame suggests that astronomers could find many additional transients in this cluster and others like it through regular monitoring with Webb.

A kaiju star

Among the transients the team identified, one stood out in particular. Located in a galaxy that existed about 3 billion years after the big bang, it is magnified by a factor of at least 4,000. The team nicknamed the star system "Mothra" in a nod to its "monster nature," being both extremely bright and extremely magnified. It joins another lensed star the researchers previously identified that they nicknamed "Godzilla." (Both

Godzilla and Mothra are giant monsters known as kaiju in Japanese cinema.)

Interestingly, Mothra is also visible in the Hubble observations that were taken nine years previously. This is unusual because a very specific alignment between the foreground galaxy cluster and the background star is needed to magnify a star so greatly. The mutual motions of the star and the cluster should have eventually eliminated that alignment.

The most likely explanation is that there is an additional object within the foreground cluster that is adding more magnification. The team was able to constrain its mass to be between 10,000 and 1 million times the mass of our sun. The exact nature of this so-called "milli-lens," however, remains unknown.

"The most likely explanation is a globular star cluster that's too faint for Webb to see directly," stated Jose Diego of the Instituto de Física de Cantabria in Spain, lead author of the paper detailing the finding. "But we don't know the true nature of this additional lens yet."

The Yan et al. paper is accepted for publication in *The Astrophysical Journal*. The Diego et al. paper has been published in *Astronomy & Astrophysics*.

More information: Haojing Yan et al, JWST's PEARLS: Transients in the MACS J0416.1-2403 Field, *arXiv* (2023). DOI: 10.48550/arxiv.2307.07579

Jose M. Diego et al, JWST's PEARLS: Mothra, a new kaiju star at z = 2.091 extremely magnified by MACS0416, and implications for dark matter models, *Astronomy & Astrophysics* (2023). DOI: 10.1051/0004-6361/202347556

Provided by ESA/Hubble Information Centre

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