DEPARTMENT OF ASTRONOMY

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Exploring the End of the Cosmic Dark Ages with *JWST*

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Written Testimony for House Subcommittee on Space and Aeronautics Hearing on Nov 16, 2022:
Unfolding the Universe: Initial Science Results from the James Webb Space Telescope

While humankind has looked to the stars and wondered about our origins for millennia, it was only 100 years ago that we first realized that those fuzzy “spiral nebulae” in the night sky were not in our own Milky Way Galaxy, but rather were “island universe”, or galaxies, all their own. This transformation in our fundamental understanding of the universe — that our Galaxy was not alone — was technology driven. It was Edwin Hubble who used the (then new) 100” Hooker Telescope at Mount Wilson Observatory to measure the distance to the Andromeda Galaxy, our nearest neighbor, and proved it lied well beyond the confines of the Milky Way.

Fast forward a century, and astronomical discoveries are still tied to technological advances. Over the past 30 years *Hubble* (the space telescope) has revolutionized our understanding of galaxies, from the nearby universe to the distant universe. However, the earliest phases of the universe, when the first galaxies form and evolve, have remained elusive. When did the first galaxies form out of the dark ages? What did they look like? Are their stars similar to our own Milky Way, or fundamentally different in some way?

Answering such questions relies on another leap in technological capabilities. While *Hubble* has been, and continues to be, transformative, it is not capable of observing these early galaxies for two reasons - they are too faint and too red. The *JWST*, with its seven times larger light-gathering power and infrared sensitivity, was built for this. Science Goal #1 for JWST is “First Light in the Universe.” In this document I will share how, with just a few months of scientific data, *JWST* is already delivering on this ambitious goal, and is transforming our understanding of the universe, just as Edwin Hubble did 100 years ago.

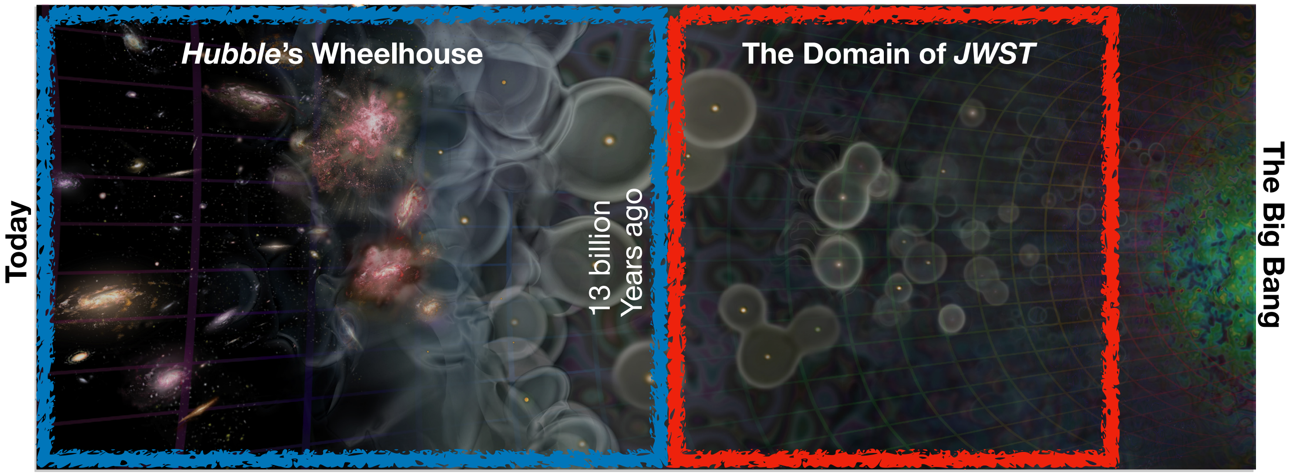


Figure 1: A representation of our cosmic timeline. The region at the left denotes the present-day universe, where large, massive spiral galaxies, like our own Milky Way, have formed. The right denotes the beginning of the universe, in the event we call the Big Bang, which took place 13.82 billion years ago. Through the amazing power of the *Hubble Space Telescope* we have learned about much of our past ~13 billion years of cosmic history. However, our “cosmic dawn”, the time when the first galaxies coalesced out of the “cosmic dark ages” following the Big Bang, has remained out of reach. *JWST* was designed (and is now delivering on its promise to) observe the formation of these earliest galaxies.

A Primer on Observing the Early Universe

The fact that we can even study early galaxies is astonishing, and relies on two curious features about our universe. The first is the nature of light itself - light cannot travel instantaneously from one place to another. Rather, it travels at a certain speed: the speed of light. This speed is fast in terrestrial terms (nearly one billion miles per hour), but is fairly crawling on astronomical scales. This means that when we look at distant objects, we don't see them as they are now, but rather we see them as they were in the past. This is inconsequential for the nearby universe; we see the Sun as it was eight minutes ago, and the nearest bright star Sirius as it was eight years ago. However, move to large enough scales and one begins to truly look significantly back in time. The *Hubble Space Telescope* has seen galaxies from over 13 billion years in the past, peering out over 90% of the history of the universe. At these limits of this amazing 30 year old facility, *Hubble* continues to see galaxies.

The knowledge of the second curious feature of our universe also dates back to Edwin Hubble, who also used his state-of-the art telescopes to show that all galaxies are moving away from each other, with more distant galaxies moving more quickly. This discovery means that our Universe is expanding. This has an effect on the light we receive from these receding galaxies. As the light moves through expanding space, the light waves get stretched, meaning that the light we observe is *redder* than it was when it was emitted, with the amount of *red-shifting* proportional to a galaxy's distance. This means that all galaxies, by the time we observe their light here on Earth, look a little redder than they would if they were not moving away from us, and the most distant galaxies look the most red. Astronomers call this quantity the "redshift" of a galaxy, and it is analogous to distance. The most redshifted galaxies, those with the highest redshift number, have the greatest distance.

However, while distance is useful, a more intuitive quantity is time. Figure 2 below shows the "lookback time" - how far back in time we are seeing — versus the redshift number of a galaxy.

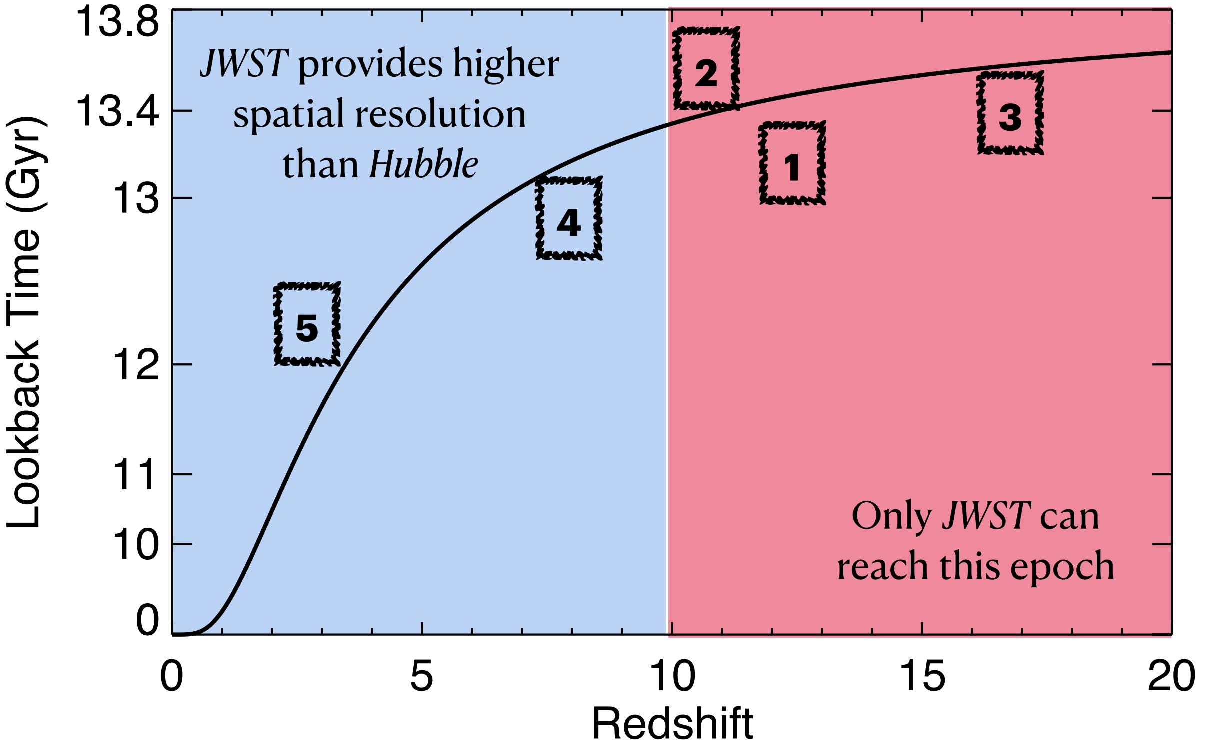


Figure 2: The relation between galaxy "redshift" and the lookback time. Looking at galaxies at greater redshifts allows us to see how they appeared earlier in the history of our Universe. The numbered points denote the redshifts of the five key results discussed below.

This is an extremely useful feature - one can observe a galaxy, and by examining how redshifted it looks, we can place it at its correct time in our cosmic history. This "redshift" quantity is something we can estimate fairly well with imaging, and very precisely with spectroscopy (spectroscopy is a type of observation where we take the light from an object and use a dispersive element (like a prism) to split the light into its component wavelengths, revealing significantly more information). Together, the ability to peer back in time coupled with the ability to determine distances due to redshift allows us to pursue *the study of galaxy evolution*, and truly understand how galaxies form and evolve.

Why does this matter? This is our true origins story. Humans have long wondered where we came from and why are we here. The study of galaxy evolution pushes this desire to understand our origins to its limits. Not just where did humans come from, or our Earth, or our Solar System, but where did our *Galaxy* come from?

Moving into the First 500 Million Years with *JWST*

The *Hubble Space Telescope* has produced several iconic images related to the early universe, none more so than the Hubble Ultra Deep field. Its predecessor, the Hubble Deep Field, showed humanity what happens if you point a powerful telescope at an otherwise empty region of the sky, and open the camera's shutter for hundreds of hours. This program, which was somewhat controversial at the time (some astronomers though we would see nothing!) showed us that the universe is ***filled*** with galaxies! Our best estimate today is that our observable universe contains ***trillions*** of galaxies.

Through a number of legacy *Hubble* programs, we have learned a great deal about galaxy evolution. However, as *Hubble* is primarily a visible light telescope, it is unable to see galaxies at redshifts beyond 10. At greater redshifts, all of the light from those extremely distant galaxies is redshifted out of the visible wavelength regime, and into the infrared. These galaxies are also quite faint (not only are they at extremely great distances, they are intrinsically much smaller and fainter than our Milky Way), meaning that a more powerful telescope is needed to collect their photons.

With the immensely successful launch and deployment of *JWST,* that telescope is here. The 6.5 meter diameter primary mirror of *JWST* is seven times the area of *Hubble*'s mirror, allowing us to see much fainter objects. *JWST*'s mirror and instruments are also optimized to detect infrared photons, perfect for studying the early universe. With *JWST*, we can thus now, for the first time in human history, look to our ultimate origins - when did the first galaxies form out of the cosmic dark ages?

The Cosmic Evolution Early Release Science Survey

Some of the first science data collected by *JWST* was for a suite of 13 "Early Release Science" (ERS) programs, designed to obtain data across all areas of astronomy with all *JWST* instruments, all of which would be immediately publicly available. Here I will show some key early results from one of these surveys, called the "Cosmic Evolution Early Release Science Survey" (or CEERS), for which I am the Principal Investigator. CEERS targets the early universe by obtaining imaging with two of *JWST*'s cameras (the Near-Infrared Camera, NIRCam, and the Mid-Infrared Imager, MIRI). CEERS will also, next month, obtain spectroscopy with the Near-Infrared Spectrograph (NIRSpec) as well as with a spectroscopic mode of NIRCam. With the redder light that these instruments are sensitive to, CEERS was designed to perform a census of the redshift of 10 universe, and push our cosmic horizons back into the cosmic dark ages. We show a color image of our current CEERS dataset in Figure 3.

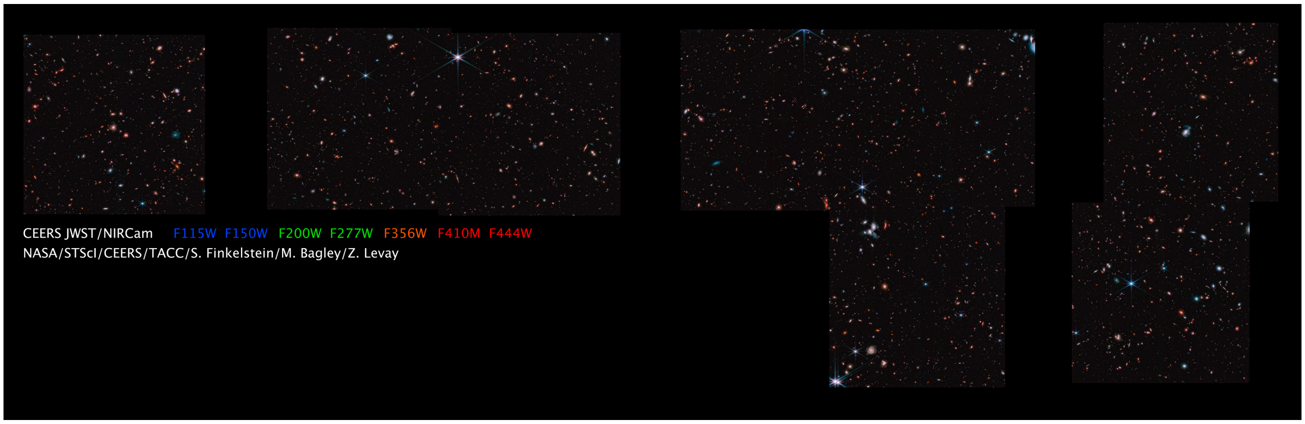


Figure 3: The first epoch of CEERS imaging, obtained in late June 2022. These images contain ~40,000 galaxies, from the nearby universe to some from the earliest cosmic epochs.

Science Result 1: An Unexpectedly Early Object - “Maisie’s Galaxy”

The first CEERS data were obtained in late June, and released in mid-July following NASA’s Early Release Observation press release. A group of six astronomers met on the campus of the University of Texas at Austin to reduce the data (the process of taking the raw data frames and combining them into the data ready for scientific measurements). Within a matter of days, it became clear that there was an unexpectedly distant galaxy present. While *JWST* was built to find the earliest galaxies, these ERS programs were limited in size, thus our team did not believe that the CEERS would be deep enough to push much beyond a redshift of 11.

To our surprise, as we analyzed this object, we realized it was a redshift of 12 galaxy! This means that the light we are seeing left this galaxy about 370 million years after the Big Bang, and has been traveling for over 13.4 billion years to reach our telescopes. What did we call this astounding object? It had been discovered on my daughter’s birthday, and she had been asking me to name a galaxy after her. Though I told her we didn’t usually do that, in what started as a nickname for the object the collaboration eventually decided to adopt the name “Maisie’s Galaxy” for this amazing galaxy. While it is difficult to make sweeping conclusions from just one galaxy, the simple fact that we can see Maisie’s Galaxy at this extremely early time places the best constraints yet on the end of the cosmic dark ages. We show a zoom in on Maisie’s Galaxy in Figure 4. This paper, led by the CEERS team, has been accepted to the Astrophysical Journal Letters, as the first paper in a Focus Issue on the CEERS project.

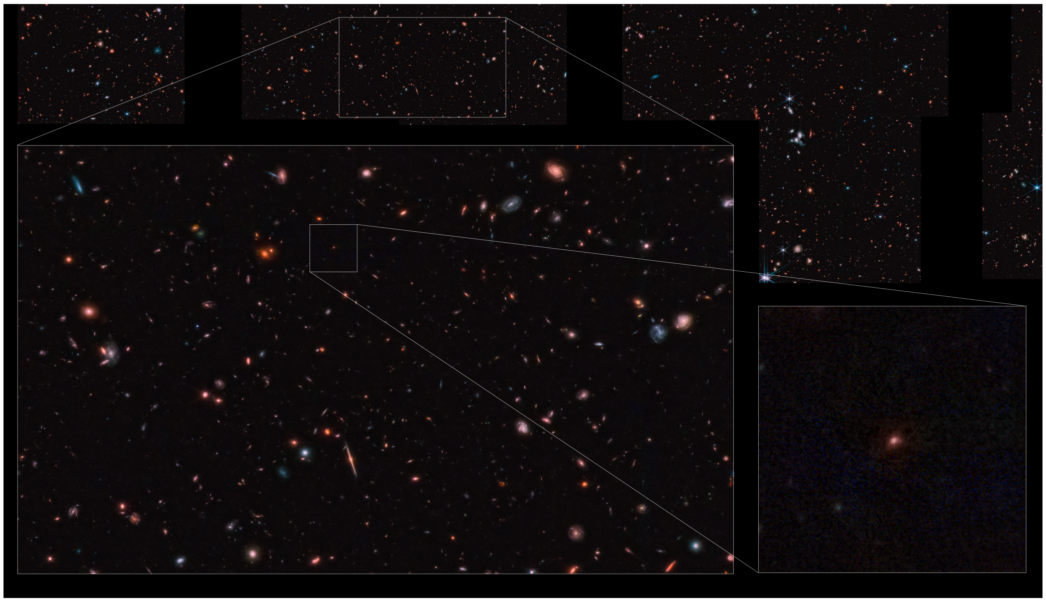
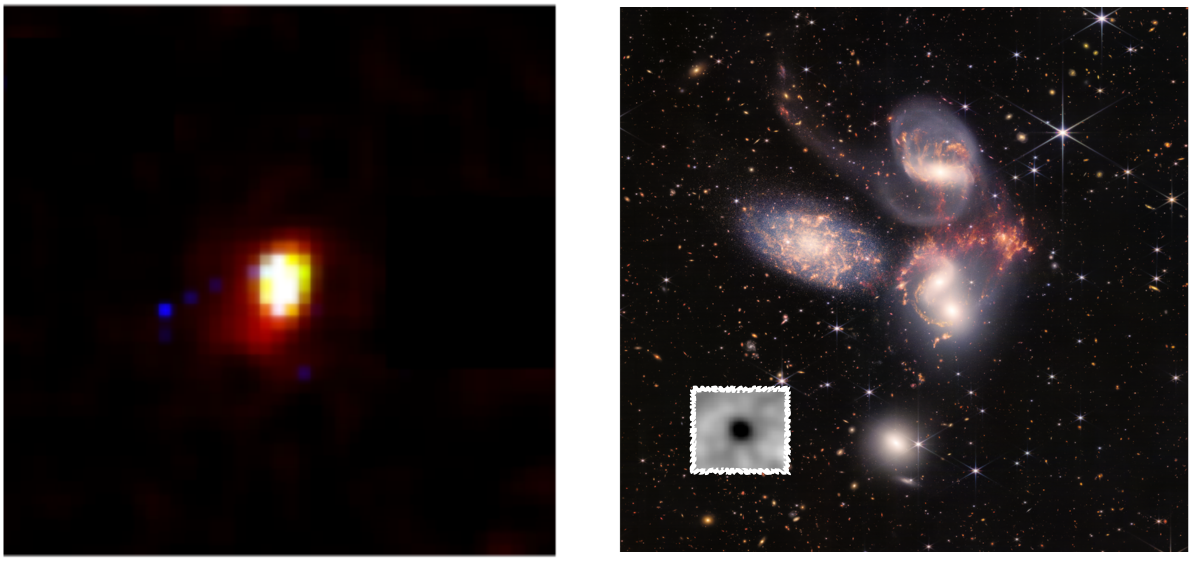


Figure 4: “Maisie’s Galaxy” - one of the first JWST discoveries. This object is a galaxy with a redshift of 12, seen at a time only 370 million years after the Big Bang, or over 97% of the way back in our cosmic history. *Reference: Finkelstein et al. 2022a*

Science Result 2: Massive Monsters at Cosmic Dawn

Two other studies from this summer found something else very surprising - very bright galaxies which appeared to come from a redshift of 17! Such galaxies are completely unexpected — no modern theoretical simulation predicts that our universe could form such massive "monster" galaxies just ~250 million years after the Big Bang. In Figure 5 we show these galaxies. The first one, originally shared in a submitted paper led by a group at the University of Edinburgh, was identified in the CEERS field. The second one, shared in a submitted paper by a group at the University of Tokyo, was found in the Stephan's Quintet field. This latter field was taken as part of *JWST*'s Early Release Observation program. What is amazing is that these latter data were not intended to study the early universe, but *JWST* is so powerful that every field is a deep field! Given the unexpected nature of these sources, confirmation of their extreme redshifts is a must. *JWST* is already scheduled to take a spectrum of the source in the CEERS field (along with Maisie's Galaxy) in December; these data will provide a precise redshift.

The Stephan's Quintet galaxy was recently observed at millimeter wavelengths with the Atacama Large Millimeter Array (ALMA). In a paper just submitted for publication by a University of Texas at Austin postdoctoral researcher, they found that this galaxy had no detectable emission at these very long wavelengths in the ALMA data, which rules out many alternative redshifts, making an extremely high redshift more likely. These observations also highlight the synergies between NASA's space telescopes and NSF's ground-based portfolio. Finally, should our universe truly crank out these massive monsters, they will make excellent targets for study with NASA's upcoming *Nancy Grace Roman Space Telescope*, which will study areas of the sky much wider than *JWST*, allowing better characterization of the abundance of rare, bright galaxies.



<u>Figure 5</u>: Two objects which appear to be galaxies at the amazing redshift of 17. If these redshifts are confirmed, they are coming from a time less than 250 million years after the Big Bang, surprisingly early. The galaxy on the left was discovered in the CEERS imaging, serendipitously close to Maisie's Galaxy, allowing them both to be followed up with spectroscopy in December. The galaxy on the right was discovered in the Stephan's Quintet Early Release Observation data. *References: Donnan et al. 2022; Harikane et al. 2022*

Science Result 3: A Population of Early Galaxies - Are Early Stars Different?

Maisie was just the beginning - as we continue to work on the CEERS *JWST* imaging data, and are able to produce better and more accurate measurements, we have begun to build up a true representative sample of early galaxies. The CEERS team has just submitted a paper for publication showcasing a sample of 26 very distant galaxies, ranging from redshifts of 9 to nearly 17 (shown in Figure 6 below). We compared to a wide variety of theory-based predictions, and found that nearly all models failed to predict this high abundance of such early galaxies (this paper has been submitted to the Astrophysical Journal Letters). This is exciting, as it means that the physical processes dominant in these early galaxies are different than what the models assume, pointing to very different physical conditions for star formation.

One exciting solution would be if the stars in these early galaxies are different from those today. In the Milky Way galaxy, the average mass of a star is about that of our Sun. However, it has been predicted that the early galaxies, due to their very small amount of heavy atomic elements, would have typical star masses of ~10-50X that of our Sun. As more massive stars are brighter and bluer. this would lead to these galaxies being more luminous, and thus perhaps easy to detect. In Figure 6 below, you can see these galaxies appear quite blue, thus this is not unlikely! Our upcoming spectroscopy can confirm this exciting implication.

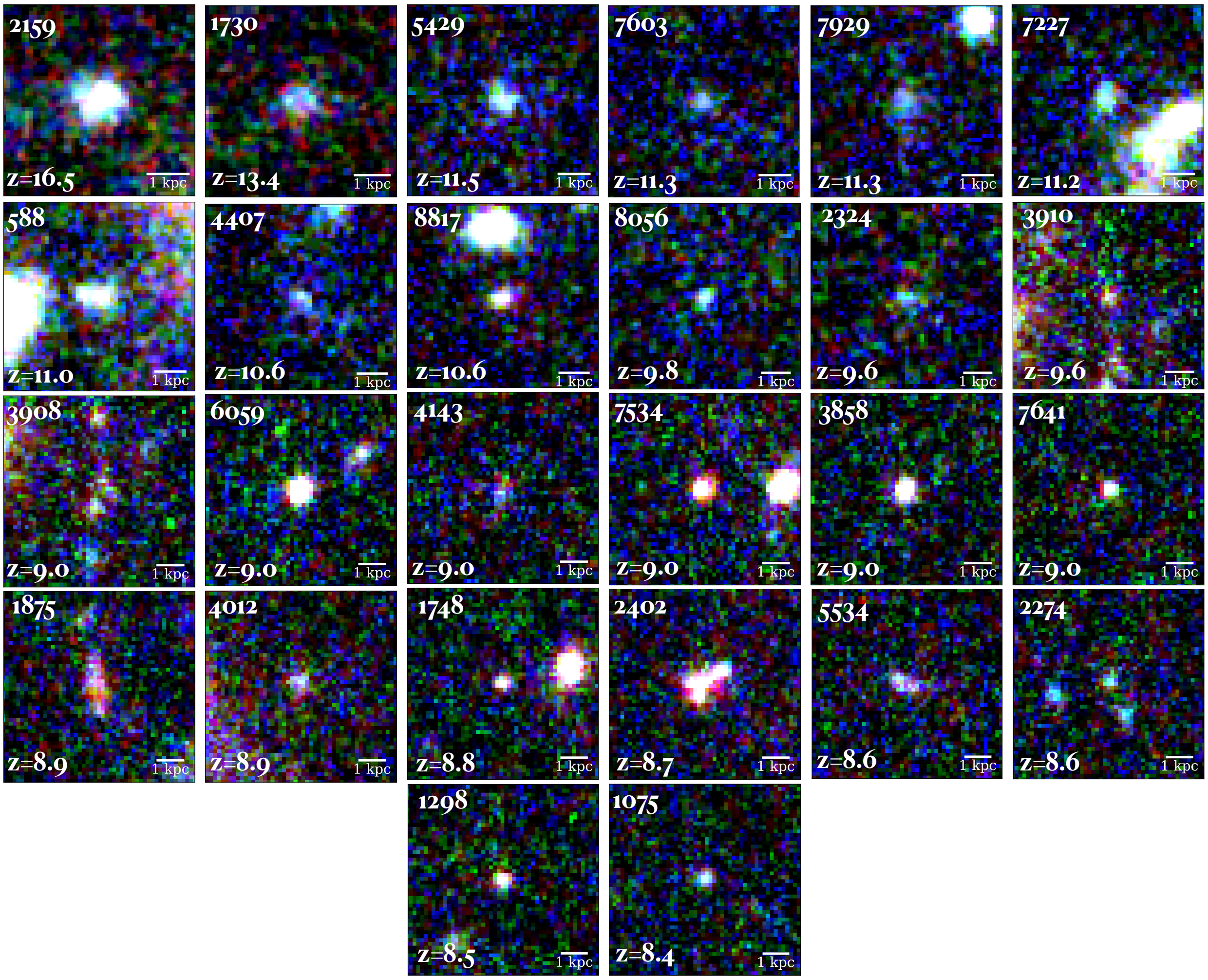


Figure 6: A compilation of an amazing 26 early galaxies, ranging in redshift from 8.4 to 16.5, all discovered in CEERS. The colors are chosen to show the intrinsic colors of these galaxies, highlighting that many are very blue. The abundance of these sources, should their distances be confirmed with spectroscopy, indicates that stars in the very early universe are fundamentally different from those in our Milky Way. *Reference: Finkelstein et al. 2022b*

Science Result 4: Seeing the True Nature of Hubble's Earliest Discoveries

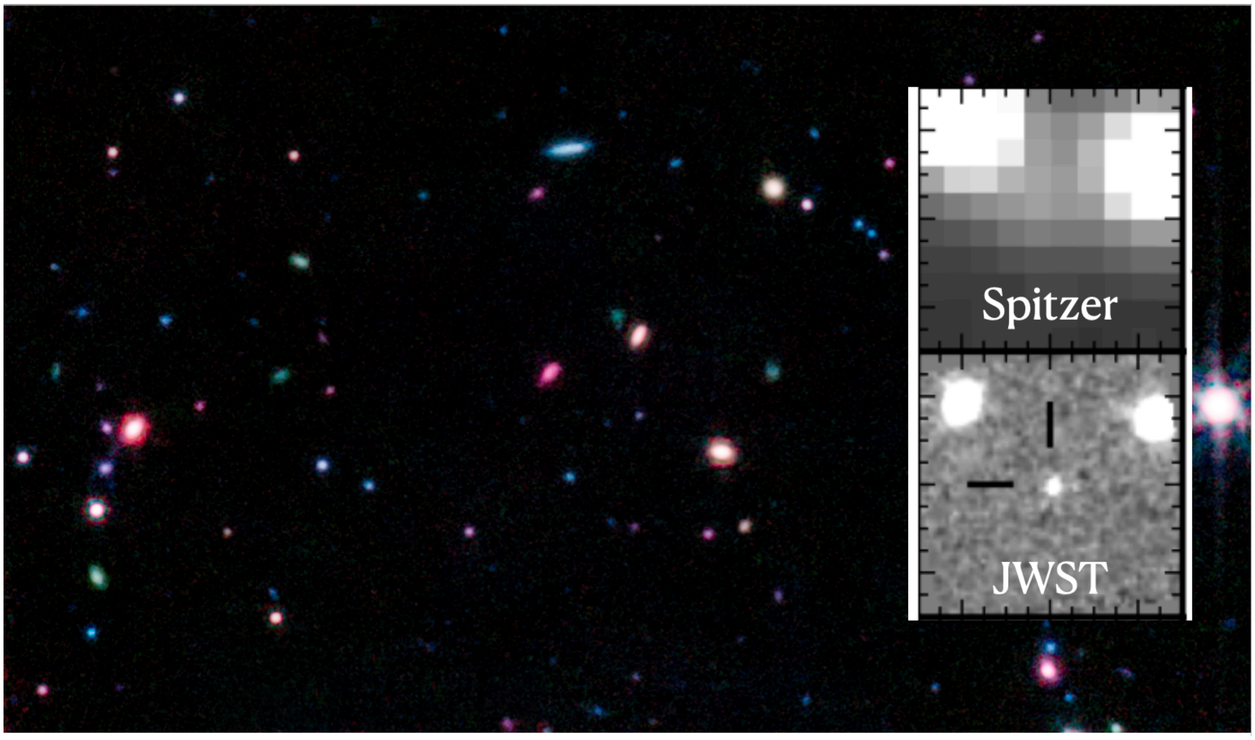


Figure 7: A color image of one of the CEERS MIRI instrument observations. The inset shows a redshift of 8.7 galaxy, showing the difference between NASA's former Spitzer Space Telescope and JWST's MIRI instrument at similar wavelengths. The incredible improvement in resolution with *JWST* for these observations paves the way to understand the mass in stars in the early universe. *Reference: Papovich et al. 2022 (in preparation)*

In addition to imaging with NIRCam, which operates at slightly redder wavelengths than *Hubble*, CEERS also obtained imaging with MIRI, which observes at even longer wavelengths. Figure 7 above shows a color compilation of a portion of our MIRI imaging. These MIRI data are critical for a variety of analyses, from star-formation and black hole activity in the nearby universe which is obscured by cosmic dust, to emission from older stars in the early universe.

The inset image shows an example of the latter - the top portion shows the image of a galaxy at a redshift of 8.7. This galaxy was originally discovered with *Hubble* data, but *Hubble* was only sensitive to the light from young stars, so the total mass of this galaxy was uncertain. NASA's Spitzer Space Telescope is sensitive to light from older stars, but its resolution was too poor (as shown in the top inset panel) to accurately measure the emission from this galaxy. The bottom inset panel shows the CEERS/MIRI image of this galaxy at wavelengths ~4X longer than accessible to Hubble. While the previous Hubble+Spitzer constraints allowed this galaxy to have a very high mass, with the improved JWST observations we can constrain this mass to be fairly low. These observations pave the way for larger MIRI surveys to constrain the total amount of mass in stars formed in the early universe.

Science Result 5: A Complexity of Galactic Structure at Cosmic Noon

The improved spatial resolution afforded by JWST allows the first true invitations into the morphological structure of galaxies beyond a redshift of 2. We find that galaxies at high redshift (>3, more than 11 billion years into the past) have a wide diversity of morphologies, including galaxies with disks, bulges, those that look like spheroids, and those that are irregular. Some galaxies have morphologies that are different between *HST* and *JWST*. This due to the difference in image depth between CEERS and the previous *HST* imaging, the difference in rest-frame wavelength, and the difference in resolution. Sometimes, this difference means that we can see disks in the *JWST* imaging that were not apparent in the HST imaging (see examples in Figure 8). With HST imaging alone, some of these galaxies look very irregular or like spheroids since the disks themselves were too faint to detect. This means that even at these early times, disks were already in place for some galaxies. Further analysis will show how these disks compare to those in today's universe and to determine when in the universe's history they were able to form.

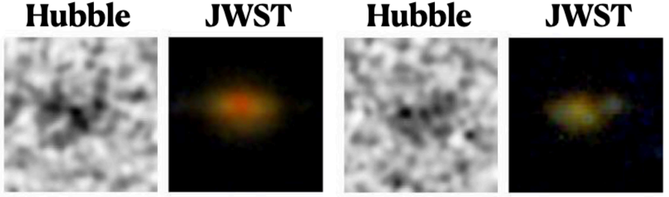


Figure 8: A comparison of *Hubble* imaging of two galaxies to *JWST* imaging from he CEERS survey. The redder light collected by *JWST* gives a more comprehensive look into these galaxies. The *Hubble* imaging, where the light is dominated by young, massive stars, cooers very clumpy. The *JWST* images sho a smoother profile, showing that there is a large number of older, lower-mass stars present, which Hubble was not sensitive to. *Reference: Kartaltepe et al. 2022*

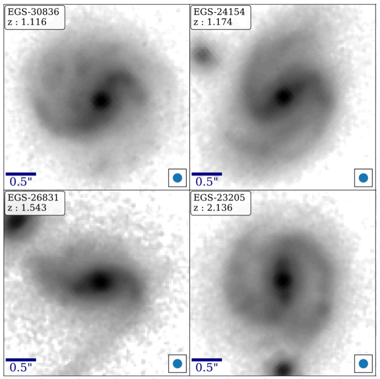


Figure 9: A view of distant galaxies akin to our Milky Way is made possible by *JWST*. JWST's unprecedented high-resolution NIRCam images reveal elongated bar structures in galaxies at redshifts from 1 to 2, thereby unveiling some of the earliest barred spirals known to date. The presence of bars can transform the evolution of galaxies, and our own Milky Way is a barred spiral. With *Hubble*, typically barred galaxies could only be studied out to redshifts of 1. *Reference: Guo, Jogee et al. 2022*

Stellar bars – central elongated features in the disk of spiral galaxies — are important structures that shape the evolution of galaxies by channeling gas into their central regions where it is rapidly converted into new stars in "starburst" episodes. Most spiral galaxies in the present-day Universe, including our Milky Way, host a bar feature, but a long-standing question is: when did such features first appear in the Universe? With *Hubble*, typically bars could only be robustly identified out to redshifts of ~1, when the Universe was ~40% of its present age. *JWST*'s unprecedented high-resolution mid-infrared images are now unveiling barred spirals out to redshifts of at least 2, when the Universe was almost twice as young, as shown in Figure 9. This has profound implications for theoretical models of the formation of barred galaxies, possibly akin to our own Milky Way, and for galaxy evolution pathways.

What Comes Next?

The CEERS survey, by its very definition, is our first look into our cosmic beginnings. The remainder of *JWST*'s first year of observations contains a wide portfolio of observations, from the first *JWST* ultra-deep fields (two of them!) to an early universe survey wider than the full moon on the sky (known as COSMOS-Web). And even this first year is just the tip of the iceberg, with many years of exciting *JWST* observations to come.

Most exciting for the near future will be spectroscopy. First and foremost, this will allow astronomers to precisely measure the redshift of a galaxy (by measuring the observed wavelengths of redshifted spectral features like atomic emission lines). This step of "spectroscopic confirmation" is extremely necessary to validate the exciting science results (#1-3) presented above. The CEERS project has a spectroscopic component, with data coming in during the second half of December. The Space Telescope Science Institute has also authorized a "Director's Discretionary Time" spectroscopic observation of both Maisie's Galaxy and the redshift of 17 object in CEERS described above, also happening in December. For those galaxies that we can confirm to be in the early universe, these spectra will also be rich with information on the types of stars (are they more massive?), and the abundance of heavy elements (are these galaxies nearly chemically pristine?).

While the knowledge gained from these early *JWST* observations has truly been transformative across all of astronomy, with the vast amounts of new data to come, this firehouse of knowledge gained will not slow for the foreseeable future.

Disclaimer: This text represents the thoughts and opinions of the author, and does not represent the University of Texas at Austin.

References Cited

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Finkelstein, S., Bagley, M., Arrabal Haro, P. et al. 2022a, "A Long Time Ago in a Galaxy Far, Far Away: A Candidate z ~ 12 Galaxy in Early JWST CEERS Imaging", Accepted to the Astrophysical Journal Letters (preprint available at: https://arxiv.org/abs/2207.12474)

Finkelstein, S., Bagley, M., Ferguson, H. et al. 2022b, "CEERS Key Paper I: An Early Look into the First 500 Myr of Galaxy Formation with JWST", Submitted to the Astrophysical Journal Letters (preprint available at:https://arxiv.org/abs/2211.05792)

Guo, K., Jogee, S., Finkelstein, S. et al. 2022, "First Look at z > 1 Bars in the Rest-Frame Near-Infrared with JWST Early CEERS Imaging", Submitted to the Astrophysical Journal (preprint available at: https://arxiv.org/abs/2210.08658)

Harikane, Y., Ouchi, M., Oguri, M. Et al. 2022, "A Comprehensive Study on Galaxies at z ~ 9 – 17 Found in the Early JWST Data: UV Luminosity Functions and Cosmic Star-Formation History at the Pre-Reionization Epoch", Submitted to the Astrophysical Journal (preprint available at: https://arxiv.org/abs/2208.01612)

Kartaltepe, J., Rose, C., Vanderhoof, B. et al. 2022, "CEERS Key Paper IV: The Diversity of Galaxy Structure and Morphology at z = 3 – 9 with JWST", Submitted to the Astrophysical Journal Letters (preprint available at: https://arxiv.org/abs/2210.14713)

Papovich, C., Cole. J, Yang, G. et al. 2022, "CEERS Key Paper VI: Stellar Populations and Star-Formation Histories of Star-Forming Galaxies at $4 < z < 9$ from rest-frame >1 micron imaging", in preparation for submission to the Astrophysical Journal Letters

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Academic Positions

The University of Texas at Austin, Austin, TX

Professor	Fall 2022 – Present
Associate Department Chair	Fall 2019 – Present
Associate Professor	Fall 2017 – Summer 2022
Assistant Professor	Fall 2012 – Summer 2017

The University of Texas at Austin, Austin, TX — Sept. 2011 – Aug. 2012

Hubble Fellow

- Faculty Contact: Professor Karl Gebhardt

Texas A&M University, College Station, Texas — Sept. 2008 – Aug. 2011

Postdoctoral Research Associate

- Faculty Advisor: Professor Casey Papovich

Education

Arizona State University, Tempe, Arizona

Ph.D. Physics, Emphasis in Astronomy — August 2008

- Advisor: Professor James E. Rhoads
- Dissertation: Physical Properties and Dust Effects in High-Redshift Lyman Alpha Galaxies

University of Washington, Seattle, Washington

B.S. Astronomy and Physics — June 2003

Honors and Awards

- 2020 UT Austin Provost's Teaching Fellowship
- 2017-2018 Dads' Association Centennial Teaching Fellowship
- 2017 Asa Briggs Visiting Fellow, University of Sussex
- 2016 UT Austin College of Natural Sciences Teaching Excellence Award
- 2015-2016 McDonald Observatory Board of Visitors Teaching Excellence Award
- Hubble Prize Postdoctoral Fellowship (awarded in 2011)

Publications

Summary: 220 papers published in or submitted to peer-reviewed journals, with an h-index of 58. Of these, I am the lead author on 23 papers, which have >2500 citations combined. Recent important papers are:

1. Finkelstein, S. L. et al. **2022**, *CEERS Key Paper I: An Early Look into the First 500 Myr of Galaxy Formation with JWST*, Submitted to the Astrophysical Journal Letters
2. Bagley, M., Finkelstein, S. L. et al. **2022**, *CEERS Epoch 1 NIRCam Imaging: Reduction Methods and Simulations Enabling Early JWST Science Results*, Submitted to the Astrophysical Journal Letters
3. Finkelstein, S. L. et al. **2022**, *A Long Time Ago in a Galaxy Far, Far Away: A Candidate $z \sim 12$ Galaxy in Early JWST CEERS Imaging*, Astrophysical Journal Letters, in press

4. Finkelstein, S. L. and Bagley, M. **2022**, *On the Co-Evolution of the AGN and Star-Forming Galaxy Ultraviolet Luminosity Functions at* $3 < z < 9$, Astrophysical Journal, in press
5. Larson, R., Finkelstein, S., Hutchison ,T. et al. **2022**, *Searching for Islands of Reionization: A Potential Ionized Bubble Powered by a Spectroscopic Overdensity at* $z = 8.7$, Astrophysical Journal, 930, 104
6. Finkelstein, S. L. et al. **2022**, *A Census of the Bright* $z = 8.5$*–11 Universe with the Hubble and Spitzer Space Telescopes*, Astrophysical Journal, 928, 52
7. Finkelstein, S. L. et al. **2019**, *Conditions for Reionizing the Universe with A Low Ionizing Photon Escape Fraction*, Astrophysical Journal, 879, 36
8. Livermore, R., Finkelstein, S., & Lotz, J. **2017**, *Directly Observing the Galaxies Likely Responsible for Reionization*, Astrophysical Journal, 835 113

MENTORSHIP EXPERIENCE

- 2021–Present: Advisor of graduate student Alexa Morales, who is working on chemical enrichment in the early universe.
- 2020–Present: Advisor of graduate student Oscar Chavez Ortiz, who is studying Lyman alpha emission and reionization.
- 2020–Present: Advisor of graduate student Katie Chworowsky, who is working on quiescent galaxies at high redshift.
- 2020–Present: Advisor of postdoc Gene Leung, who is leading my groups work on HETDEX and SHELA.
- 2019–2022: Advisor of graduate student Adam McCarron, who is studying the physical properties of high-redshift galaxies identified by HETDEX.
- 2016–Present: Advisor of graduate student Rebecca Larson, who is working on two *HST* grism spectroscopic surveys I am involved in, searching for Lyα emission lines in the epoch of reionization.
- 2018–Present: Advisor of postdoc Micaela Bagley, who is leading my groups preparation for the CEERS *JWST* program.
- 2013 – 2019: Advisor of graduate student Matthew Stevans, who studied the growth of galaxy stellar masses using a 24 deg^2 K-band imaging survey in the SHELA field. He went on to the data science sector
- 2013 – 2019: Advisor of graduate student Intae Jung, who used using high-resolution *Hubble* imaging to study resolved stellar populations at high redshift, and performed spectroscopic studies of Lyα as a probe of reionization. He went on to a prize NASA Postdoctoral Program fellow at Goddard Space Flight Center.
- 2013 – 2018 : Co-advisor of graduate student Jason Jaacks, who used simulations to study the tracking of galaxy progenitors and descendants, as well as to make predictions for a JWST Deep Field. He went on to a job in the data science sector.
- 2012–2016: Advisor of graduate student Mimi Song, who led a project on near-infrared spectroscopic observations of LAEs discovered in the HETDEX pilot survey, and stellar mass functions of very high-redshift galaxies. She went on to a prize NASA Postdoctoral Program fellow at Goddard Space Flight Center.
- 2014 – 2018: Advisor of postdoc Isak Wold, who will work on the HETDEX project. He is currently building our photometric catalog in the SHELA field, and will ultimately

study the evolution of the Lyα luminosity function. He went on to a prize NASA Postdoctoral Program fellow at Goddard Space Flight Center.

• 2013 – 2017: Advisor of postdoc Rachael Livermore, who led my group's work on the Hubble Frontier Fields. Rachael went on to an ARC prize postdoctoral fellow at Melbourne University.
• I have worked with 15 undergraduate students while at UT Austin.

Awarded Grants and Fellowships

Summary: Total of $6.2M awarded as PI since starting as faculty in 2012. Recent highlights are:

2022 UT Austin Spark Grant, $200,000 (**Finkelstein PI**)
- *Solving Reionization with ERMOS on the Giant Magellan Telescope*

JWST Cycle 1 General Observer Grant, $309,297 (**Finkelstein Co-PI**),
- *NGDEEP: Next Generation Deep Extragalactic Exploratory Public Survey*

2021 NASA ADAP Grant, $495,418 (**Finkelstein PI; C. Casey Co-PI**)
- *Leveraging Spitzer and VIRUS to Investigate Reionization and the Growth of Massive Cosmic Structures*

JWST Cycle 1 Early Release Science Grant, $1.3M (**Finkelstein PI**, Individual grant $430,470)
- *Cosmic Evolution Early Release Science Survey*

2020 NSF AAG Grant, $229,660 (Finkelstein PI)
- *The Onset of Star-Formation Quenching in Massive Galaxies in the Early Universe*

2019 NSF AAG Grant, $459,079 (Finkelstein PI)
- *Leveraging the Hobby Eberly Telescope Dark Energy Experiment to Understand Lyα Emission, Galaxy Evolution, and Reionization*

Recent Invited Talks

Hebrew University of Jerusalem, Seminar (remote), November 2022
Santa Cruz Galaxy Formation Workshop, Santa Cruz, CA, August 2022
EAS Annual Meeting, June 2022
Flatiron Institute CCA, Seminar, May 2022
UC Riverside, Colloquium, April 2022
Colby College, Colloquium, Sept 2021
UC Santa Barbara, Colloquium, Dec 2020
NASA Goddard Space Flight Center, Colloquium, Oct 2020

Selected Professional Experience

Member, Executive Committee, NASA Cosmic Origins Analysis Group (2019–2022)
James Webb Space Telescope Review Panel Member, Cycle 1
Chair, HETDEX Galaxies and AGN Science Working Group (2019–2021)
Member, Hubble Space Telescope Users Committee (2019–2022)
Member, NASA IRTF Keck Users Committee (2018–2021)
PI, JWST ERS Program (2017–Present)

Selected Teaching Experience

INSTRUCTOR, The University of Texas at Austin 2013 – Present
- Instructor of AST301, a 200-student astronomy survey course.
- Instructor of AST358, an upper-level undergraduate course on galaxies.
- Instructor of AST376, an under/graduate experiential telescope observing course.
- Instructor of AST386, a graduate course on galaxy evolution at high redshift.