

JWST: One Giant Leap Towards Observing the First Stars

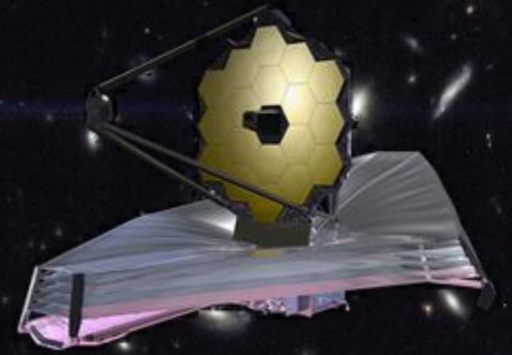
Dan Coe

Space Telescope Science Institute

- ESA/AURA Astronomer
- NIRSpec MOS Support

Johns Hopkins University

dancoe.space

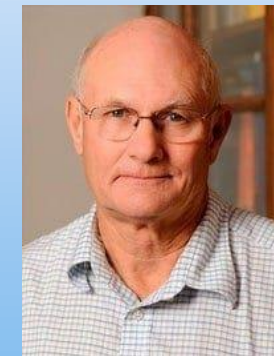




ACS Science Team Meeting, Aspen, CO, 10 Sept. 2003



Advanced Camera for Surveys
Hubble ACS GTO Team
PI Holland Ford
Deputy PI Garth Illingworth

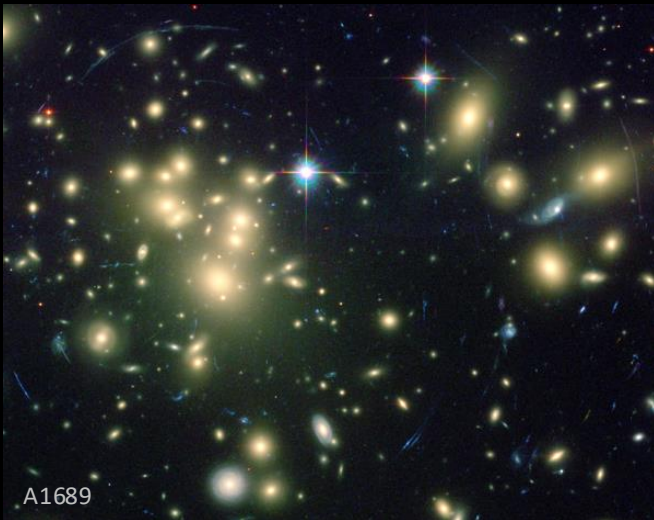


also including
Marc Postman
Mark Clampin
Rychard Bouwens
Dan Kelson
Dan Magee
Dan Coe

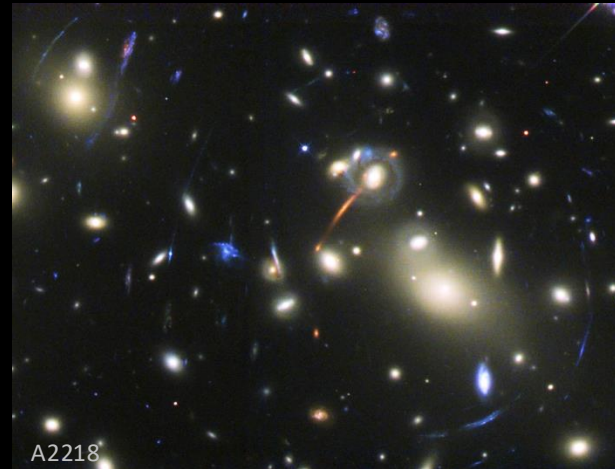
ACS GTO galaxy cluster lensing



NASA, ESA, and D. Coe (JPL/Caltech and STScI) STScI-PRC10-37



A1689



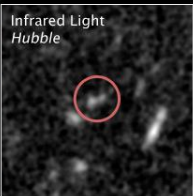
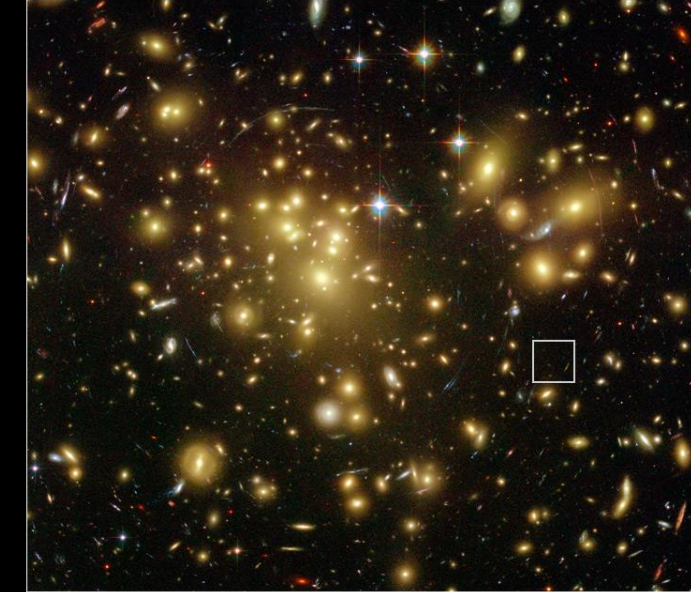
A2218



A1703

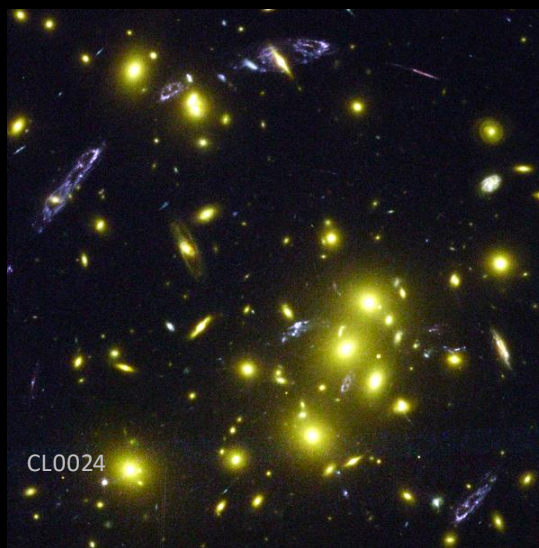
Distant Gravitationally Lensed Galaxy
Galaxy Cluster Abell 1689

Hubble Space Telescope
ACS/WFC NICMOS

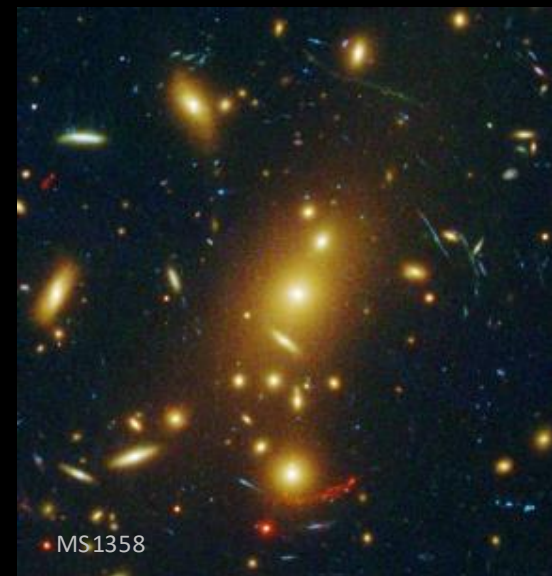


NASA, ESA, and L. Bradley (JHU), R. Bouwens (UCSC), H. Ford (JHU), and G. Illingworth (UCSC)

STScI-PRC08-08a



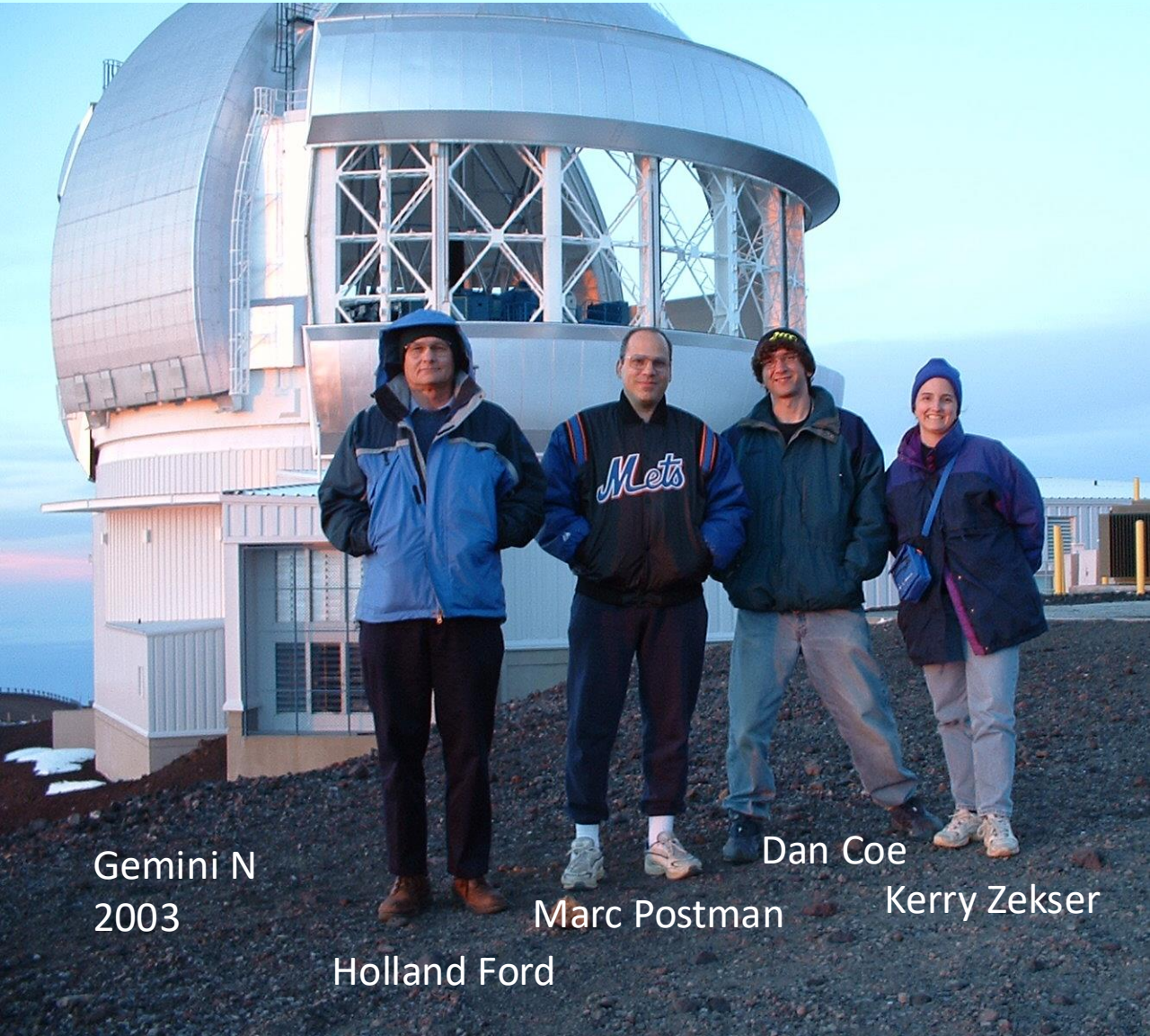
CL0024



MS1358

Dan Coe - CLASH - STScI

$z > 7$ was hard from the ground!



Gemini N
2003

Holland Ford
Dan Coe
Marc Postman
Kerry Zekser

Granada, Spain



Jun 26, 2025

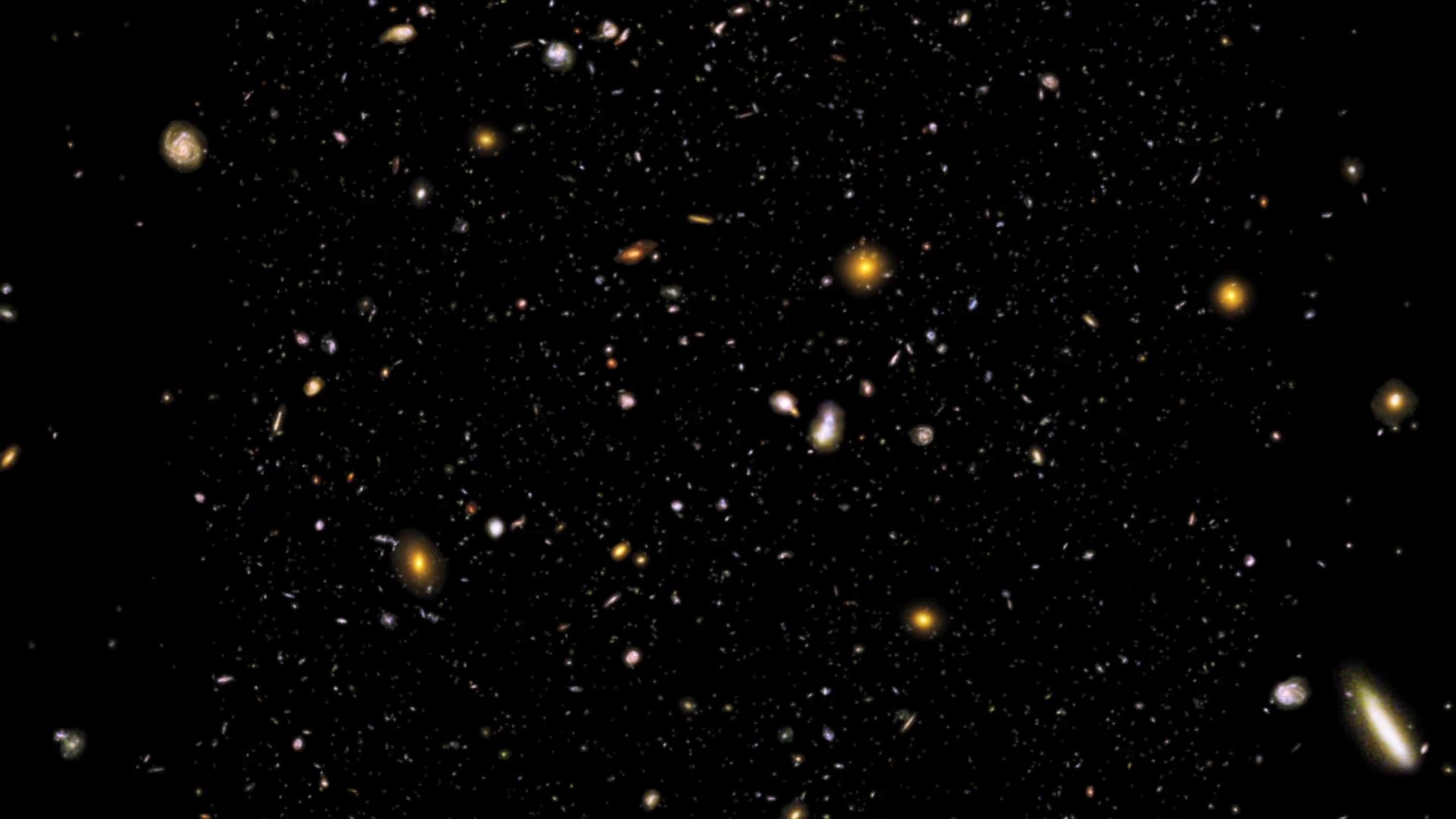
Dan Coe - GarthFest



“We came all this way to explore the Moon,
and the most important thing is that
we discovered the Earth.”

– Bill Anders, Apollo 8
Earthrise photo 1968





Only when it is dark enough can you see the stars



Twenty thousand people
spent thousands of days
with billions of dollars
to look back in time
billions of years and
explore our origins



Image credit: Northrop Grumman
<https://www.flickr.com/photos/nasawebbtelescope/51765688333>

Only when it is dark enough can you see the stars



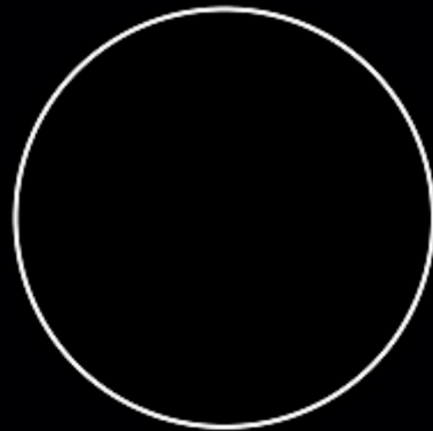
Formation of the first stars

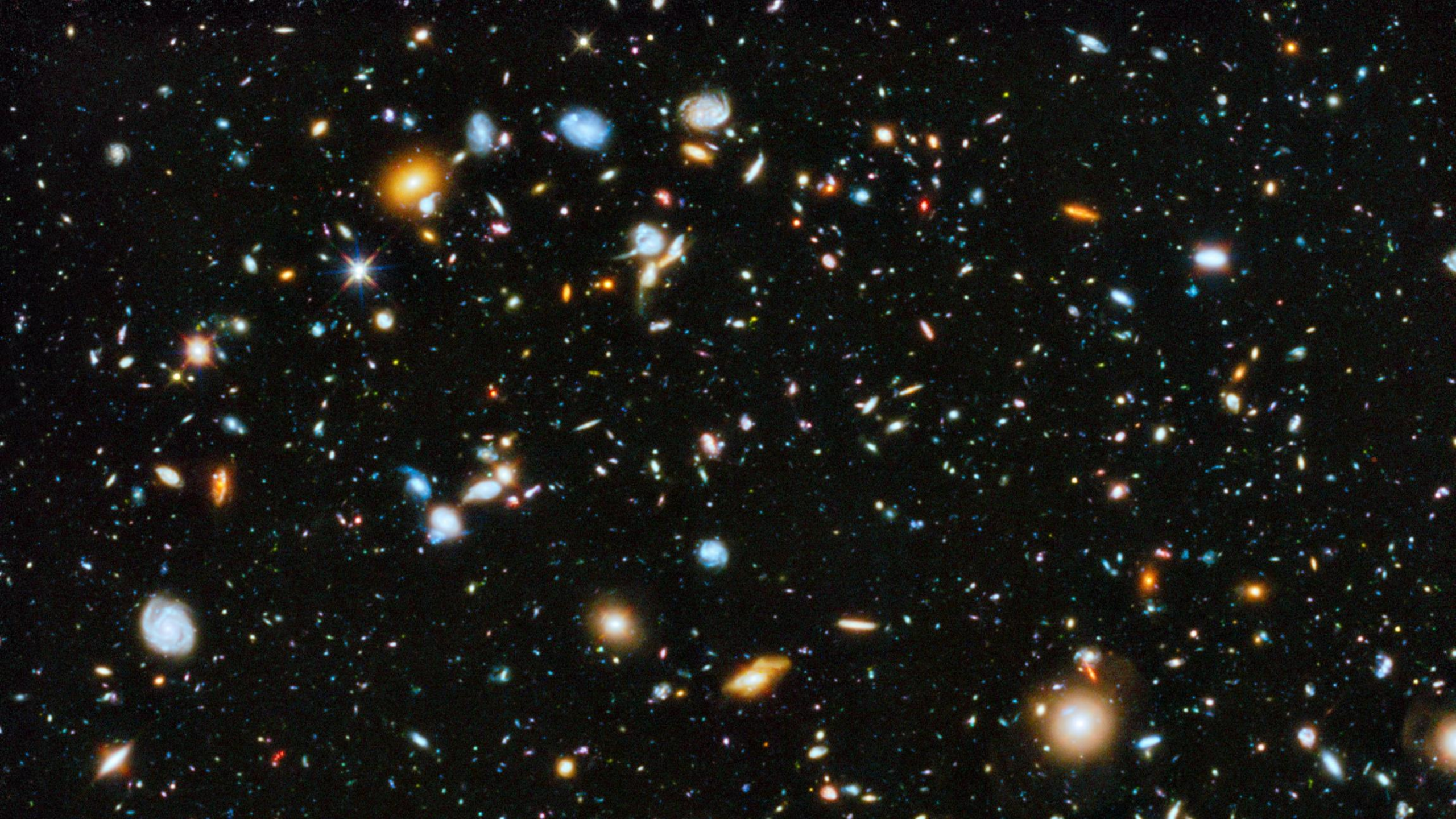
SPHINX Simulation

Harley Katz



135.3 Myr









Hubble Frontier Fields

6 cluster lenses and blank fields in parallel



PI Jennifer Lotz

Abell 2744

parallel field

HDFI science working group

chair: James Bullock (UC Irvine)
Mark Dickinson (NOAO)
Steven Finkelstein (UT Austin)
Adriano Fontana (INAF, Rome)
Ann Hornschemeier Cardiff (GSFC)
Jennifer Lotz (STScI)
Priya Natarajan (Yale)
Alexandra Pope (U Mass)
Brant Robertson (Arizona)
Brian Siana (UC Riverside)
Jason Tumlinson (STScI)
Michael Wood-Vasey (U Pitt)

Frontier Fields deep imaging of 6 clusters + parallels

Abell 2744

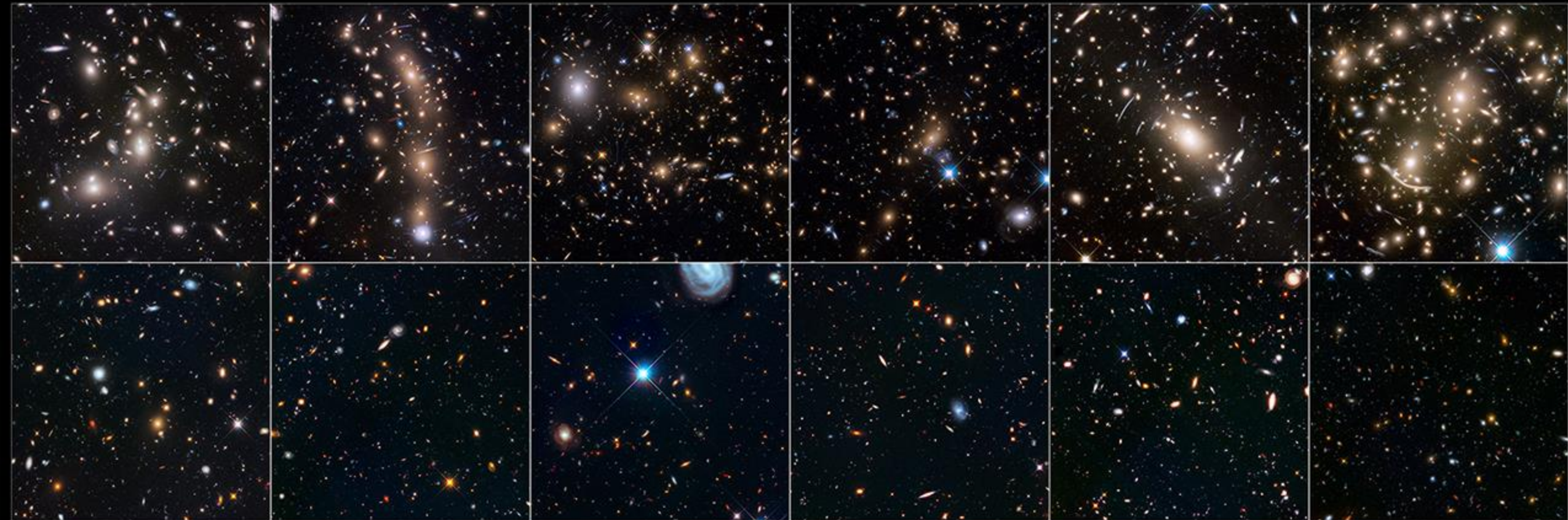
MACS J0416.1-2403

MACS J0717.5+3745

MACS J1149.5+2223

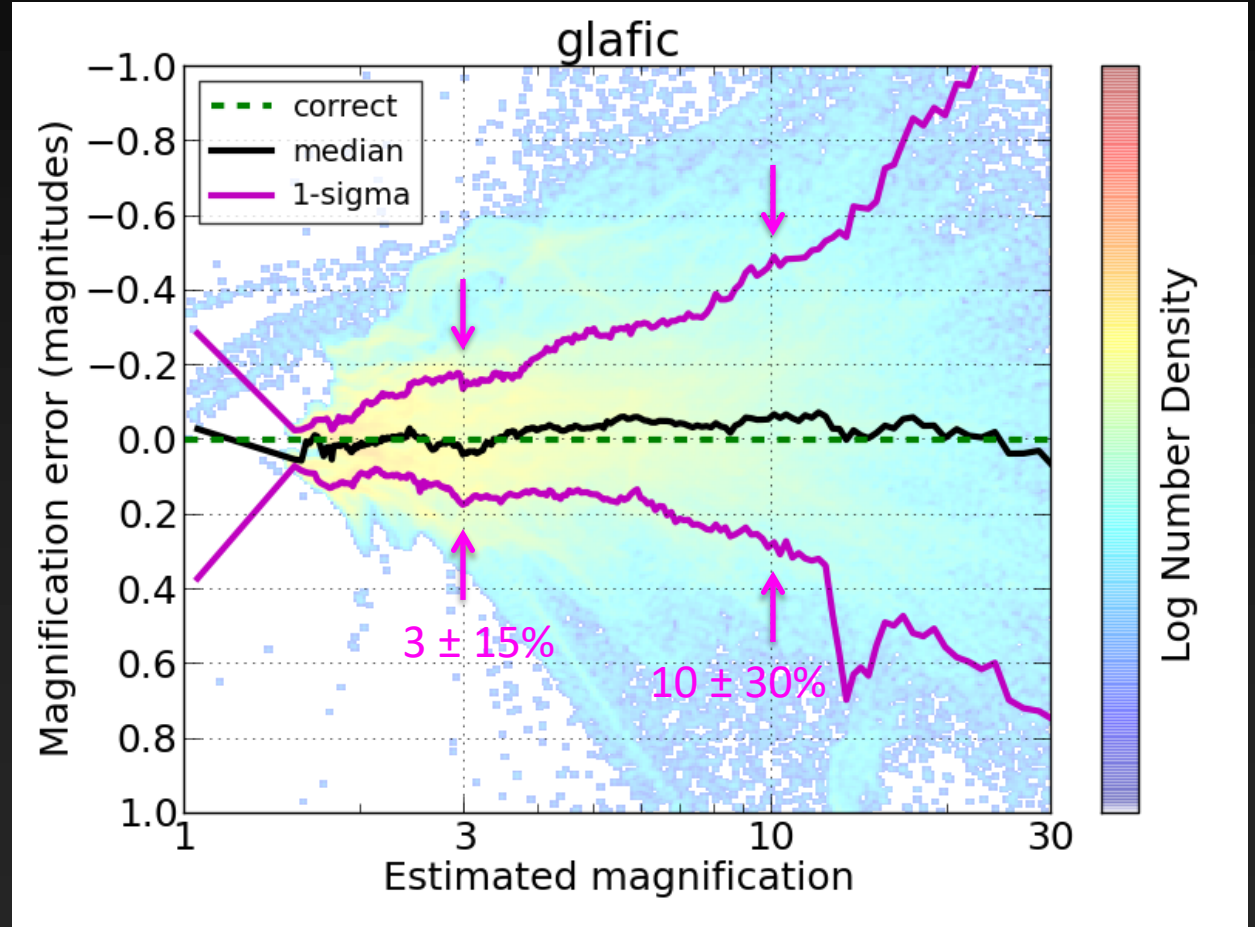
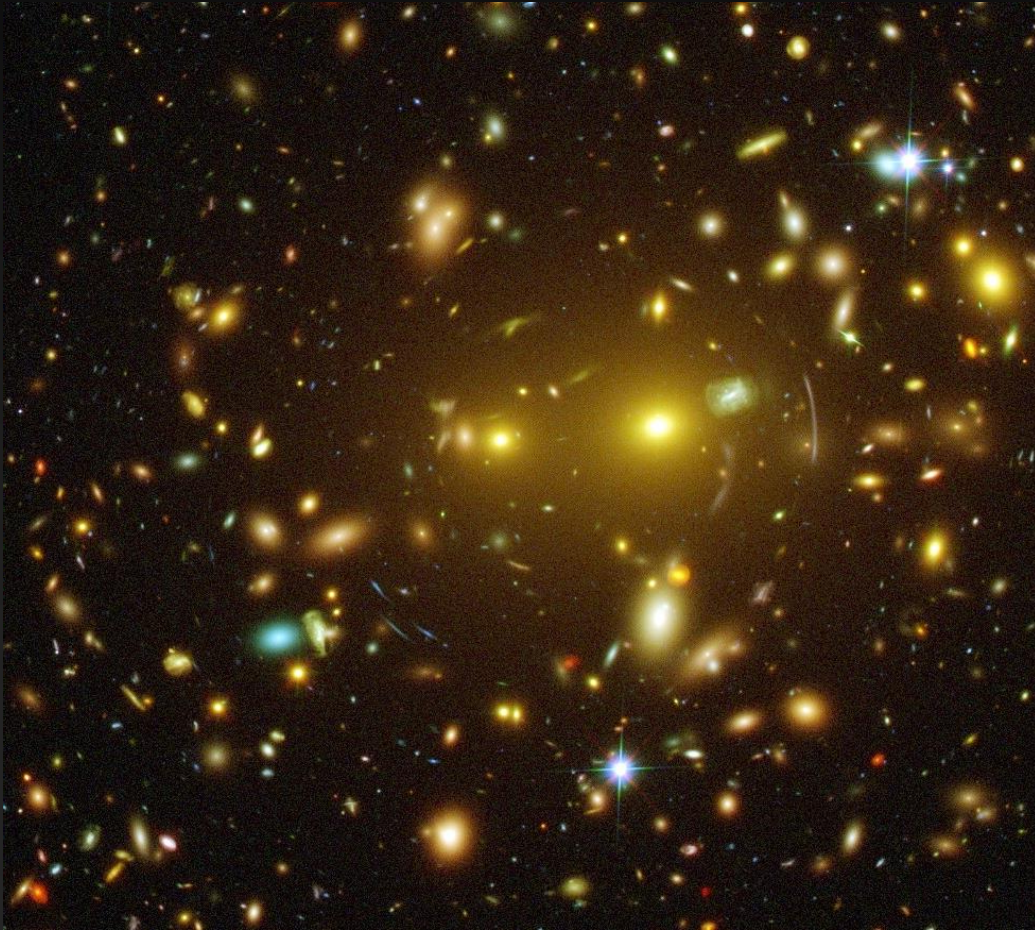
Abell S1063

Abell 370



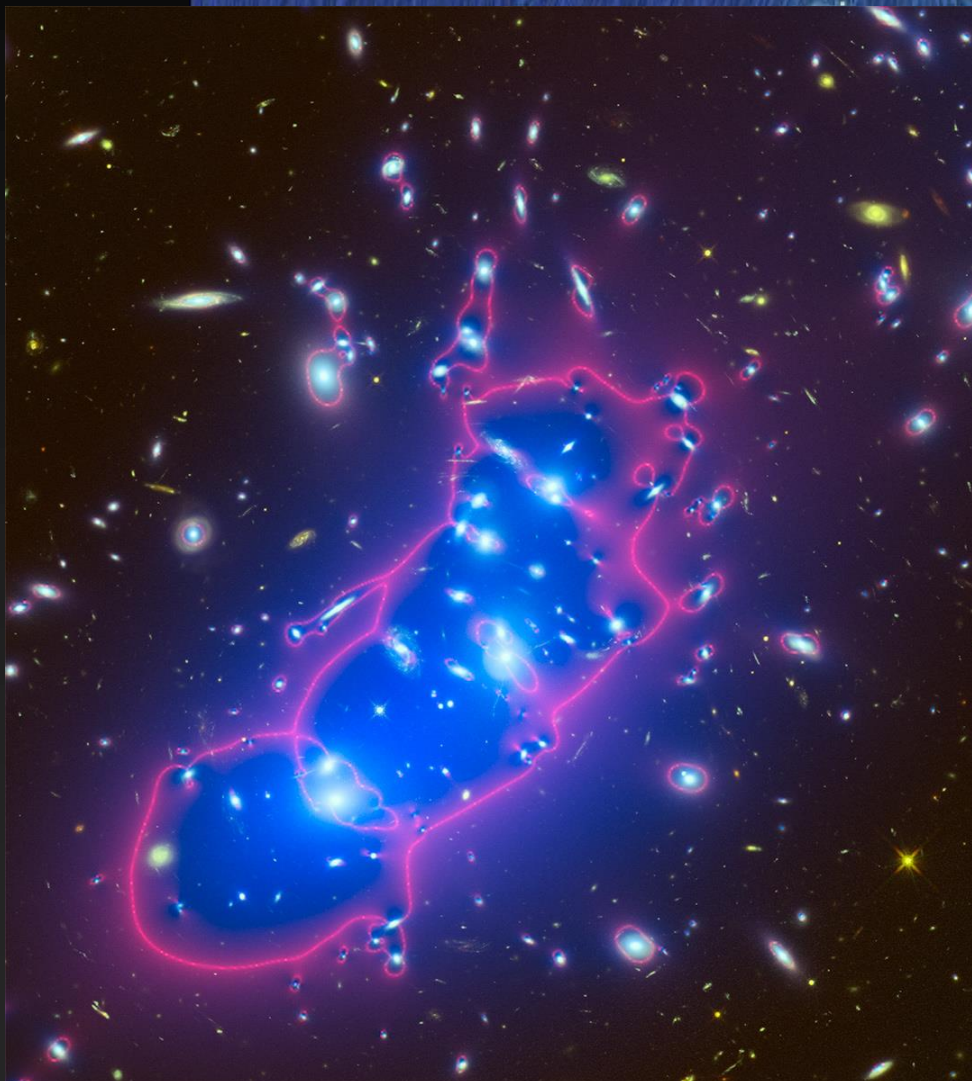
lensing magnification uncertainties quantified

galaxy cluster simulations + lensing analyses (Meneghetti+17)



public lensing magnification estimates

brought lensing community together



archive.stsci.edu/prepds/frontier/lensmodels/webtool/output_000879_JD1C.html

archive.stsci.edu/prepds/frontier/lensmodels/webtool/output_000879_JD1C.html

Hubble Frontier Fields lens model magnification estimates

Output saved to [output_000879_JD1C.html](#)

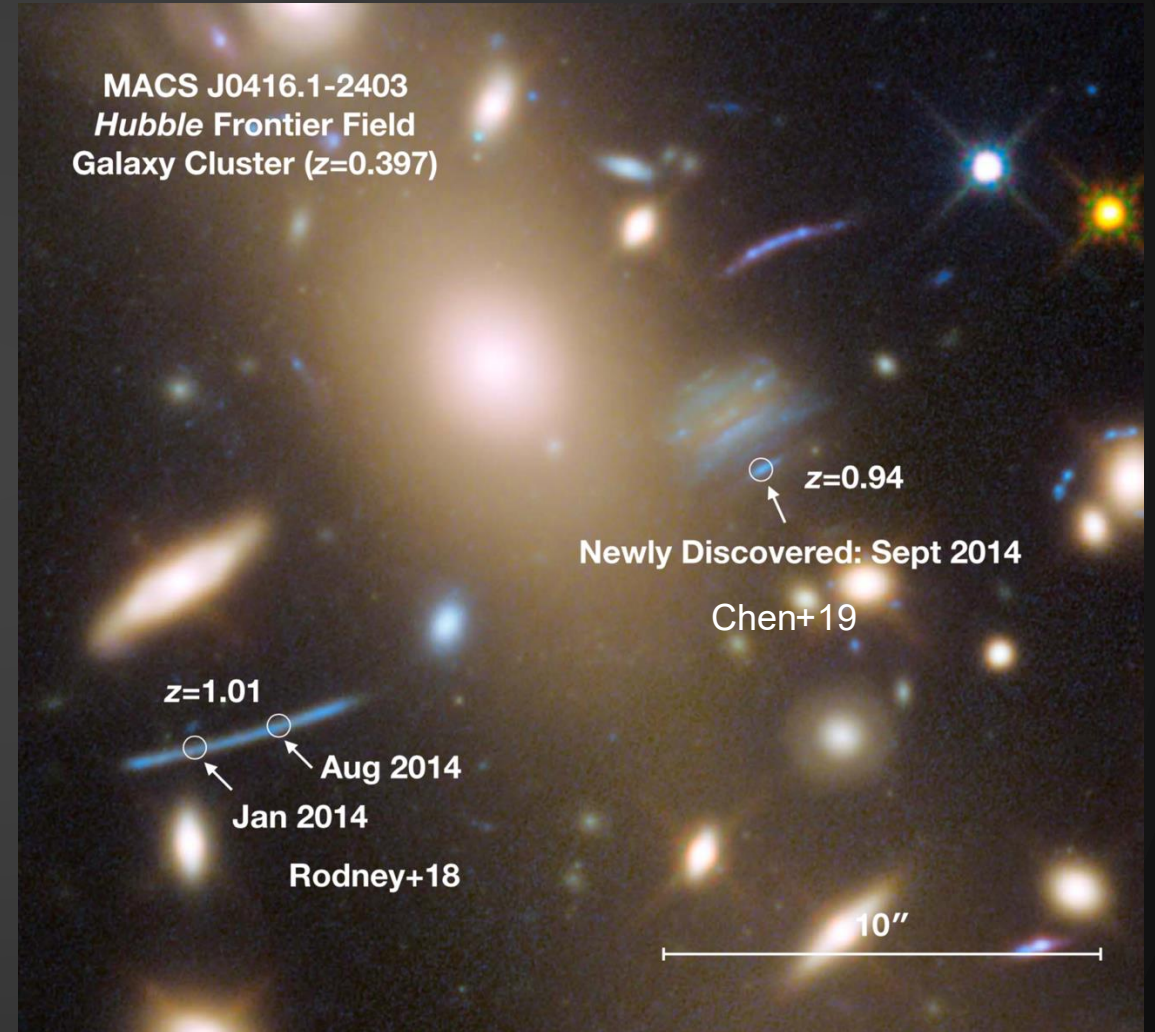
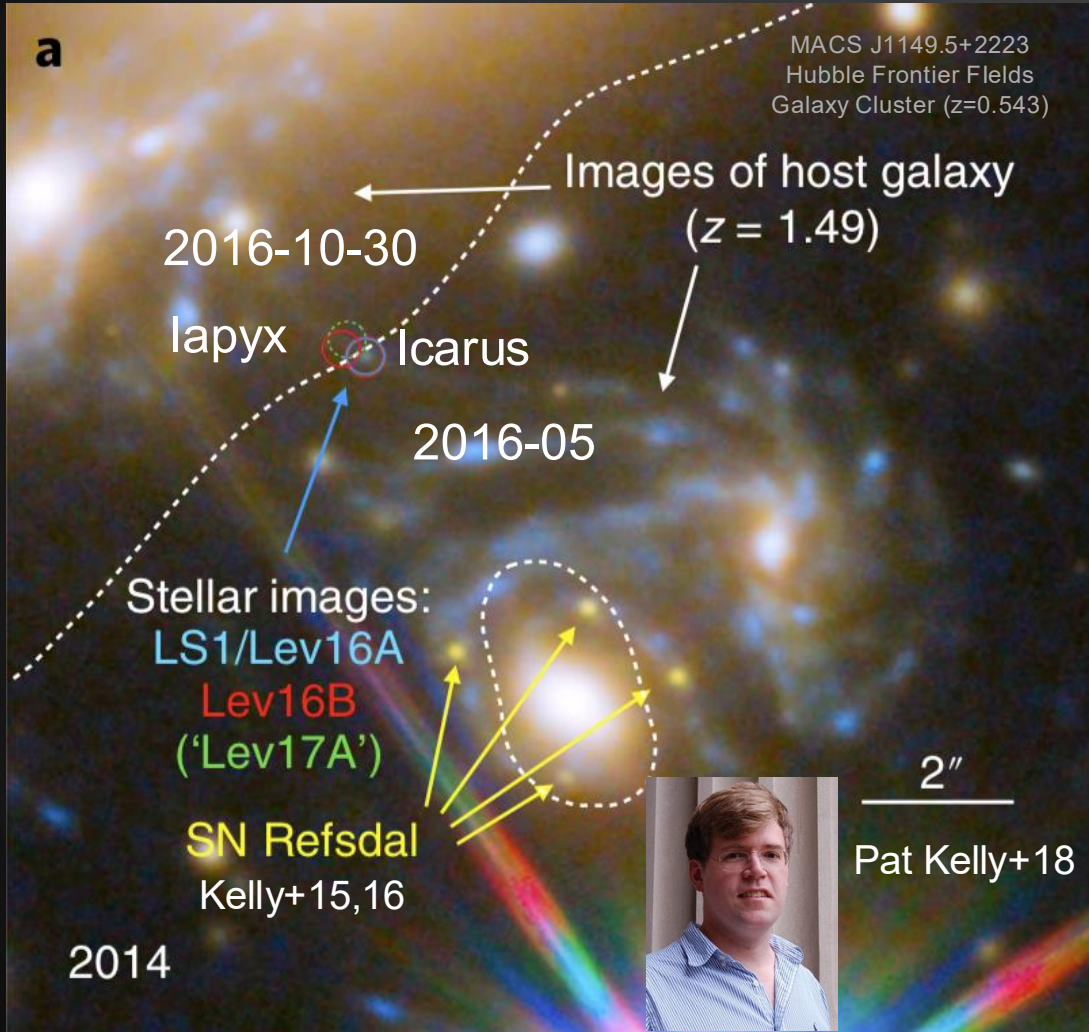
Lensing cluster: Abell 2744 ($z = 0.308$)

Lensed source ($z = 9.8$):
 RA, Dec = (00:14:18.607, -30:24:31.36) = (3.57753, -30.40871)
 observed radius = 0.0 arcseconds

Magnification estimates with uncertainties from multiple teams

CATS	2.95 best;	$2.99^{+0.06}_{-0.05}$	[2.93, 3.05]	median and 68.3% confidence range
CATSv2				
Sharon	2.81 best;	$2.70^{+0.20}_{-0.11}$	[2.60, 2.90]	median and 68.3% confidence range
Sharonv2	2.92 best;	$2.86^{+0.16}_{-0.08}$	[2.78, 3.02]	median and 68.3% confidence range
Zitrin-NFW	2.95 best;	$3.65^{+1.13}_{-0.76}$	[2.89, 4.78]	median and 68.3% confidence range
Zitrin-LTM	37.07 best;	$5.41^{+4.60}_{-1.81}$	[3.60, 10.01]	median and 68.3% confidence range
Zitrin-LTM-Gauss				
GLAFIC	3.08 best;	$3.02^{+0.17}_{-0.18}$	[2.84, 3.18]	median and 68.3% confidence range
Williams	1.48 best;	$1.52^{+0.17}_{-0.19}$	[1.33, 1.69]	median and 68.3% confidence range
Williamsv2				
Bradac	4.59 best;	$3.45^{+0.37}_{-0.41}$	[3.04, 3.82]	median and 68.3% confidence range
Merten	2.76 best;	$7.76^{+14.29}_{-3.03}$	[4.74, 22.05]	median and 68.3% confidence range

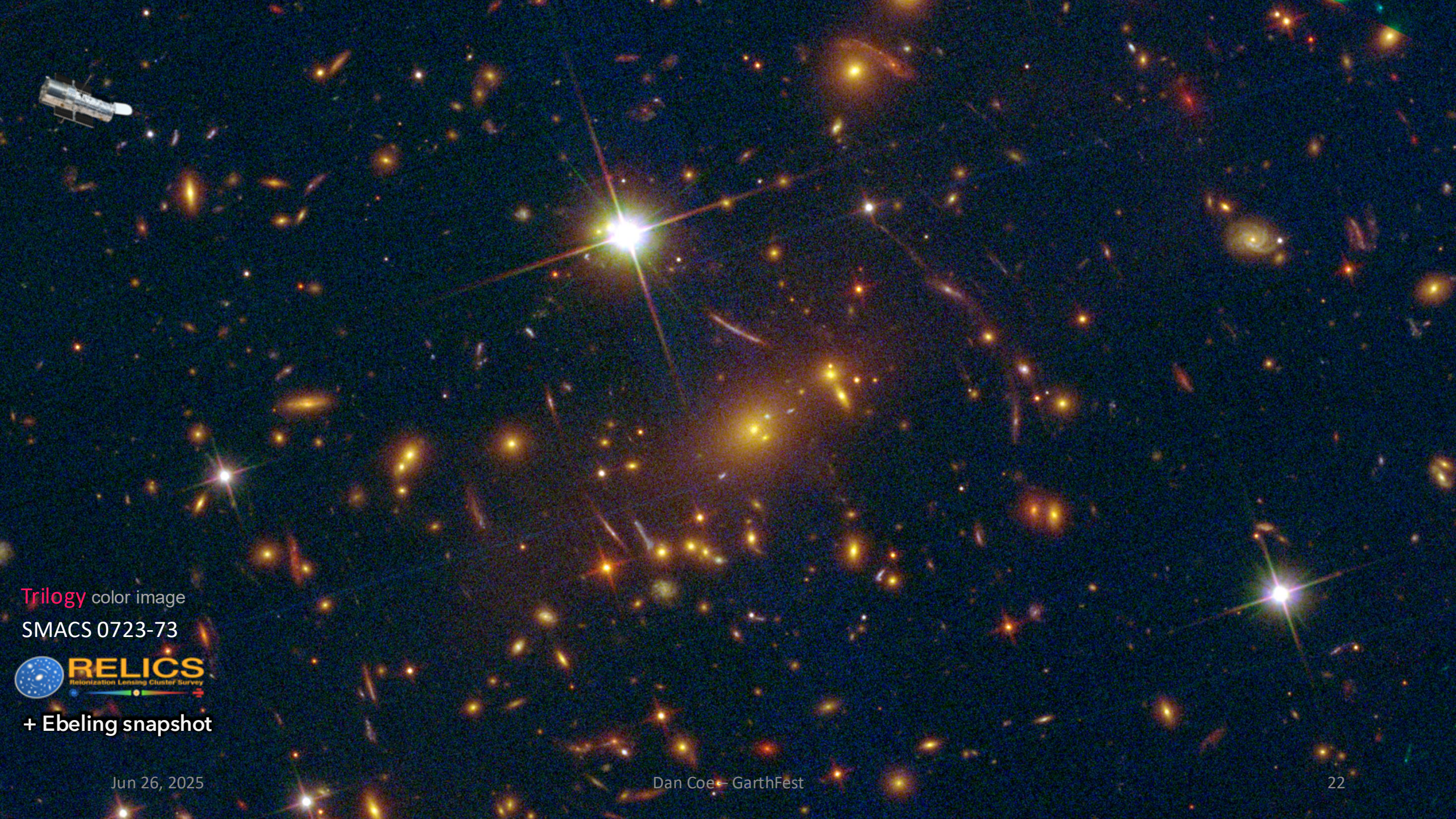
Individual stars discovered at $z \sim 1 - 1.5$



Wedding cake of large lensing surveys



HST orbits	# clusters	Depth: orbits / cluster
840	6	140
524	25	20
188	41	5



Trilogy color image

SMACS 0723-73



+ Ebeling snapshot

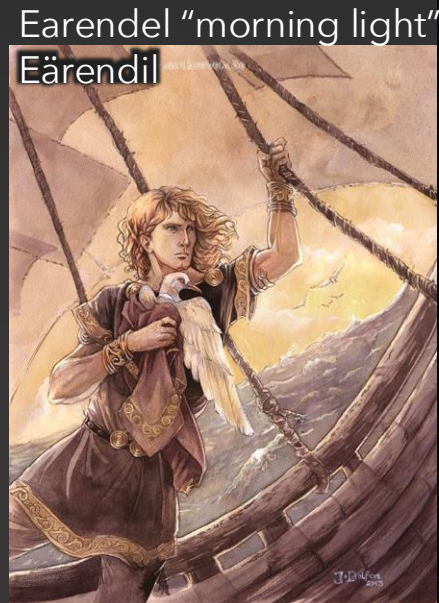


JWST was designed to study the first stars

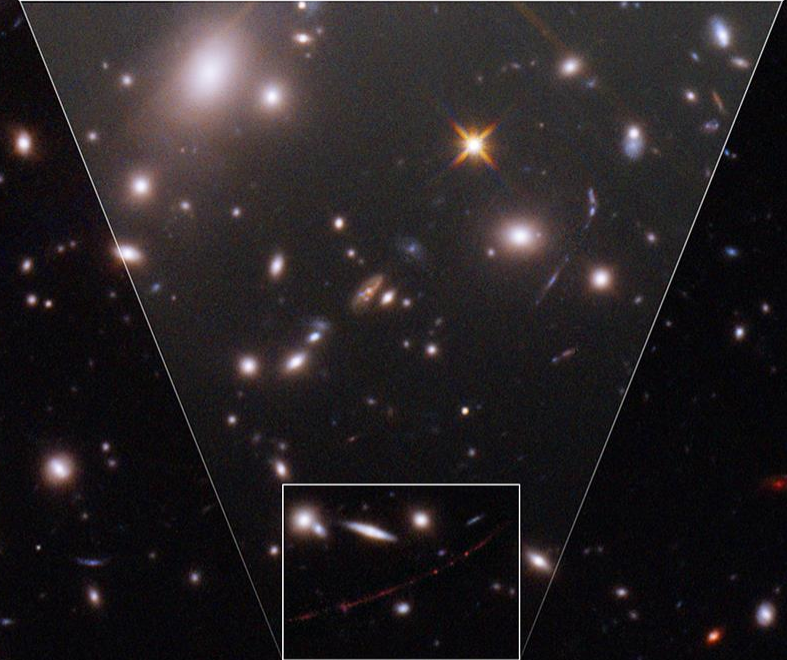
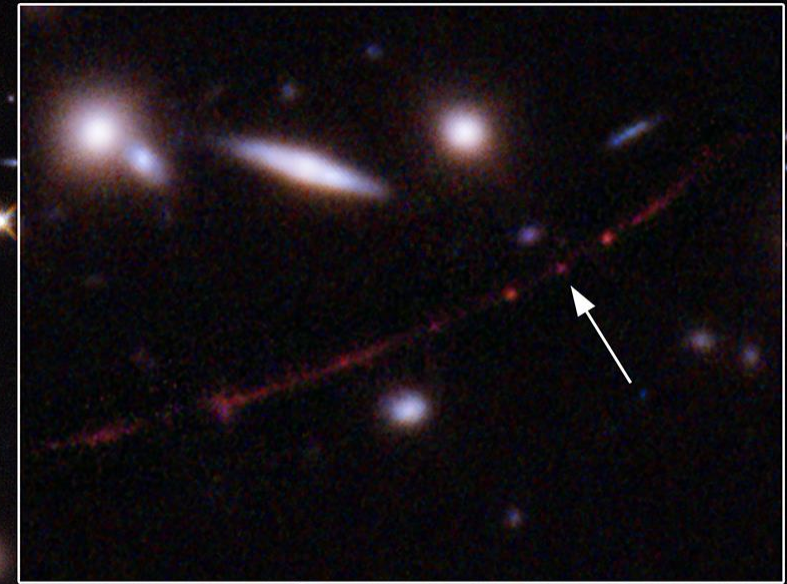
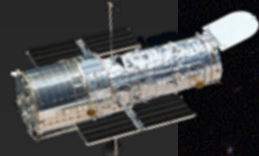
We found one with Hubble to look at with JWST

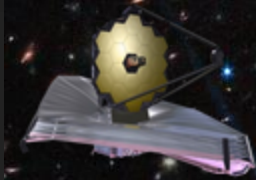
Earendel $z = 6$ star system observed 1 Gyr after the Big Bang magnified by thousands

Brian Welch et al. 2022 Nature



WHL0137-08





Cosmic Spring

JWST
collaborative
spirit

some of the many folks
who have contributed



Abdurro'uf
Tiger Hsiao
Keduse Worku
Brian Welch
Gourav Khullar
Guillaume Mahler
Ashish Kumar Meena
Lukas Furtak
Yolanda Jiménez-Teja
Rosa Newshore
Alex Benitez
Paola Dimauro
Intae Jung
Rebecca Larson
Lily Whitler
Adélaïde Claeysens
Adam Carnall
Jacqueline Antwi-Danso
Ebraheem Farag
Rachana Bhatwadekar
Meridith Joyce
Wenlei Chen
Sinclair Manning

Seiji Fujimoto
Taylor Hutchison
Lamiya Mowla
Vasily Kokorev
Namrata Roy
Xinfeng Xu
Victoria Strait
Karthik Iyer
Ramesh Mainali
Adam Casselman
Lillian Santos-Olmsted
Anton Vikaeus
Patricia Bolan
David Nicholls
Peter Senchyna
Ikko Shimizu
Mengtao Tang
Tom Resseguier
Janvi Madhani
Celia Mulcahey
Kyle O'Connor
Javier Alvarez
Alejandro Crespo

Larry Bradley
Eros Vanzella
Angela Adamo
Gabriel Brammer
Dan Coe
Jose Maria Diego
Rogier Windhorst
Adi Zitrin
Mario Nonino
Kirk Barrow
Marusa Bradac
Pratika Dayal
Megan Donahue
Selma E. de Mink
Erik Zackrisson
Jay Anderson
Stephan McCandliss
Steven Finkelstein

Swara Ravindranath
Brenda Frye
Patrick Kelly
Nir Mandelker
Masamune Oguri
Keren Sharon
Christopher Conselice
Frank Timmes
Jan Eldridge
Colin Norman
Dan Stark
Jinmi Yoon
Lisa Kewley
Pascal Oesch
Marc Postman
Tom Broadhurst
Alaina Henry
Bethan James

Jane Rigby
Lou Strolger
Francesco Valentino
Ana Acebron
Gabriel B. Caminha
Christian Binggeli
Michael Florian
Masami Ouchi
Roberto Avila
Susan Kassin
Nor Pirzkal
Russell Ryan
David Law
Felipe Andrade-Santos
Takahiro Morishita
Matthew Bayliss

Jun 26, 2025

Dan Coe – GarthFest

Cosmic Spring JWST follow up of Hubble's best & brightest lensed high-z galaxies



Distant Galaxy Lensed by Cluster MACS J0647

HST ■ ACS ■ WFC3

MACS0647-JD ($z \sim 11$)
most distant lensed galaxy
with Hubble

JD3

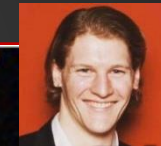
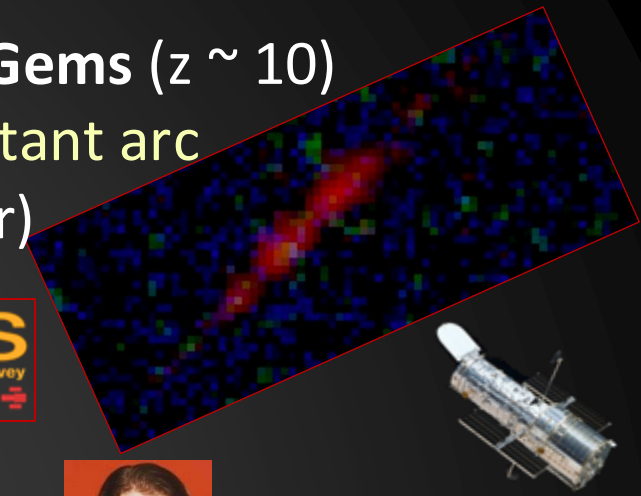
JD1

JD2

Cosmic Spring

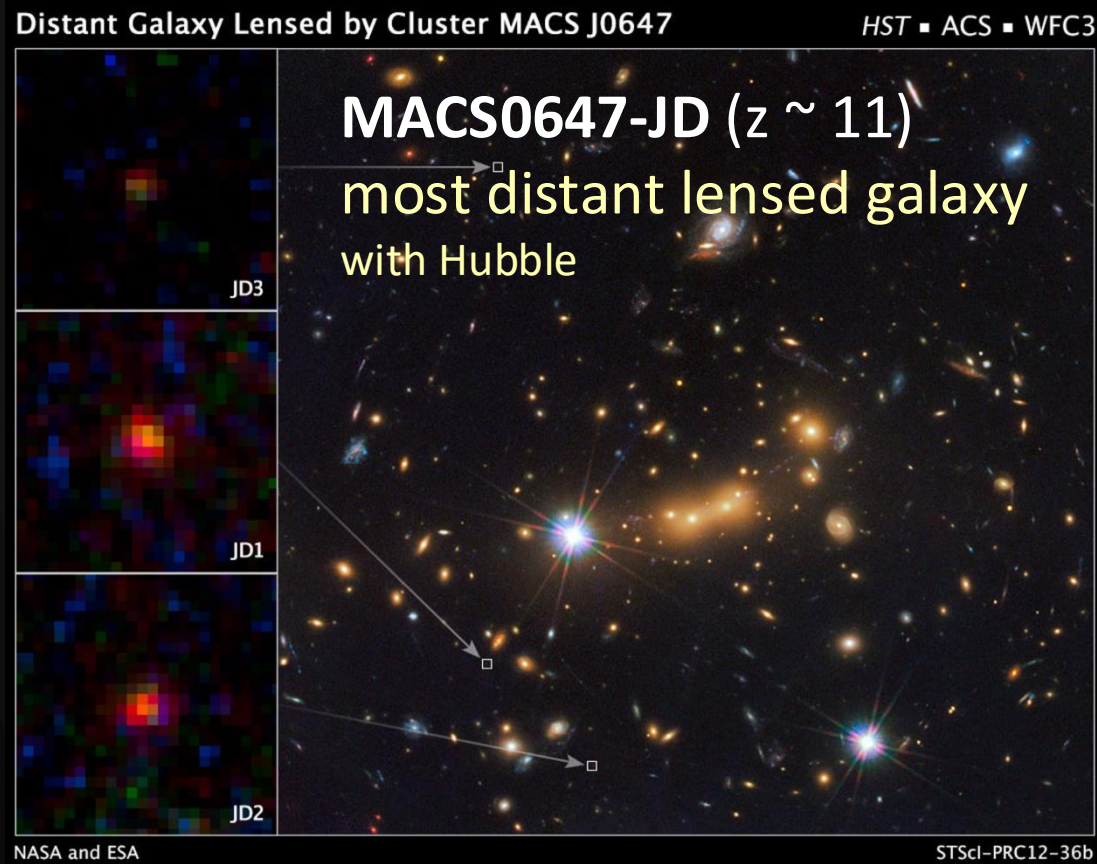
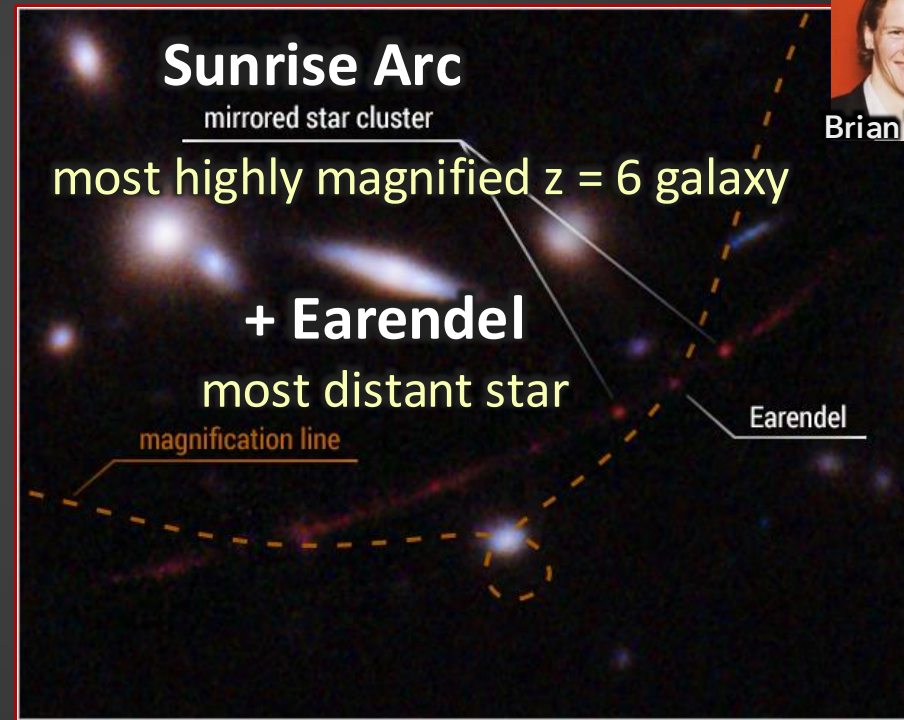
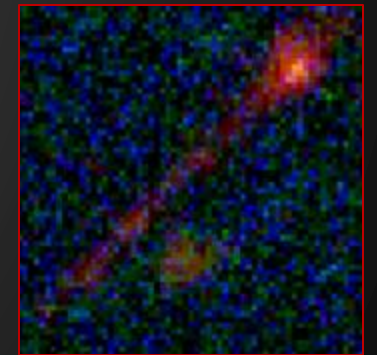
JWST follow up of Hubble's best & brightest lensed high-z galaxies

Cosmic Gems ($z \sim 10$)
most distant arc
(500 Myr)



Brian Welch

MACS0308-zD1
brightest $z > 6$
galaxy ($H \sim 23.3$)



Cosmic Spring

cosmic-spring.github.io
public data, code, papers

JWST
collaborative
spirit



Abdurro'uf
JHU → Indiana



Tiger Hsiao
JHU / Harvard
→ Austin CFC



Keduse Worku
JHU



Tom Resseguier
JHU



Rebecca Larson
RIT → STScI



Intae Jung
STScI



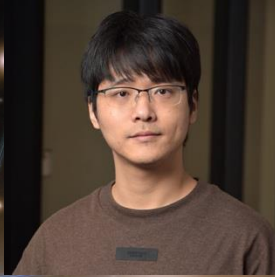
Calum Hawcroft
STScI



Brian Welch
GSFC → ISSI



Taylor Hutchison
GSFC



Xinfeng Xu
Northwestern

other

- 2312.03065 Meghana Killi $z = 4.5$ Little Red Dot
- 2301.02209 Abdurro'uf $z = 0.3 - 6$ resolved galaxies
- 2309.02504 Anton Vikaeus $z \sim 6 - 11$ Balmer breaks
- 2210.01777 Larry Bradley $z \sim 9 - 13$ galaxies

$z = 4.8$ lensed star

- 2308.00042 Lukas Furtak
- 2211.13334 Ashish Kumar Meena

Earendel $z = 5.9$ lensed star

- 2208.09007 Brian Welch

Sunrise Arc $z = 5.9$

- 2211.09839 Eros Vanzella

Cosmic Gems arc $z = 9.6$

- 2401.03224 Angela Adamo
- 2404.10770 Larry Bradley
- > in prep. Matteo Messa
- > in prep. Eros Vanzella

MACS0647-JD $z = 10.2$ merger

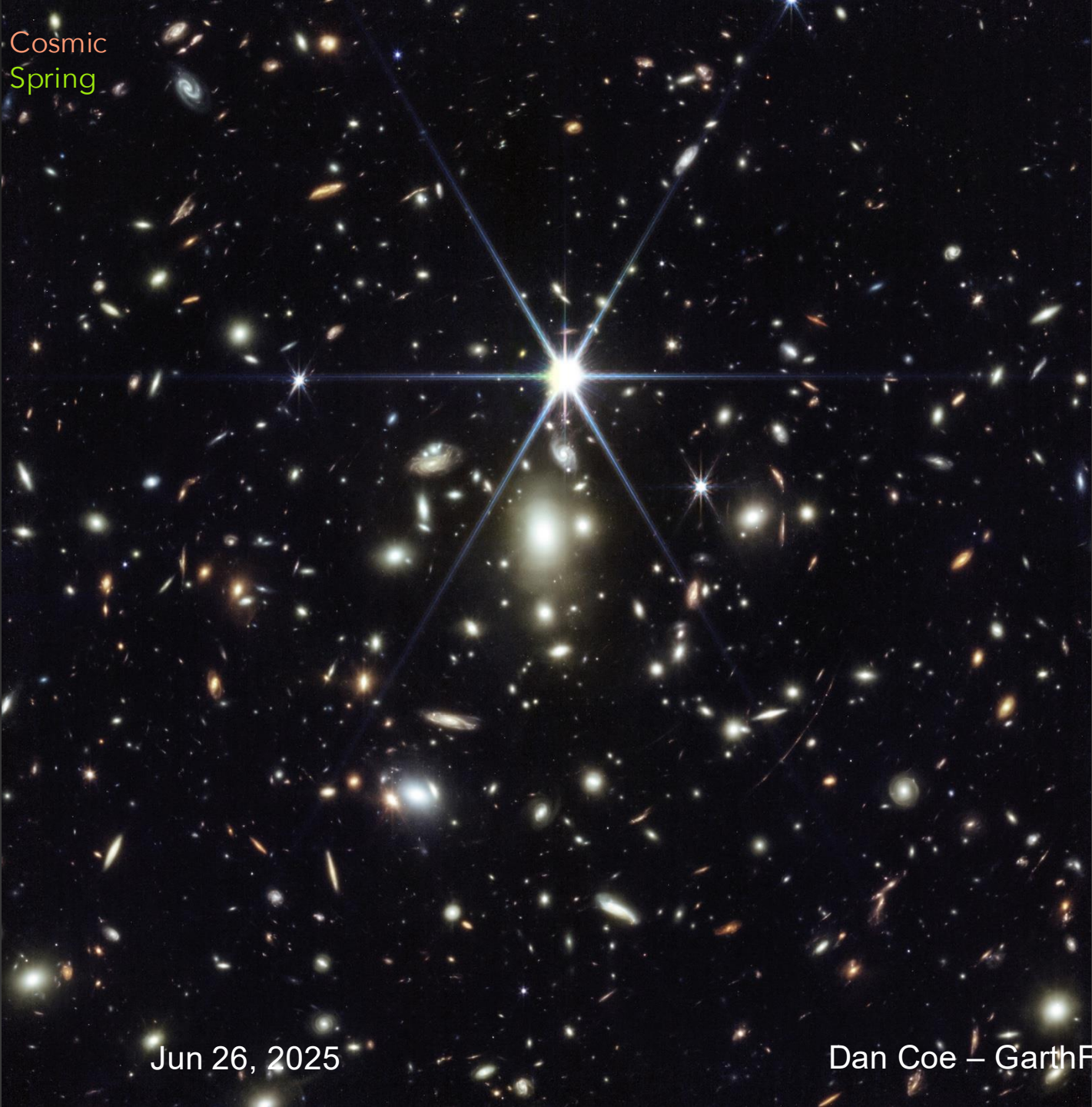
- 2210.14123 Tiger Hsiao
- 2305.03042 Tiger Hsiao
- 2404.16201 Abdurro'uf
- 2210.14123 Tiger Hsiao
- 2404.16201 Abdurro'uf



Brian Welch



Cosmic
Spring



Jun 26, 2025

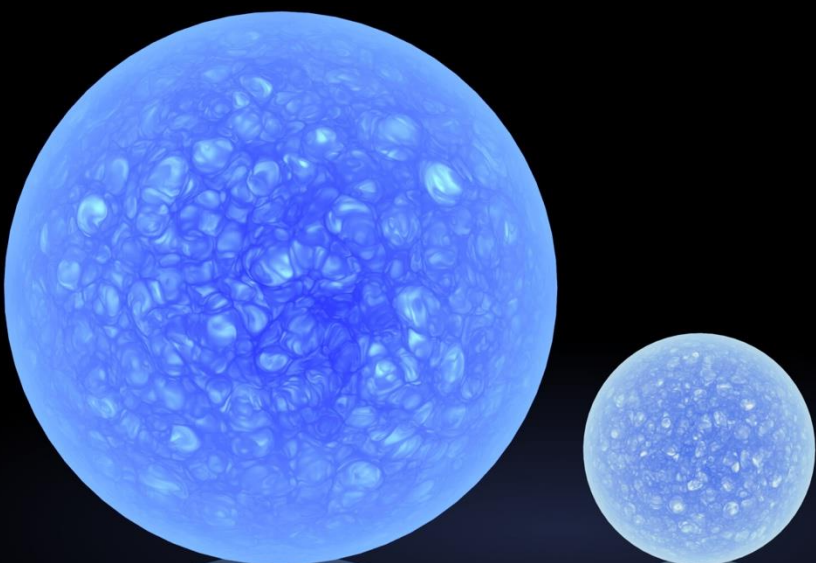
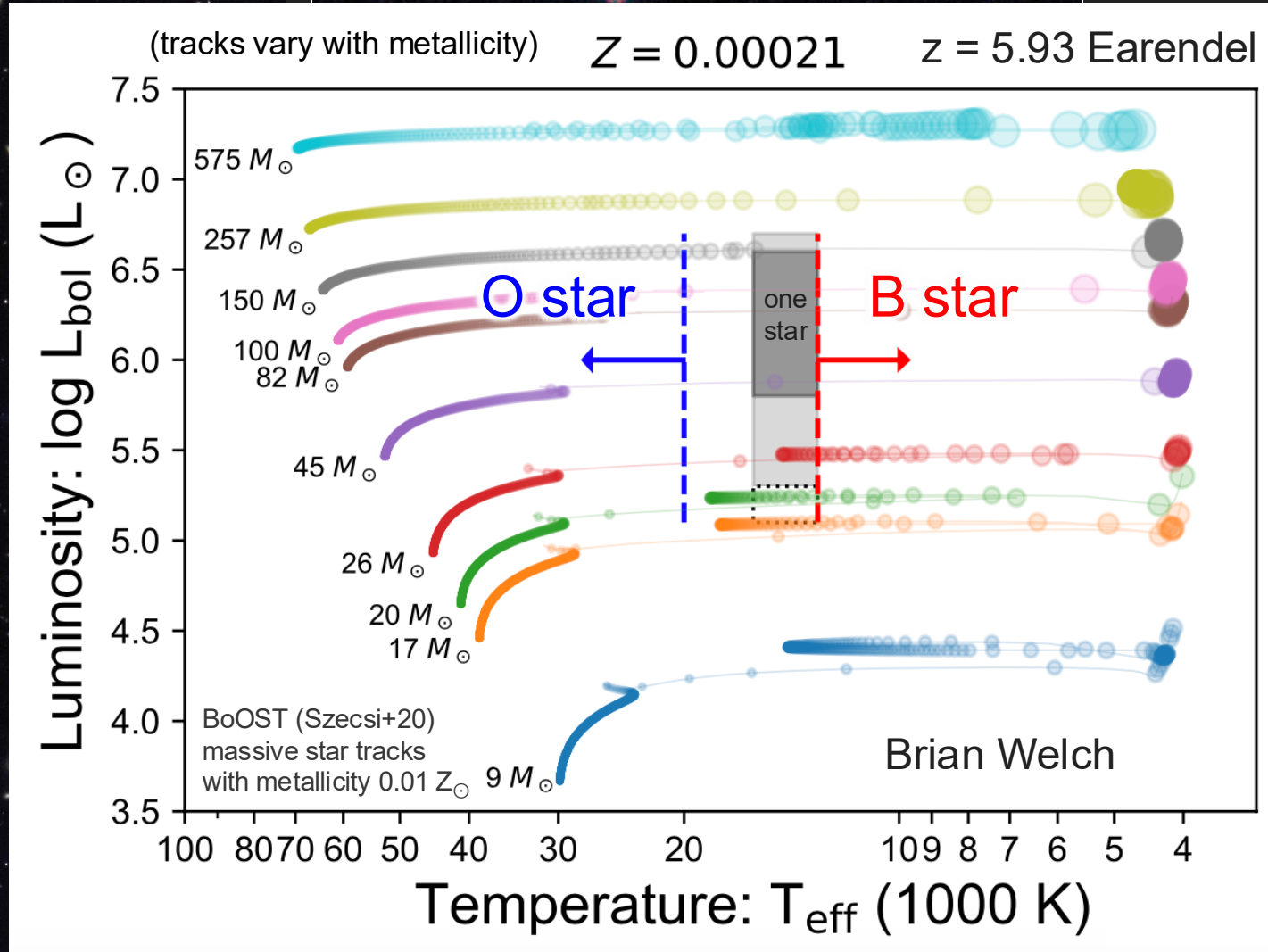
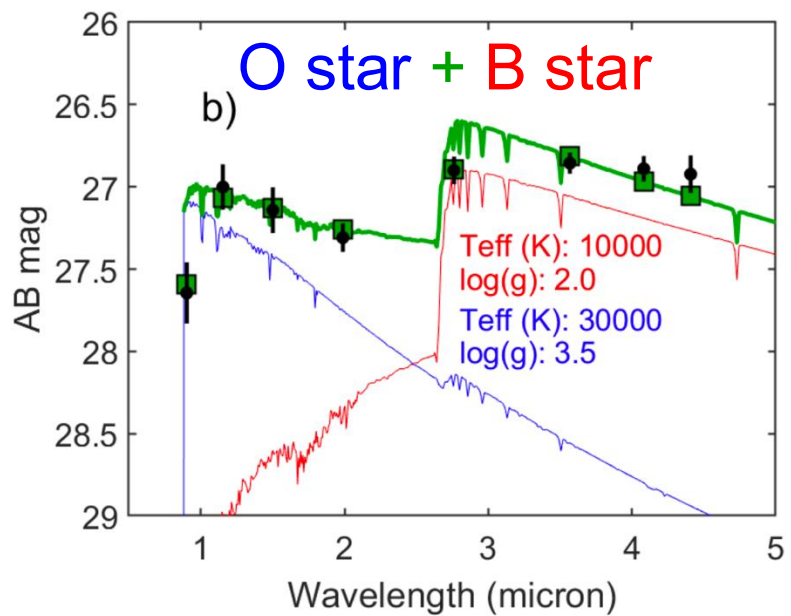
Dan Coe – GarthFest



Earendel
 $z = 5.93$
950 Myr



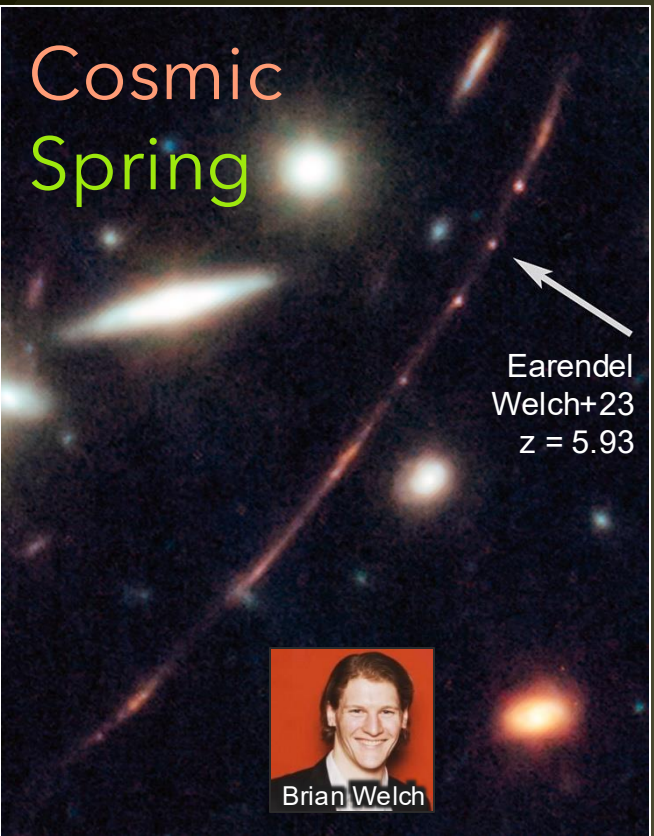
Brian
Welch



Jun 26, 2025 O

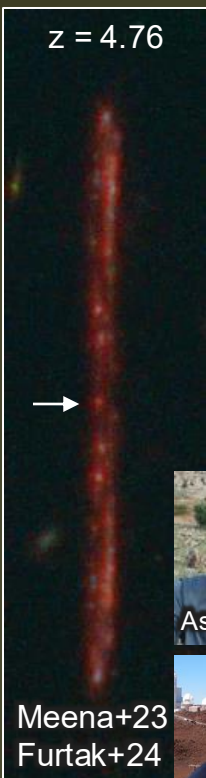
B

Cosmic Spring



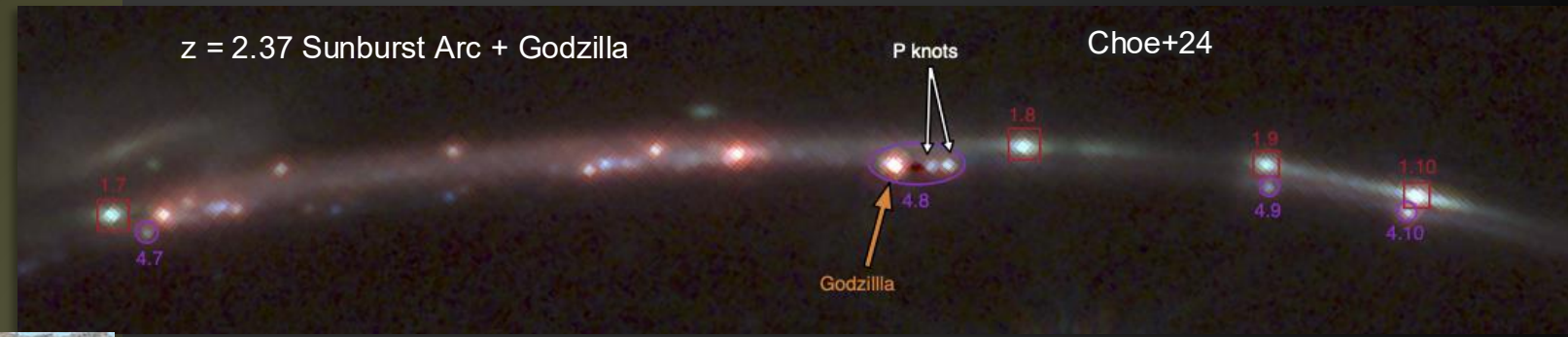
Brian Welch

$z = 4.76$



Individual stars

$z = 2.37$ Sunburst Arc + Godzilla



Choe+24



Asish Meena

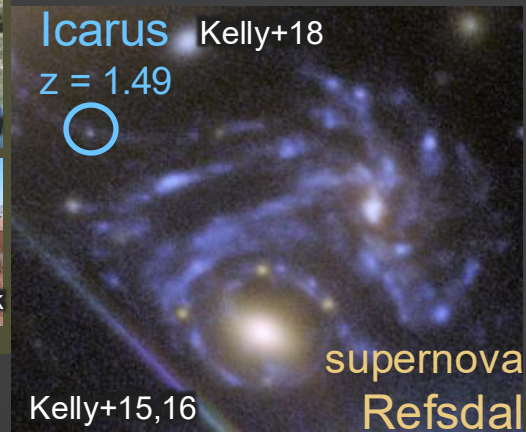


Lukas Furtak

Meena+23
Furtak+24

Icarus Kelly+18

$z = 1.49$



supernova
Refsdal

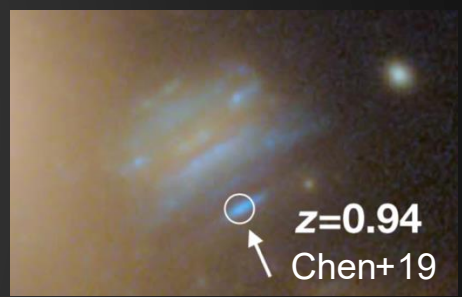
Kelly+15,16

$z=1.01$



Jan 2014

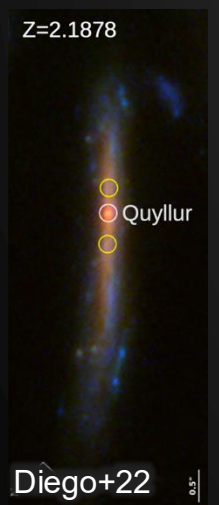
Rodney+18



$z=0.94$

Chen+19

$Z=2.1878$



Quyllur

Diego+22

$Z=2.09$



MOTHRA

Diego+23

$z = 1.78$



supernova
H0pe

Polletta+24

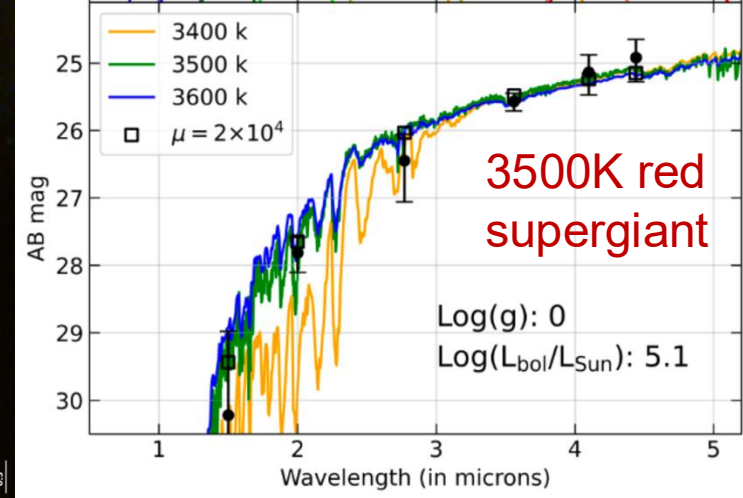
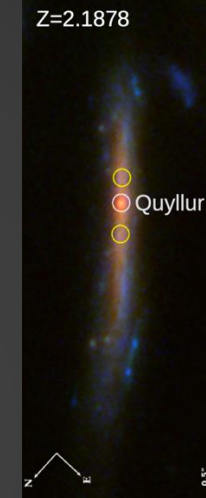
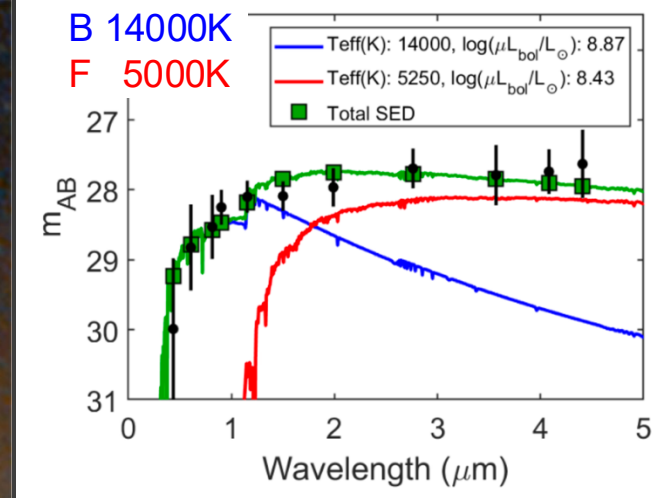
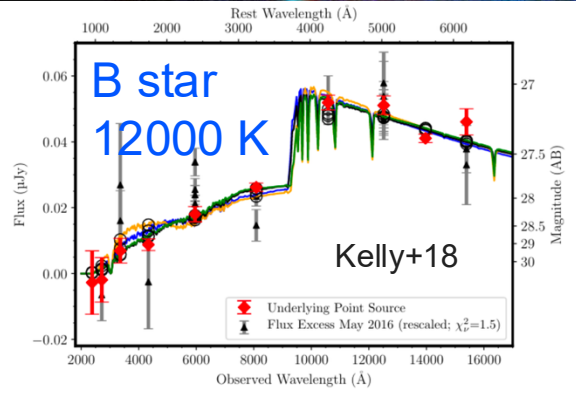
$z = 0.73$ Cosmic Dragon
40 transient stars
Fudamoto+24



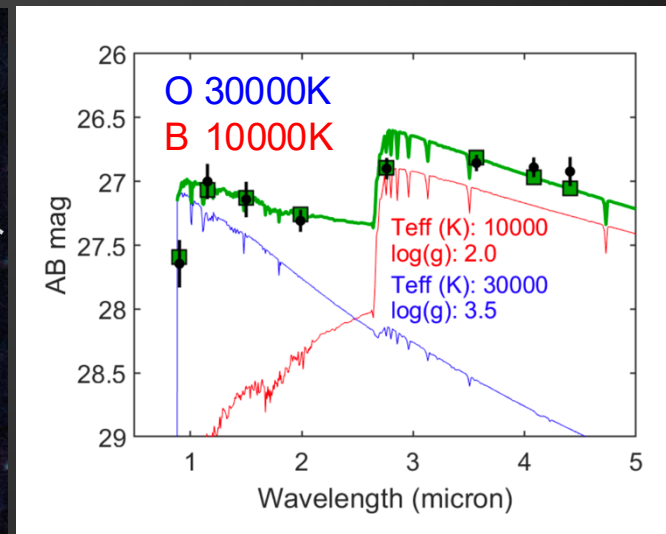
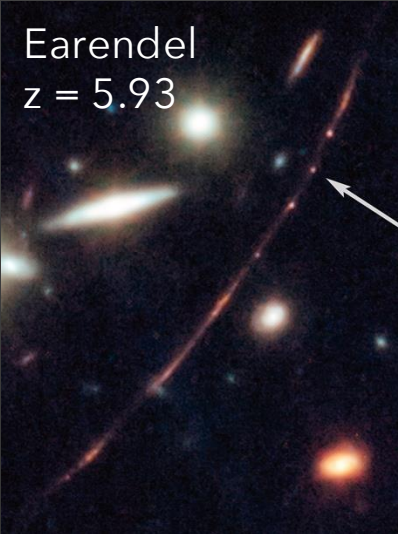
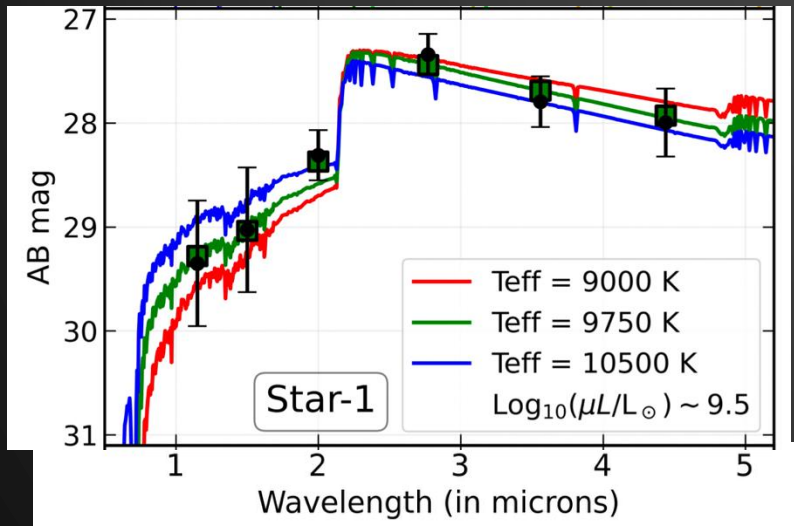
Distant star temperatures



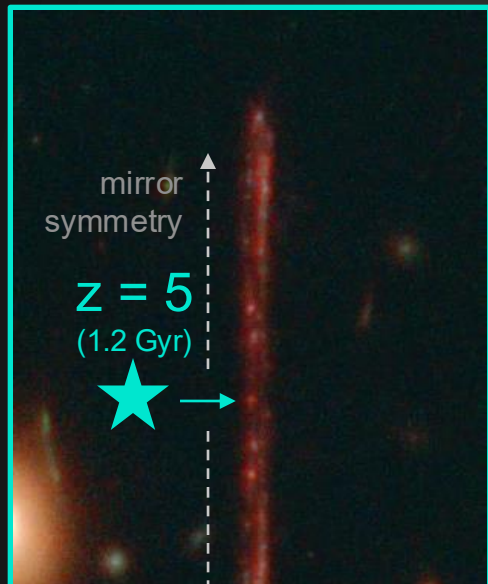
Icarus
z = 1.49



z = 4.76

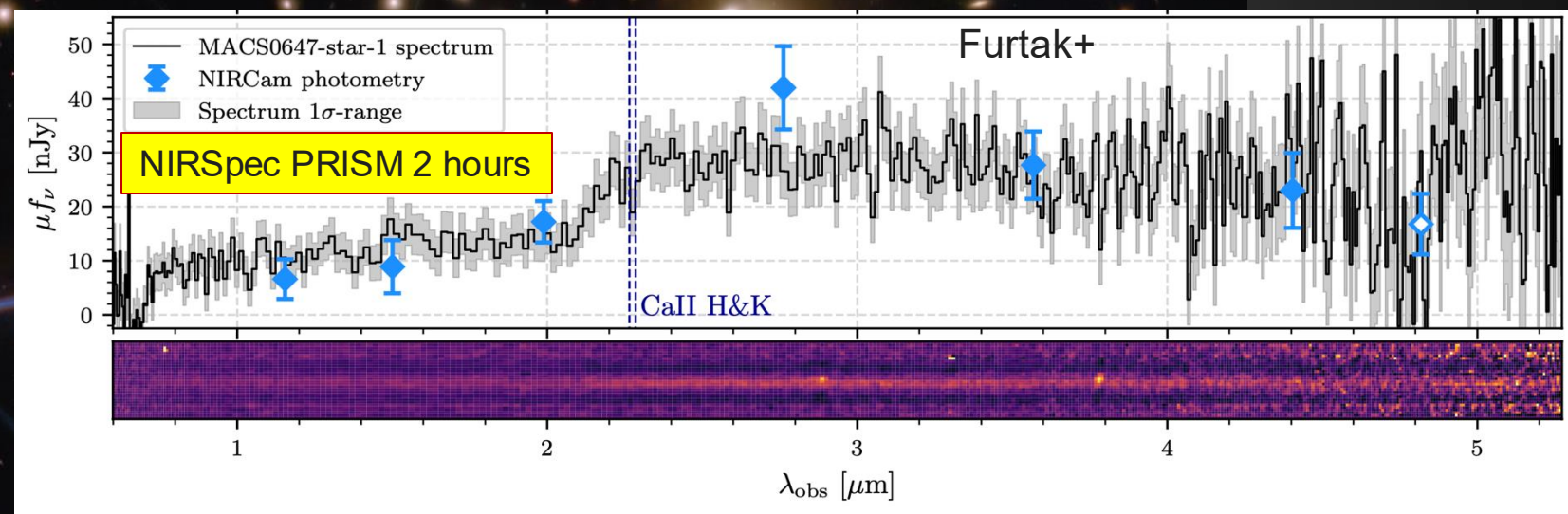
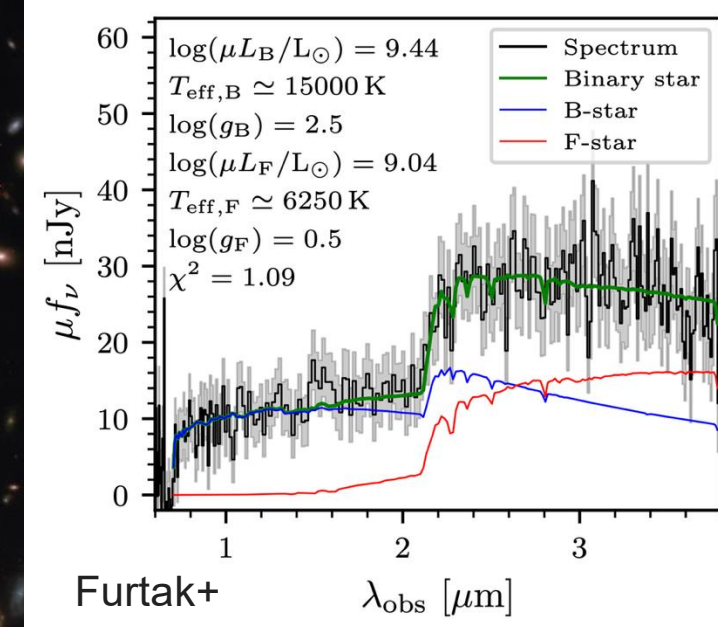
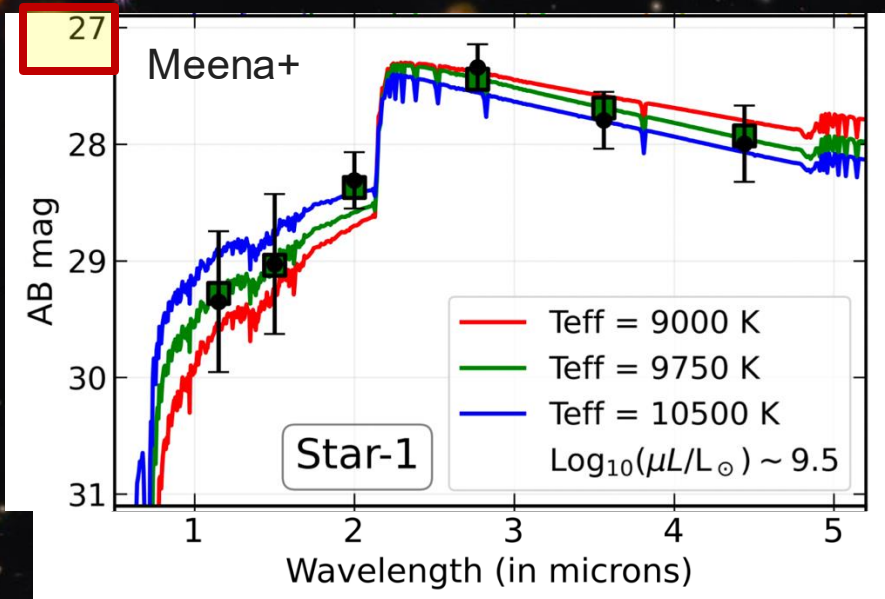


z = 5 star SED and spectrum



Ashish Meena et al.
arXiv:2211.13334

Lukas Furtak et al.
arXiv:2308.00042



MACS 0647+70

Image: Alyssa Pagan

Dan Coe – MIT JWST First Light

Predicted JWST NIRSpec spectra of stars

stellar temperature from continuum, Balmer absorption lines



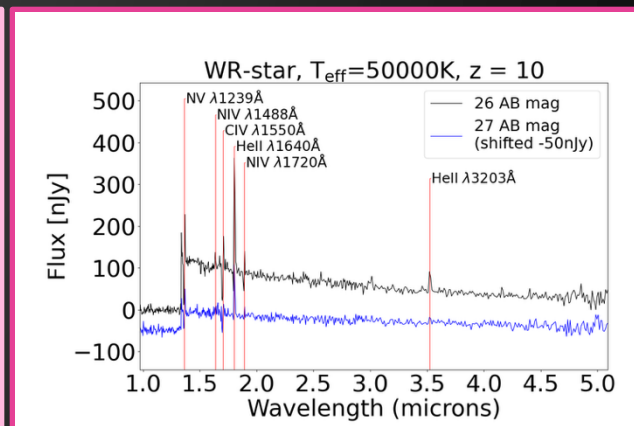
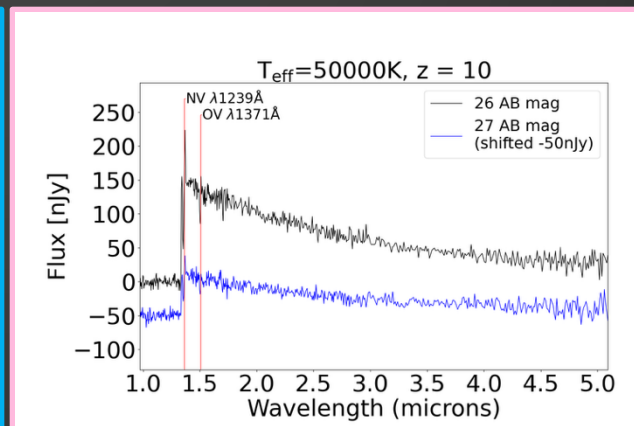
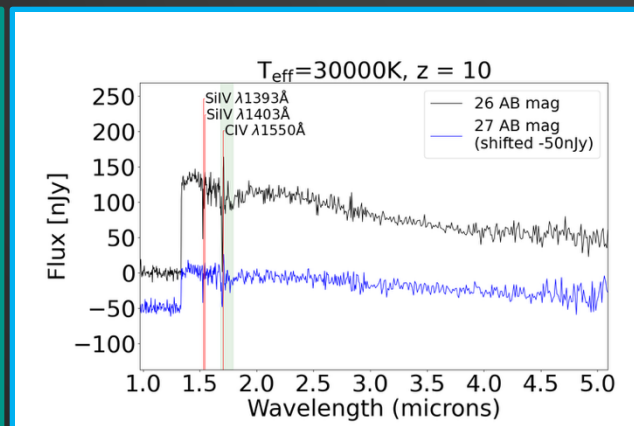
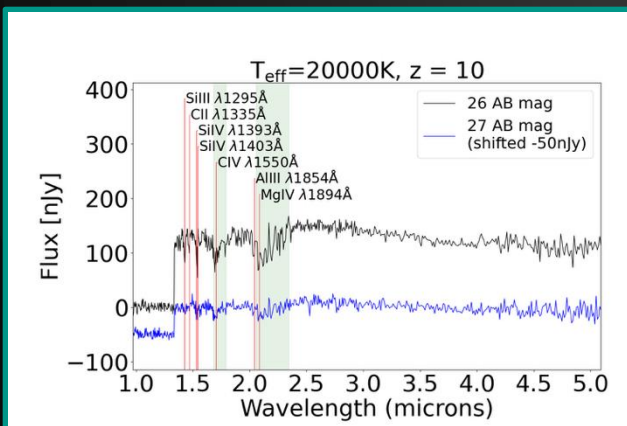
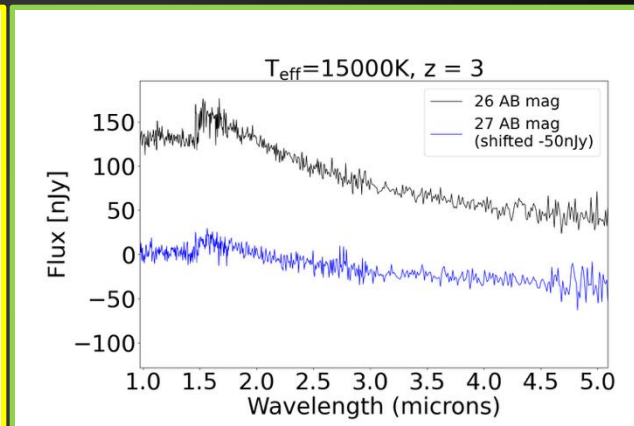
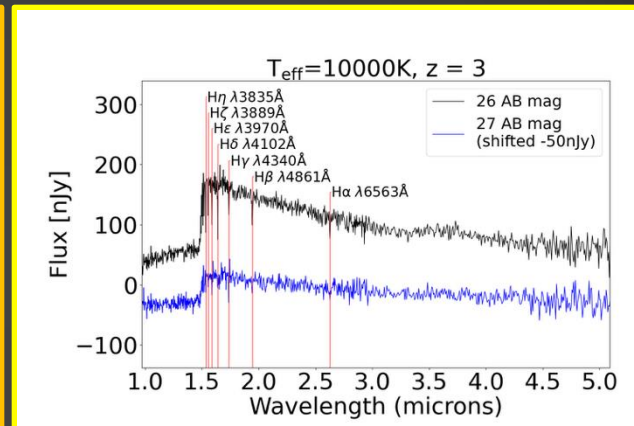
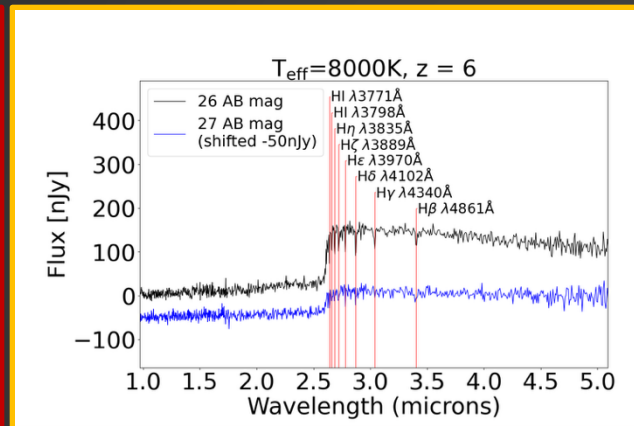
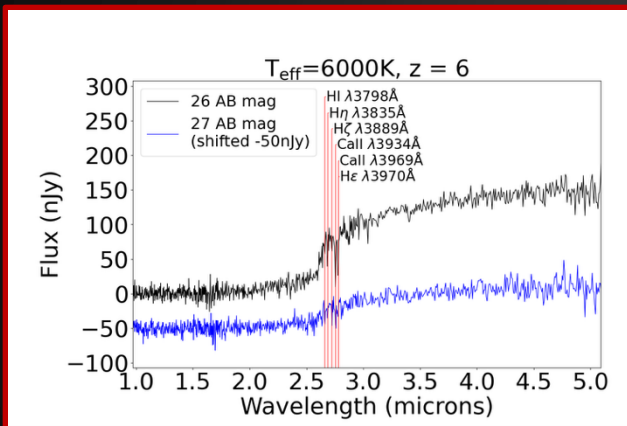
Emma Lundqvist

simulated 50 hours in each medium grating: G140M, G235M, G395M

arXiv:2404.10817



Erik Zackrisson



predicted spectral line features



CIV: outflow wind strength

Emma Lundqvist

($T > 15000\text{K}$)

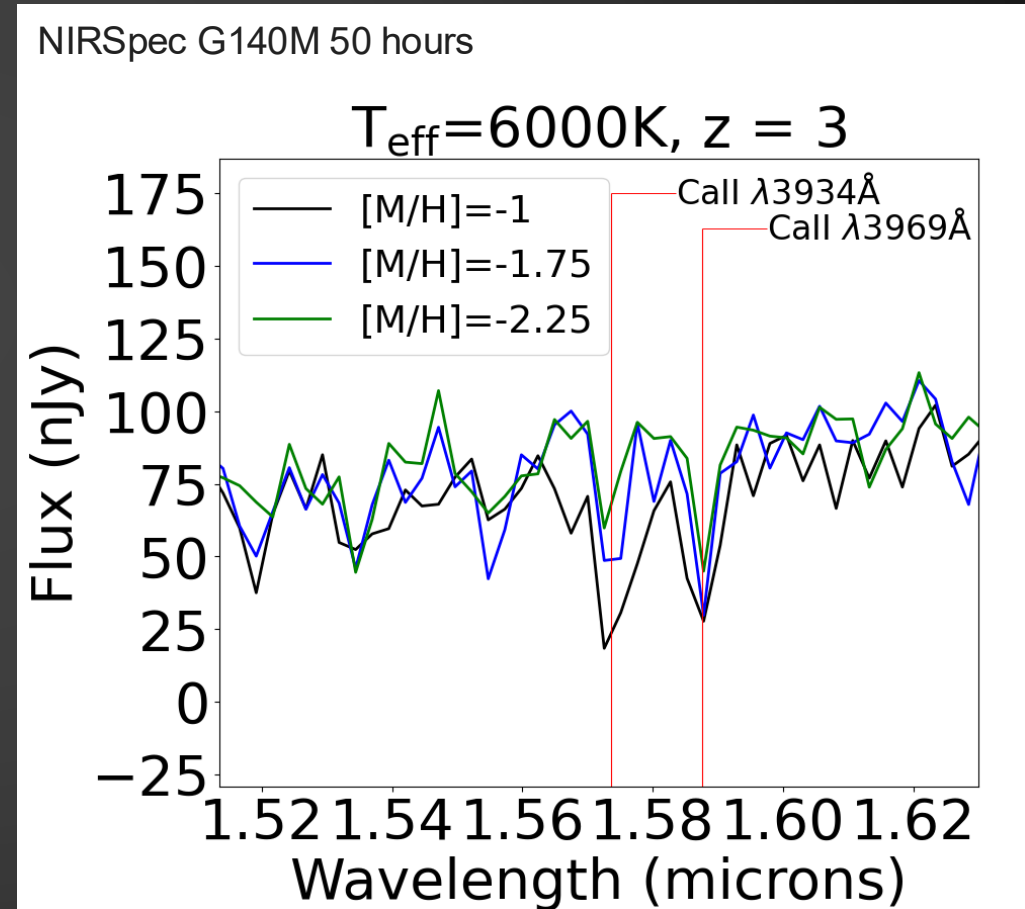
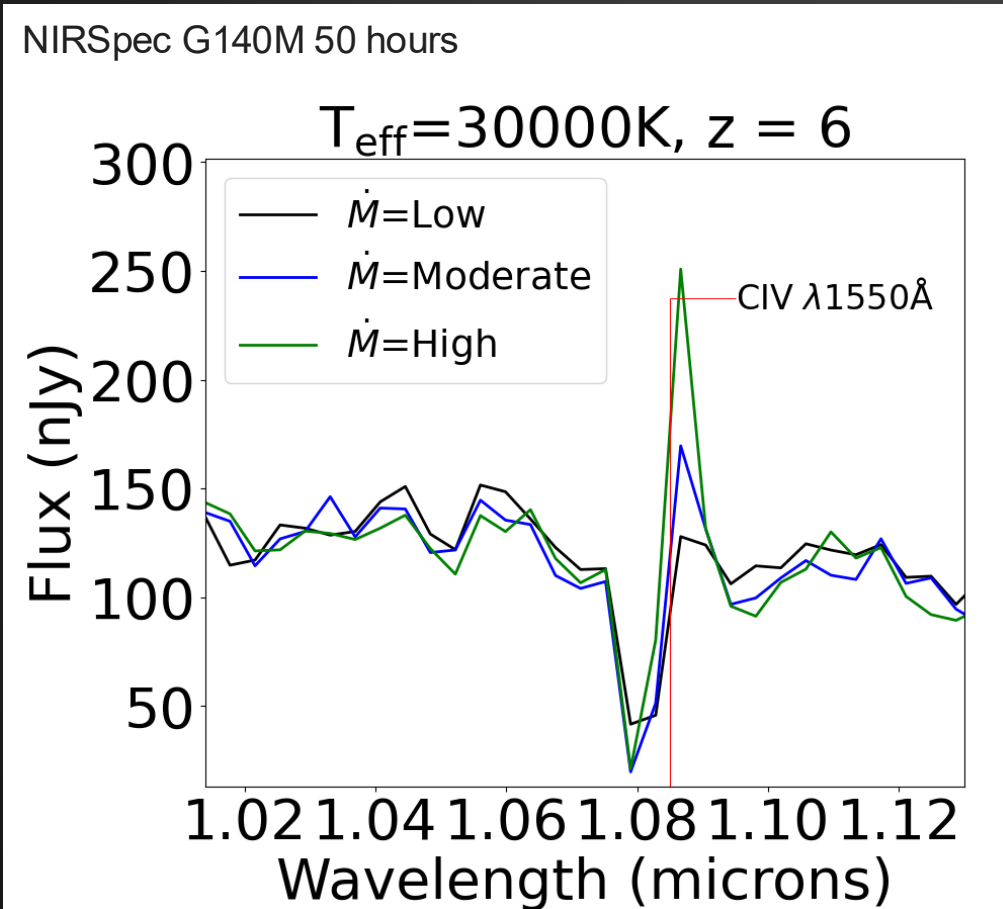
arXiv:2404.10817



Call: **metallicity?**

Erik Zackrisson

($T \sim 6000\text{K}$)

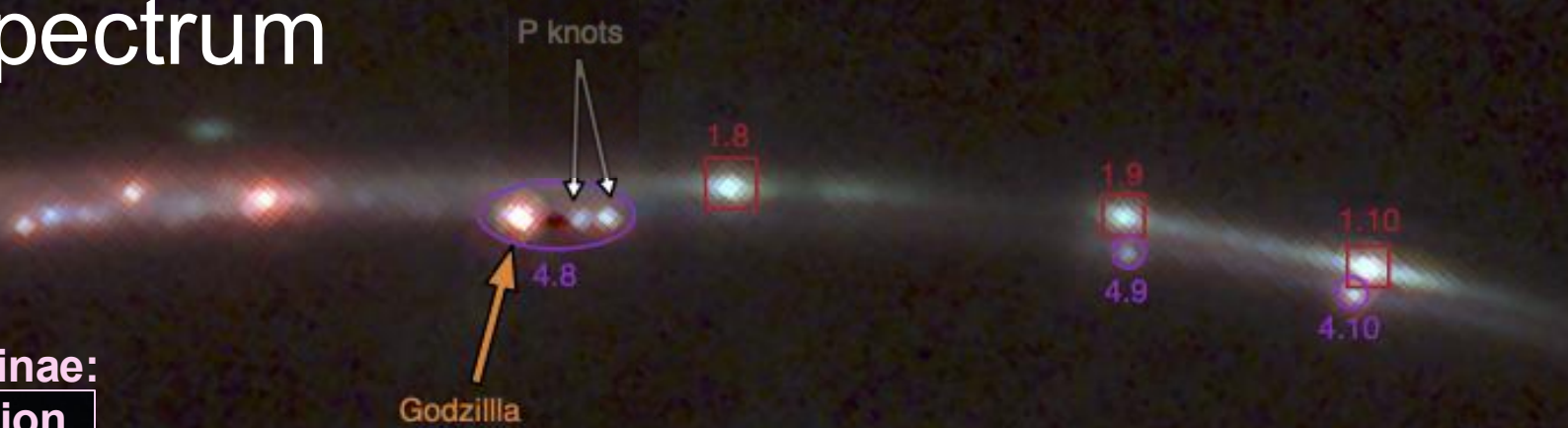
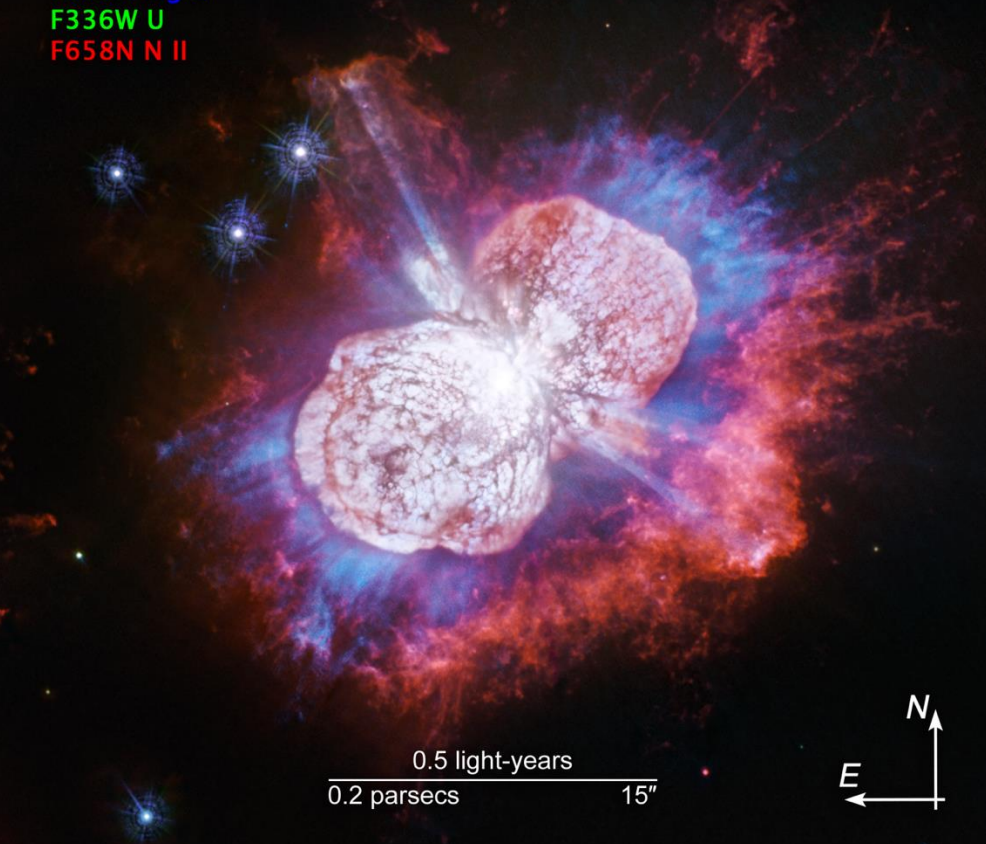


$z = 2.37$ star spectrum

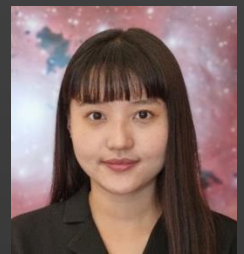
“Godzilla” AB mag 22
magnified by $\sim 7000\times$
in the Sunburst Arc

spectrum resembles Eta Carinae:
luminous blue variable eruption
+ smaller hot blue companion

Eta Carinae
HST WFC3/UVIS
F280N Mg II
F336W U
F658N N II

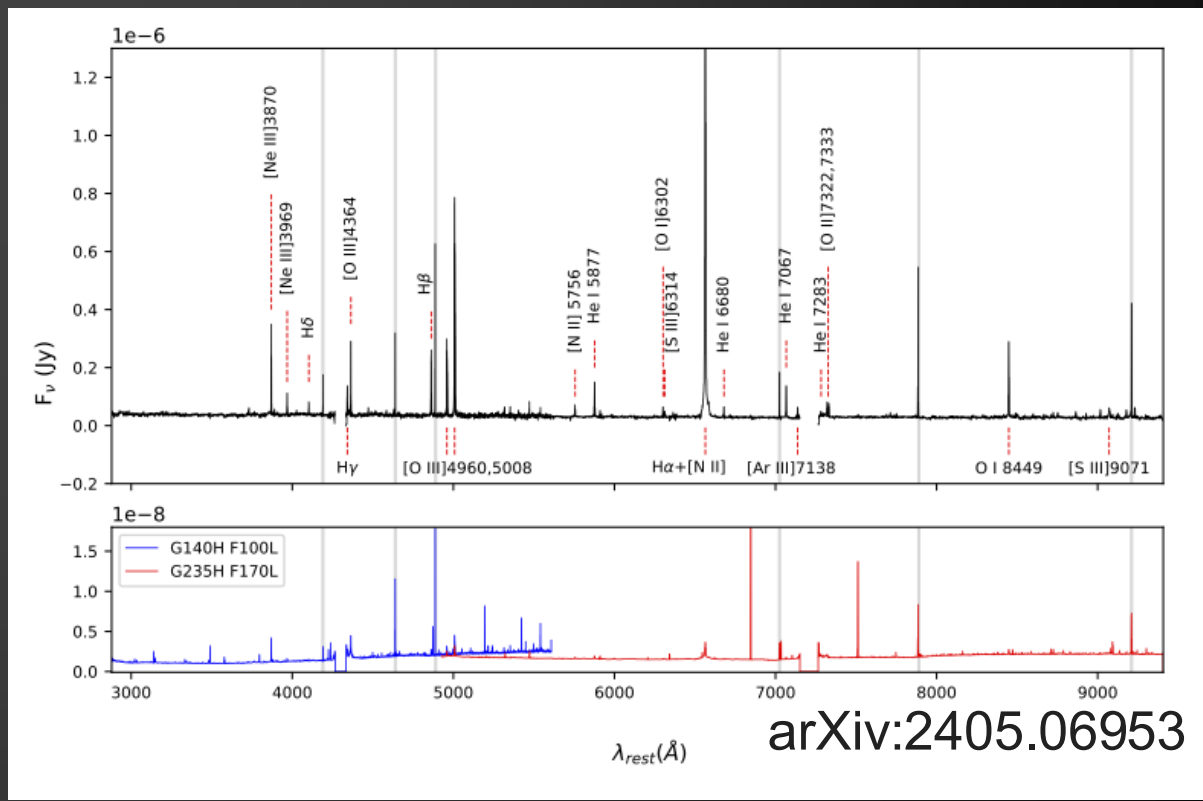


Godzilla



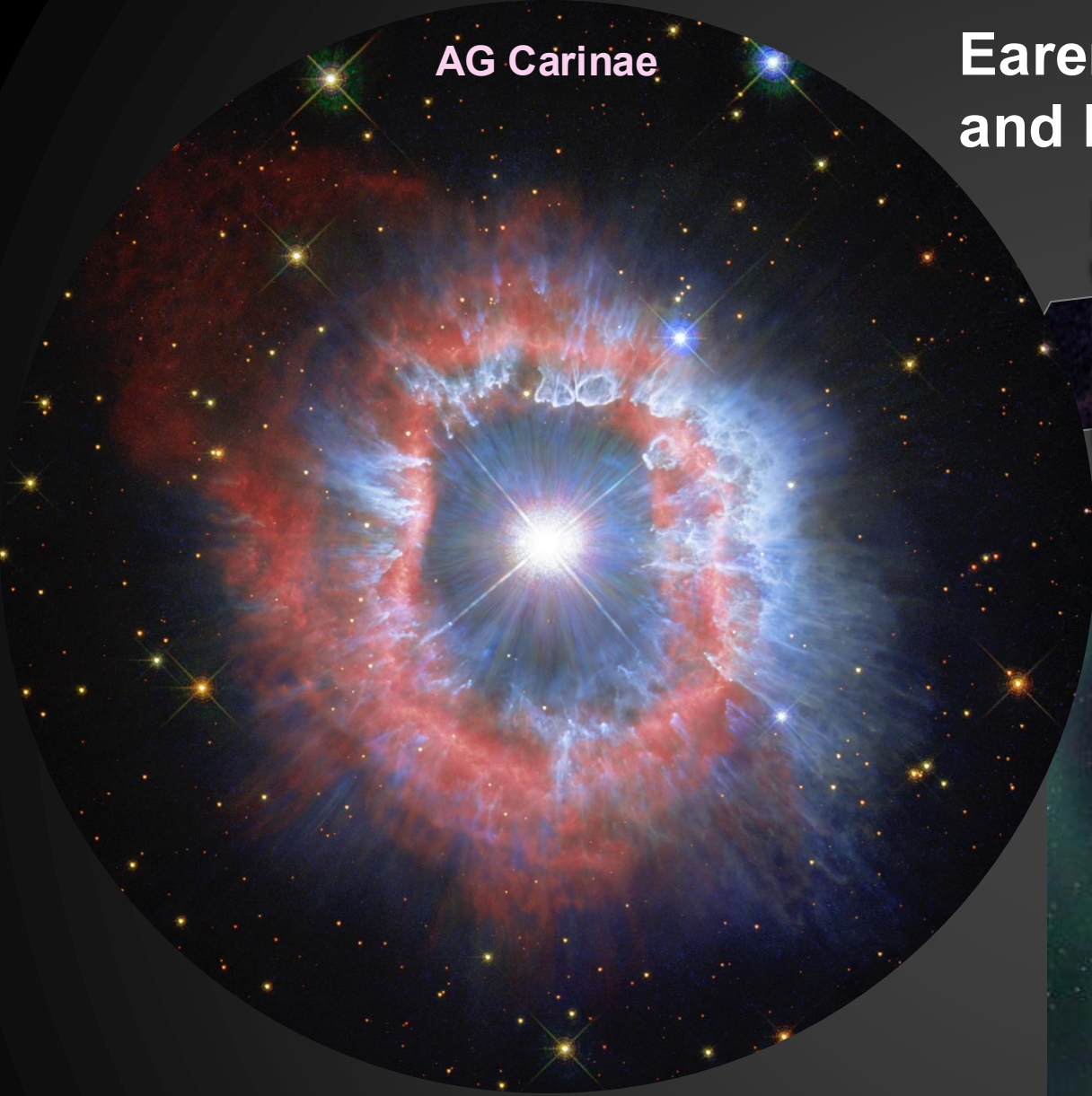
Suhyeon
Choe

Dan Coe – First Stars VII



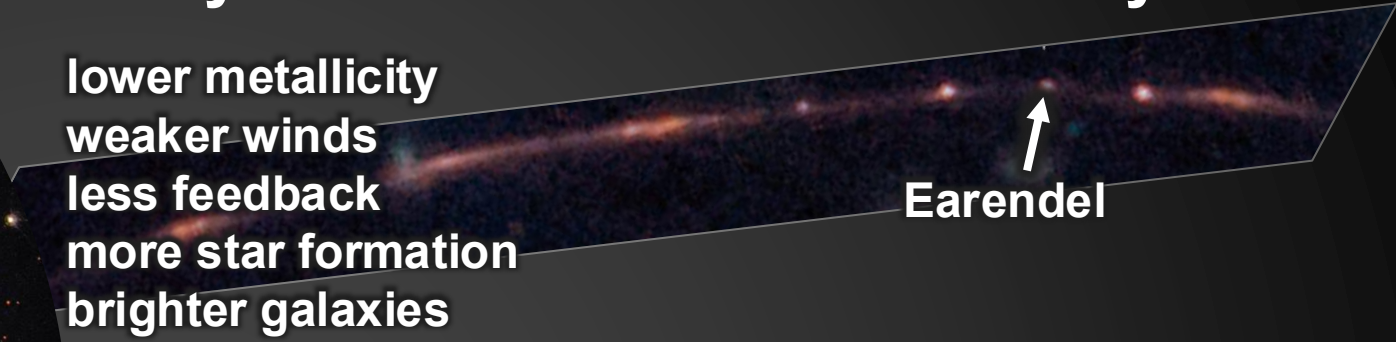
arXiv:2405.06953

AG Carinae



Earendel spectrum could reveal stellar winds and heavy elements in the first billion years

- lower metallicity
- weaker winds
- less feedback
- more star formation
- brighter galaxies



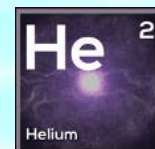
a few nearby stars



The first stars
were probably
very different



First-generation star



Theoretical supermassive “Population III” star
made of only hydrogen and helium

Star Cluster Formation

STARFORGE Simulation

Mike Grudić

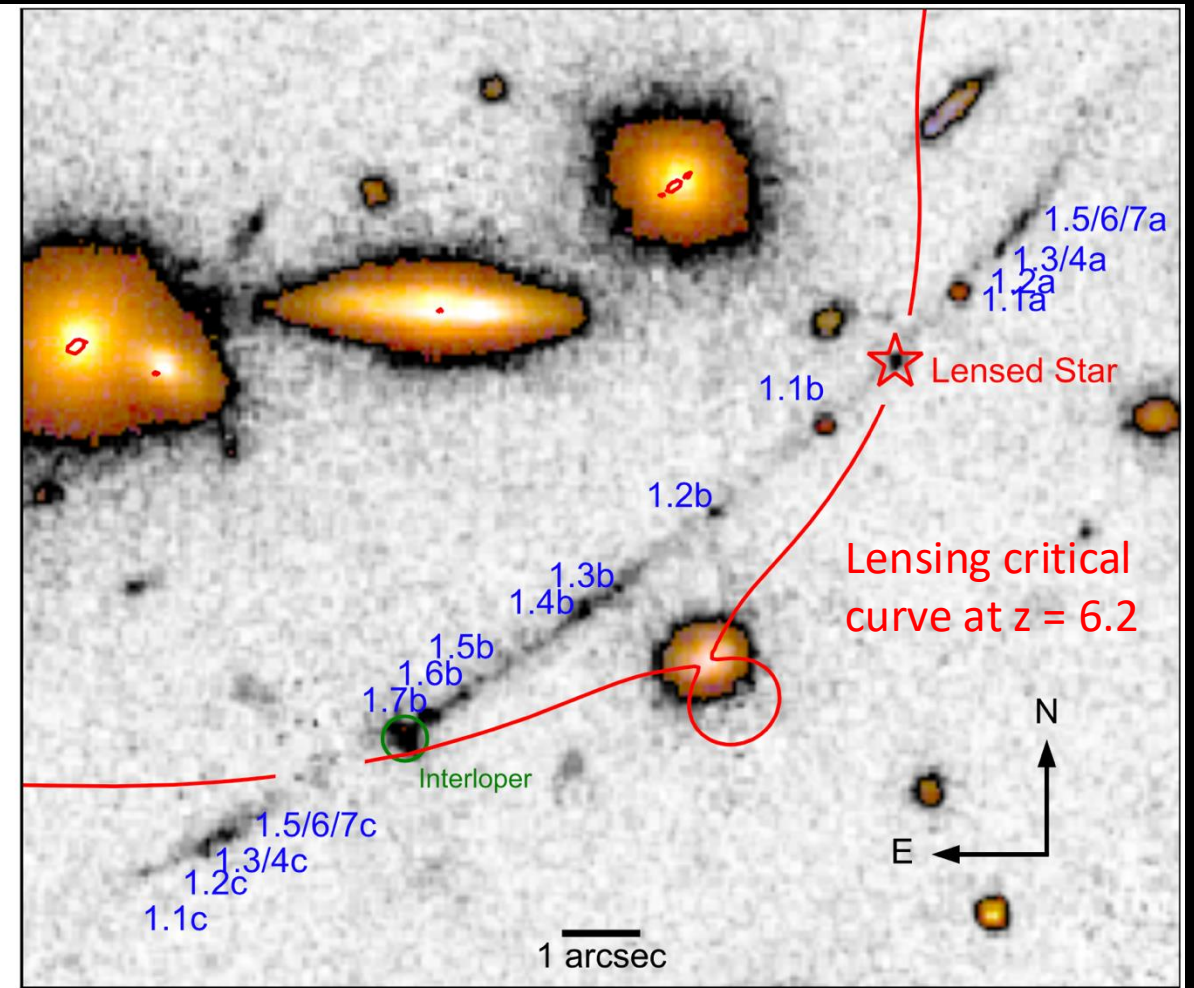
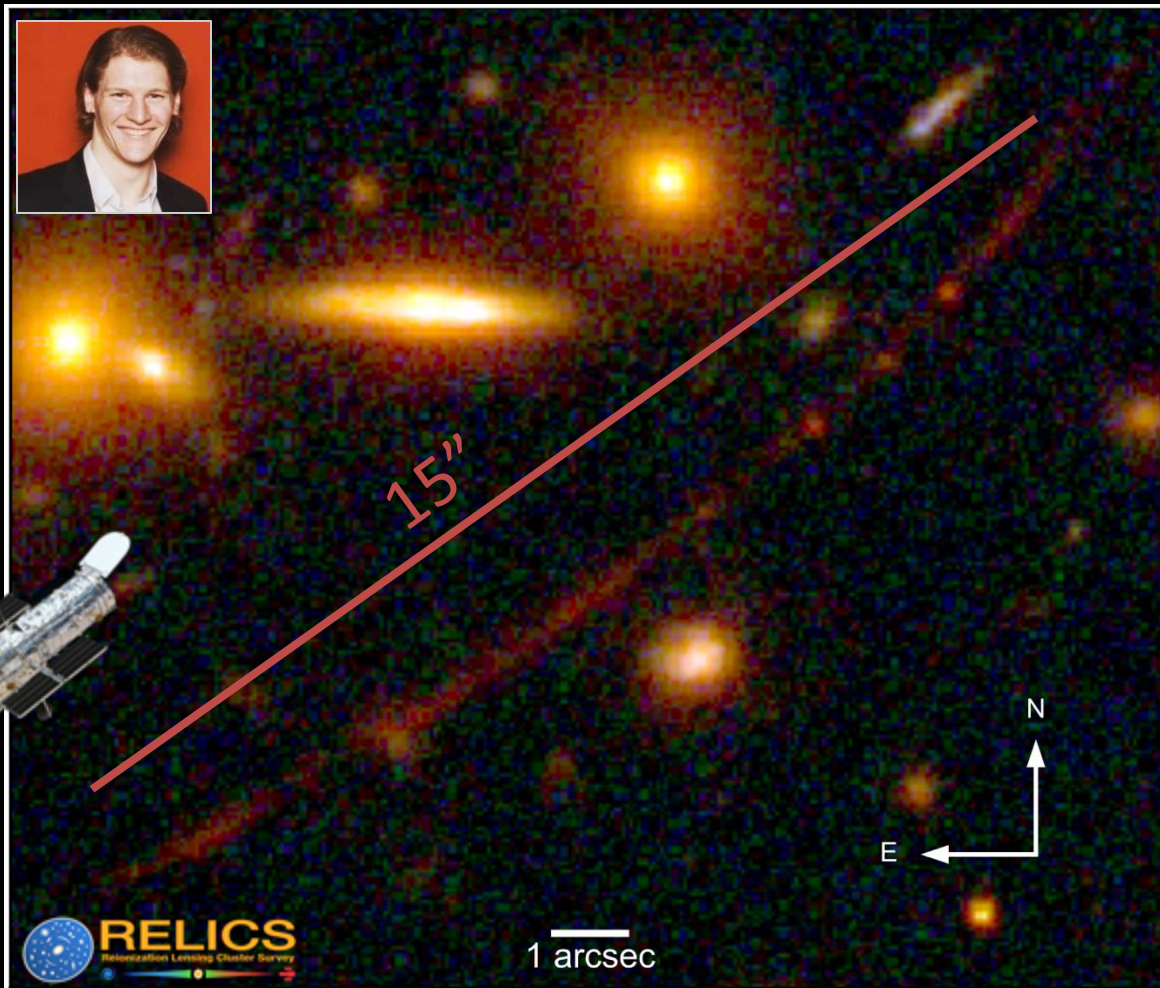


The most highly magnified galaxy in the first billion years

Sunrise Arc ($z \sim 6.2$) 900 Myr

Brian Welch et al. arXiv:2207.03532

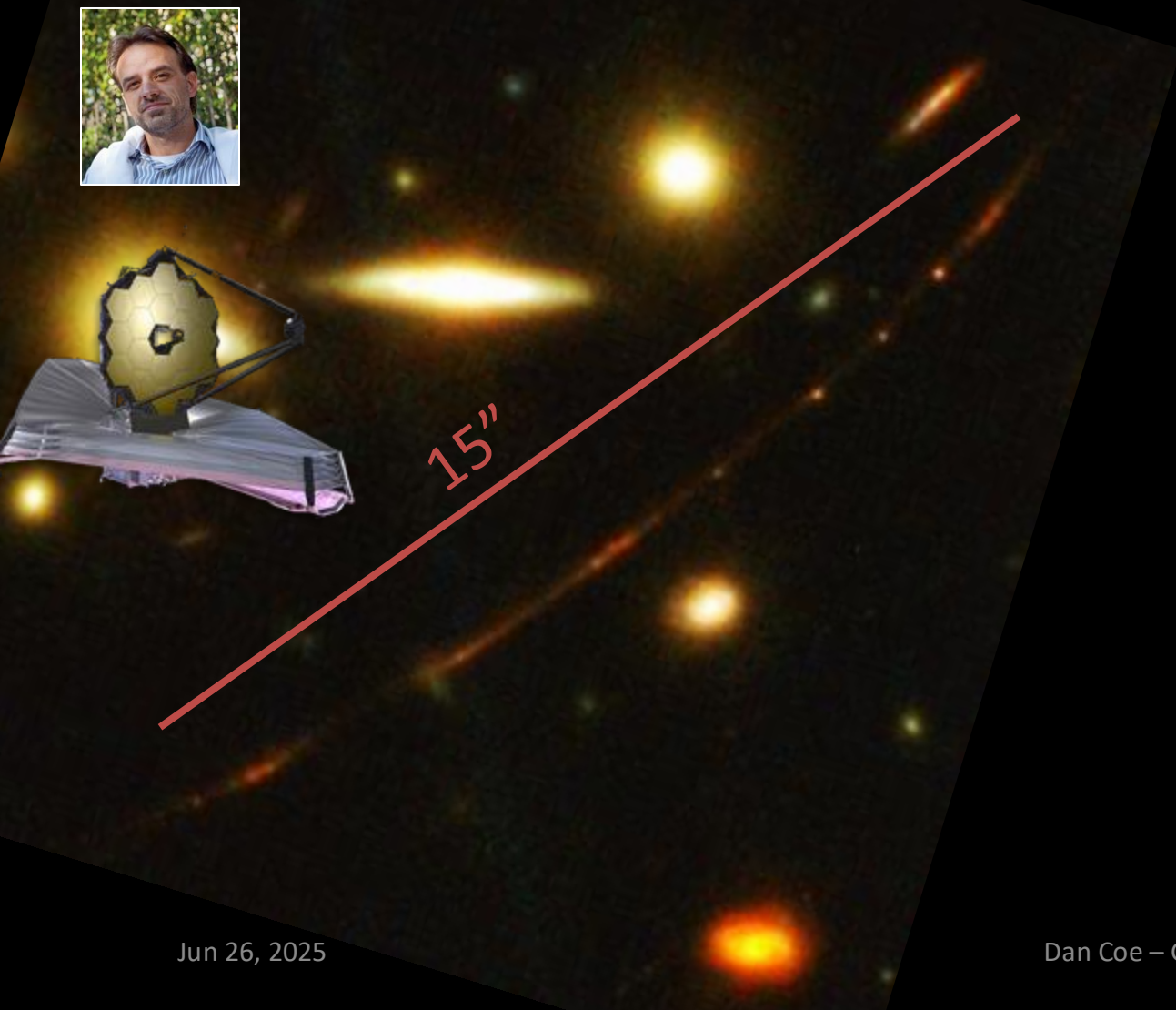
7 tiny parsec-scale star clusters at $z \sim 6$



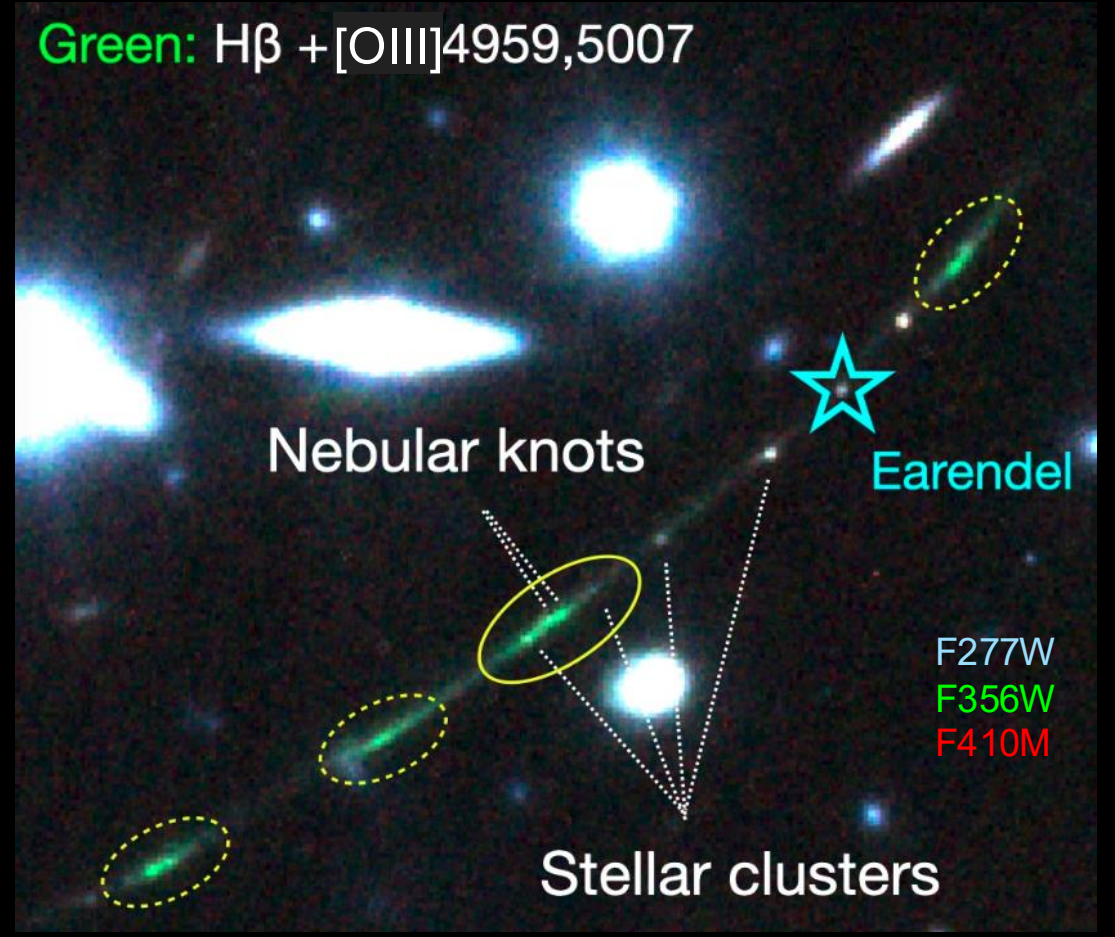
The most highly magnified galaxy in the first billion years

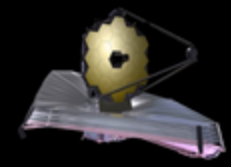
Sunrise Arc ($z \sim 6.2$) 900 Myr

Eros Vanzella et al. arXiv:2211.09839



intense emission revealed in NIRCcam imaging

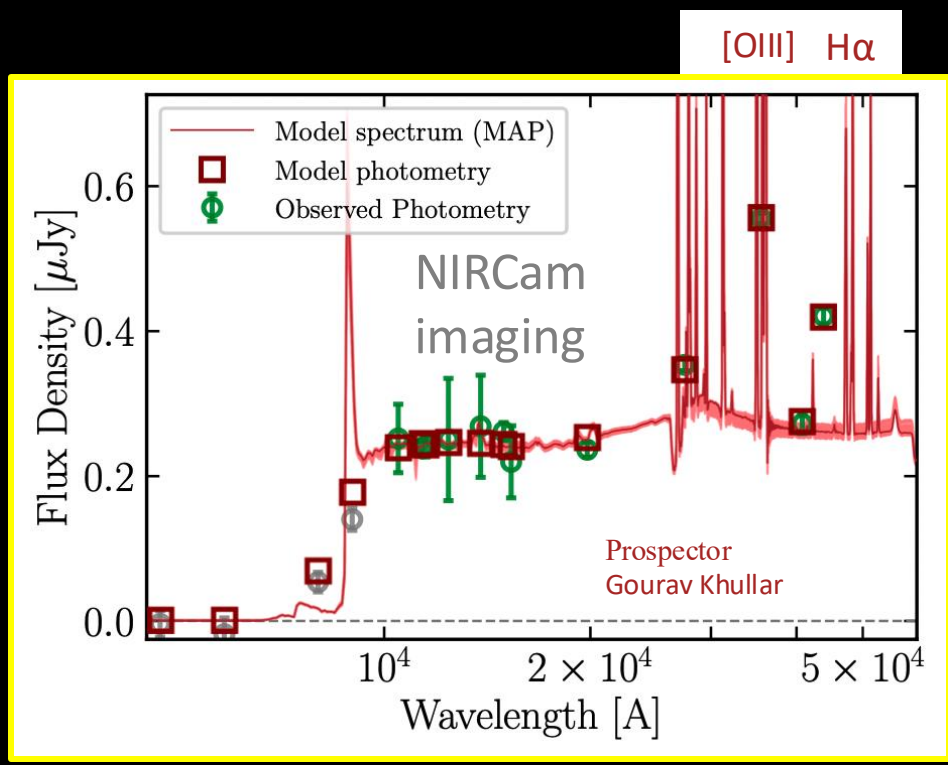
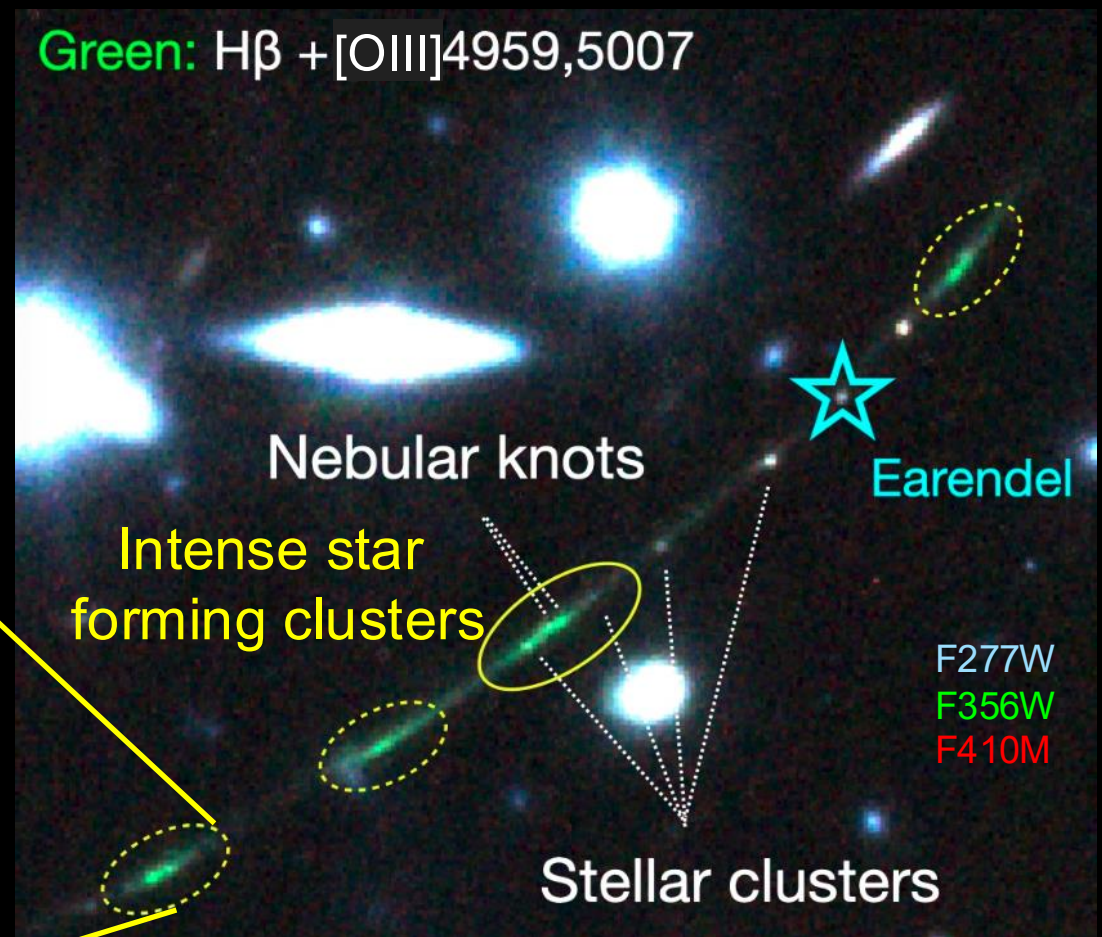


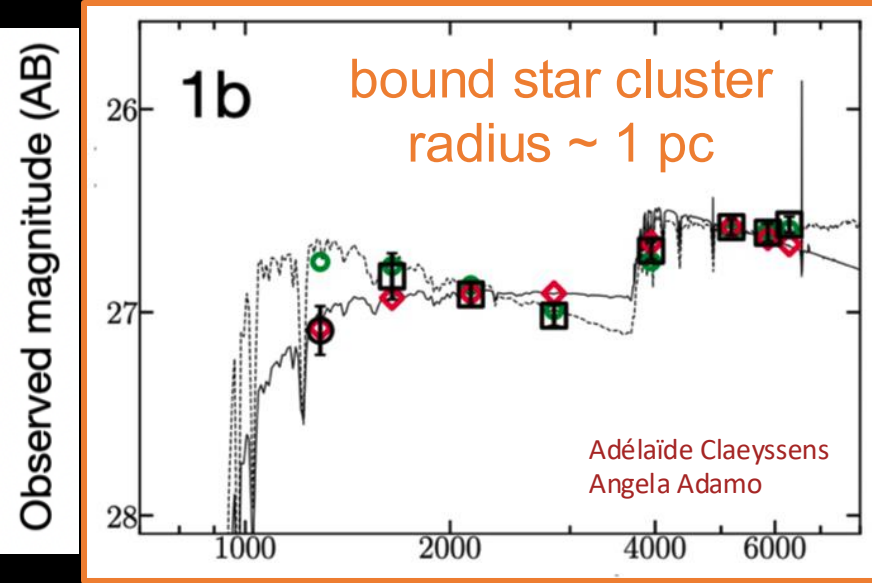


Intense [OIII] from young stars < 5 Myr confirmed in spectrum

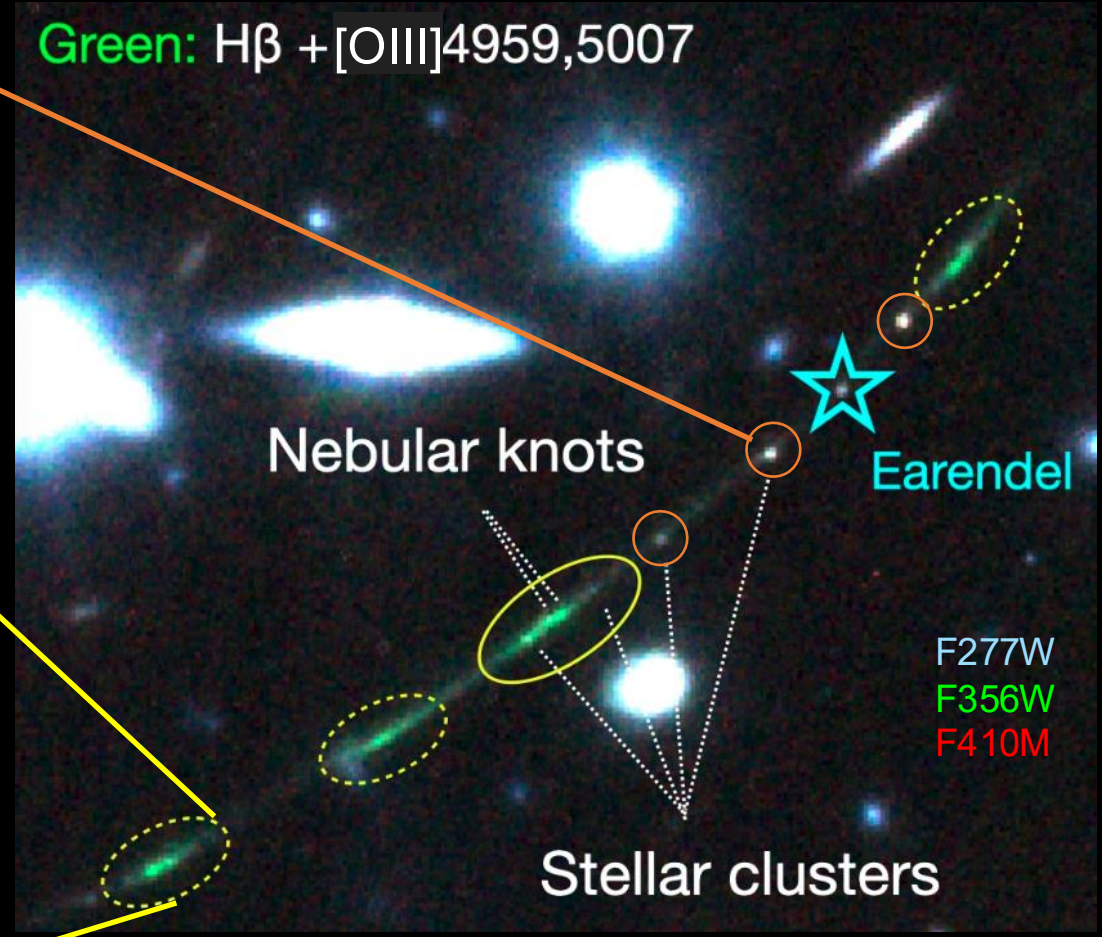
Sunrise Arc ($z=5.9$) 950 Myr

Green: $H\beta$ + [OIII]4959,5007



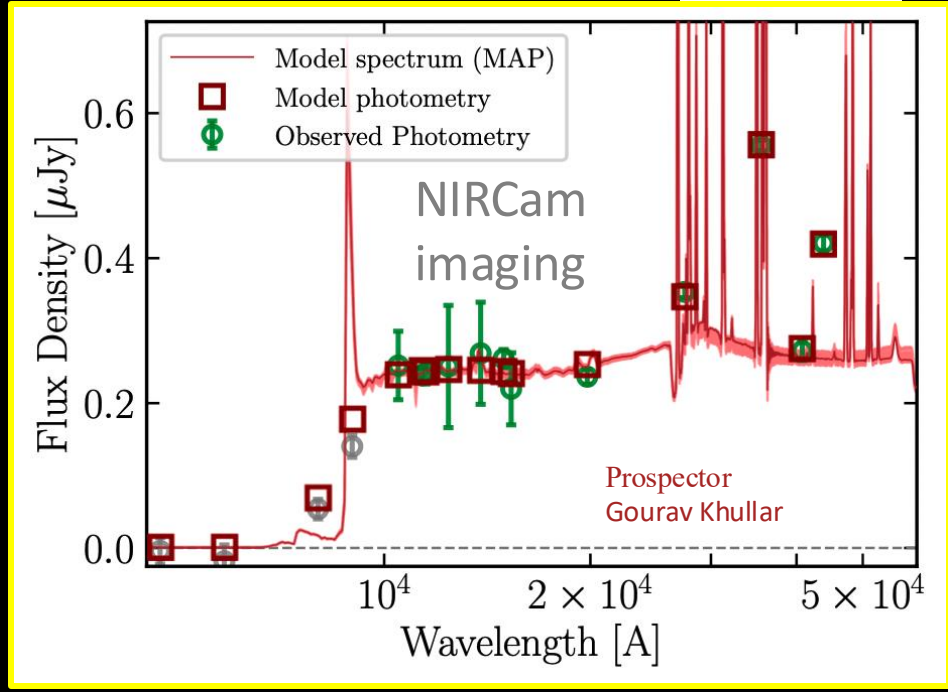


Sunrise Arc ($z=5.9$) 950 Myr
 Eros Vanzella et al. arXiv:2211.09839
 older gravitationally bound star clusters
 radii as small as 1 pc



Intense star forming clusters

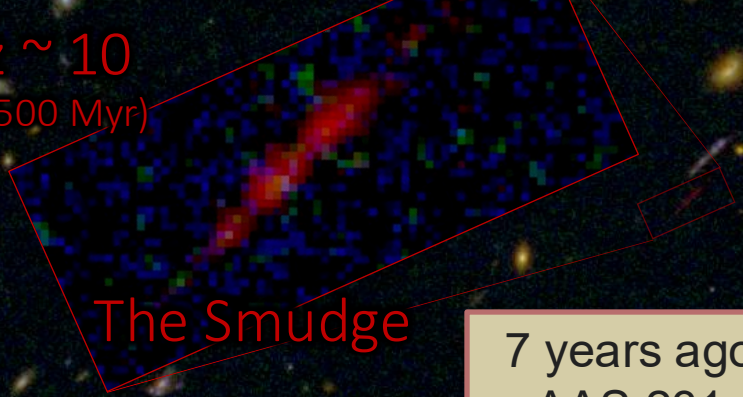
[OIII] H α



SPT0615-JD: the most distant arc known



$z \sim 10$
(500 Myr)



The Smudge

7 years ago
AAS 231
press conference



Brett
Salmon

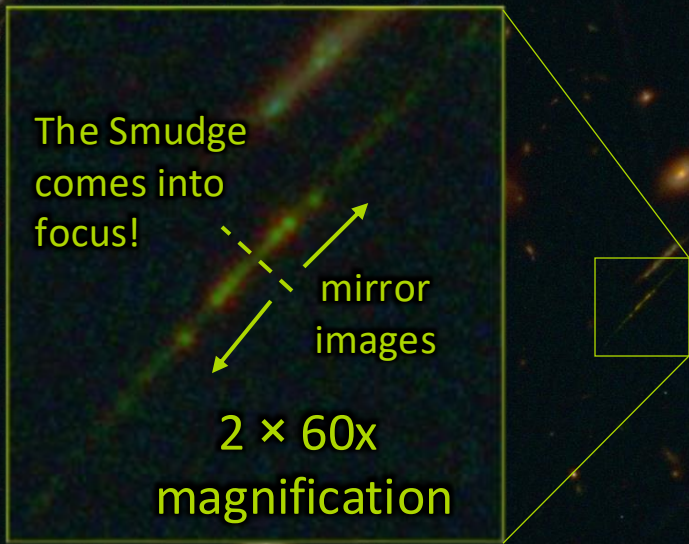


Victoria
Strait



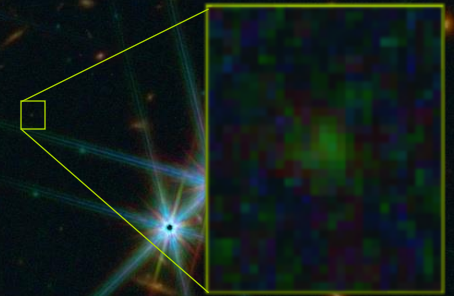
Rachel
Paterno-
Mahler

Cosmic Gems arc

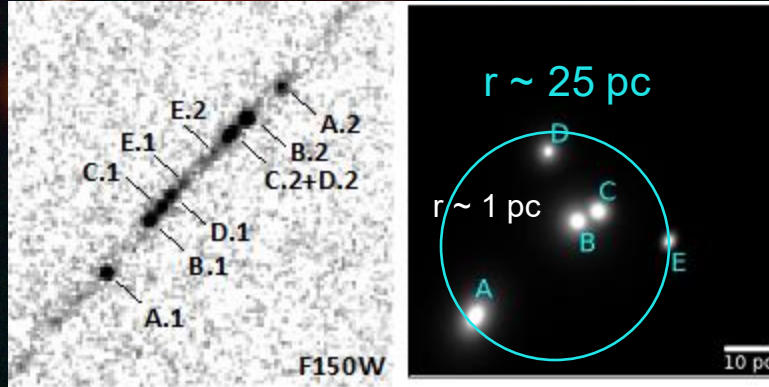
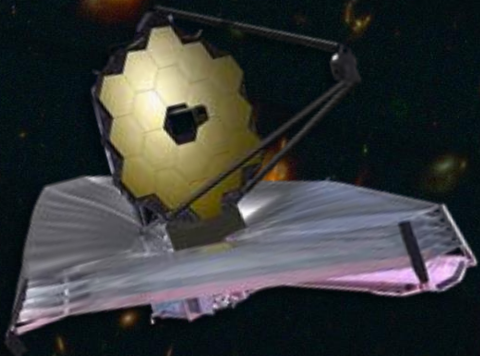


lensed
AB mag 24.5
5" long

delensed
AB mag 29.7
 $M_{UV} = -17.8$
 $M_* \sim 4e7 M_{\odot}$



2x magnification
AB mag 28.4



Angela
Adamo



Larry
Bradley

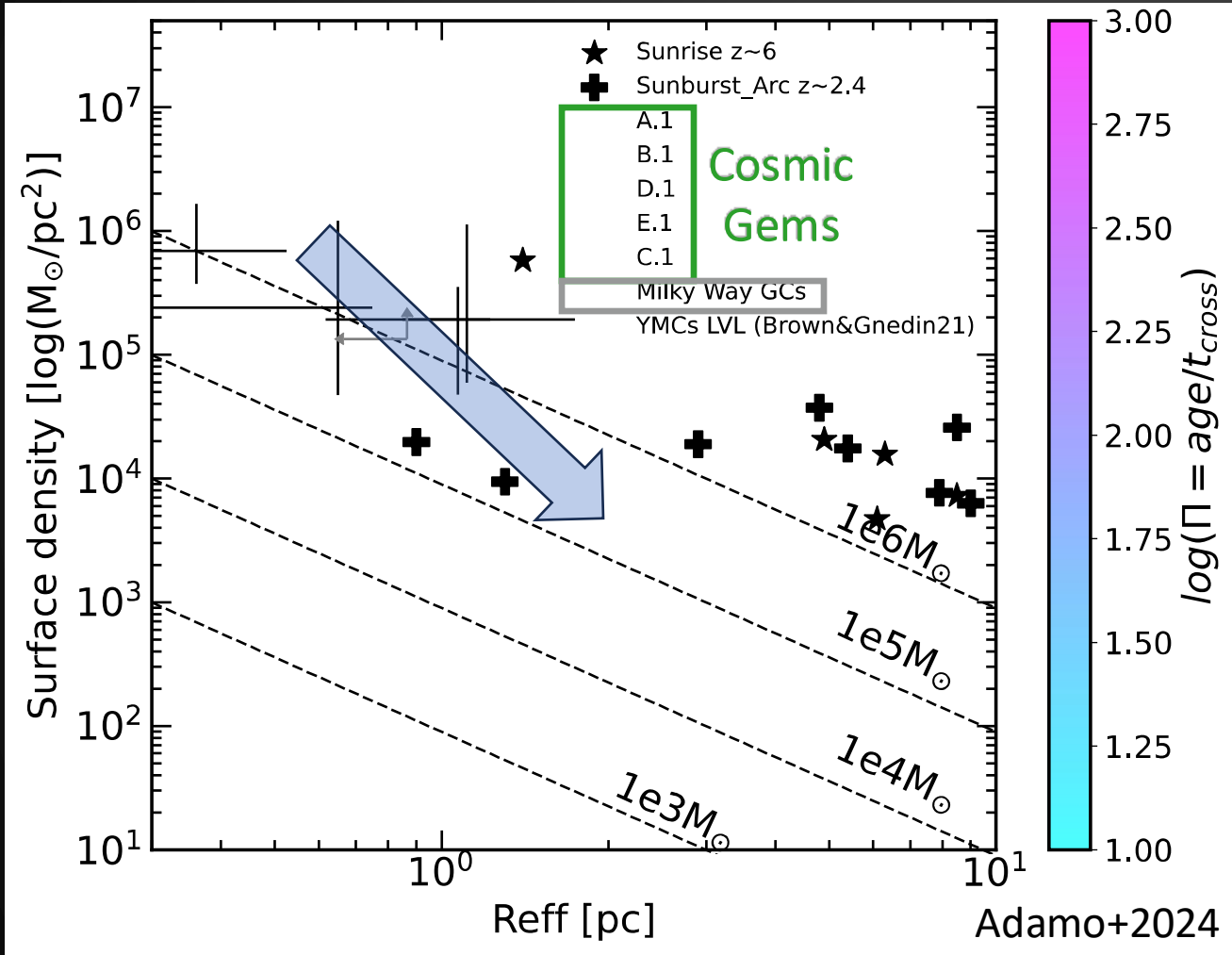
Cycle 2
GO 4246
PI Bradley

Jun 26, 2025

Dan Coe – GarthFest

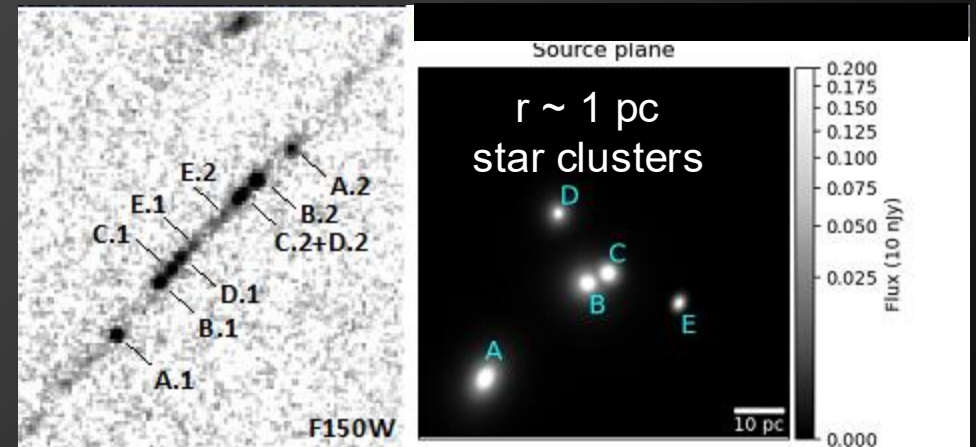
Cosmic
Spring

Cosmic Gems: most distant bound star clusters known



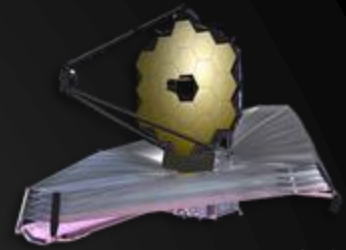
very small and dense clumps $\sim 2e6 M_{\odot}$
 gravitationally bound ($\text{age} > 10 \text{ yr}^3/\text{GM}$)

Expected to evolve, relax, and expand
 to resemble globular clusters
 in our own galaxy



The first star clusters

One giant leap towards observing the first stars



Cosmic Gems arc
 $z \sim 10$
 (500 Myr)

Cosmic
 Spring

Sunrise Arc
 $z = 5.93$
 (1 Gyr)

Sparkler
 $z = 1.38$
 (4.5 Gyr)

SMACS0723
 $z = 0.390$
 (9.4 Gyr)

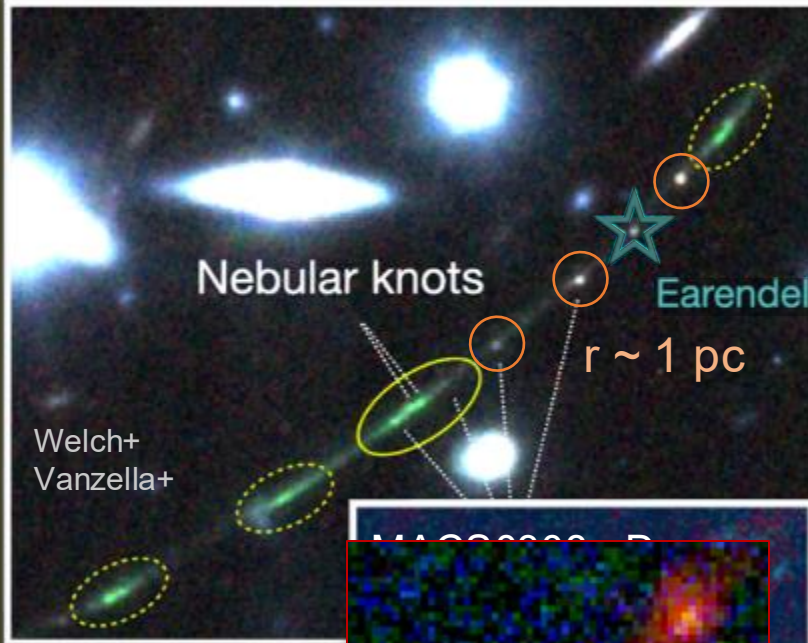
Messier 80
 $z = 0$
 (13.8 Gyr)

Adamo+
 Bradley+

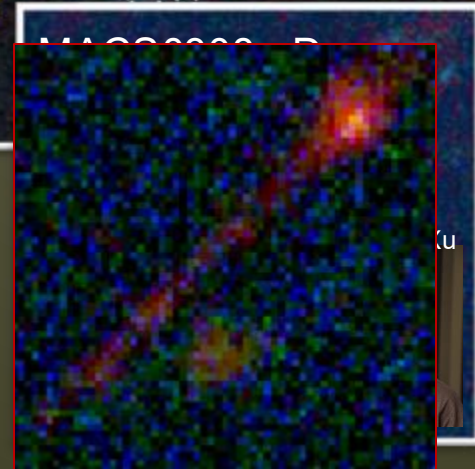
Lensed Galaxy
 Redshift (z): 10.2

$r \sim 1$ pc

Mirrored Star Clusters
 Redshift (z): 10.2



Welch+
 Vanzella+

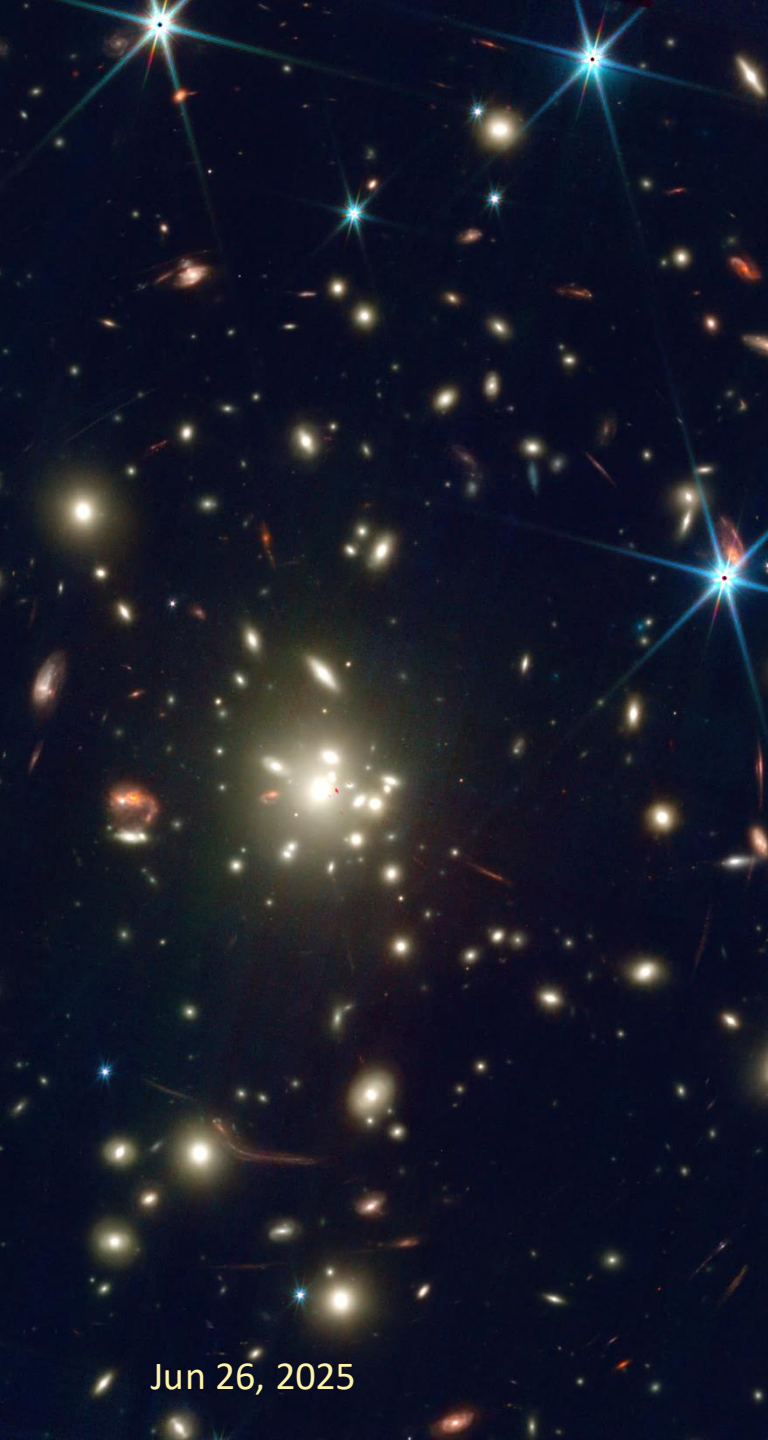


Mowla & Iyer+
 Claeysens+
 Adamo+



Faisst+; Lee+
 Harris+; Martis+





Cube WAVE
1105
2.8703 3.6703 4.4703 5.2703 3.60449
First Previous Stop Play Next Last



high-resolution spectroscopy
+ lensing resolve structure

SAOImage ds9

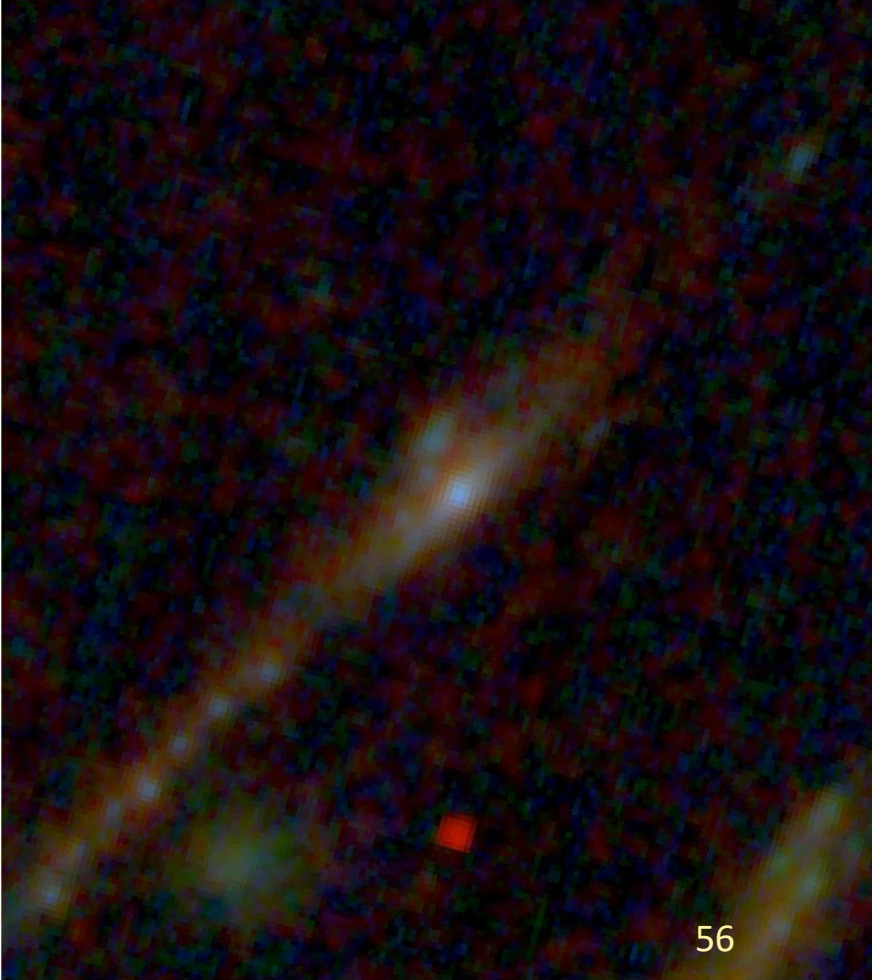
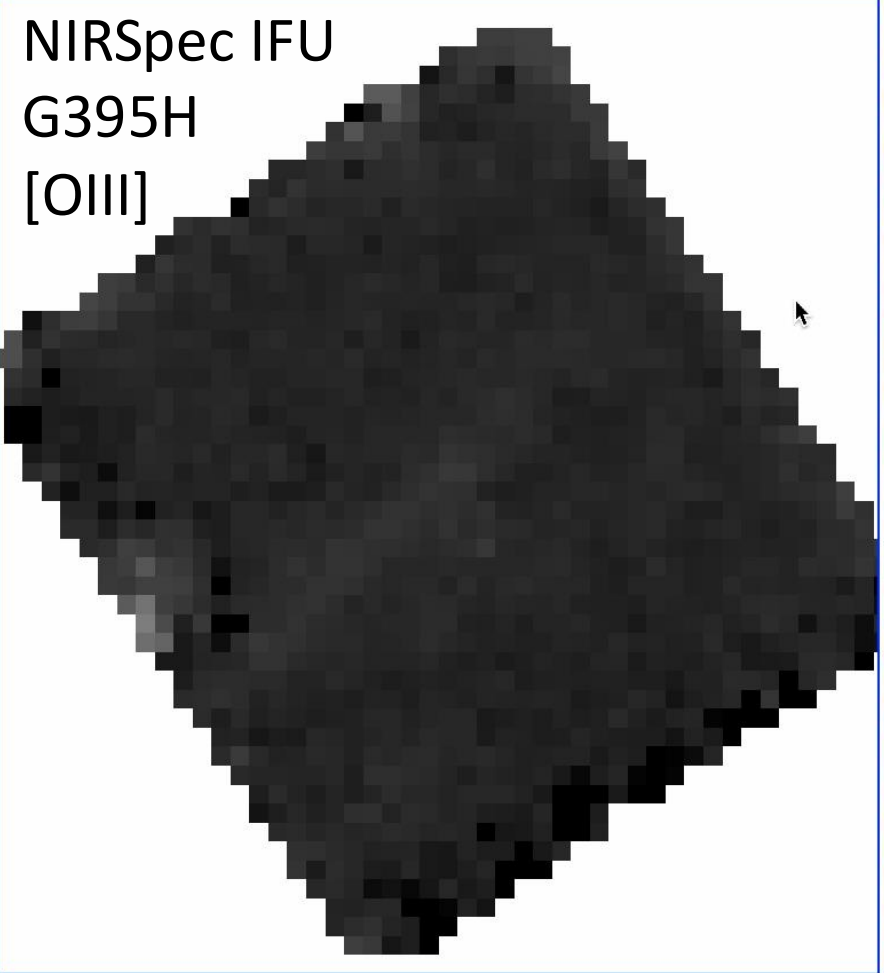
File: jw05293-o001_t001_nirspec_g395h-f290lp_s3d.fits[SCI]

Object Value: nan

fk5	α	3:08:53.498	δ	+26:44:56.25
Physical	X	17.018	Y	1.699
Image	X	17.018	Y	1.699
Frame 1	x	16.525		0.000 °

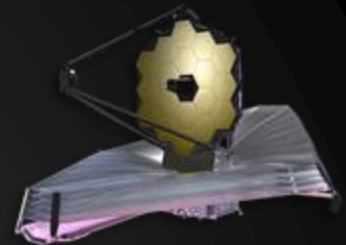
Dan Coe – GarthFest

file edit view frame bin zoom scale color region wcs help
new rgb 3d delete clear single tile blink first prev next last



The first star clusters

One giant leap towards observing the first stars



Cosmic Gems arc
 $z \sim 10$
 (500 Myr)

Cosmic
 Spring

Sunrise Arc
 $z = 5.93$
 (1 Gyr)

Sparkler
 $z = 1.38$
 (4.5 Gyr)

SMACS0723
 $z = 0.390$
 (9.4 Gyr)

Messier 80
 $z = 0$
 (13.8 Gyr)

Adamo+
 Bradley+

Lensed Galaxy
 Redshift (z): 10.2

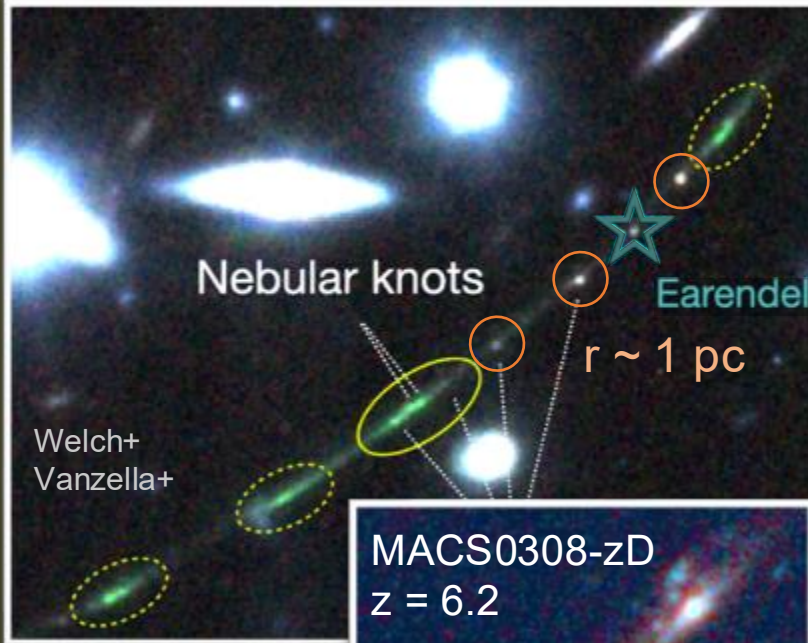
$r \sim 1$ pc

Mirrored Star Clusters
 Redshift (z): 10.2

MACS0647-JD
 $z = 10.17$

$r \sim 70$ pc, 20 pc

Hsiao+
 Hsiao & Abdurro'uf+
 Abdurro'uf+
 Hsiao & Álvarez+



MACS0308-zD
 $z = 6.2$

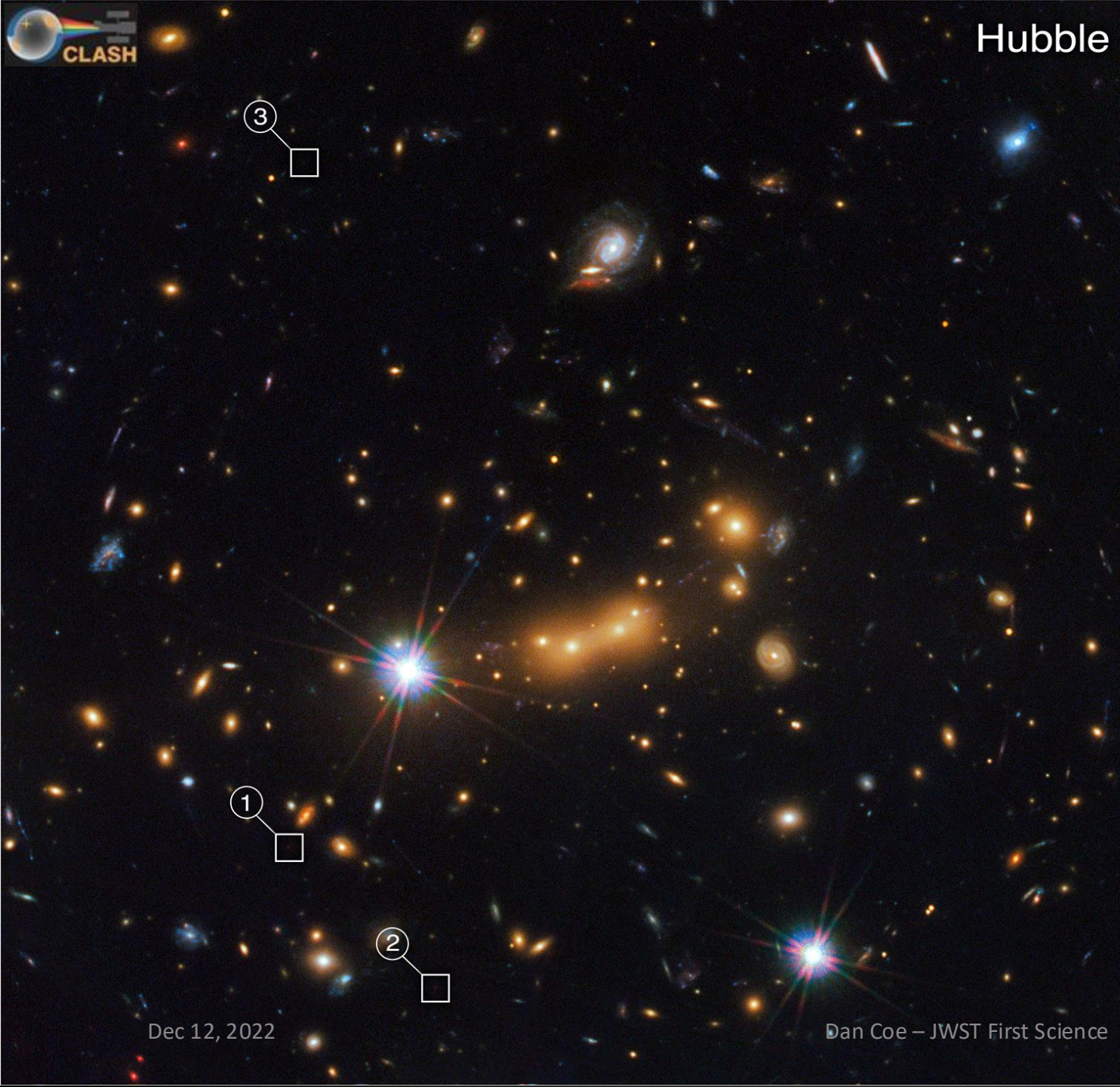


Mowla & Iyer+
 Claeyssens+
 Adamo+



Faisst+; Lee+
 Harris+; Martis+





Dec 12, 2022

Dan Coe – JWST First Science

Look again at that dot

JD 1

MACS0647-JD
 $z \sim 11$ (400 Myr)
Coe et al. 2013

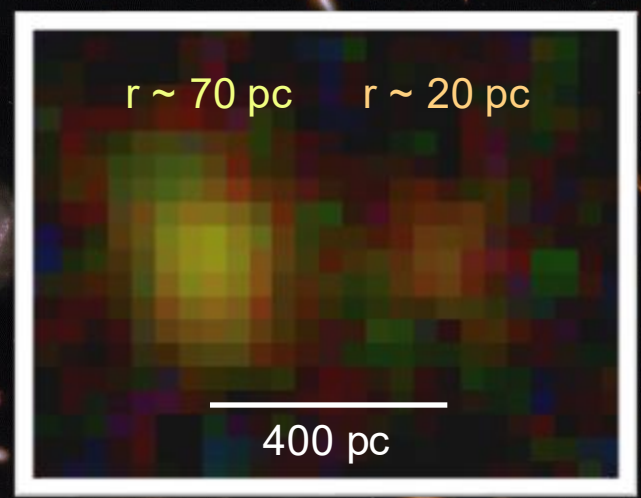
12 years ago
AAS 221

JD 2

JD 3



Look again at those dots

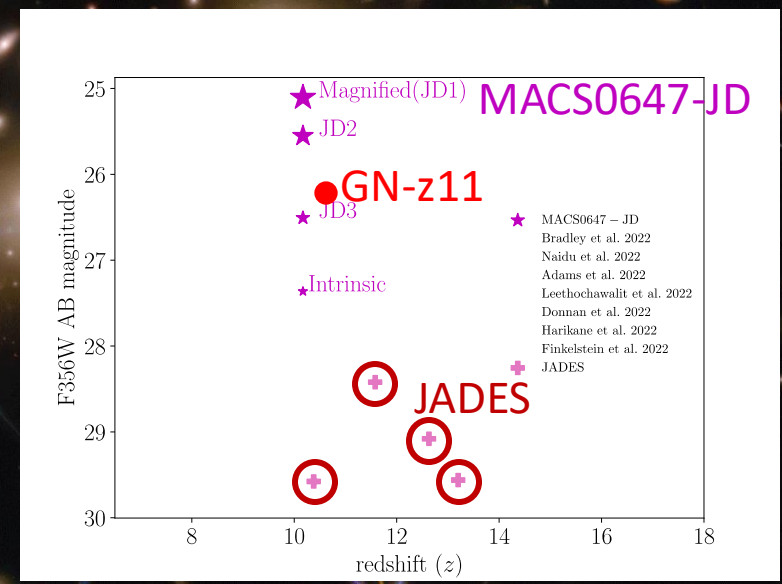


JD 1

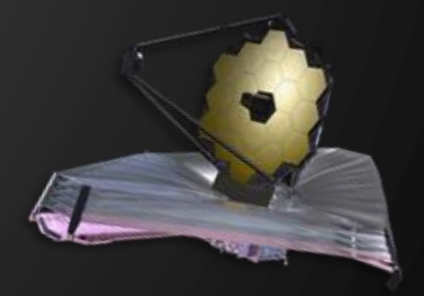
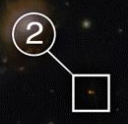
MACS0647-JD
z = 10.17 (460 Myr)



Tiger Hsiao Abdurro'uf



JD 2



JD 3

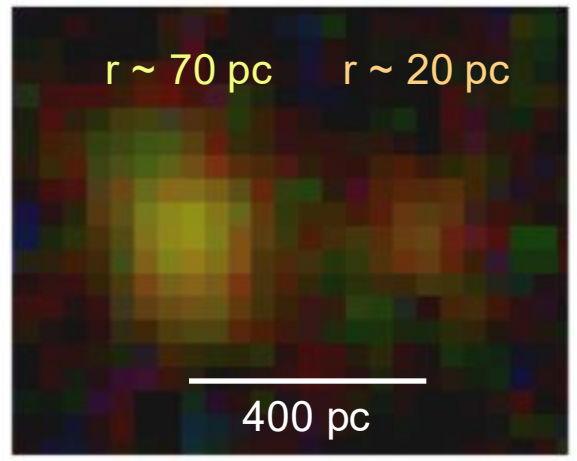
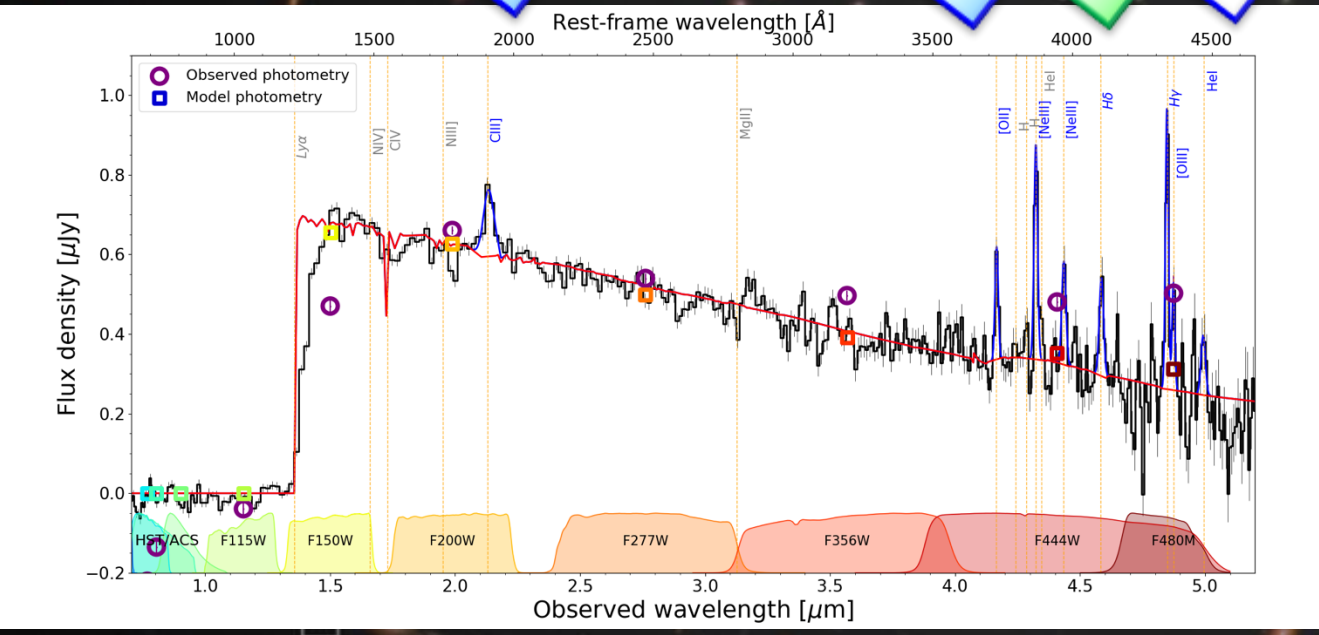
Spectrum reveals heavy elements

Carbon

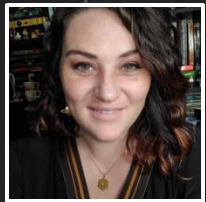
Oxygen

Neon

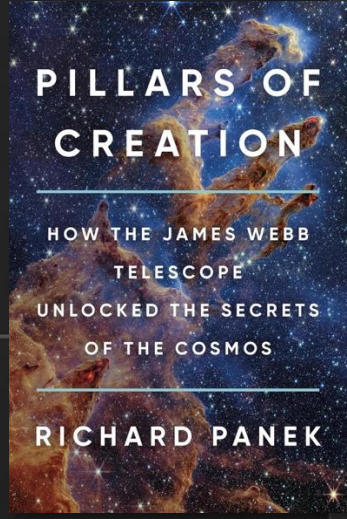
Hydrogen



2 years ago
AAS 241



Rebecca Larson



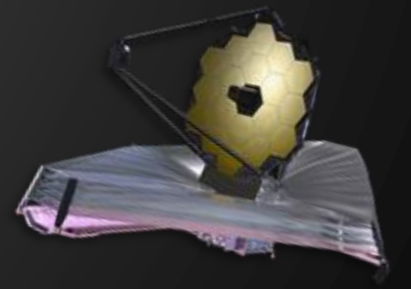
MACS0647-JD
 $z = 10.17$ (460 Myr)
13.3 Byr ago



Tiger Hsiao



Abdurro'uf



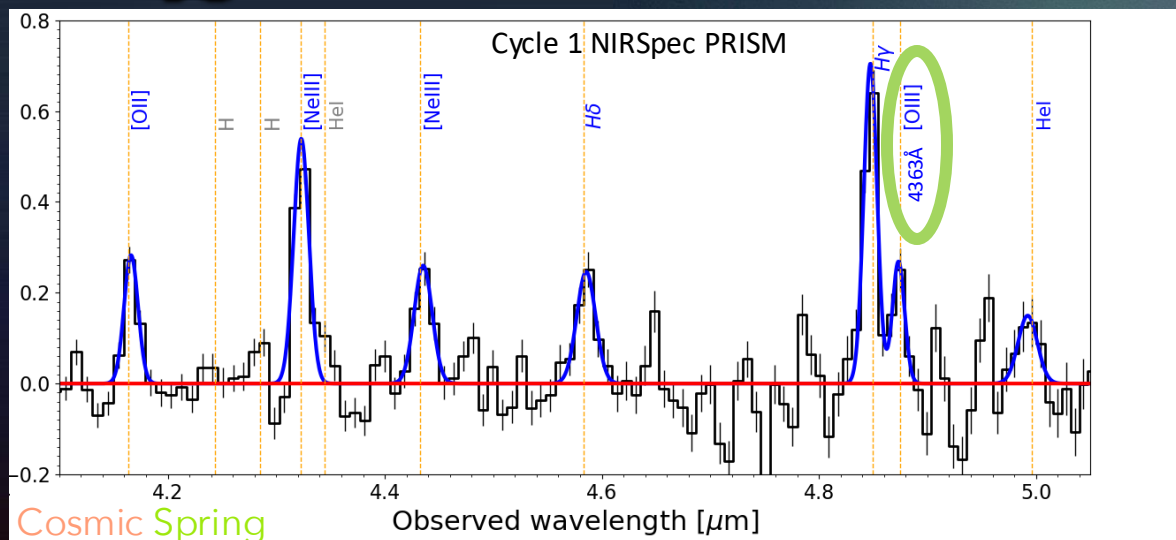


Tiger Hsiao & Abdurro'uf et al.
 (co-lead authors)
 arXiv:2305.03042

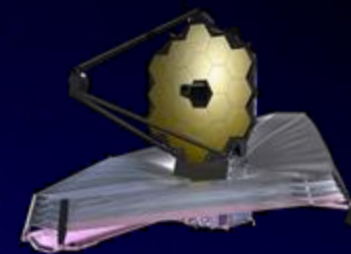
MACS0647-JD

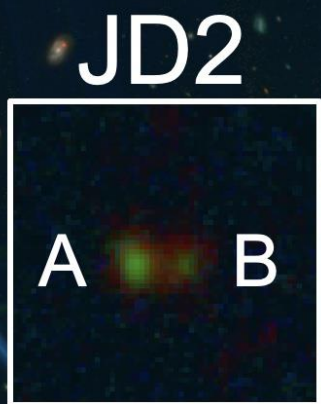
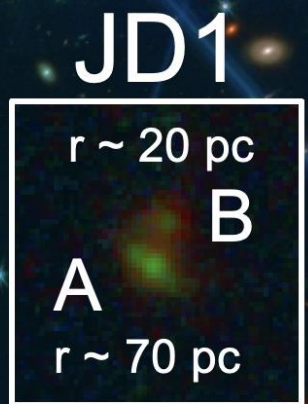
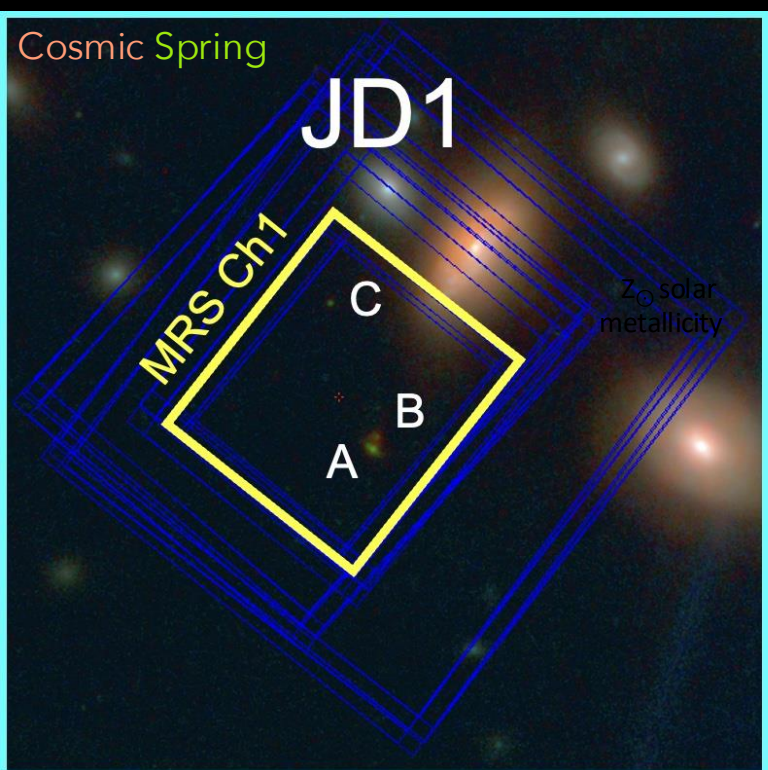
$z = 10.17$ (460 Myr) 13.3 Gyr ago

most distant detection of the
 auroral line [OIII] 4363Å
 for direct measurement
 of oxygen abundance: **13% solar**



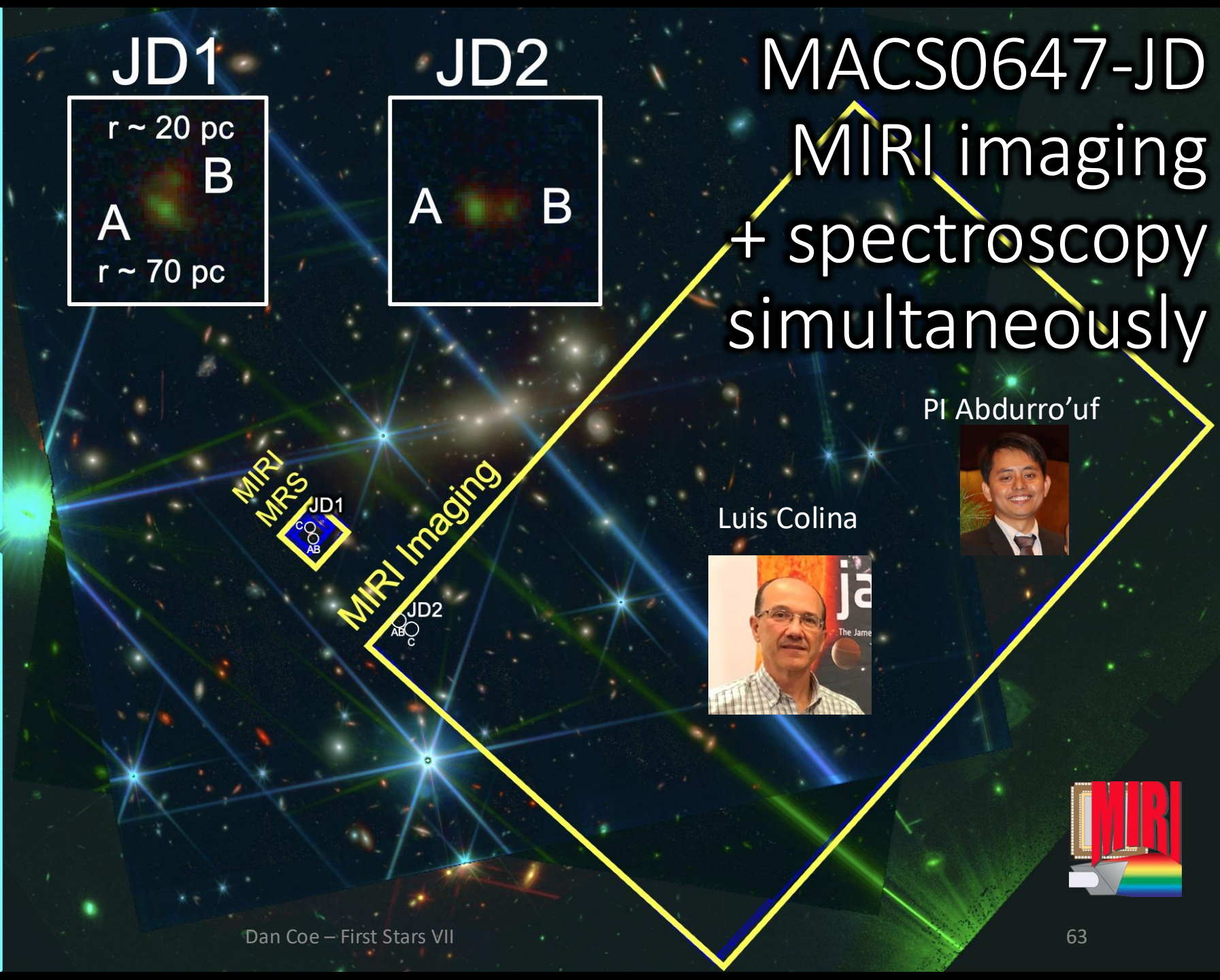
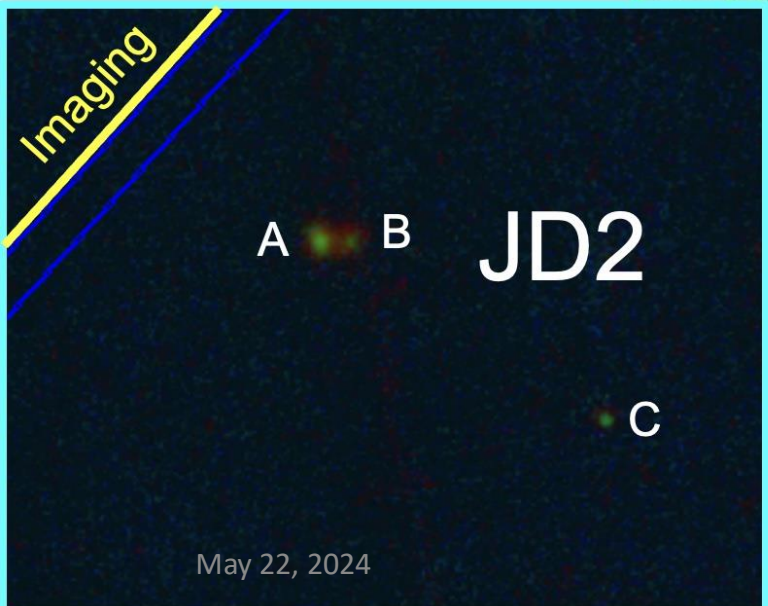
[OIII] 5008Å





MACS0647-JD

MIRI imaging
+ spectroscopy
simultaneously



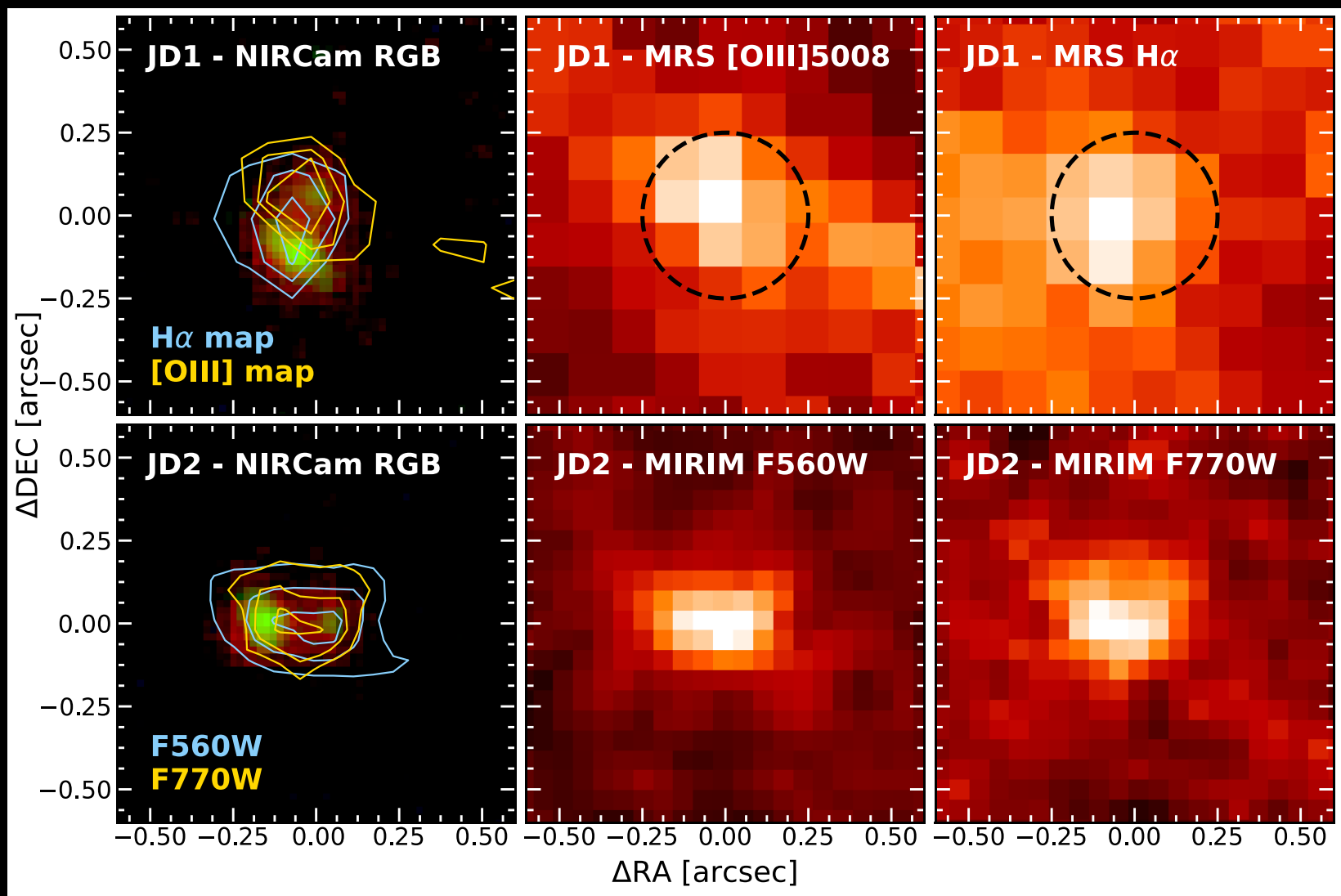
PI Abdurro'uf



Luis Colina



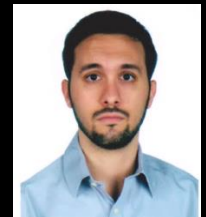
MIRI detects MACS0647-JD (z=10.17)



MIRI MRS IFU reductions:
Javier Álvarez-Márquez



MIRI image reductions:
Alex Crespo Gómez



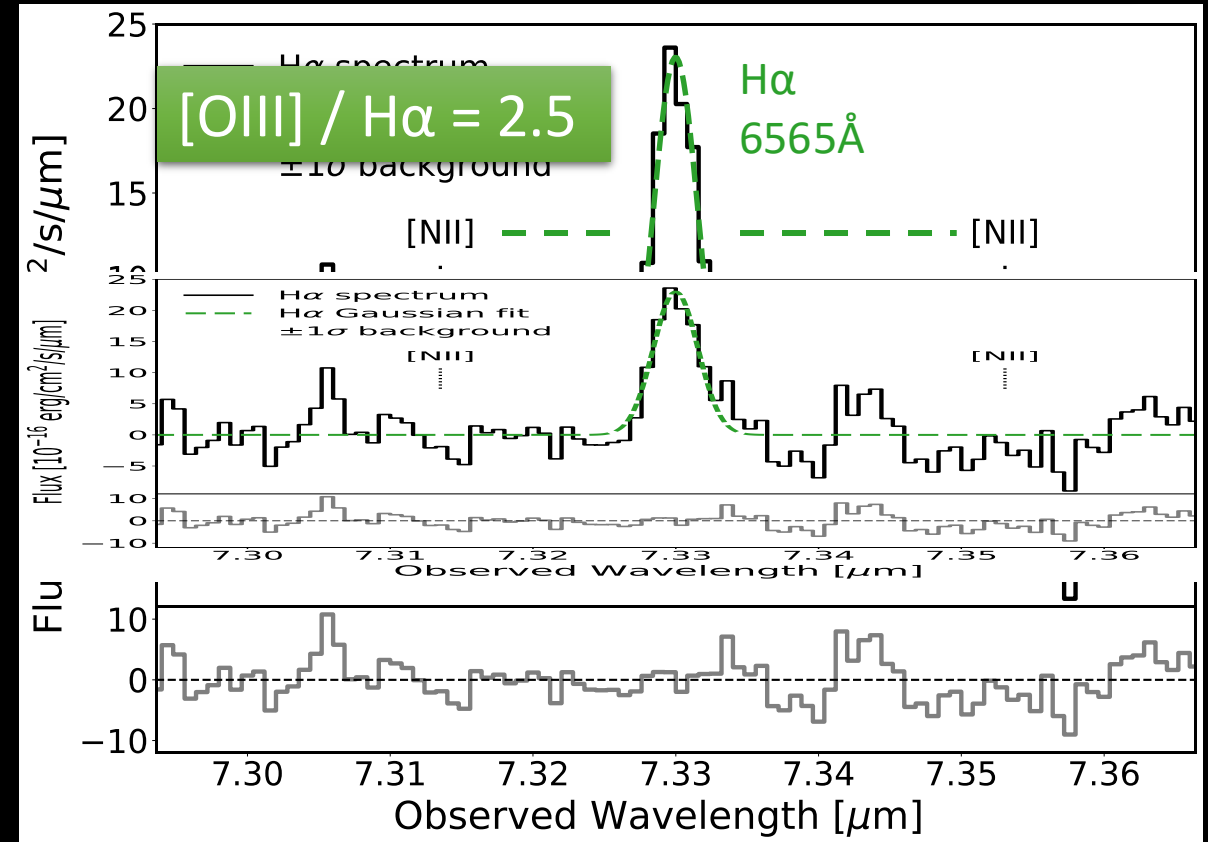
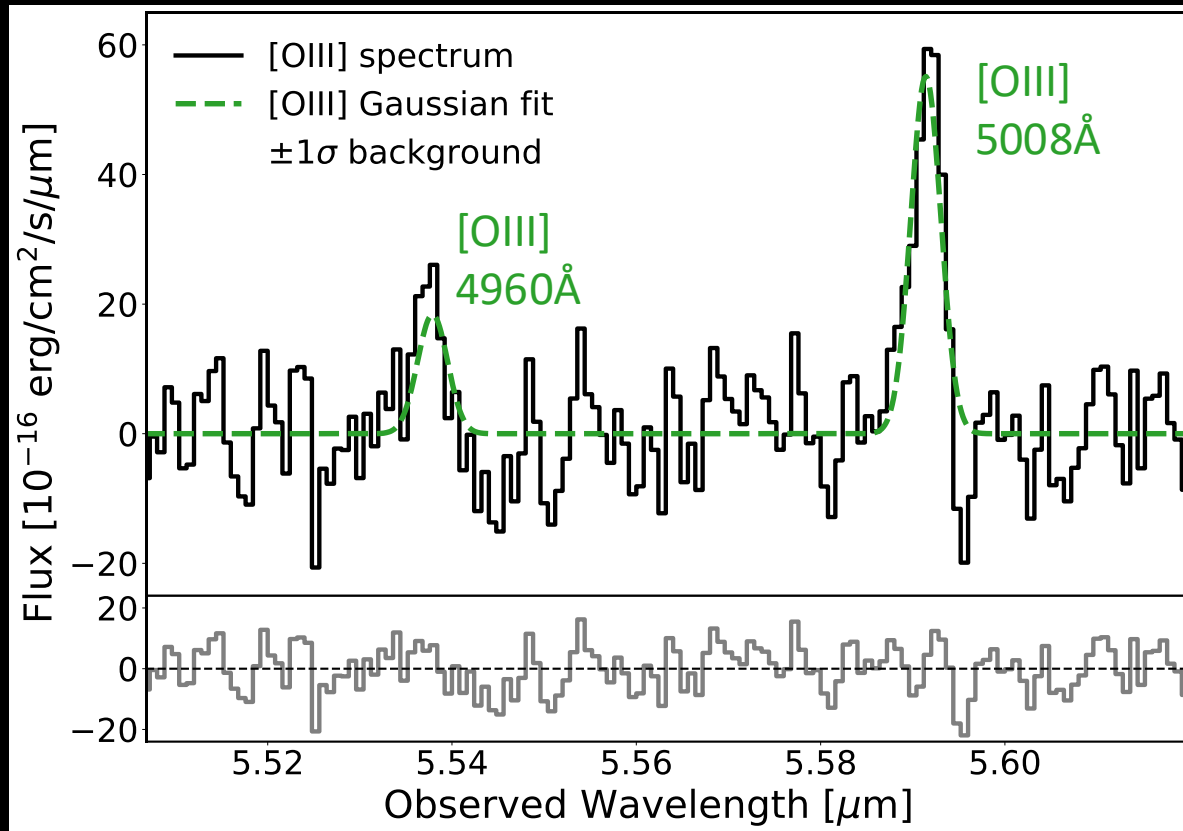
paper:
Hsiao & Álvarez et al. 2024

MIRI MRS: [OIII], H α in MACS0647-JD (z=10.17)

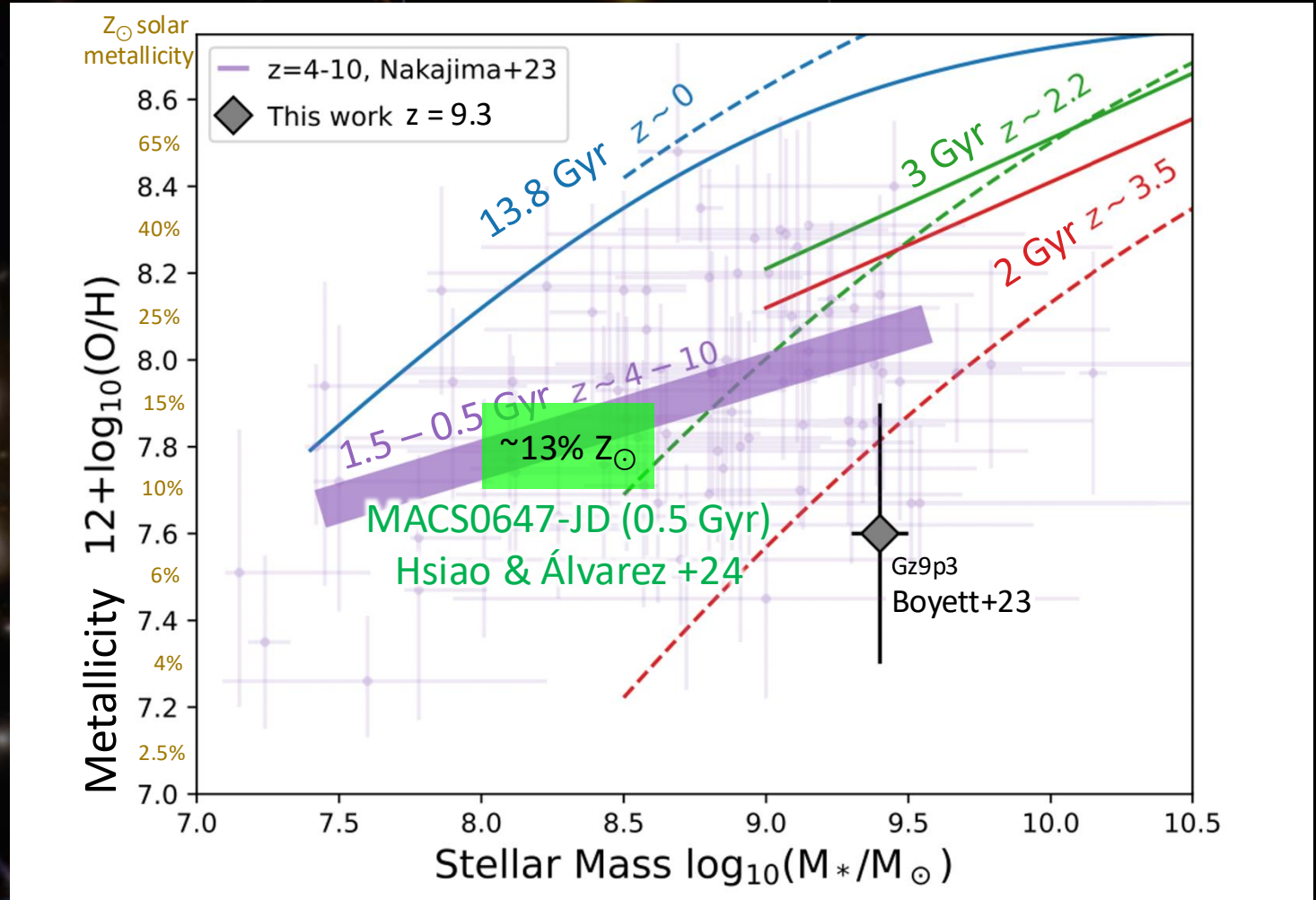


MIRI MRS reductions and analysis: Javier Álvarez
 paper: Tiger Hsiao & Javier Álvarez et al. 2024

SFR = $5.0 \pm 0.6 M_{\odot} / \text{yr}$
 $\log(\xi_{\text{ion}}) = 25.3 \pm 0.1$
 $\log(U) = -1.9 \pm 0.1$



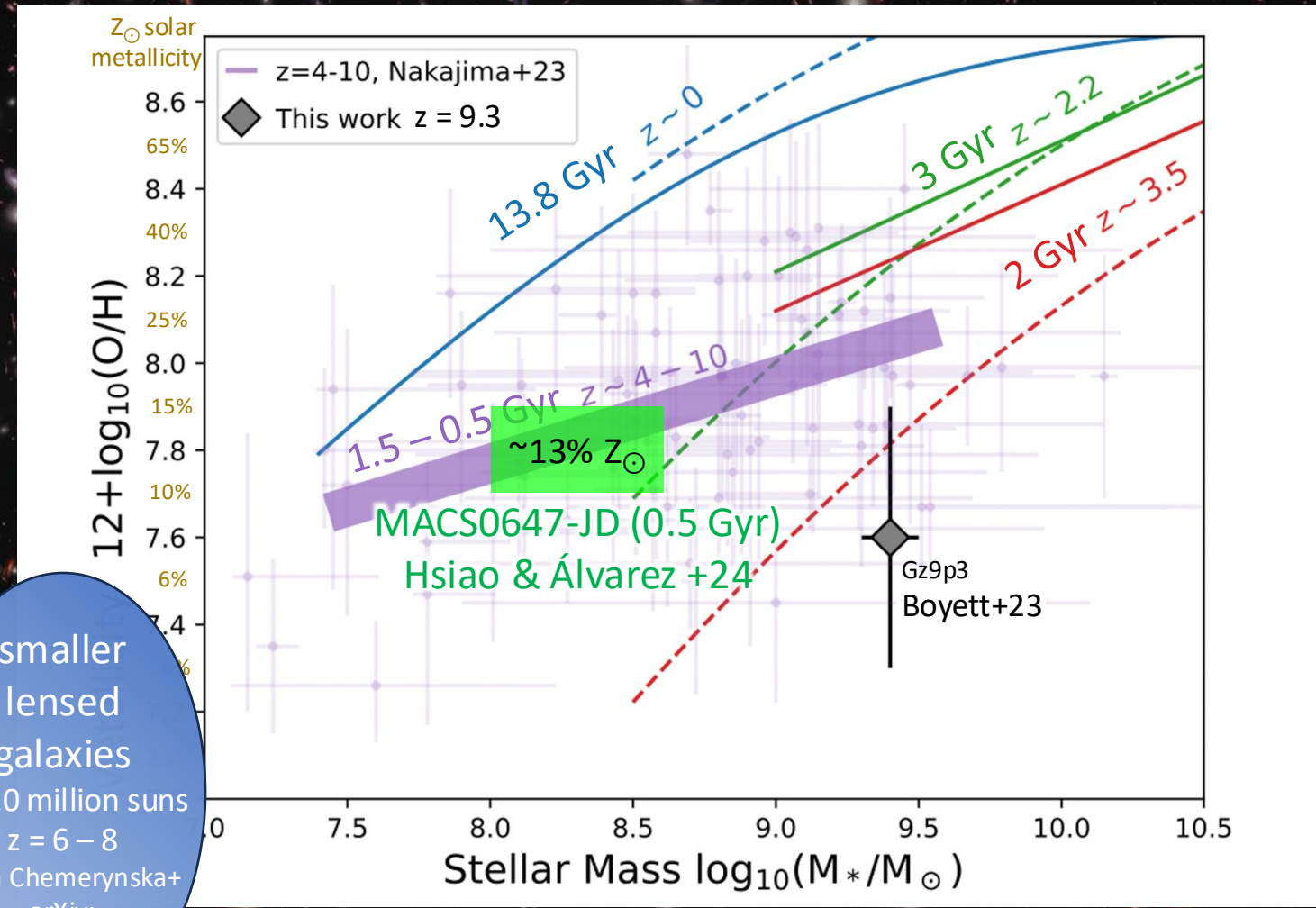
MACS0647-JD direct metallicity (0.5 Gyr) consistent with other measurements (1.5 – 0.5 Gyr)



1

2

Finding smaller lensed galaxies with less oxygen



6% solar metallicity

4%

2.5%

1.5%

1%



smaller lensed galaxies
 1 – 10 million suns
 $z = 6 - 8$
 Iryna Chemerynska+
 arXiv:
 2407.17110

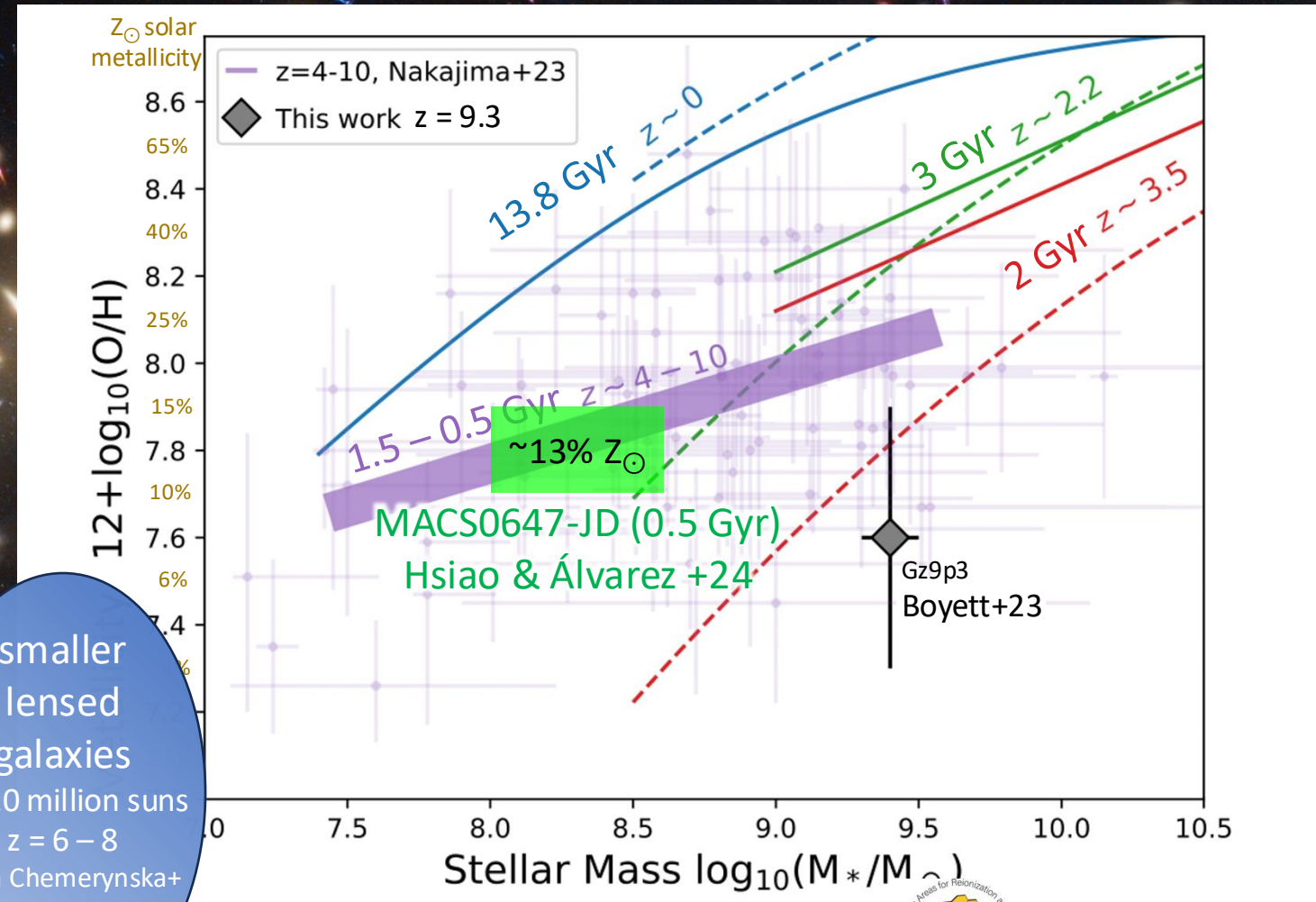
Finding smaller lensed galaxies with less oxygen

oxygen < 1% solar
mass ~10,000 suns
z = 6.64 lensed
Eros Vanzella+
arXiv:2305.14413

6% solar
metallicity
4%
2.5%
1.5%
1%



smaller
lensed
galaxies
1 – 10 million suns
z = 6 – 8
Iryna Chemerynska+
arXiv:
2407.17110



MACS0416



JWST VENUS

Vast Exploration for Next Unknowns

PI Seiji Fujimoto



Cycle 4: 60 galaxy clusters NIRCam

Cycle 5: 10 NIRSpec MOS

video: Hollis Akins

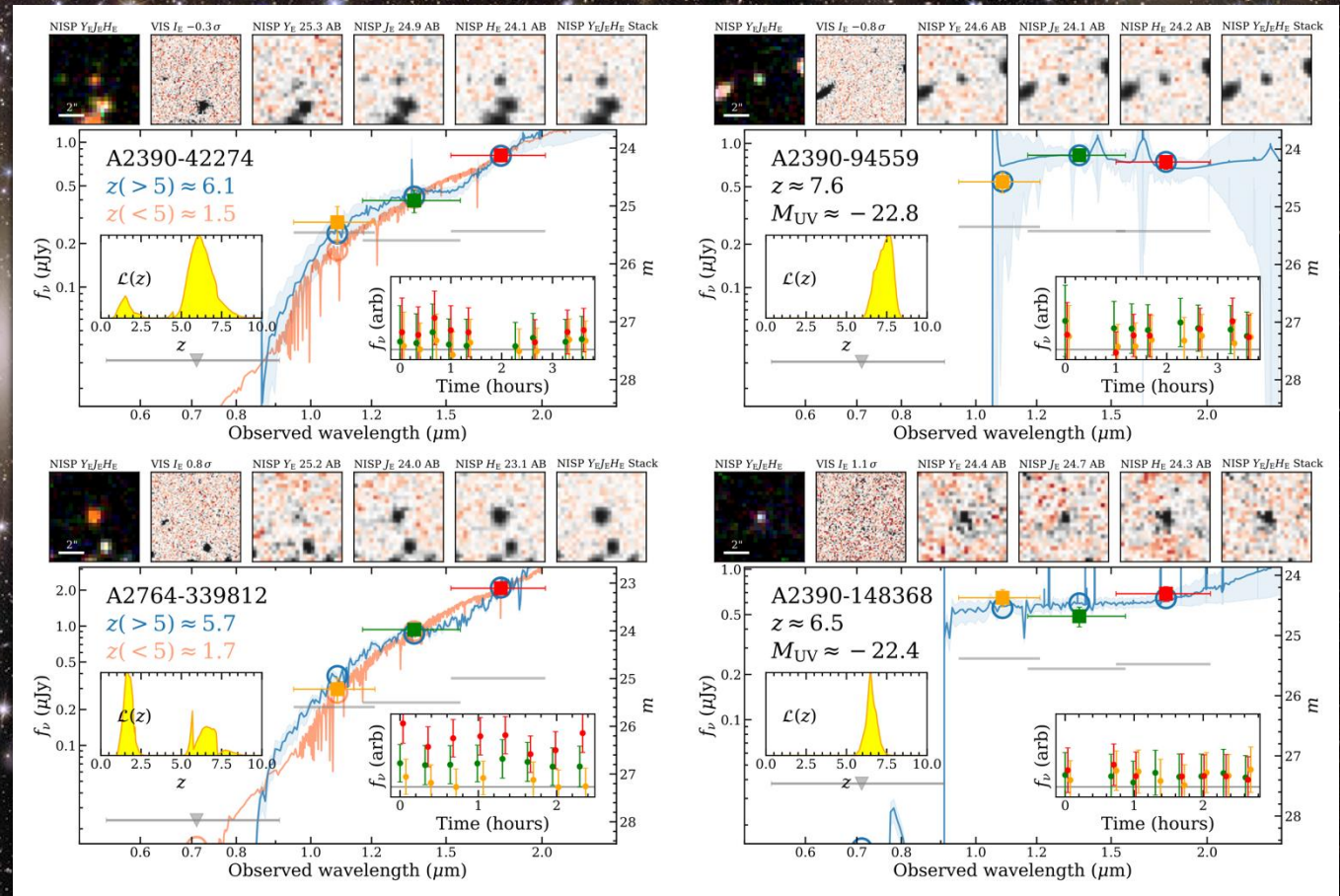


The best & brightest high-z galaxies & stars have yet to be discovered!

Euclid and Roman will observe much more sky delivering many distant galaxies and stars

Euclid candidates require follow-up with JWST

Weaver+; Atek+



JWST image size

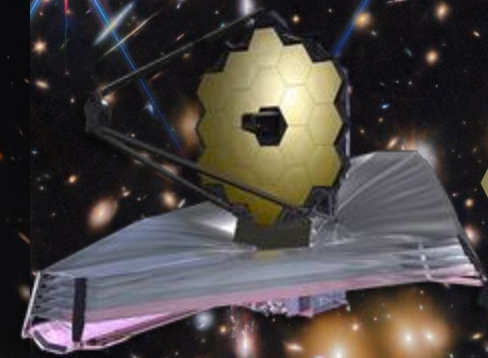


Perseus Cluster
 Credit: ESA/Euclid/Euclid Consortium/NASA
 J.-C. Cuillandre/CEA Paris-Saclay/G. Anselmi (image processing)

Jun 26, 2025

JWST has made giant leaps towards the first stars

- 👉 working together, we accomplish great things
- ★ individual stars observed at $z = 6$; need spectra
- 🌀 star clusters traced back to their origins at $z = 10$
- 🔍 lensing reveals lower mass, lower metallicity galaxies
- 🚀 what's next? NIRSpec IFU, VENUS, Euclid, Roman



Thank
you
Garth!

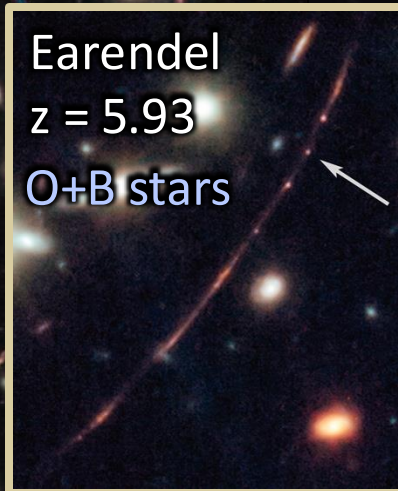


Abdurro'uf
JHU → Indiana



Tiger Hsiao
JHU / Harvard
→ Austin CFC

Earendel
 $z = 5.93$
O+B stars

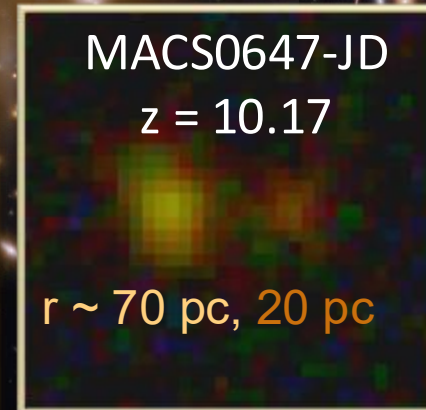


MACS0308-z6
 $z = 6.2$



MACS0647-JD
 $z = 10.17$

$r \sim 70$ pc, 20 pc



Lensed Galaxy
Redshift (z): 10.2

Cosmic Gems arc

$r \sim 1$ pc

Adamo+
Bradley+

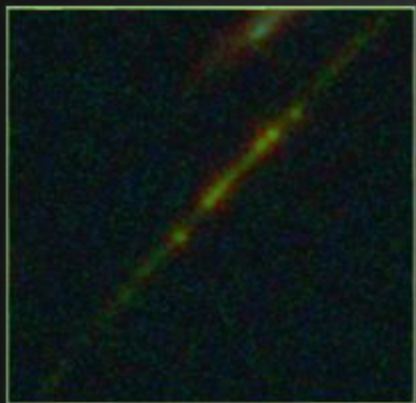
Mirrored Star Clusters
Redshift (z): 10.2



Thousands of astronomers have written a thousand papers on galaxies w/ JWST
highz.space/jwst/papers – compiled by Nimish Hathi

Dense star clusters and mergers may drive starbursts helping to explain abundance of “bright” early galaxies

Observed star clusters suggest high star formation efficiency

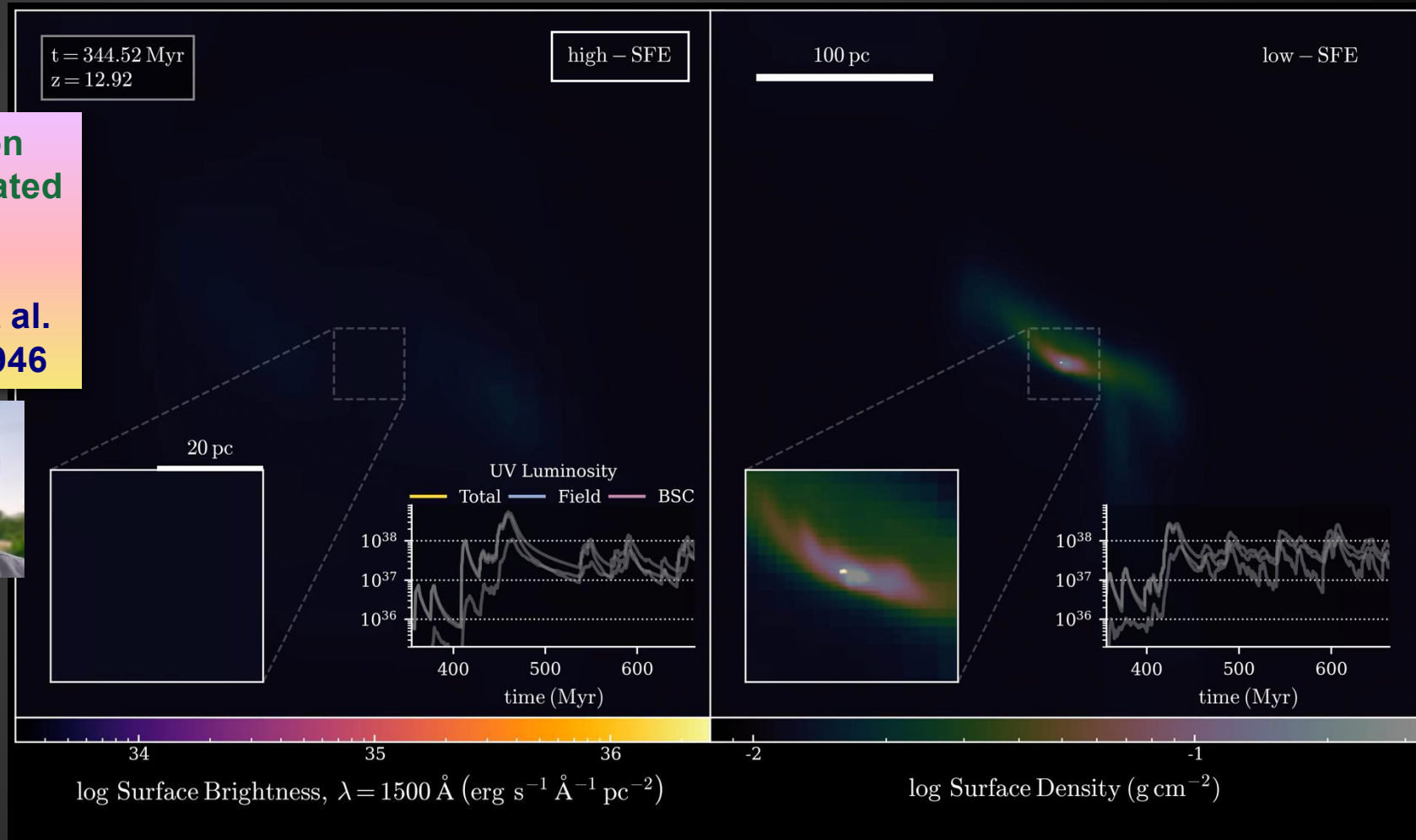


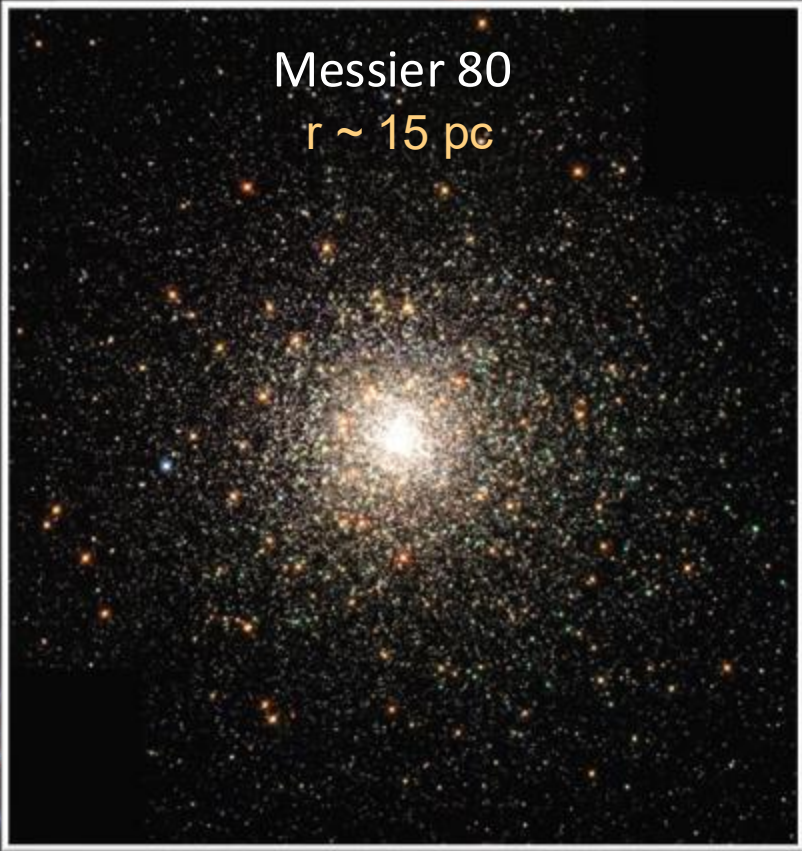
High-resolution
(0.1 pc) simulated
high-z galaxy

Fred Garcia et al.
arXiv:2212.13946

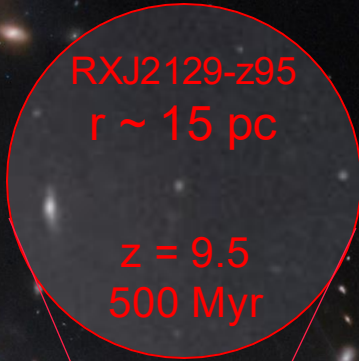


upcoming
Cycle 3 GO 5917
PI Eros Vanzella
NIRSpec IFU prism
MIRI MRS long





Messier 80
 $r \sim 15 \text{ pc}$



RXJ2129-z95
 $r \sim 15 \text{ pc}$

$z = 9.5$
500 Myr

3 lensed
images



Hayley Williams
et al. 2023

RXJ2129 (PI Pat Kelly)
<https://esawebb.org/images/potm2302a/>