Shedding new light on the first billion years of the Universe

GECO Conference
Marseille, July 3-7 2023

Deconstructing the Hubble Sequence with JWST

Shedding new Light on Galaxies Star-formation Quenching History since the End of Cosmic Dawn

Thibaud Moutard

LAM Laboratoire d'Astrophysique de Marseille · cnes Centre National d'Études Spatiales · MIRI European Consortium · NASA | ESA | CSA jwst

MIDIS Collaborators: P. Rinaldi, P. Perez-Gonzalez, O. Ilbert, M. Annunziatella, L. Boogaard, Jens Melinder
L. Colina, G. Östlin & the MIRI-EC High-z Team

Credit: NASA, ESA, CSA, and STScI

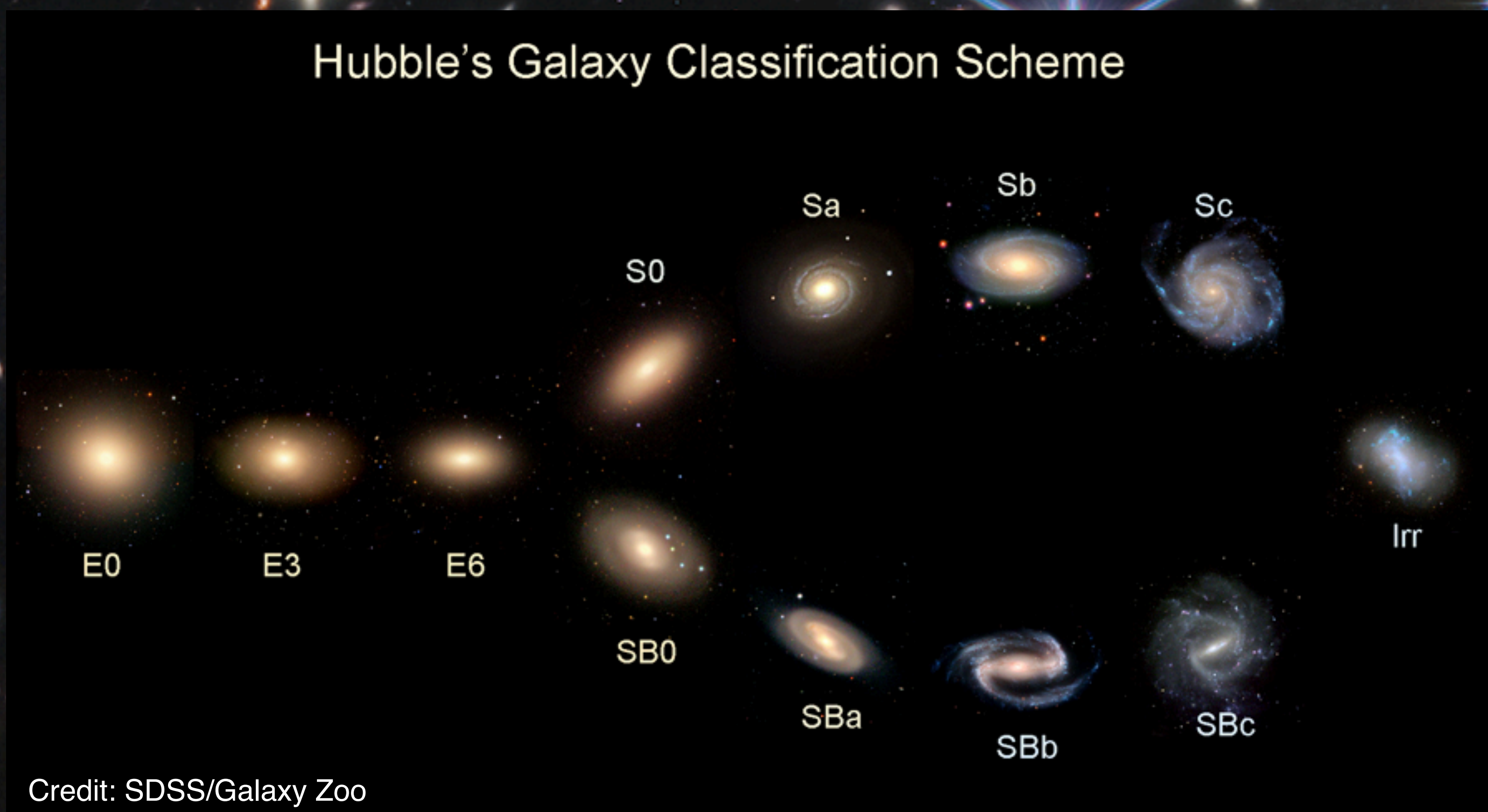
GALAXIES DIVERSITY AND DISTRIBUTION

GALAXIES DIVERSITY AND DISTRIBUTION

MULTI-WAVELENGTH OBSERVATIONS HAVE REVEALED
THE TREMENDOUS DIVERSITY OF GALAXIES
(MORPHOLOGIES, SPECTRAL TYPES & ENVIRONMENTS)

GALAXY EVOLUTION SCHEME

ON AVERAGE, SPIRALS ARE (OPTICALLY) BLUE, ELLIPTICALS ARE RED
(~90% OF GALAXIES IN THE LOCAL UNIVERSE)

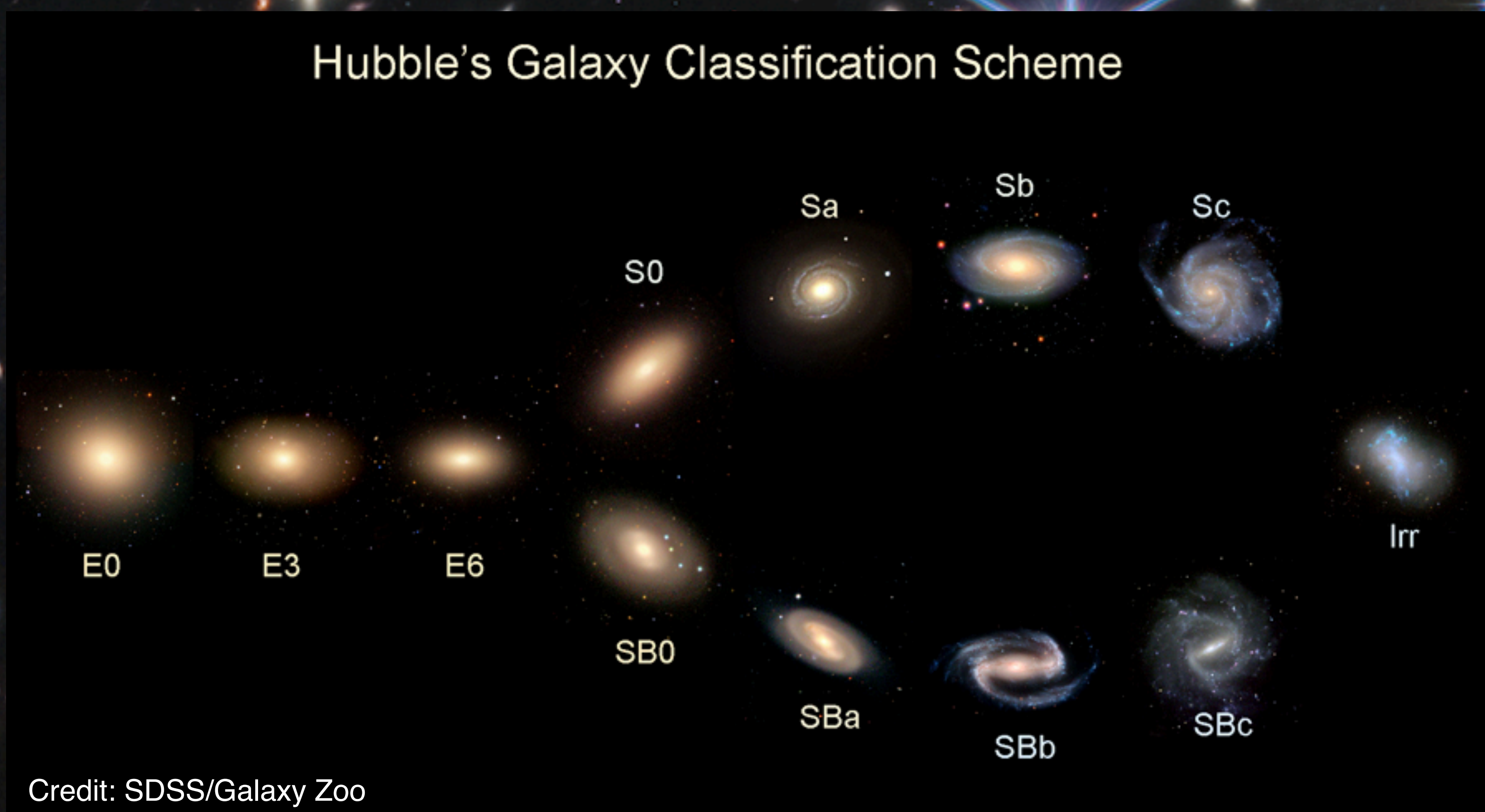


Credit: SDSS/Galaxy Zoo

Credit: NASA, ESA, CSA, and STScI

GALAXY EVOLUTION SCHEME

ON AVERAGE, SPIRALS ARE (OPTICALLY) BLUE, ELLIPTICALS ARE RED
(~90% OF GALAXIES IN THE LOCAL UNIVERSE)



ACTUALLY, SLIGHTLY MORE COMPLICATED…

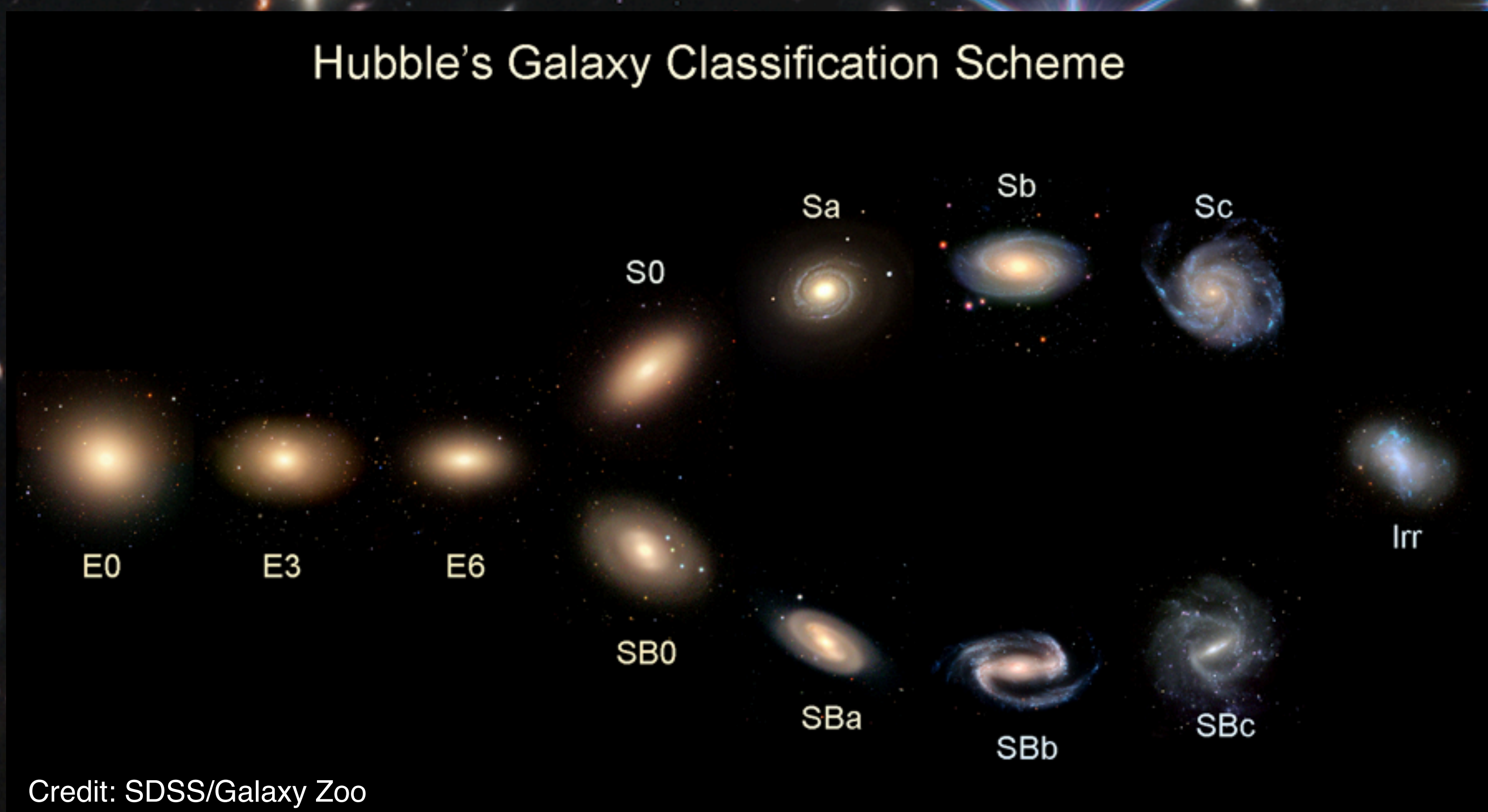
z ~ 0.05

Schawinski et al. (2014)

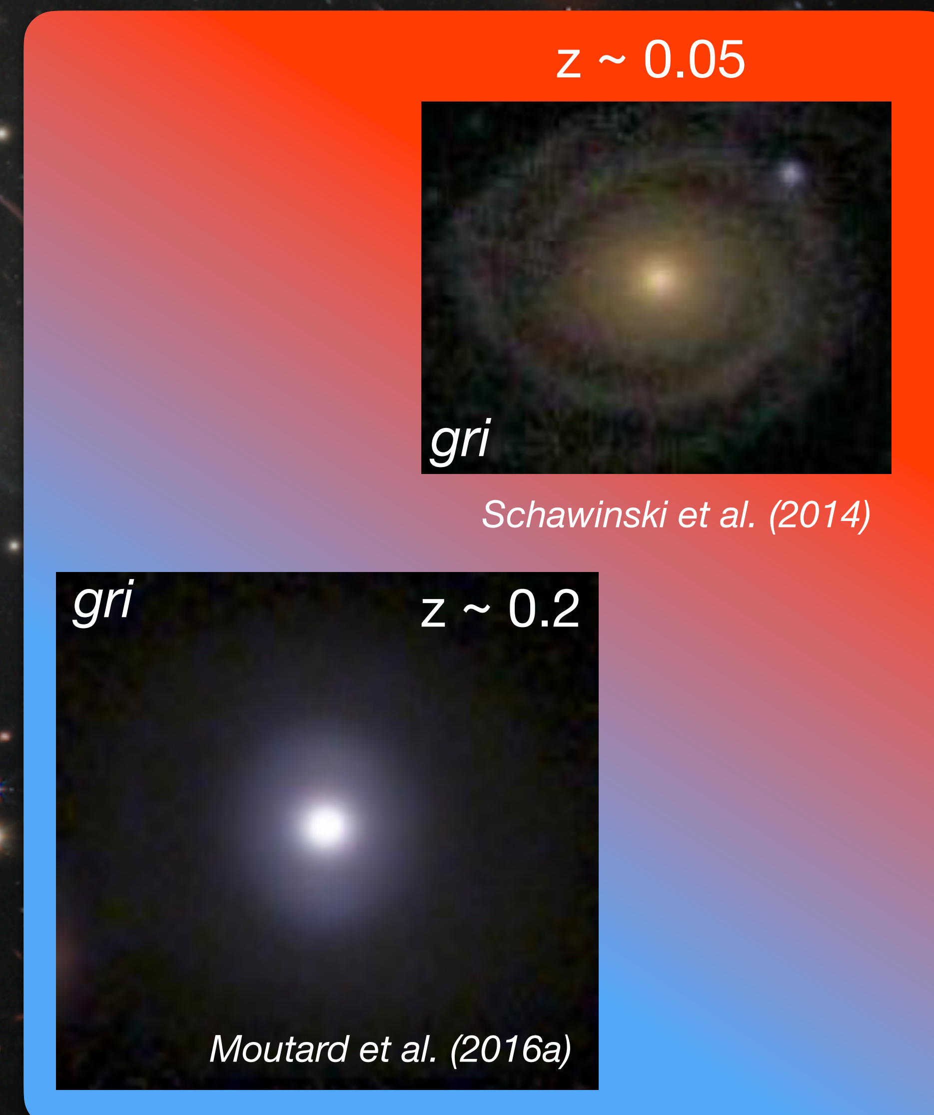
Credit: NASA, ESA, CSA, and STScI

GALAXY EVOLUTION SCHEME

ON AVERAGE, SPIRALS ARE (OPTICALLY) BLUE, ELLIPTICALS ARE RED
(~90% OF GALAXIES IN THE LOCAL UNIVERSE)



ACTUALLY, SLIGHTLY MORE COMPLICATED…

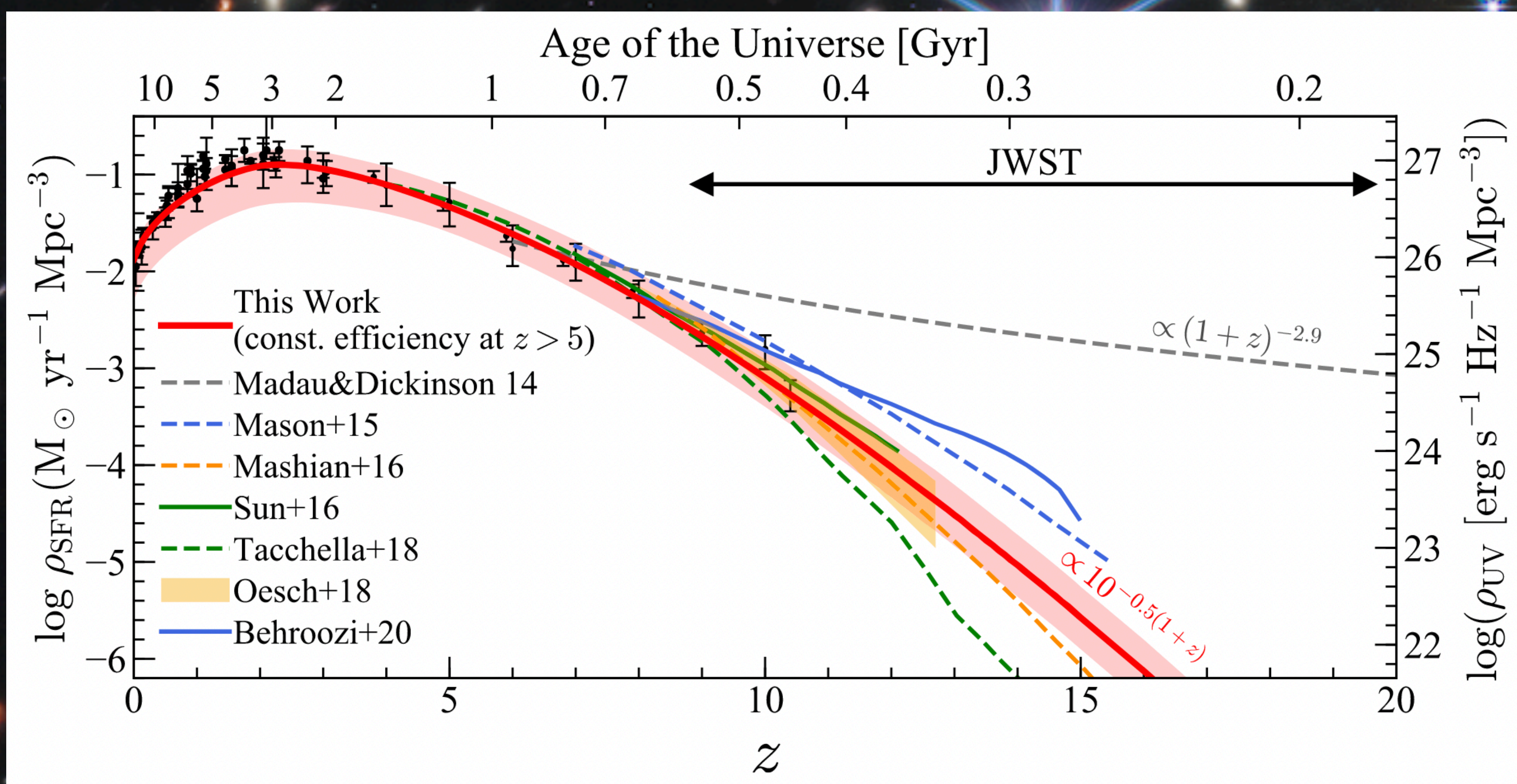


WHAT ABOUT THE 10% OF BLUE ELLIPTICAL AND RED SPIRAL GALAXIES OBSERVED IN THE LOCAL UNIVERSE…
AND BEYOND?

Credit: NASA, ESA, CSA, and STScI

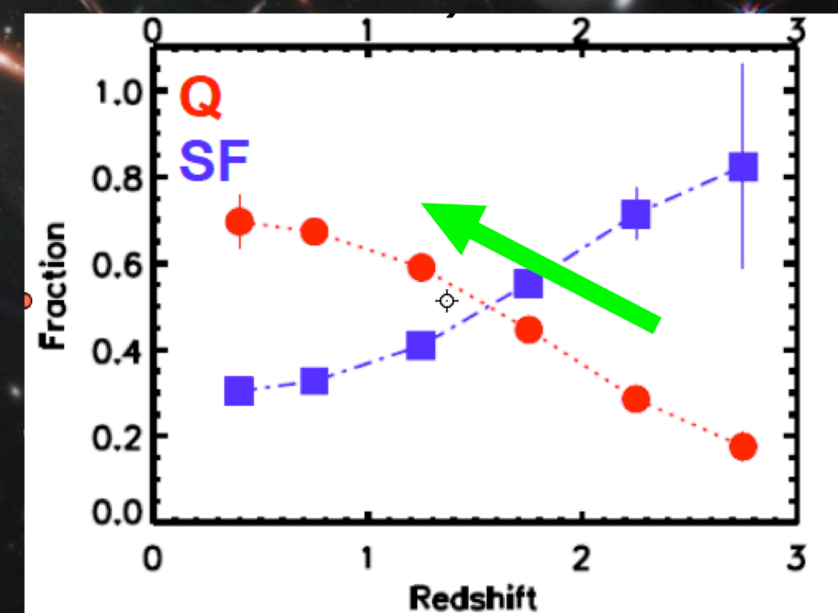
GALAXIES FATE

COSMIC STAR FORMATION HISTORY EXHIBITS A MAXIMUM AT 1 < z < 3, AT COSMIC NOON



Harikane et al. 2021

QUIESCENT GALAXIES FRACTION CONTINUOUSLY RISING SINCE z ~ 4



Mortlock et al. 2015

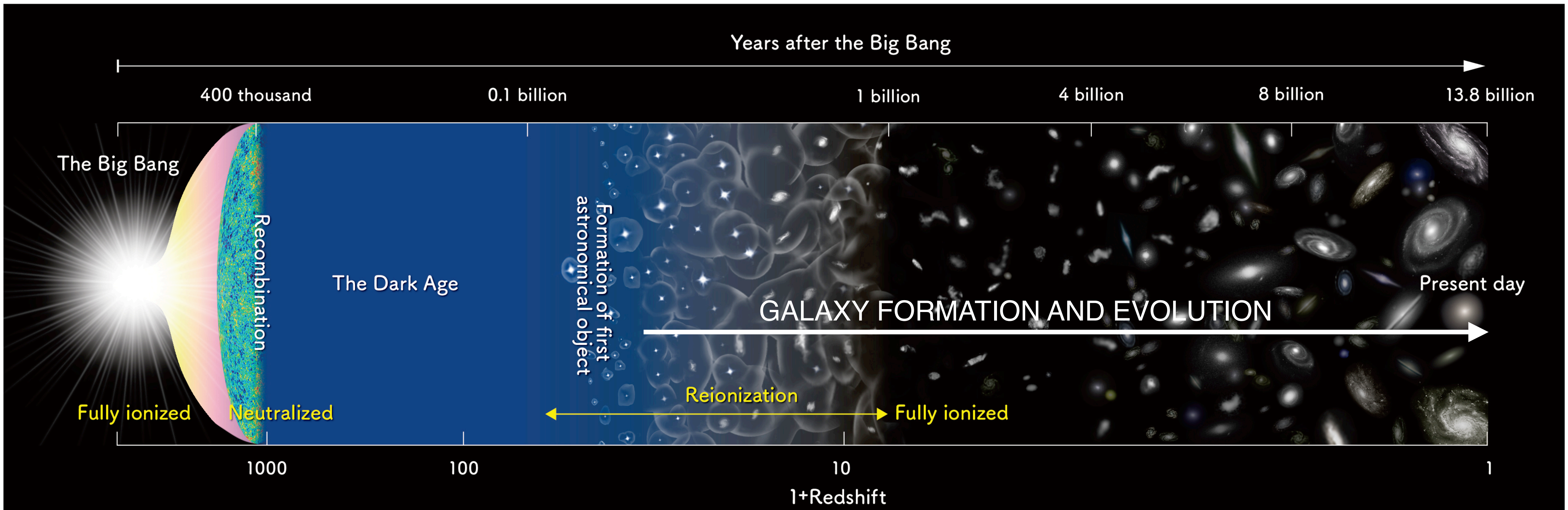
Credit: NASA, ESA, CSA, and STScI

EVENTUALLY, GALAXY STAR FORMATION IS OBSERVED TO STOP, FOR GOOD.

WHY AND HOW?

GALAXIES FATE

GALAXY EVOLUTION IS EXPECTED TO HAVE COVERED ≥ 13 BILLION YEARS

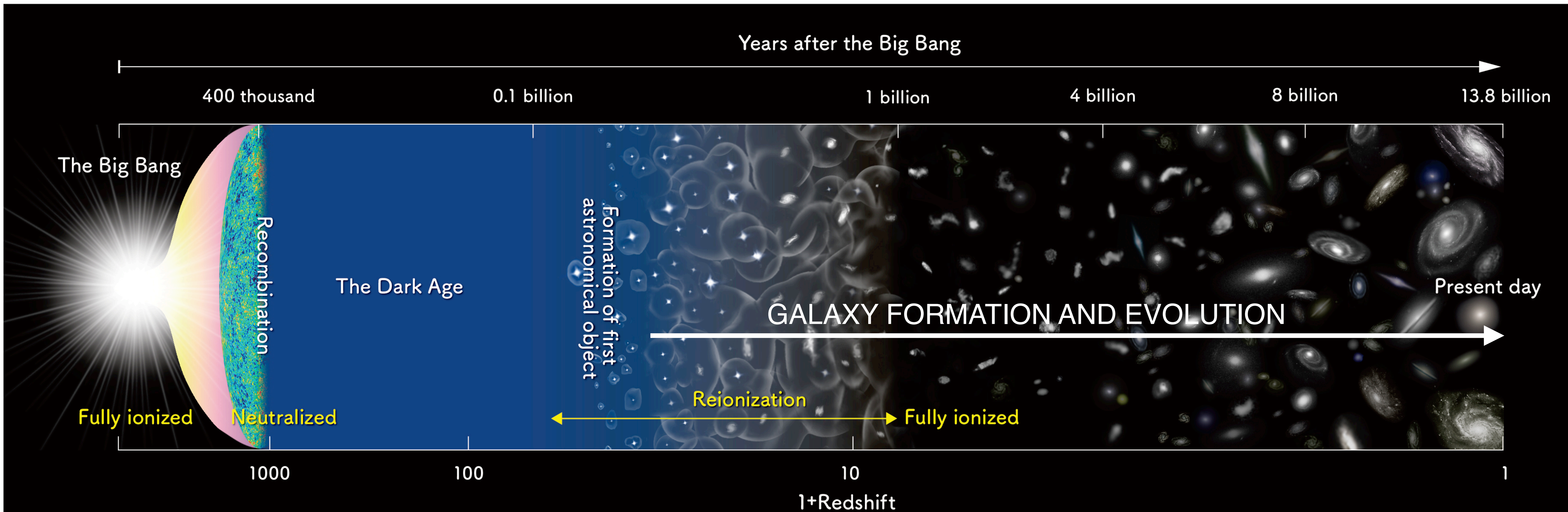


Credit: NAOJ/ NOAO

Credit: NASA, ESA, CSA, and STScI

GALAXIES FATE

GALAXY EVOLUTION IS EXPECTED TO HAVE COVERED ≥ 13 BILLION YEARS



Credit: NAOJ/ NOAO

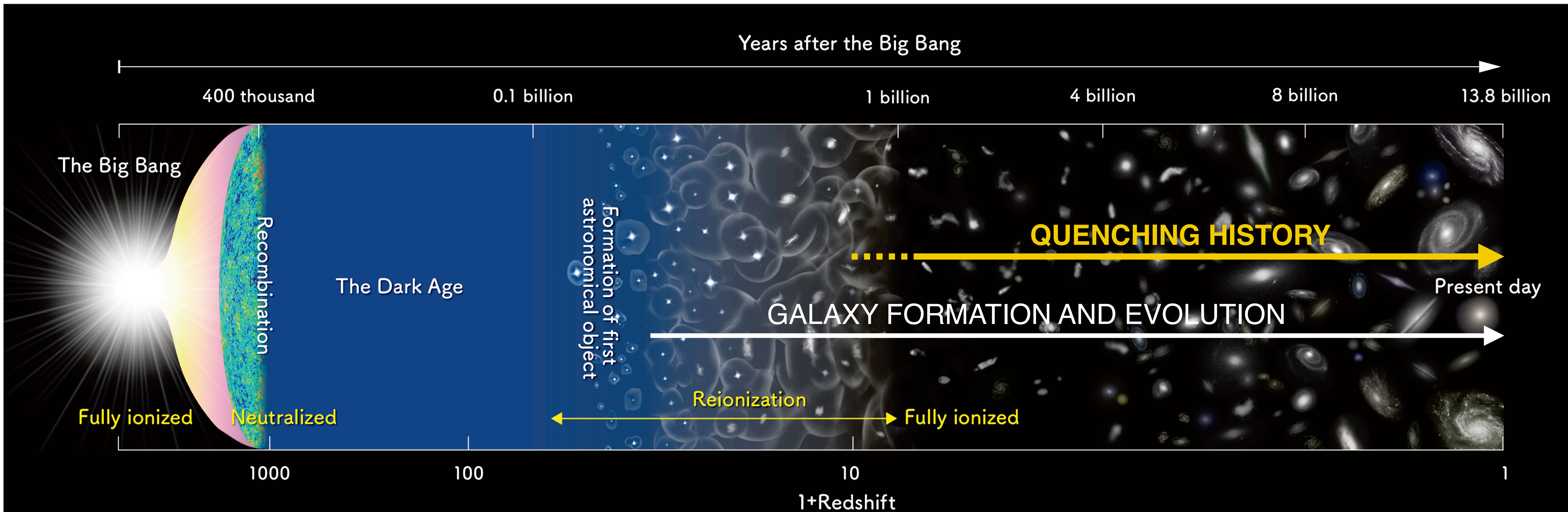
~ 1 BILLION YEARS AFTER THE BIG BANG,
FIRST CONFIRMED QUIESCENT/PASSIVE GALAXIES ARE OBSERVED
(E.G. DAVIDZON+17, MERLIN+19, CHWOROWSKY+23)

Credit: NASA, ESA, CSA, and STScI

GALAXIES FATE

Credit: NASA, ESA, CSA, and STScI

GALAXY EVOLUTION IS EXPECTED TO HAVE COVERED ≥ 13 BILLION YEARS



Credit: NAOJ/ NOAO

~ 1 BILLION YEARS AFTER THE BIG BANG,
FIRST CONFIRMED QUIESCENT/PASSIVE GALAXIES ARE OBSERVED
(E.G. DAVIDZON+17, MERLIN+19, CHWOROWSKY+23)

SF QUENCHING HISTORY IS EXPECTED TO HAVE COVERED ≥ 12 BILLION YEARS

GALAXIES FATE

DIFFERENT FLAVOURS OF STAR FORMATION QUENCHING

Slow Quenching of Evolved, Massive Galaxies

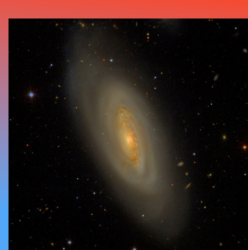
Faber et al. 2007
Peng et al. 2010, 2015
Schawinski et al. 2014
Moutard et al. 2016a,b, 2020b

Fast Quenching of Low-Mass Satellite Galaxies

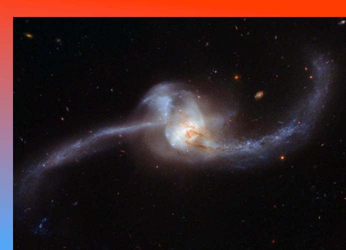
Faber et al. 2007
Peng et al. 2010, 2012
Schawinski et al. 2014
Moutard et al. 2016a,b, 2018

Fast Quenching of Massive Galaxies at Early Epochs

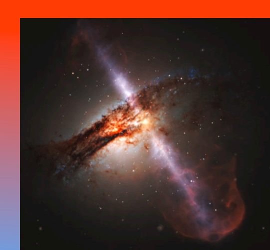
Di Matteo et al 2005
Hopkins et al. 2006
Menci et al. 2006
Merlin et al 2019



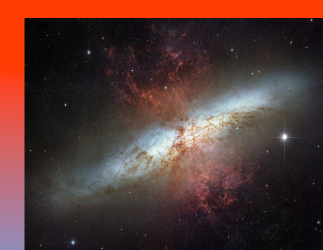
STARVATION



MERGERS



AGN FEEDBACK



STARBURST

RAM PRESSURE

GALAXIES FATE

DIFFERENT FLAVOURS OF STAR FORMATION QUENCHING

Slow Quenching of Evolved, Massive Galaxies

Faber et al. 2007
Peng et al. 2010, 2015
Schawinski et al. 2014
Moutard et al. 2016a,b, 2020b

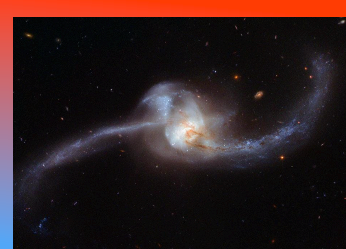
Fast Quenching of Low-Mass Satellite Galaxies

Faber et al. 2007
Peng et al. 2010, 2012
Schawinski et al. 2014
Moutard et al. 2016a,b, 2018

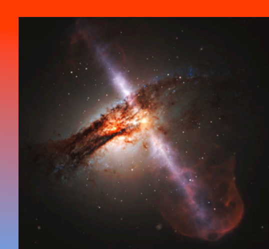
Fast Quenching of Massive Galaxies at Early Epochs

Di Matteo et al 2005
Hopkins et al. 2006
Menci et al. 2006
Merlin et al 2019

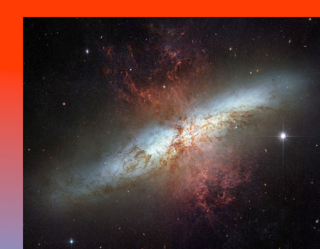
STARVATION



MERGERS



AGN FEEDBACK



STARBURST

RAM PRESSURE

WHAT ARE THE PRECISE MECHANISMS AT PLAY IN THOSE DIFFERENT QUENCHING CHANNELS?

Credit: NASA, ESA, CSA, and STScI

GALAXIES FATE

DIFFERENT FLAVOURS OF STAR FORMATION QUENCHING

Slow Quenching of Evolved, Massive Galaxies

Faber et al. 2007
Peng et al. 2010, 2015
Schawinski et al. 2014
Moutard et al. 2016a,b, 2020b

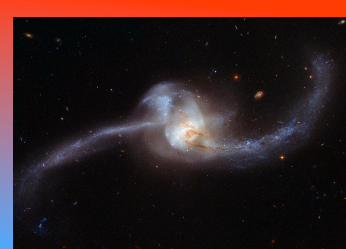
Fast Quenching of Low-Mass Satellite Galaxies

Faber et al. 2007
Peng et al. 2010, 2012
Schawinski et al. 2014
Moutard et al. 2016a,b, 2018

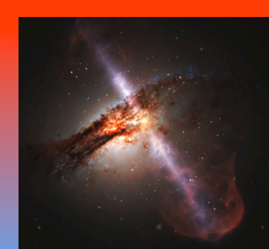
Fast Quenching of Massive Galaxies at Early Epochs

Di Matteo et al 2005
Hopkins et al. 2006
Menci et al. 2006
Merlin et al 2019

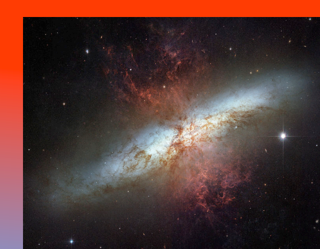
STARVATION



MERGERS



AGN FEEDBACK



STARBURST

RAM PRESSURE

WHAT ARE THE PRECISE MECHANISMS AT PLAY IN THOSE DIFFERENT QUENCHING CHANNELS?

WHAT CAN WE LEARN FROM GALAXIES MORPHOLOGY ABOUT THOSE DIFFERENT QUENCHING CHANNELS?

GALAXIES FATE

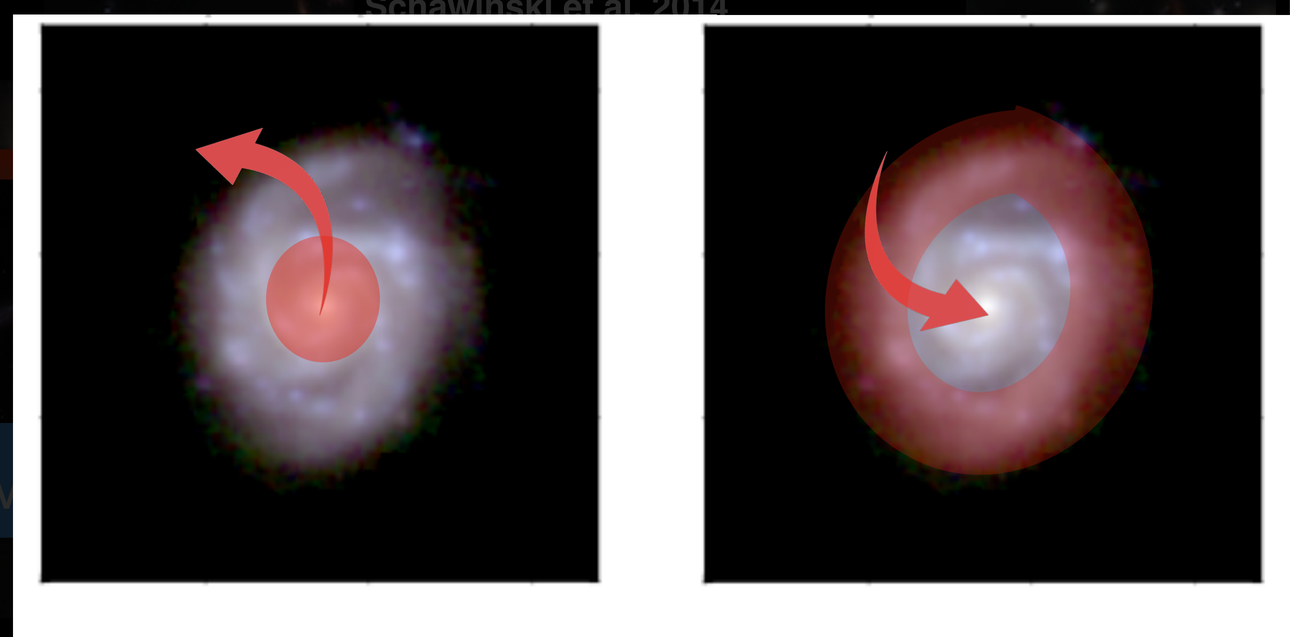
DIFFERENT FLAVOURS OF STAR FORMATION QUENCHING

Slow Quenching of Evolved, Massive Galaxies	Fast Quenching of Low-Mass Satellite Galaxies	Fast Quenching of Massive Galaxies at Early Epochs
Faber et al. 2007 Peng et al. 2010, 2015 Schawinski et al. 2014 Moutard et al. 2016a,b, 2020b	Faber et al. 2007 Peng et al. 2010, 2012 Schawinski et al. 2014	Di Matteo et al 2005 Hopkins et al. 2006 Menci et al. 2006 Merlin et al 2019


STARVATION


RAM PRESSURE

Morphology or SFR change first?



Outside-in or inside-outquenching?

WHAT ARE THE PRECISE MECHANISMS AT PLAY IN THOSE DIFFERENT QUENCHING CHANNELS?

WHAT CAN WE LEARN FROM GALAXIES MORPHOLOGY ABOUT THOSE DIFFERENT QUENCHING CHANNELS?

WITNESSING GALAXIES FATE SINCE COSMIC DAWN

FROM AN OBSERVATIONAL AND STATISTICAL POINT OF VIEW, WE HAVE TWO MAIN REQUIREMENTS

1. We need to explore galaxies extended parameter space:
   - spectra / colours
   - morphologies
   - environments

2. We need to probe ***all*** galaxy populations, and therefore a large volume:
   - high depth
   - large area

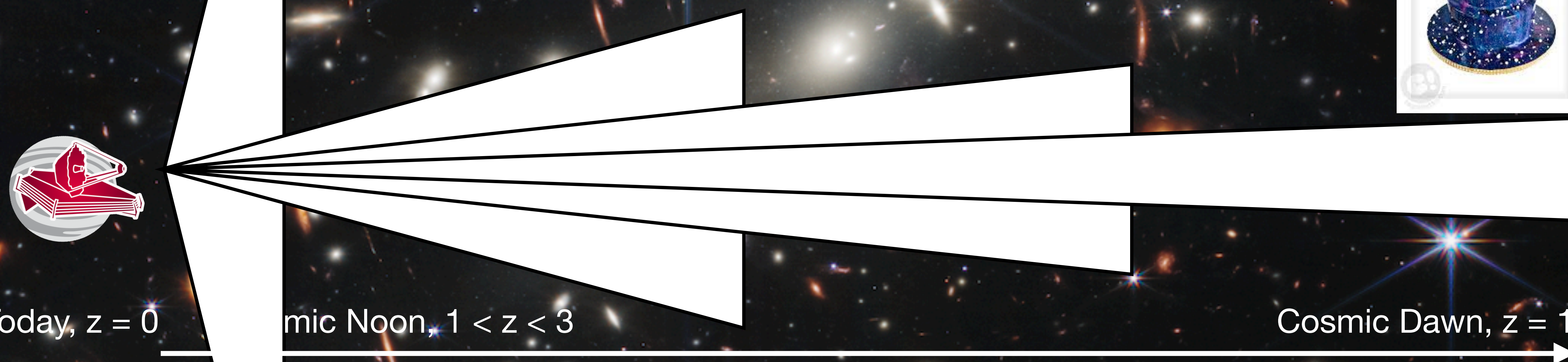
Credit: NASA, ESA, CSA, and STScI

WITNESSING GALAXIES FATE SINCE COSMIC DAWN

FROM AN OBSERVATIONAL AND STATISTICAL POINT OF VIEW, WE HAVE TWO MAIN REQUIREMENTS

1. We need to explore galaxies extended parameter space:
   - spectra / colours
   - morphologies
   - environments

2. We need to probe ***all*** galaxy populations, and therefore a large volume:
   - high depth
   - large area



A SOLUTION CONSISTS IN COMBINING SURVEYS OF DECREASING AREA/ INCREASING DEPTH, FOLLOWING A WEDDING-CAKE APPROACH

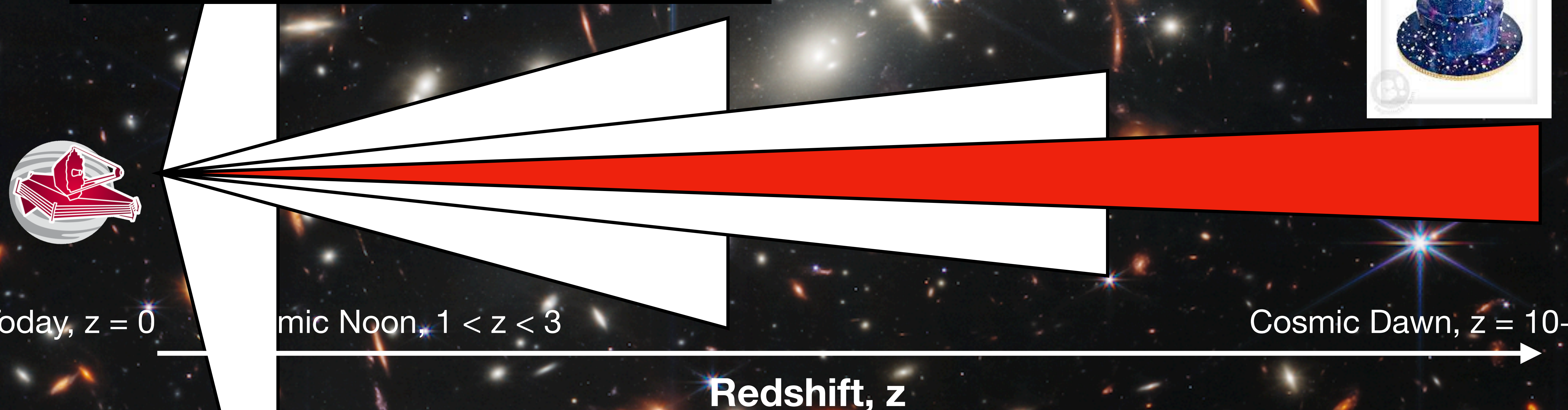
Credit: NASA, ESA, CSA, and STScI

WITNESSING GALAXIES FATE SINCE COSMIC DAWN

FROM AN OBSERVATIONAL AND STATISTICAL POINT OF VIEW, WE HAVE TWO MAIN REQUIREMENTS

1. We need to explore galaxies extended parameter space:
 - spectra / colours
 - morphologies
 - environments

2. We need to probe ***all*** galaxy populations, and therefore a large volume:
 - high depth
 - large area



A SOLUTION CONSISTS IN COMBINING SURVEYS OF DECREASING AREA/ INCREASING DEPTH, FOLLOWING A WEDDING-CAKE APPROACH

LET'S FOCUS ON THE DEEPEST LAYER OF SUCH JWST-BASED SURVEY…

THE MIRI DEEP IMAGING SURVEY (MIDIS) GTO PROGRAM

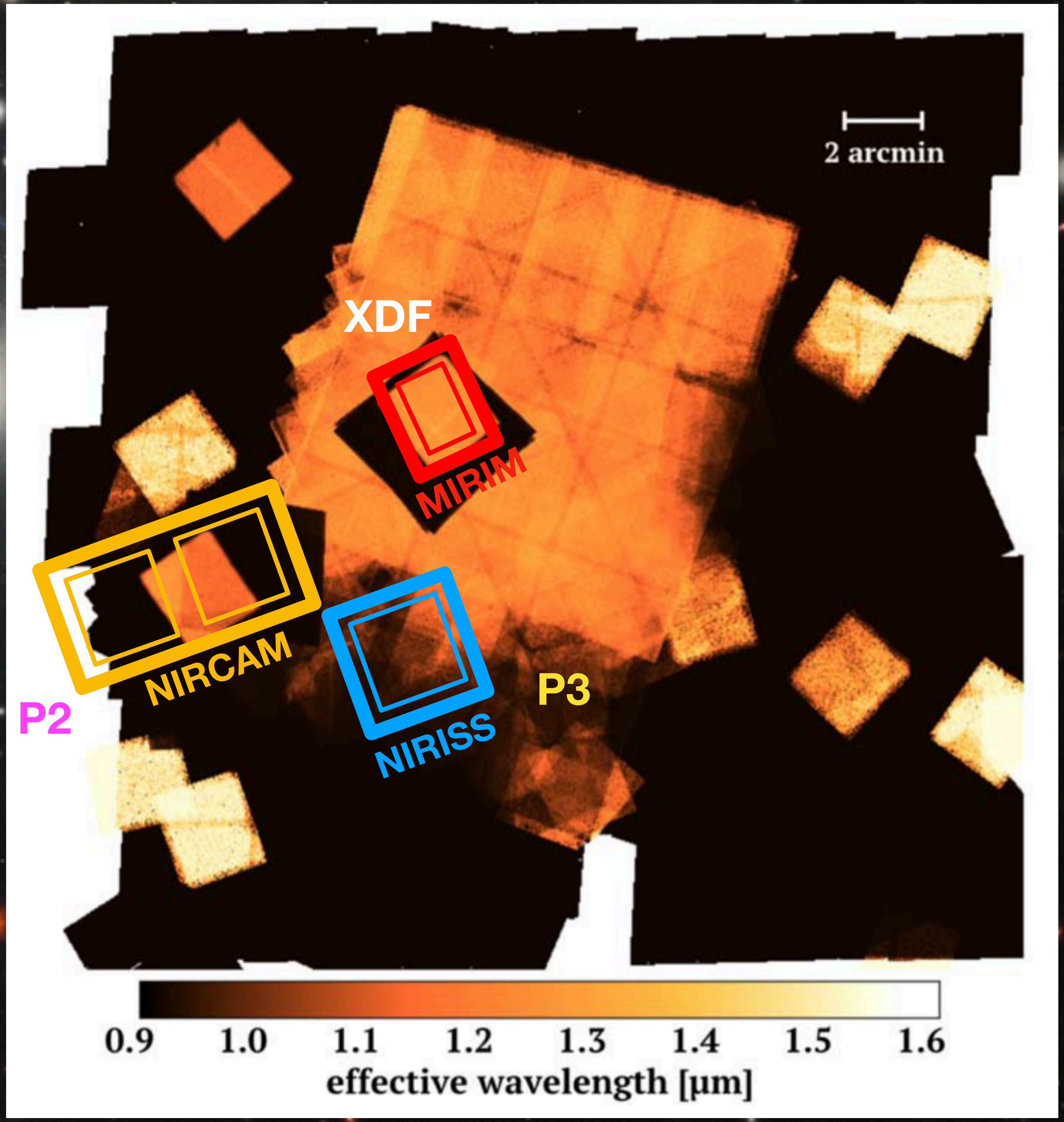
In a nutshell

HUDF coverage

Filter	Time now	Point source depth 5σ (mag, CGS)
MIRI F560W	172090 s (47.8 hours)	28.70 (r=0.14”)
NIRCam F115W	110502 s (30.6 hours)	30.87 (r=0.055”)
NIRCam F277W	57979 s (16.1 hours)	30.92 (r=0.055”)
NIRCam F356W	52524 s (14.6 hours)	30.79 (r=0.076”)
NIRISS F115W grism	19927 s (5.5 hours)	25.88, 5.5×10^{-18} (r=0.1”)
NIRISS F150W grism	19927 s (5.5 hours)	25.59, 3.6×10^{-18} (r=0.1”)
NIRISS F200W grism	17436 s (4.8 hours)	24.97, 3.9×10^{-18} (r=0.1”)
NIRISS F115W imaging	1073 s (0.3 hours)	28.23 (r=0.1”)
NIRISS F150W imaging	1073 s (0.3 hours)	28.32 (r=0.1”)
NIRISS F200W imaging	1073 s (0.3 hours)	28.49 (r=0.1”)

…actually ≥**0.5 mag deeper** than expected :)

Lots of ancillary HST observations



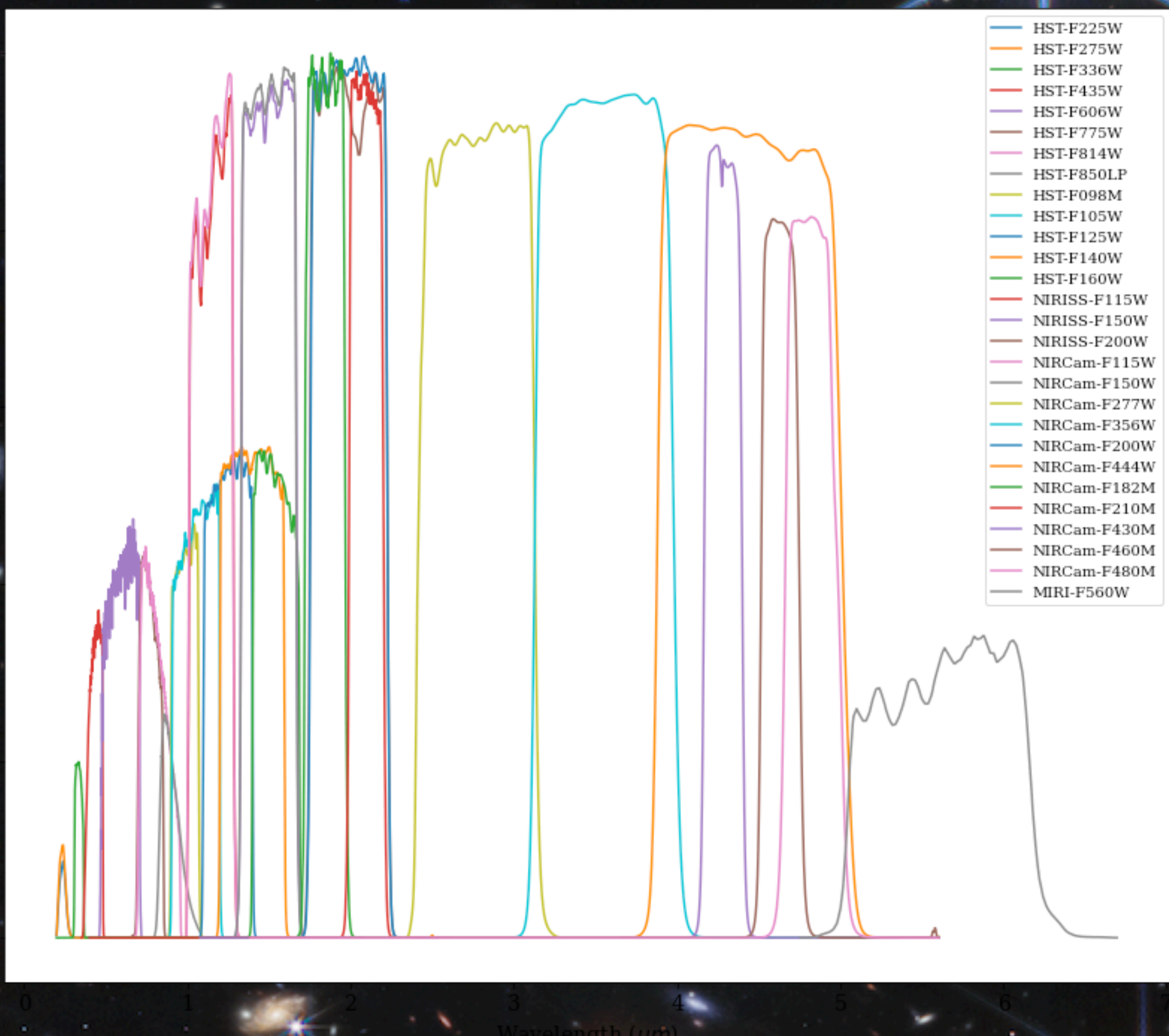
Whitaker et al. 2019

THE MIRI DEEP IMAGING SURVEY (MIDIS) GTO PROGRAM

Current status : MIDIS + Ancillary

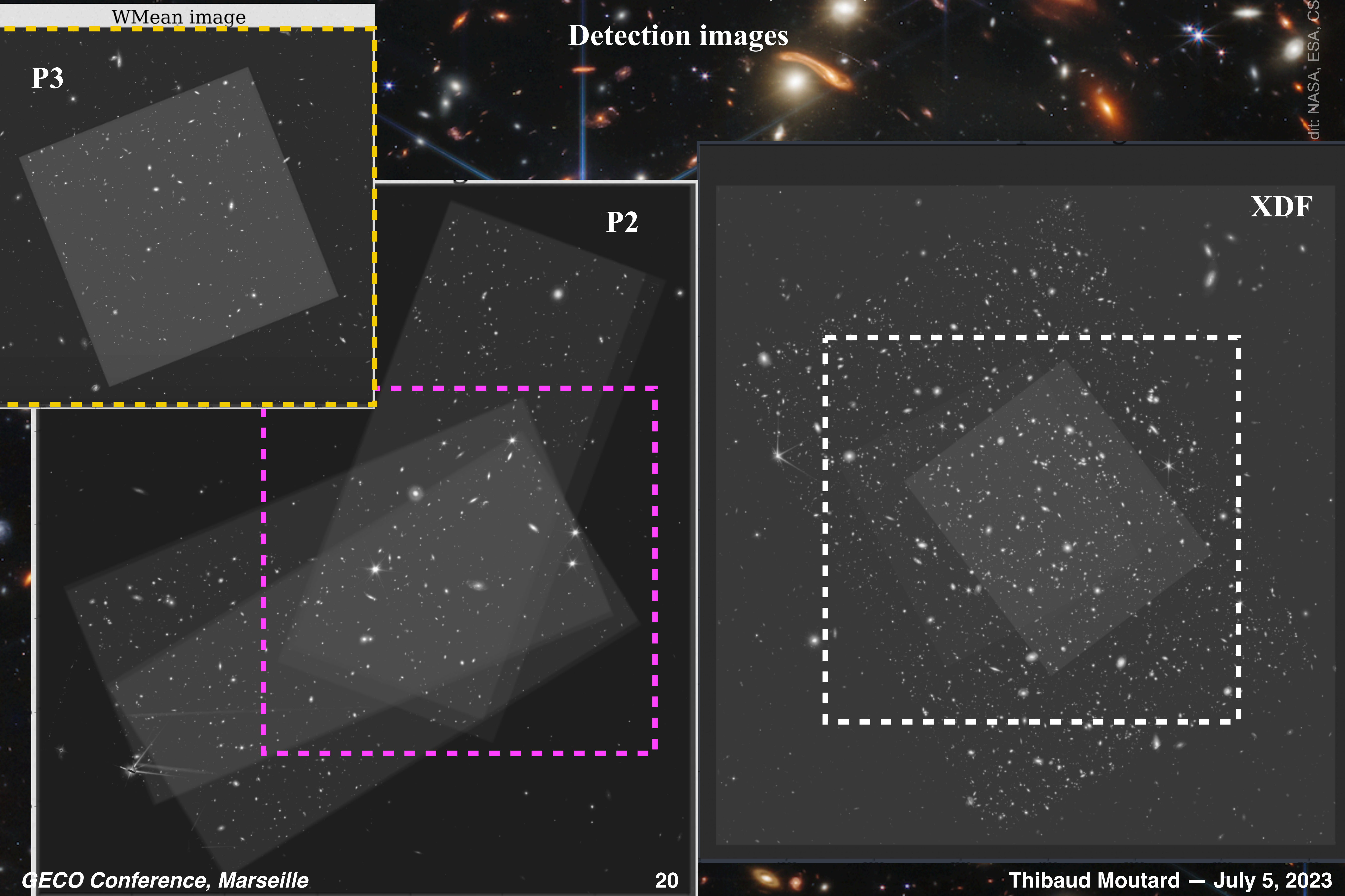
***MIDIS GTO** (Ostlin et al. in prep)*
***+ JADES GTO prog.** (Rieke+23)*
***+ JEMS & NGDEEP GOs** (Williams+23, Bagley+23)*
***+ HLS** (Whitaker+19)*

Lots of ancillary HST observations + extensive JWST coverage

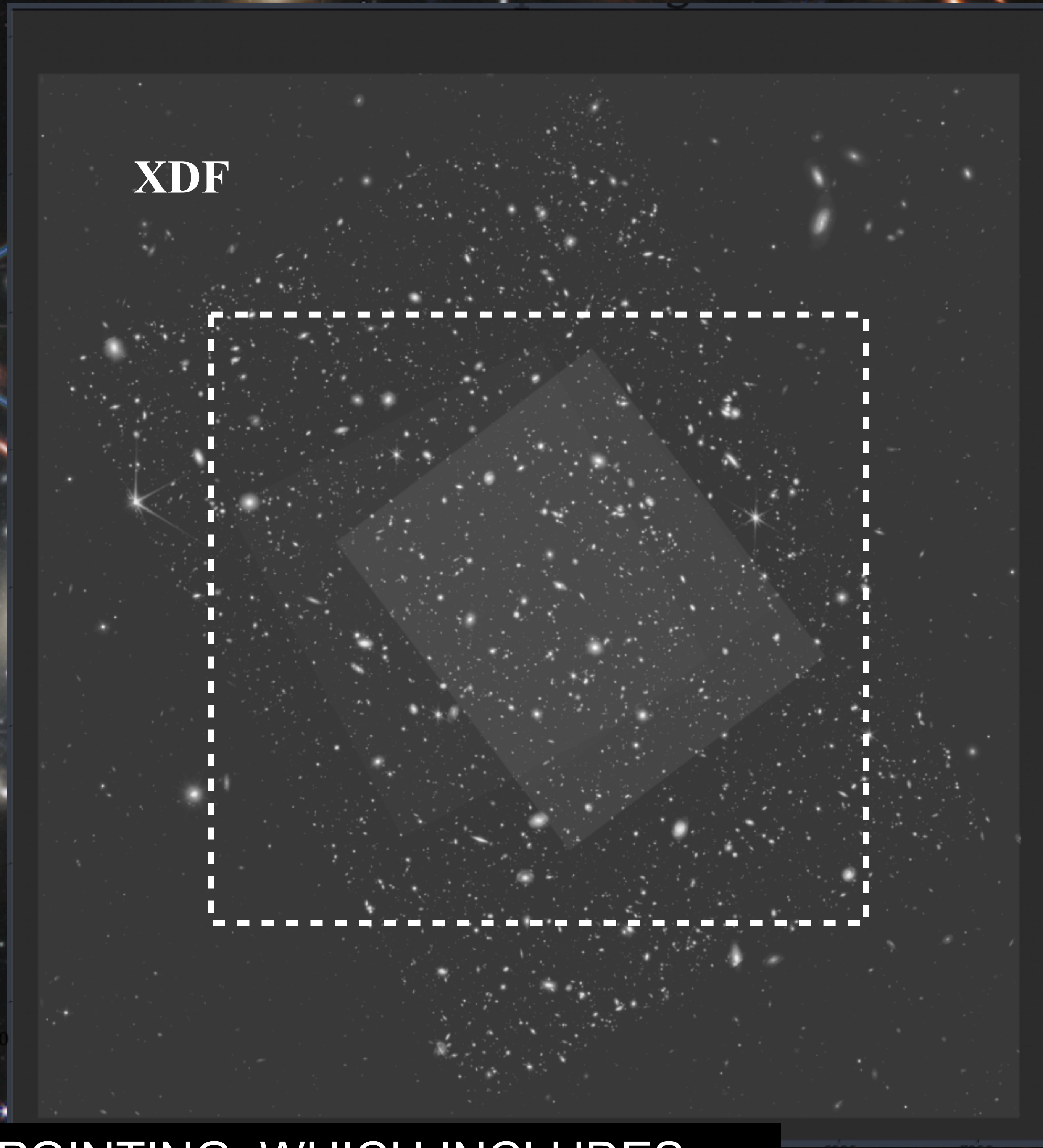


THE MIRI DEEP IMAGING SURVEY (MIDIS) GTO PROGRAM

Detection images



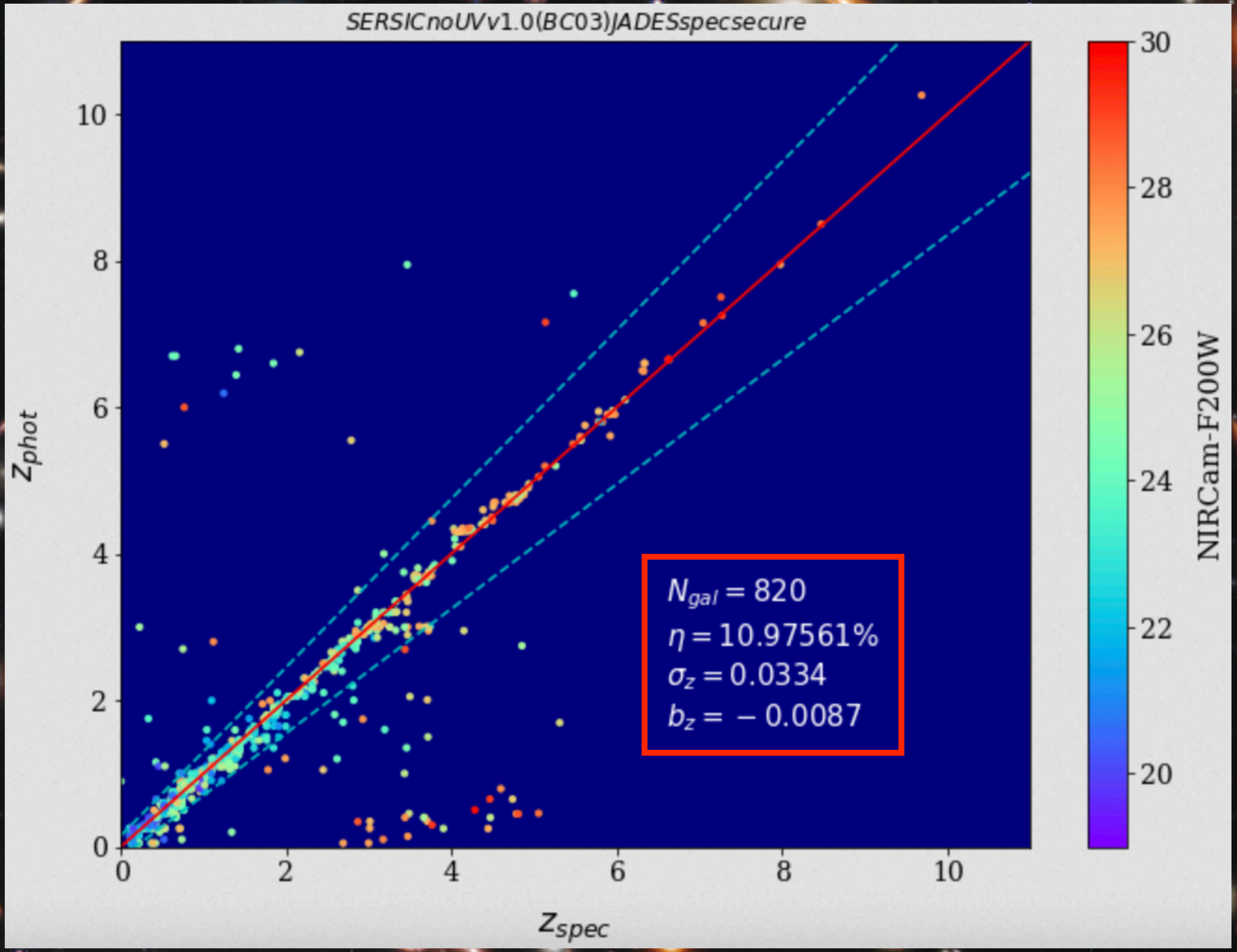
GALAXY PROPERTIES ANALYSIS IN THE XDF



LET'S FOCUS ON THE XDF POINTING, WHICH INCLUDES 29MAG-DEEP F560W OBSERVATIONS

GALAXY PROPERTIES ANALYSIS IN THE XDF

Photo-z accuracy

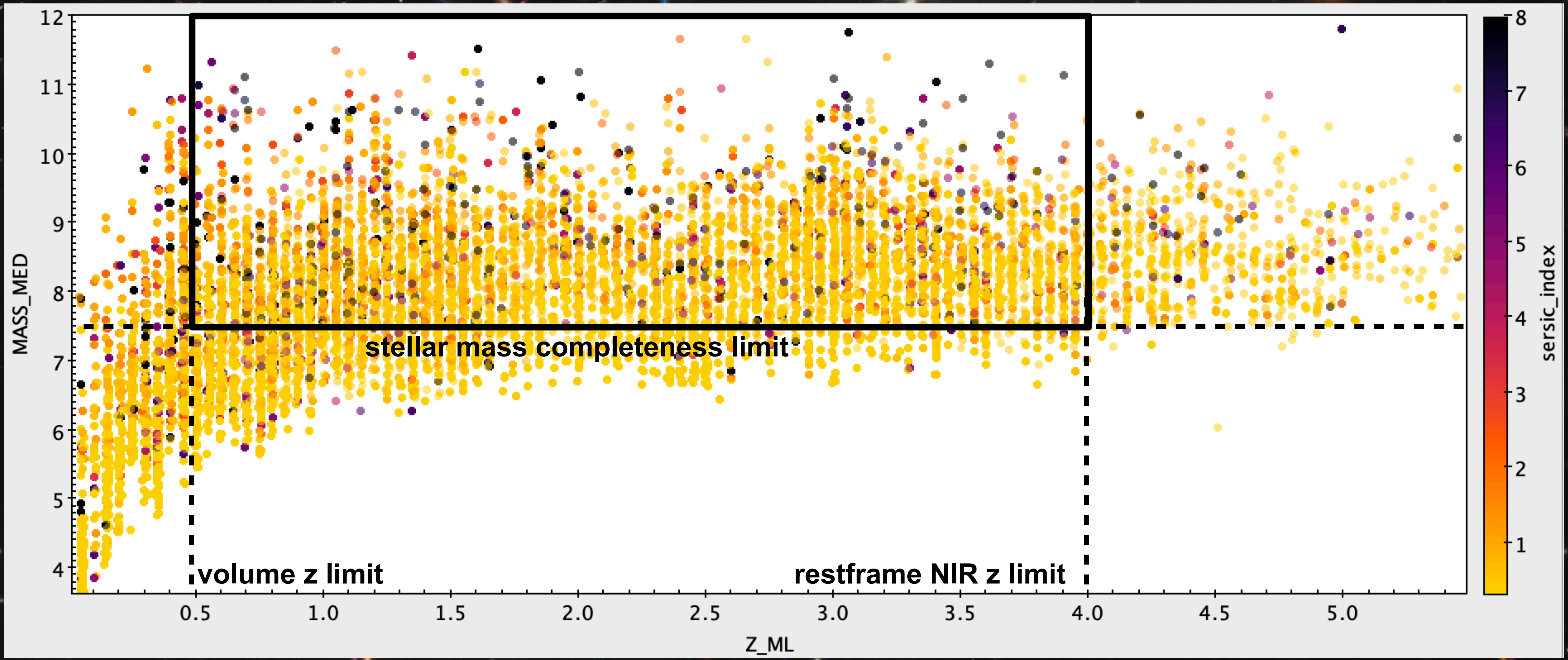


Moutard et al. in prep.

Highly reliable photo-z from Sersic profile-fitted photometry

GALAXY PROPERTIES ANALYSIS IN THE XDF

Redshift distribution of galaxies stellar masses and Sersic indexes



Moutard et al. in prep.

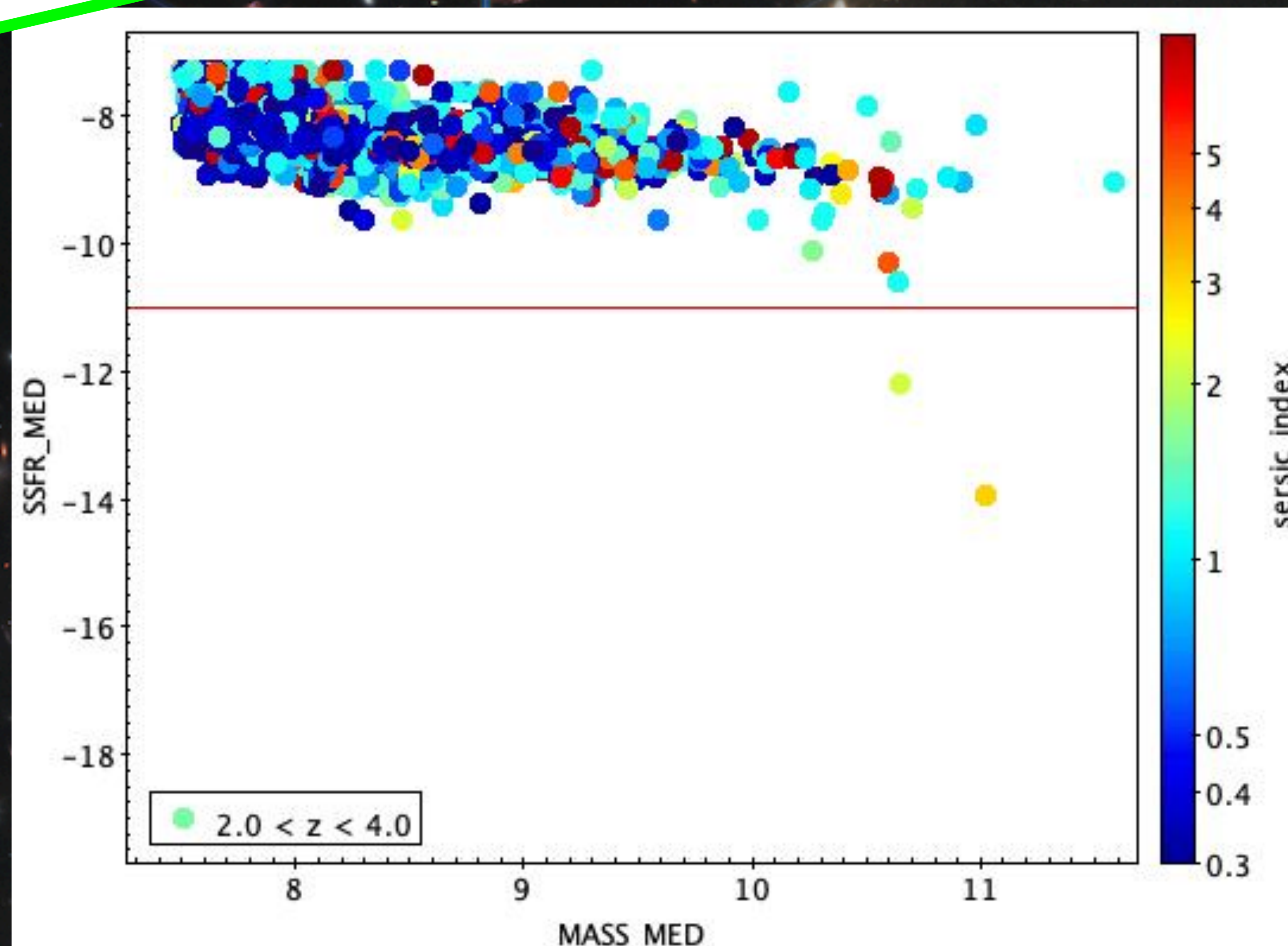
Credit: NASA, ESA, CSA, and STScI

USING SE++ TO DETECT & FIT THE PROFILE OF MIDIS GALAXIES

AND LEPHARE++ & BC03 MODELS TO ESTIMATE THEIR PROPERTIES

GALAXY PROPERTIES ANALYSIS IN THE XDF

PRELIMINARY RESULTS

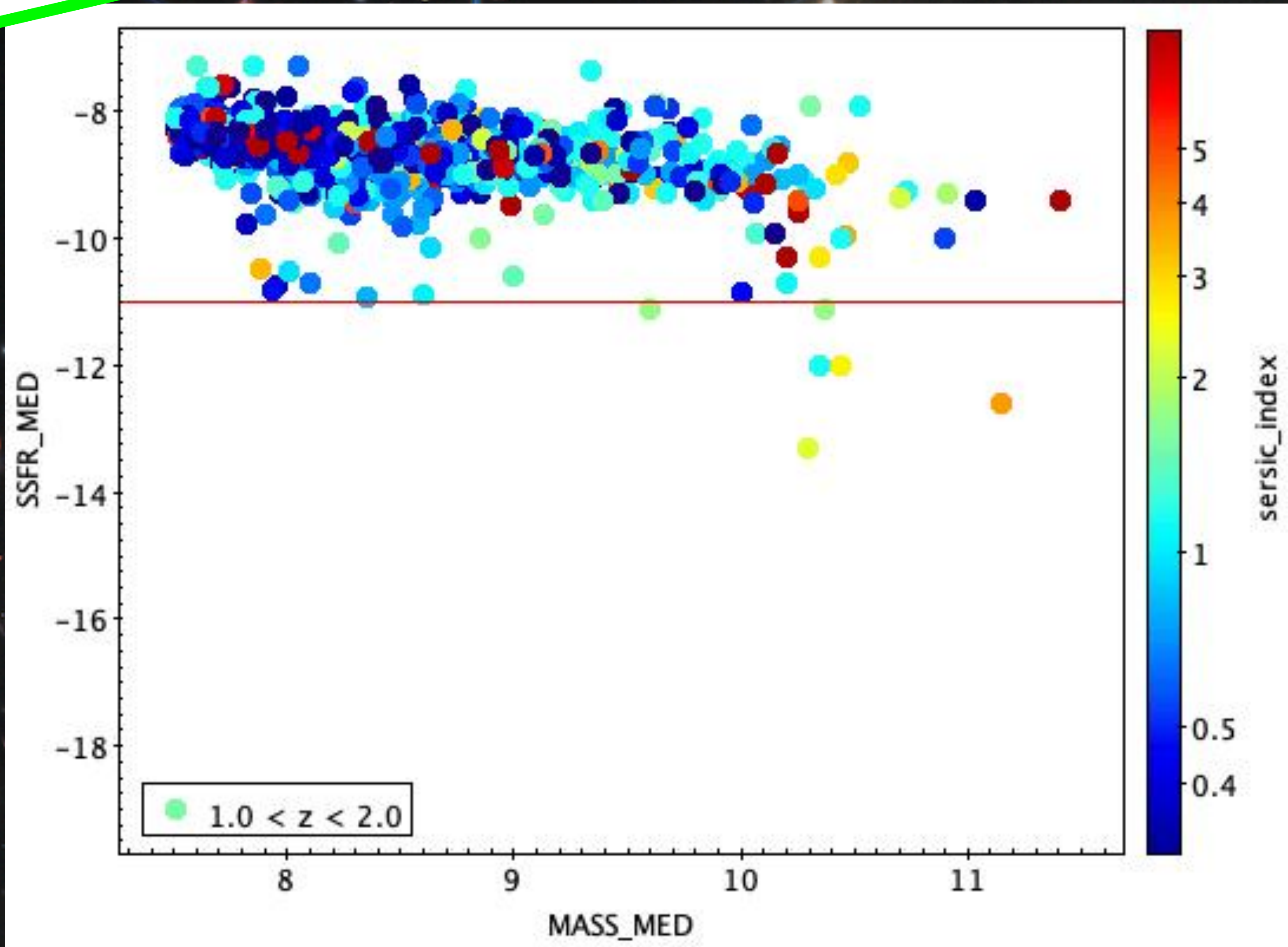


Moutard et al. in prep.

Credit: NASA, ESA, CSA, and STScI

GALAXY PROPERTIES ANALYSIS IN THE XDF

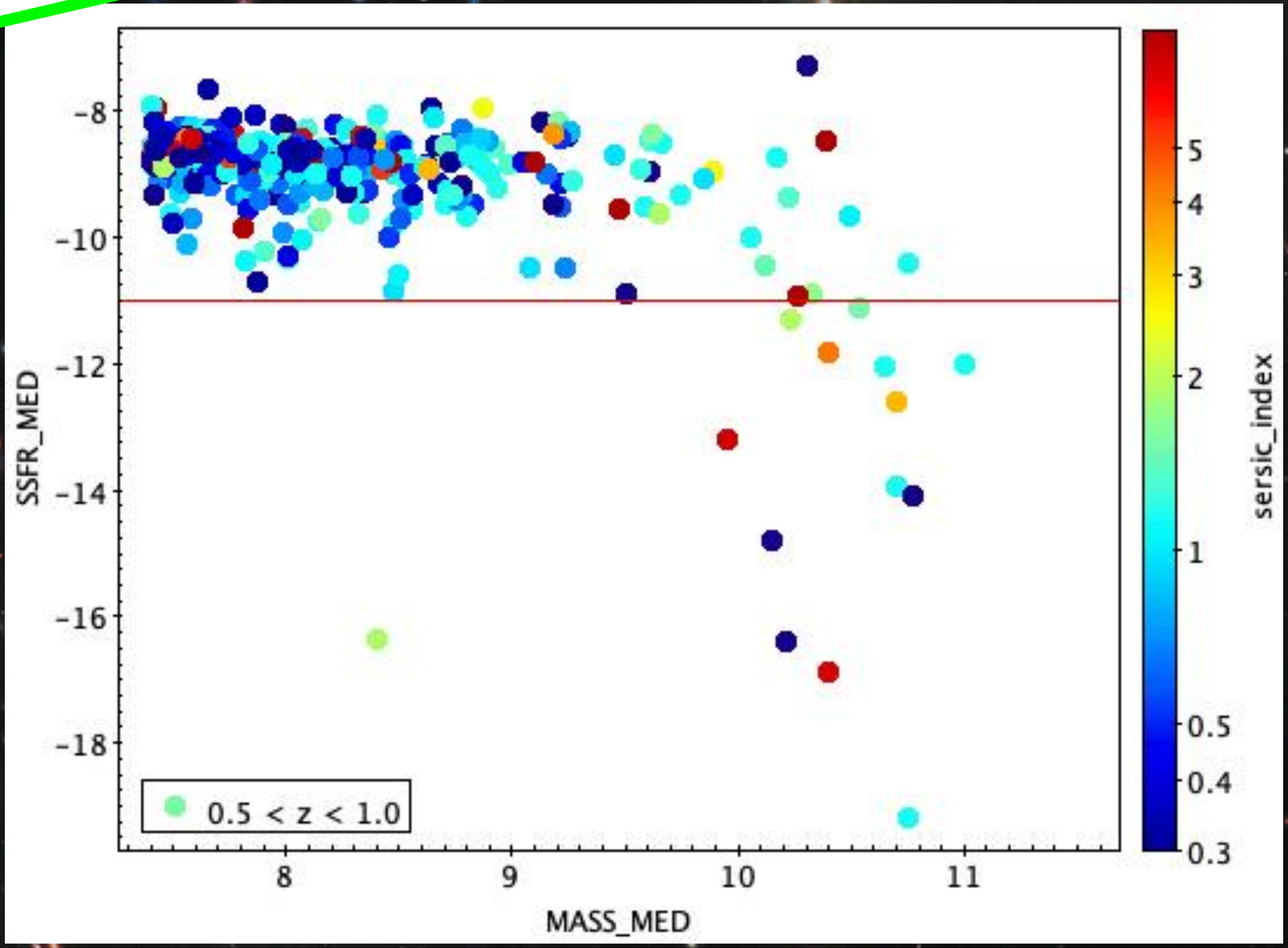
PRELIMINARY RESULTS



Moutard et al. in prep.

GALAXY PROPERTIES ANALYSIS IN THE XDF

PRELIMINARY RESULTS



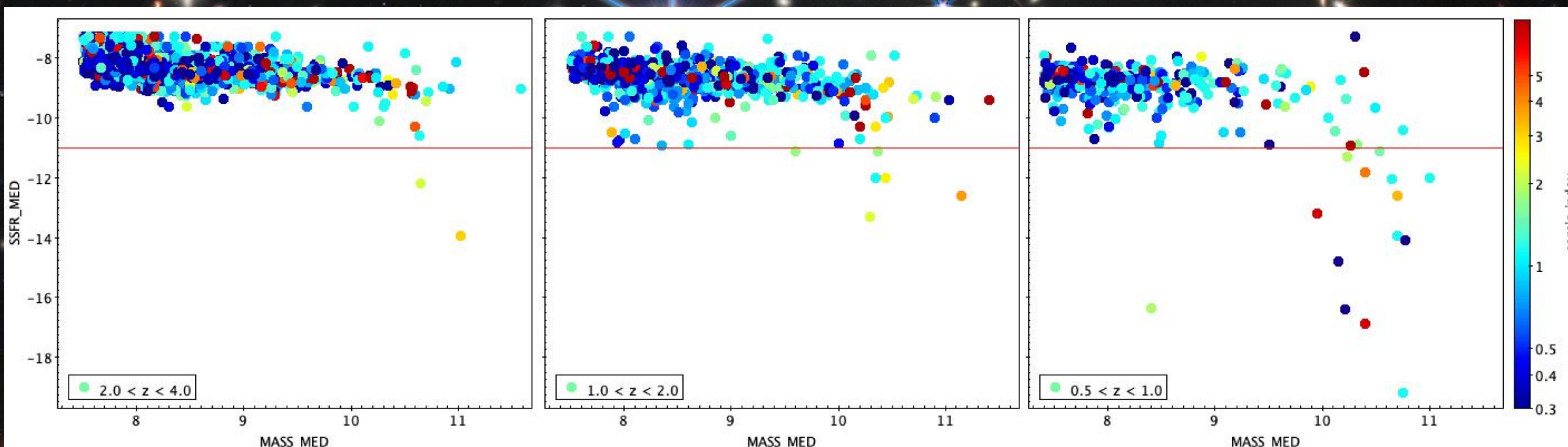
Moutard et al. in prep.

GALAXY PROPERTIES ANALYSIS IN THE XDF

Credit: NASA, ESA, CSA, and STScI

PRELIMINARY RESULTS

COSMIC TIME →



PRELIMINARY —*I SAID PRELIMINARY* RESULTS

1. QUIESCENT GALAXIES MAINLY ELLIPTICAL (n > 1) @ Z > 1
2. RED DISCS ONLY APPEAR @ Z < 1

SUMMARY

* The MIDIS GTO Program includes the deepest MIRI observations so far, down to 29.5AB at 5.6μm

* Combination of MIRI +NIRCam +HST observations allows for morphology characterisation & accurate photo-z and physical properties estimation since redshift = 4

Credit: NASA, ESA, CSA, and STScI

SUMMARY

* The MIDIS GTO Program includes the deepest MIRI observations so far, down to 29.5AB at 5.6µm

* Combination of MIRI +NIRCam +HST observations allows for morphology characterisation & accurate photo-z and physical properties estimation since redshift = 4

Preliminary results:

1 Quiescent galaxies mostly elliptical @ z > [illegible]
=> early quenching and morphology transformation appear to go hand in hand
2 Quiescent galaxies morphology appear[illegible] diversify with cosmic time since [illegible]
=> would confirm a big picture [illegible] star formation quenching channel[illegible] around cosmic noon

SUMMARY

* The MIDIS GTO Program includes the deepest MIRI observations so far, down to 29.5AB at 5.6μm

* Combination of MIRI +NIRCam +HST observations allows for morphology characterisation & accurate photo-z and physical properties estimation since redshift = 4

Preliminary results:

1 Quiescent galaxies mostly elliptical @ z > 1
—> early quenching and morphology transformation appear to go hand in hand

Credit: NASA, ESA, CSA, and STScI

SUMMARY

Credit: NASA, ESA, CSA, and STScI

* The MIDIS GTO Program includes the deepest MIRI observations so far, down to 29.5AB at 5.6μm

* Combination of MIRI +NIRCam +HST observations allows for morphology characterisation & accurate photo-z and physical properties estimation since redshift = 4

Preliminary results:

1 Quiescent galaxies mostly elliptical @ $z > 1$
--> early quenching and morphology transformation appear to go hand in hand

2 Quiescent galaxies morphology appear to diversify with cosmic time since redshift = 1
--> would confirm a big picture where different star formation quenching channels emerged around cosmic noon.

Credit: NASA, ESA, CSA, and STScI