

Panchromatic WFC3 survey of galaxies at intermediate z : Early Release Science program for Wide Field Camera 3.

Principal Investigator: Prof. Robert W. O'Connell

Institution: The University of Virginia

Electronic Mail: rwo@virginia.edu

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SURVEY

Instruments: WFC3

Proprietary Period: 0

Orbit Request	Prime	Parallel
Cycle 16	104	0

Abstract

The unique panchromatic capabilities of WFC3 will be used to survey the structure and evolution of galaxies at the peak of the galaxy assembly epoch. Deep ultraviolet and near-IR imaging and slitless spectroscopy of existing deep multi-color ACS fields will be used to gauge star-formation and the growth of stellar mass as a function of morphology, structure and surrounding density in the critical epoch $1 < z < 4$. Images in the F225W, F275W, and F336W filters will identify galaxies at $z < 1.5$ from their UV continuum breaks, and provide star-formation indicators tied directly to both local and $z > 3$ populations. Deep near-IR (F125W and F160W) images will probe the stellar mass function well below $10^9 M_{\text{sun}}$ for mass-complete samples. Lastly, the WFC3 slitless UV and near-IR grisms will be used to measure redshifts and star-formation rates from H-alpha and rest-frame UV continuum slope. This WFC3 ERS program will survey one 4×2 mosaic for a total area of 50 square arcminutes to 5-sigma depths of $m_{\text{AB}} = 27$ in most filters from the mid-UV through the near-IR.

This multicolor high spatial resolution data set will allow the user to gauge the growth of galaxies through star-formation and merging. High precision photometric and low-resolution spectroscopic redshifts will allow accurate determinations of the faint-end of the luminosity and mass functions, and will shed light on merging and tidal disruption of stellar and gaseous disks. The WFC3 images will also allow detailed studies of the internal structure of galaxies, and the distribution of young and old stellar populations. This program will demonstrate the unique power of WFC3 by applying its many diverse modes and full panchromatic capability to a forefront problem in astrophysics.

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Investigators:

	Investigator	Institution	Country
PI	Prof. Robert W. O'Connell	The University of Virginia	USA/VA
CoI	Dr. Bruce Balick	University of Washington	USA/WA
CoI	Dr. Howard E. Bond	Space Telescope Science Institute	USA/MD
CoI	Dr. Daniela Calzetti	University of Massachusetts	USA/MA
CoI*	Dr. C. Marcella Carollo	Eidgenossische Technische Hochschule (ETH)	Switzerland
CoI*	Dr. Michael J. Disney	University of Wales, College of Cardiff (UWCC)	UK
CoI	Dr. Michael A. Dopita	Australian National University	Australia
CoI	Prof. Jay A. Frogel	The Ohio State University Research Foundation	USA/OH
CoI	Dr. Donald N. B. Hall	University of Hawaii	USA/HI
CoI	Dr. Jon A. Holtzman	New Mexico State University	USA/NM
CoI	Dr. Patrick J. McCarthy	Carnegie Institution of Washington	USA/DC
CoI*	Dr. Francesco Paresce	European Southern Observatory - Germany	Germany
CoI	Dr. Abhijit Saha	National Optical Astronomy Observatories, AURA	USA/AZ
CoI*	Prof. Joseph Silk	University of Oxford	UK
CoI	Dr. Alistair R. Walker	National Optical Astronomy Observatories - CTIO	Chile
CoI	Dr. Brad C. Whitmore	Space Telescope Science Institute	USA/MD
CoI	Dr. Rogier A. Windhorst	Arizona State University	USA/AZ
CoI	Dr. Erick Young	University of Arizona	USA/AZ

Number of investigators: 18

* ESA investigators: 4

Target Summary:

Target	RA	Dec	Magnitude
WFC3-ERSII-1	03 32 37.0680	-27 40 47.06	V = 27.0 +/- 0.5
WFC3-ERSII-2	03 32 25.7540	-27 41 44.62	V = 27.0 +/- 0.5
WFC3-ERSII-3	03 32 14.4370	-27 42 38.93	V = 27.0 +/- 0.5
WFC3-ERSII-4	03 32 3.3580	-27 43 33.18	V = 27.0 +/- 0.5
WFC3-ERSII-5	03 32 41.1650	-27 43 14.12	V = 27.0 +/- 0.5
WFC3-ERSII-6	03 32 30.0880	-27 44 8.51	V = 27.0 +/- 0.5

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Target	RA	Dec	Magnitude
WFC3-ERSII-7	03 32 18.7670	-27 45 6.04	V = 27.0 +/- 0.5
WFC3-ERSII-8	03 32 7.4430	-27 46 0.31	V = 27.0 +/- 0.5

Observing Summary:

Target	Config Mode and Spectral Elements	Flags	Orbits
WFC3-ERSII-1	WFC3/UVIS Imaging F225W		12
	WFC3/UVIS Imaging F275W		
	WFC3/UVIS Imaging F336W		
	WFC3/IR Imaging F098M		
	WFC3/IR Imaging F125W		
	WFC3/IR Imaging F160W		
WFC3-ERSII-5	WFC3/UVIS Imaging F225W		12
	WFC3/UVIS Imaging F275W		
	WFC3/UVIS Imaging F336W		
	WFC3/IR Imaging F098M		
	WFC3/IR Imaging F125W		
	WFC3/IR Imaging F160W		
WFC3-ERSII-2	WFC3/UVIS Spectroscopic G280		14
	WFC3/UVIS Imaging F225W		
	WFC3/UVIS Imaging F275W		
	WFC3/UVIS Imaging F336W		
	WFC3/IR Spectroscopic G141		
	WFC3/IR Imaging F098M		
	WFC3/IR Imaging F125W		
WFC3/IR Imaging F160W			
WFC3-ERSII-6	WFC3/UVIS Spectroscopic G280		14
	WFC3/UVIS Imaging F225W		
	WFC3/UVIS Imaging F275W		
	WFC3/UVIS Imaging F336W		
	WFC3/IR Spectroscopic G141		
	WFC3/IR Imaging F098M		

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Target	Config Mode and Spectral Elements	Flags	Orbits
WFC3-ERSII-3	WFC3/IR Imaging F125W		14
	WFC3/IR Imaging F160W		
	WFC3/UVIS Spectroscopic G280		
	WFC3/UVIS Imaging F225W		
	WFC3/UVIS Imaging F275W		
	WFC3/UVIS Imaging F336W		
	WFC3/IR Spectroscopic G141		
	WFC3/IR Imaging F098M		
WFC3-ERSII-7	WFC3/IR Imaging F125W		14
	WFC3/IR Imaging F160W		
	WFC3/UVIS Spectroscopic G280		
	WFC3/UVIS Imaging F225W		
	WFC3/UVIS Imaging F275W		
	WFC3/UVIS Imaging F336W		
	WFC3/IR Spectroscopic G141		
	WFC3/IR Imaging F098M		
WFC3-ERSII-4	WFC3/IR Imaging F125W		12
	WFC3/IR Imaging F160W		
	WFC3/UVIS Imaging F225W		
	WFC3/UVIS Imaging F275W		
	WFC3/UVIS Imaging F336W		
	WFC3/IR Imaging F098M		
	WFC3/IR Imaging F125W		
	WFC3/IR Imaging F160W		
WFC3-ERSII-8	WFC3/UVIS Imaging F225W		12
	WFC3/UVIS Imaging F275W		
	WFC3/UVIS Imaging F336W		
	WFC3/IR Imaging F098M		
	WFC3/IR Imaging F125W		
	WFC3/IR Imaging F160W		

Total prime orbits: 104

■ Scientific Justification

Scientific Background: Galaxy Assembly at the peak of Cosmic Star-Formation

The study of the formation and evolution of galaxies and large scale structure is one of the most active interfaces between theory and observation in modern astrophysics. Galaxies are formed gradually over cosmic time from a combination of merging and internal star-formation, regulated by feedback from stellar winds, supernovae, and/or AGN. The origin of the Hubble sequence is not yet fully understood, but it is likely related to the balance between major mergers versus minor accretion events and steady infall. The critical epoch for the assembly of massive galaxies appears to be the 4 Gyr span from redshift $z \simeq 3$ to $z \simeq 1$.

At redshifts $\gtrsim 2-3$, deep HST imaging surveys and ground-based spectroscopy have revealed a paucity of massive galaxies and few classical disks or spheroids. Large ground-based spectroscopic surveys targeting $z \lesssim 1$ — coupled with HST imaging — have shown that massive galaxies are largely mature, and that the Hubble sequence is well developed by this epoch. While there may be about a $\sim 50\%$ growth in the stellar mass in spheroids in the last ~ 7 Gyr, the process of galaxy assembly was largely completed by $z \simeq 1$. The interim period, from redshifts of $z \sim 3$ to $z \sim 1$, is the era in which most of the stellar mass in galaxies is accumulated, and when galaxies acquire the characteristic structural and dynamical properties that define them today. WFC3 was specifically built to study this critical epoch in detail.

Science Aspects of WFC3 ERS program II

The HST WFC3 will provide a unique opportunity to connect the local and distant galaxy populations. By sampling the vacuum UV with high sensitivity and the angular resolution afforded by a diffraction limited 2.4 m telescope, WFC3 can observe star-forming regions in galaxies over most of the Hubble time. The near-IR channel on WFC3 will allow restframe visible band photometry of distant galaxies to very low stellar masses, and over areas large enough to provide representative samples. Together, the panchromatic images produced by WFC3 will allow the user to deconstruct distant galaxies into their constituent substructures and examine their internal stellar populations. In this early release science program, the UV and IR channels of WFC3 will be used to provide a small, but representative sampling of the capabilities of WFC3, to examine the formation and evolution of galaxies in the critical galaxy assembly epoch. With the exquisite spectral coverage, fine pixel sampling, and high sensitivity of WFC3, amongst others the following science aspects will be addressed with these ERS data:

- At what redshifts did the Hubble sequence first appear?
- How do the structural properties of disk and spheroid galaxies evolve over time?
- What contributions do different morphological types and mass ranges make to the global star-formation rate density at different epochs?
- How do the rest 1500 Å luminosity function and density evolve at $z \lesssim 3$?
- How do the mass densities of spheroids and disks evolve at $z \lesssim 3$?
- What is the faint-end slope of the luminosity function, and how does it evolve with epoch?

Understanding the answers to these and a number of other questions will provide insight into the processes of galaxy formation and assembly. We hope that the community will use this WFC3 ERS data set to evaluate the new capabilities of HST with WFC3, and use WFC3 through GO programs in HST Cycles 17 and beyond.

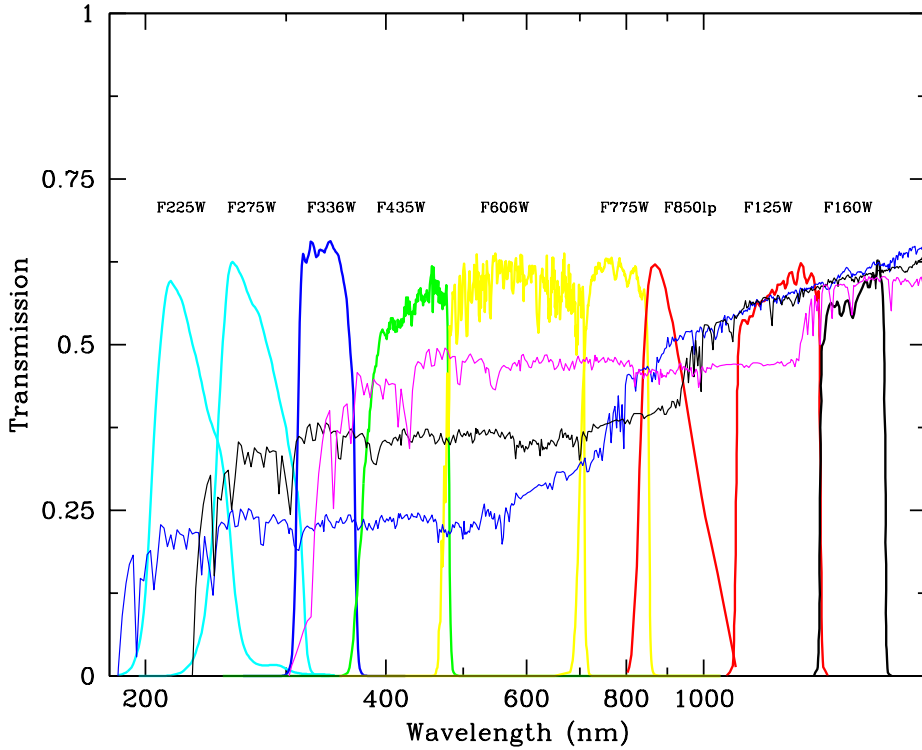


Fig. 1: The full HST filter set for the proposed WFC3 ERS imaging of the GOODS fields. Spectral energy distributions for three model galaxies with ages of 3, 2, and 1 Gyr and redshifts of 1.0, 1.5, and 2.5 are shown as blue, black and magenta curves, respectively. These show that the UVIS filters sample the Lyman- α forest and Lyman continuum breaks, while the near-IR filters will probe the 4000 Å and Balmer breaks. Additional photometry is available from ground-based K-band imaging, and Spitzer/IRAC imaging at 3.5, 4.5, 5.6 and 8.5 micron.

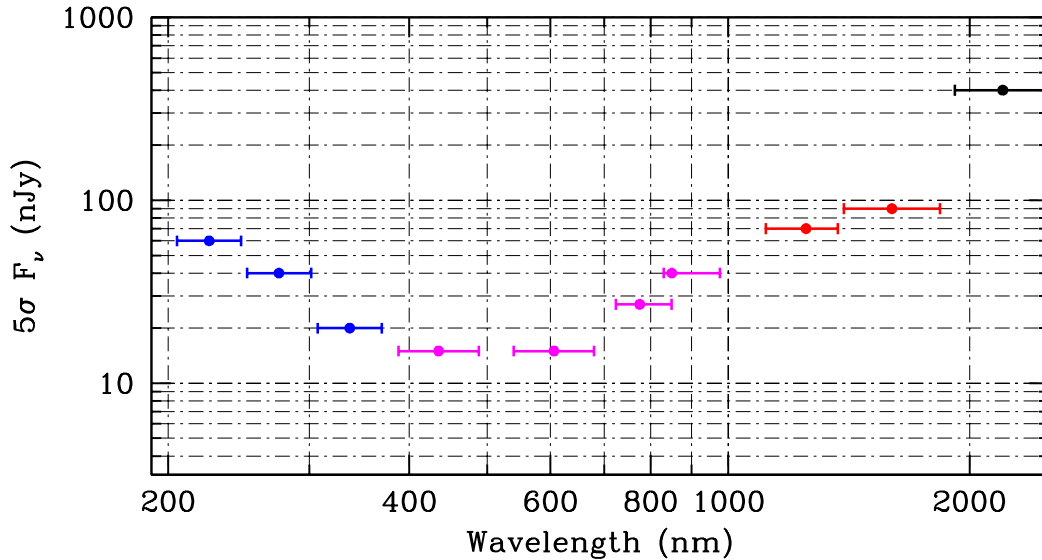


Fig. 2: 5σ depths in nJy for the WFC3 UVIS (blue) and IR (red) filters in the ERS intermediate redshift galaxy survey. These depths refer to $0''.2$ diameter apertures, and are based on the orbit totals from Table 1 using the current WFC3 ETC. The depth of the ACS F435W, F606W, F775W, and F850LP images are shown in magenta. Ground-based images to $K(AB)=25$ mag are shown in black.

■ Description of the Observations

Filter Set: The critical new data that WFC3 can provide in this field are deep vacuum near-UV images and sensitive near-IR photometry over fields larger than those practical with NICMOS. Three of the broad-band WFC3 mid-UV filters will be used, and two of the broad NIR filters to image fields previously observed with HST/ACS to build a relatively deep panchromatic imaging survey to AB=26.5–27 mag. In addition to these broad-band filters, we will use the WFC3 UV prism and near-IR grism to obtain slitless spectroscopy of hundreds of faint galaxies. The WFC3 UV prism and near-IR grism will trace primary indicators of star-formation — the Lyman- α and H- α emission-lines — over the redshift range from $z \simeq 0.7$ –2.2 and 0.7–1.6, respectively. The WFC3 ERS grism program will thus cover the peak of the cosmic star formation history at $1 \lesssim z \lesssim 2$, using two of the most important star-formation measures, while also providing metallicity independent reddening indicators. Both dispersers provide capabilities that cannot be reproduced from the ground (access to the vacuum UV and slitless spectroscopy in the near-IR).

The addition of the low-resolution ($R \simeq 50$ –100) spectra will also allow the user to obtain accurate spectro-photometric redshifts for objects as faint as $m(\text{AB}) \simeq 25$ –26 mag. The redshift precision is expected to be a few percent or $\sigma_z/(1+z) = 0.02$ –0.03, allowing accurate determination of the galaxy luminosity function and to map small-scale clustering and large-scale structure at redshifts from $z \simeq 0.5$ to $z \simeq 3$ across the WFC3 ERS mosaic.

To make the best use of the limited HST spacecraft time, this WFC3 ERS program would be most efficiently carried out in existing HST Treasury fields. The Great Observatories Origin Deep Survey (GOODS) fields are among the best candidate fields, since they contain deep four-color ACS imaging, slitless grism spectra from ACS, and a wealth of ground- and space-based data. The total HST filter set provided by the WFC3 ERS imaging of the GOODS fields is shown in Fig. 1. WFC3 will add the F225W, F275W and F336W filters in the WFC3 UVIS channel and the F125W and F160W filters in the WFC3 IR channel. Together with the available GOODS ACS F435W, F606W, F775W and F850LP filters, the new WFC3 UVIS and IR filters will provide a total of 9 HST filters. Fig. 1 over-plots the spectral energy distribution of model galaxies at $z = 1.0$, 1.5 and 2.5 with ages of 3, 2 and 1 Gyr, respectively, on top of the WFC3 ERS filters. The WFC3 UV filters will be particularly powerful in accessing the Lyman- α forest and Ly continuum breaks, while the near-IR filters will probe the 4000 Å and Balmer breaks in this redshift range.

Areal Coverage: To make a significant contribution to this field, one needs to cover an area that breaks new ground in both the UV and near-IR, and that will yield a statistically significant sample. Given the constraint on the total amount of time available, and the desire to use a panchromatic filter set, this WFC3 ERS program will observe one 4×2 WFC3 mosaic, approximately covering $10' \times 5'$ in extent, or about an area of $620'' \times 310''$. This will probe comoving scales of roughly 5–10 Mpc, and will provide a sample of several thousand galaxies to AB $\lesssim 27$ mag. The IR images will be dithered to match the UVIS field of view.

Filters and Depths: The WFC3 ETC was used to estimate the depths in each filter, adopting a limit of $5\text{-}\sigma$ in a $0''.2$ diameter aperture to allow direct comparison with the GOODS imaging depth. The results are summarized in Table 1, which lists the number of orbits per filter and the $5\text{-}\sigma$ depths in AB magnitudes and F_ν units. It is assumed that 2400 seconds is available in each orbit for on-source observation.

Table 1. Filters and Depths of the WFC3 ERS program.

Channel	GRISM	Filter 1	Filter 2	Filter 3	Filter 4	TOTAL *
WFC3/UVIS	G280	F225W	F275W	F336W		
Orbits	2 **	2	2	1		7x4=28
Depth (AB)	25.7	26.9	27.0	27.0		5x4=20
nJy	180	60	40	20		Sub=48
ACS/WFC	G800L	F435W	F606W	F775W	F850LP	
Orbits	PEARS	3	2.5	2.5	5	GOODS
Depth (AB)	27.0	28.5	28.5	27.8	27.3	
nJy	53	15	15	27	40	
WFC3/IR	G141	F125W	F160W			
Orbits	2	2	3			7x8=56
Depth (AB)	25.5	26.8	26.5			
nJy	210	70	90			Sub=56
TOTAL ORBITS						104

Notes to Table 1:

* The WFC3 ERS will cover one 4x2 mosaic, so the total is 8 x the number of orbits/filter.

** The G280 observations will be confined to the central four WFC3 pointings only, which are field numbers 2, 3, 6, 7 in Fig. 4.

Table 2. Layout of 8 WFC3 ERS fields, and filters/orbits per field.

Layout of fields (CDF-S; Fig. 4)	WFC3 orbits for field numbers 1, 4, 5, 8:	WFC3 orbits for field numbers 2, 3, 6, 7:
2 4 6 8	UVIS (no G280): 5 orbs	UVIS (+G280): 7 orbs
1 3 5 7	IR (+G141): 7 orbs	IR (+G141): 7 orbs
	Subtotal/field: 12 orbs	Subtotal/field: 14 orbs
	Subtotal #1458: 48 orbs	Subtotal #2367: 56 orbs
TOTAL ORBITS		104 orbs

Fig. 2 shows the depth of the proposed WFC3 observations of the GOODS fields in F_ν units. These depths are put in physical terms by comparing with with spectral synthesis models at the three fiducial redshifts. Simple stellar populations models are plotted with single bursts or exponentially declining star-formation rates with an e-folding time of 1 Gyr. Fig. 3 shows the predicted spectral energy distributions for models with ages ranging from 10 Myr to 3 Gyr, along with the $5\text{-}\sigma$ depths of the WFC3 ERS program. The three panels represent redshifts $z=1.0, 1.5$ and 2.0 , and models with stellar masses of $10^9, 4\times 10^9$, and $10^{10} M_\odot$, respectively. These SED tracks illustrate the sensitivity of the WFC3 observations. Galaxies with ongoing star-formation, even with fairly large ages, are easily detected in the WFC3 mid-UV observations. At $z\simeq 2$, maximally old $\tau\simeq 1$ models with masses of $\sim 1/3 M^*$ are above the WFC3 detection threshold in the F336W filter, while at $z\simeq 1$, WFC3 can detect young star forming galaxies with masses as low as a few $\times 10^7 M_\odot$, or about $\sim 0.01 M^*$.

WFC3 pointings: The 4×2 WFC3 ERS mosaic pointing will be located at the Northern edge of the GOODS-South field (Fig. 4). The GOODS-North field serves as a backup, in case there are scheduling issues with the GOODS-South field related to SM4/SMOV. GOODS has the advantage of having high quality four-color ACS imaging and grism data to depths that are well matched to the ERS science goals. There is also an abundance of other data: Spitzer photometry (IRAC and MIPS), Chandra X-ray imaging, HST slitless spectroscopy, ground-based redshifts and deep VLT K-band imaging. In Fig. 4 shows the ACS F850LP images of the entire GOODS-South field, and the proposed WFC3 pointings, as well as the locations of other data sets. The 8 ERS pointings are contiguous, with a tiling that can be easily expanded in WFC3 GO programs.

Data processing: The data processing will be carried out with the STScI pipeline and the WFC3 ERS data set may help beta-test the pipeline under realistic use conditions. The raw WFC3 data will be public immediately, and the OTF pipelined and drizzled WFC3 mosaics ASAP.

■ Special Requirements

HST scheduling may require that this ERS program be split into several visits. There may be an advantage to this, since it will allow the user to identify transient objects (e.g. SNe and variable AGN). Simple raster patterns will be used to fill out the IR field, and to improve sky and residual dark-current removal. Only mild constraints will be applied to the original HST ORIENTS, but the IR and UVIS will be constrained to have the *same* ORIENT, so that the multiple visits will be ORIENT-constrained to ensure that a uniform WFC3 mosaic can be produced. Scheduling the data into two separate epoch visits with the same ORIENTS should only be done if it makes HST scheduling easier.

■ Coordinated Observations

None.

■ Justify Duplications

None.

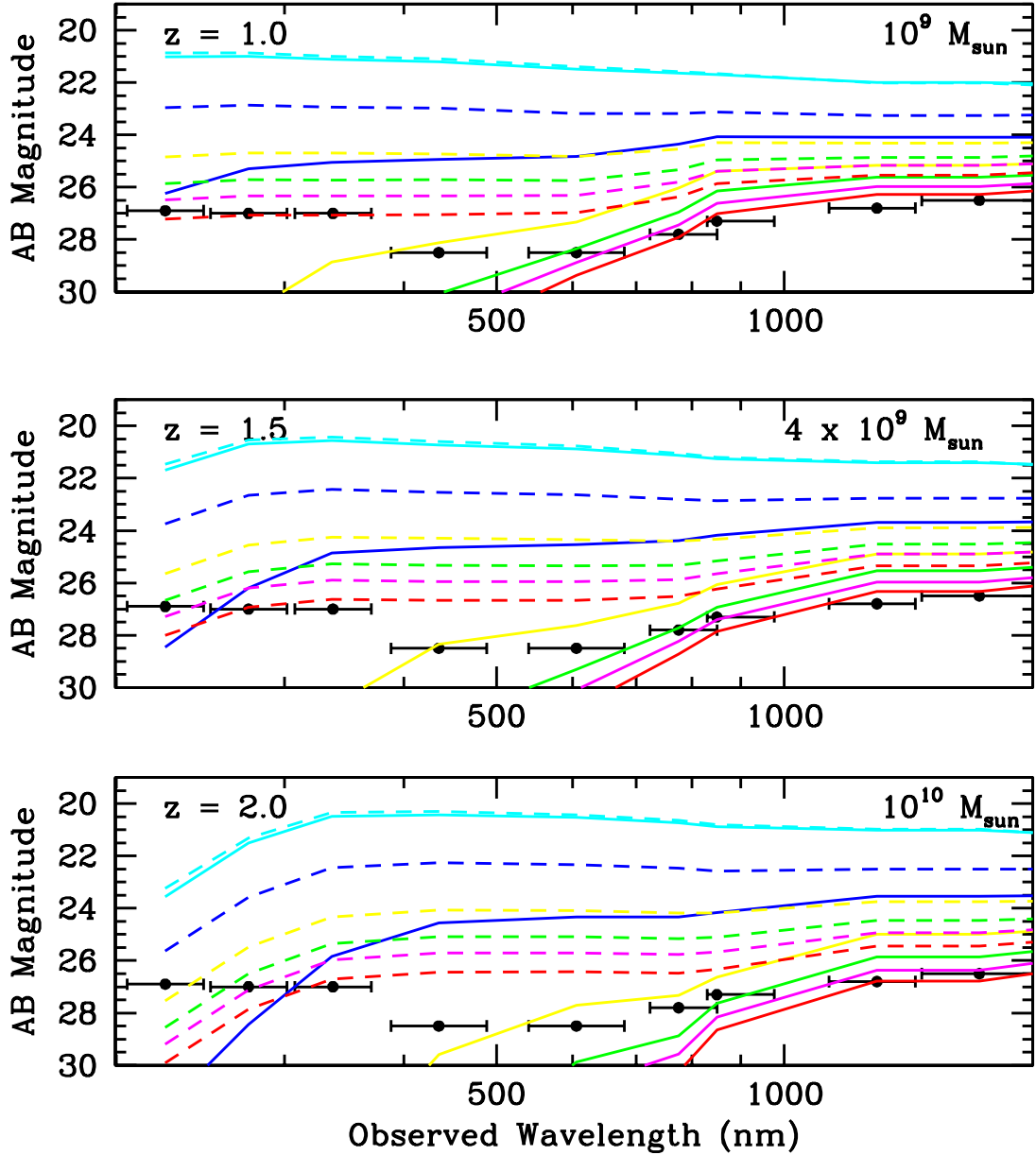


Fig. 3: The three panels show the depth of the WFC3 ERS images as horizontal bars, compared to evolving galaxy models of different masses at three redshifts. The top panel is for $z = 1$ and a stellar mass of $10^9 M_{\odot}$. The solid lines represent nearly instantaneous bursts, and the dashed lines are for declining star-formation with a 1 Gyr e-folding time. The colors refer to ages of 10, 100, 500, 1000, 1400, 2000, and 3000 Myrs from cyan to red. The center panel shows similar models at $z = 1.5$ for $4 \times 10^9 M_{\odot}$, while the lower panel is for $z = 2$ and masses of $10^{10} M_{\odot}$. At $z = 1$, the WFC3 ERS will reach to $0.02 M^*$ for reasonable star-formation histories. Note that both the flux scale and the wavelength scale are logarithmic, illustrating WFC3's exquisite panchromatic coverage and sensitivity in probing the stellar mass of galaxies through its IR channel, and the star-formation in galaxies through its UV channel.

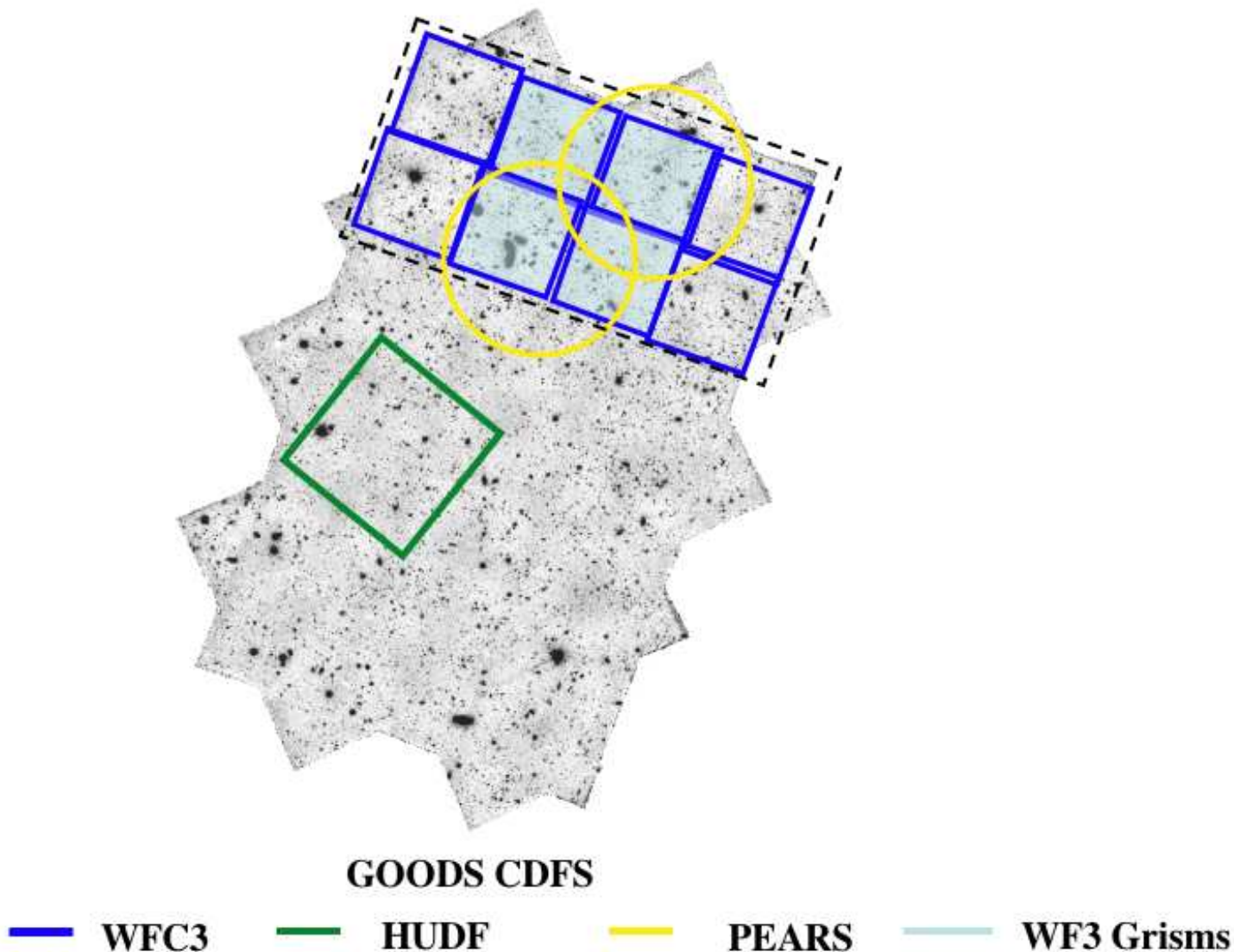


Fig. 4: The GOODS Chandra Deep Field South field with the proposed WFC3 ERS (blue) 4×2 mosaic field superposed. The PEARS ACS grism fields that overlap with the proposed pointings are shown in yellow. The green box shows the ACS Hubble Ultra Deep Field in the CDF-S. This WFC3 ERS program will image the upper $\sim 20\%$ of the GOODS-South field in the five filter set described above. The entire 4×2 mosaic will be observed with the IR grism, and the central 2×2 mosaic with the UV prism as well (fields 2, 3, 6, 7 in the Target Summary and in Table 2).