

## **Kate Whitaker**



Assistant Professor University of Connecticut [www.whitaker.physics.uconn.edu](http://www.whitaker.physics.uconn.edu)

102.097 : 12.301 : 12.1



*z***=11.1!**



------------------------------------

*z***~1.4** 

*z***~1.4**

. . . . . . . . . . . . . . . . . . <del>.</del> .

*z***=0** 

### *z***~0.3**

 $\left( 0, \right)$ 

*z***~2**





## Wide-field slitless surveys at  $z=1-2$ :

- Large, uniform, roughly unbiased samples
- Spatially-resolved line diagnostics @ HST resolution
- **Accurate redshifts** ( $\Delta z/(1+z) \sim 0.003$ ): large scale structure & stacking analyses









## **The Team**

PI: Prof. Pieter van Dokkum (Yale) **Project Manager:** Dr. Ivelina Momcheva (STScI)

#### Co-I's:

Dr. Gabriel Brammer (STScI) Prof. Dawn K. Erb (UW-Milwaukee) Prof. Marijn Franx (Leiden) Dr. Natascha Förster Schreiber (MPE) Dr. Xiaohui Fan (University of Arizona) Prof. Joseph Hennawi (MPIA) Prof. Garth Illingworth (UC Santa Cruz) Prof. Guinevere Kauffmann (MPIA) Prof. Mariska Kriek (UC Berkeley) Dr. Ivo Labbé (Leiden) Dr. Patrick McCarthy (Carnegie) Prof. Danilo Marchesini (Tufts) Dr. Anna Pasquali (MPIA) Dr. Shannon Patel (Carnegie) Dr. Ryan Quadri (Texas A&M) Prof. Hans-Walter Rix (MPIA) Prof. Charles C. Steidel (Caltech) Prof. David Wake (Open University) Prof. Katherine E. Whitaker (UConn)

#### Collaborators:

Prof. Rachel Bezanson (Pitt) Dr. Fuyan Bian (ANU) Prof. Elisabeta da Cunha (ANU) Ms. Claire Dickey (Yale) Dr. Mattia Fumagalli (Leiden) Dr. Joel Leja (Harvard/CfA) Prof. Britt Lundgren (UNC Asheville) Dr. Dan Magee (UC Santa Cruz) Dr. Michael Maseda (Leiden) Dr. Ian McGreer (University of Arizona) Mr. Stanimir Metchev (Western University) Prof. Adam Muzzin (York) Dr. Erica Nelson (MPE/Harva Dr. Pascal Oesch (Yale) Dr. Camilla Pacifici (STScI) Dr. Moire Prescott (University Dr. Sedona Price (MPE) Dr. Kasper Schmidth (UC Sa Dr. Rosalind Skelton (SAAO)









3D-HST group meeting in San Juan, Puerto Rico, October 2013

Prof. Rachel Bezanson (Pitt) Dr. Fuyan Bian (ANU) Prof. Elisabeta da Cunha (ANU) Ms. Claire Dickey (Yale) Dr. Mattia Fumagalli (Leiden) Dr. Joel Leja (Harvard/CfA) Prof. Britt Lundgren (UNC Asheville) Dr. Dan Magee (UC Santa Cruz) Dr. Michael Maseda (Leiden) Dr. Ian McGreer (University of Arizona) Mr. Stanimir Metchev (Western University) Prof. Adam Muzzin (York) Dr. Erica Nelson (MPE/Harva Dr. Pascal Oesch (Yale) Dr. Camilla Pacifici (STScI) Dr. Moire Prescott (University Dr. Sedona Price (MPE) Dr. Kasper Schmidth (UC Sa

#### **Dr. Rosalind Skelton (SA**





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3D-HST F140W Mosaics [3dhst.research.yale.edu](http://3dhst.research.yale.edu)

Kate Whitaker **Astrophysics with WFIRST @ 231st AAS Meeting** January 10, 2018







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#### Footprint of **CANDELS** and **3D-HST** Surveys [3dhst.research.yale.edu](http://3dhst.research.yale.edu)





measurements for **10s of thousands of galaxies** 





Highly complete spectroscopic coverage allows | nttp://3dhst.astro.yale.edu detailed studies of evolving galaxy properties synthesis fits to the broad band photometry. Here galaxies with a range of redshifts contribute to each row, providing rest-frame spectra from 3300–8000 Å. There



- >200,000 catalog entries
- 147 different bands, including available medium and narrow bands
- few % photometric redshifts
- morphology, rest-frame color, and stellar population parameters

#### 1.5 2.0 3.0 **CANDELS+3D-HST:**

### **• Photometric Catalogs** Skelton, Whitaker et al. 2014

### • **Grism Spectroscopy** Momcheva, Brammer et al. 2015

- $\sim$  20,000 objects to F140W<24 ( $\sim$  10<sup>5</sup> to F140W<26)
- Grism+photometry redshifts, dz/(1+*z*)~0.003
- Emission line fluxes, equivalent widths

#### **<http://3dhst.astro.yale.edu> <https://archive.stsci.edu/prepds/3d-hst/>**

![](_page_11_Picture_16.jpeg)

![](_page_11_Picture_17.jpeg)

Highly complete spectroscopic coverage allows | nttp://3dhst.astro.yale.edu detailed studies of evolving galaxy properties synthesis fits to the broad band photometry. Here galaxies with a range of redshifts contribute to each row, providing rest-frame spectra from 3300–8000 Å. There

![](_page_12_Figure_0.jpeg)

- >200,000 catalog entries
- 147 different bands, including available medium and narrow bands
- few % photometric redshifts
- morphology, rest-frame color, and stellar population parameters
- **Grism Spectroscopy** Momcheva, Brammer et al. 2015
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#### 1.5 2.0 3.0 **CANDELS+3D-HST:**

### **• Photometric Catalogs** Skelton, Whitaker et al. 2014

0.4 0.5 0.6 0.7 0.8 lrest / *µ*m • Grism+photometry redshifts, d*z*/(1+*z*)~0.003 • Emission line fluxes, equivalent widths All high level science data products publicly available!

**<http://3dhst.astro.yale.edu> <https://archive.stsci.edu/prepds/3d-hst/>**

![](_page_12_Picture_16.jpeg)

![](_page_12_Picture_17.jpeg)

![](_page_13_Picture_13.jpeg)

![](_page_13_Picture_14.jpeg)

# Science Highlights

![](_page_13_Picture_1.jpeg)

![](_page_13_Picture_2.jpeg)

![](_page_13_Picture_58.jpeg)

![](_page_13_Picture_59.jpeg)

*z***~1.4**

![](_page_13_Picture_9.jpeg)

- z=0.84 z=0.73 z=1.01 z=1.25 z=1.21 but not always (see also Wuyts et al. 2013). z=0.84 z=0.84 z=0.84 z=1.21 z=1.221 z=2.84 z=2.84 z=2.84 z=2.81 z=2.81 z=2.81 z=2.81 z=2.81 z=2.81 z=2.81 z=2.<br>21 z=2.81 z=2.81 z=2.81 z=2.81 z=2.81 z=2.82 z=2.81 z=2.81 z=2.81 z=2.81 z=2.81 z=2.81 z=2.81 z=2.81 z=2.81 z=  $z=0.84$   $-4.84$ α $\begin{array}{|c|c|c|c|}\n\hline\nz = 0.73\n\end{array}$ 1 gala $\approx$  1 gala $\approx$  1.01  $\approx$  1.01  $\approx$  1.01  $\approx$  1.25  $\approx$  generally follows the optical light but not always (see also Wuyts et al. 2013). out: they appear as point sources in the spatial direction an extended in the spectral direction.
- $\bullet$ The advantage of slitless spectroscopy is also its greatest challenge: flux from neighboring objects with overlapping objects with overlapping or  $\mathbf{S}$ t<br>t<br>L that does not be a contact of the contact r r morphologies of containing objects. A second iteration is a second in the contact of contact the contact term is a second in the c *H* ing the spectra spectra. An example of the spectra spectra spectra. An example of this contact term in the spectra spectra spectra spectra spectra. An example of the spectra spectra. An example of the spectra spectra spect model is shown in the second participate  $\mathbf{r}$ et al. 2012<br>Etimologia n<br>India els for all galaxies in the vicinity of the vicinity of the vicinity of the object Furthermore, all regions predicted to present analysis, and the present analysis, all regions predicted to the predicted id is greater than a third of the average contact in the average of the average contact in the average of the average  $\mathbf{f}$ age G141 background value were masked. This aggressive m<br>Di maps at large radii where uncertainties at large radii where uncertainties are uncertainties at large radii where uncertainties are uncertainties at large radii where  $\frac{1}{2}$ in the contact of the conta The continuum of a galaxy is modeln the best fit  $\mathbf{S}$  image. The continuum model for our V<br>e is subtracted from the 2001  $\epsilon$ remove<br>the correction and simulated<br>and simulated rection the emission line maps for stellar absorption of the emission of the emission of the extent of the emission of the emi • Star-formation activity ( $\Sigma_{\text{SFR}}(r)$ ) Wuyts et al. 2013, Nelson et al. 2016  $\frac{1}{\sqrt{2}}$  $\sum$  $^{\circ}$ S<br>2(  $\begin{bmatrix} 1 \end{bmatrix}$ era under the same conditions. The same conditions is a condition of the same conditions. The same conditions  $\sim$ r<br>S<br>L, V<br>Sla V<br>so The advantage of slitless spectroscopy is also its greater spectroscopy is also its greate traces can contain the spectrum of an object with flux  $\mathcal{O}_\mathcal{A}$ that does not be the contact of the contac ith a flat spectrum based on the direct intervals and a flat spectrum based on the direct intervals and a forma<br>Separate positions and a formations and a formations and a formations and a formations and and a formations an ice of containing objects. A second iteration is a second iteration in the contact of contact of contact iteration is a second iteration in the contact of contact in the contact of contact in the contact of contact in the  $\sim$ f<br>f<br>f et al. 2012<br>B, 2013 move contained the spectra, we see that the spectra, we subtract the spectra, we subtract the spectra, we subtract the spectra, we see that the spectra, we see that the spectra, we see the spectra, we subtract the spectra, els for all galaxies in the vicinity of the vicinity of the vicinity of the object m<br>in<br>in  $\tilde{c}$ ad<br>C<br>C masking strategy was used to reduce the uncertainty in the uncertainty in the inmaps at large radii where uncertainties in the contamination model contained containing the contact of the conta  $\begin{bmatrix} 1 \\ 2 \end{bmatrix}$  $\ddot{\textbf{c}}$ i<br>image. example galaxy is shown in the third parallel  $\mathbf{S}$ ci<br>ic<br>ic  $\overline{\mathbf{c}}$ ri<br>Di<br>, ,  $\blacksquare$ 1.<br>1.<br>5 is a map of the international control.<br>1. w<br>W images (  $\begin{bmatrix} 2 \end{bmatrix}$ era under the same conditions. The same conditions of  $\geq$  $\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$  $\frac{1}{2}$  $\binom{1}{2}$ pixel<br>An HST pixel is 0.06<br>An HST pixel is 0.06
- $f$ • Star-formation history (Hα vs. continuum) Nelson et al. 2013, 2015  $\begin{aligned} \text{(I}\ \text{d} \text{.} \end{aligned}$  $\frac{1}{2}$ ences in the spatial resolution is the spatial resolution in the spatial resolution is resolution in the spatia<br>Discrete in the spatial resolution is responsible. C<br>Je ll<br>S<br>S remains for  $\overline{z}$  $\frac{1}{2}$ ences in the spatial rest. The space  $\frac{1}{2}$  $\begin{aligned} \text{S} \\ \text{A}, \end{aligned}$
- $\overline{\phantom{a}}$  $|C|$ *W*• Dust extinction Price et al. 2014, Nelson et al. 2016 id<br>1 *W*
- **Ages** Whitaker et al. 2013, Fumagalli et al. 2016
- α emission α map to d<br>t  $\overline{O}$  spectra are extracted from the interlaced spectra are extracted from the interlaced  $\overline{O}$  $\begin{bmatrix} 2 \\ 1 \end{bmatrix}$ • **Active Galactic Nuclei** Trump et al. 2011, 2014, Bridge et al. 2016 filter was done using the use of th
- αv<br>a *HF*140 *W*• **Metallicity gradients** Jones et al. 2014, Wang et al. 2016 αin<br>formation. *HF*140 *W*
- out: they appear as point sources in the spatial direction an extended in the spectral direction. a<br>ad 2D spectrum of every object in the camera's field of view. N<br>A<br>L line in G141 the surface bit<br>and the surface of  $\overline{a}$ is this method a sample of 2676 galaxies at 2676 galaxies at 2676 galaxies at 2676 galaxies at 2676 galaxies a<br>Literature 0.<br>1.5 with spatial<br>1.5 with spatial resolutions of the spatial resolution<br>1.5 with spatial resolutions of the spatial resolution<br>1.5 with spatial resolutions of the spatial resolution<br>1.5 with spatial resolutions of the s 3.2. *Making H*α *maps* The 3D-HST spectroscopy with the 3D-HST spectroscopy with the 3D-HST spectroscopy with the 3D-HST spectroscopy<br>Contract the 3D-HST spectroscopy with the 3D-HST spectroscopy with the 3D-HST spectroscopy with the 3D-HST spe<br> grism and in<br>Andrews<br>Britannia  $\frac{1}{2}$ a<br>Ling, but the observed<br>D-HST allows in allows in allows in all<br>D-HST allows in all of 3D-HST allows in all of 3D-HST ced in this direction in this direction in the control of are taken with pointing offsets that are multiples of half pixels. The pixels from these four uncorrected frames are then c<br>c<br>\_ 1<br>2000).<br>2000 formation, effectively increase the spatial resolution,  $\epsilon$ images. Crucially, interlaces<br>Also eliminates the correlations also eliminates the correlations are the correlations are the correlations ar<br>Also eliminates tradicions are la correlation also eliminates tradicions are trad noise caused and developed a<br>Note<br>-C<br>ak<br>\_\_ ade as spectral features.<br>The spectral features is a spectral feature set of the spectral feature set of the spectral features. The spec ed the background levels in  $\mathbf{r}$ i<br>J<br>e sign in the model is the model in the background in the background in the grism data to the background in the grism data to the grism data the background in the grism data the grism data the stress of the grism data the gr Tr<br>a<br>— U<br>a<br>- $\begin{array}{c} \n\text{m} \\ \n\text{s} \n\end{array}$ np<br>e<br>— Earth limit<br>
Brammer et al. in presentation<br>
Brammer et al. in presentation<br>
Brammer et al. in presentation in presentation in presentation in presentation<br>
Brammer et al. in presentation in presentation in presentation in e<br>al<br>t<br>e al<br>P<br>-Age gradients Whitaker et al., in prep a<br>additional of view.  $\frac{1}{\sqrt{2}}$ line in G141's wavelength coverage, we obtain an H the surface brightness limits. Based on  $\mathbb{A}$ using this method of 2676 galaxies at 2676 galaxies 0.7<z<1.5 with spatially resolved H 3.2. *Making H*α *maps* The 2D-HST spectroscopy with the 3D-HST spectroscopy with the 3D-HST spectroscopy with the 3D-HST spectroscopy<br>Spectroscopy with the 3D-HST spectroscopy with the 3D-HST spectroscopy with the 3D-HST spectroscopy with the 3 grism and imaging with the a custom pipel<br>a custom pipel<br>t<br>d<br>= be internaced in<br>ite<br>internaced in are taken with pointing  $\blacksquare$ els. The pixels from these four uncorrected frames are then placed on an output grid with  $\mathbf{t}$ ti<br>2000<br>-C<br>improving the spatial resolution<br>of the spatial resolution of the spatial resolution of the spatial resolution of the spatial resolution of the<br>original resolution of the spatial resolution of the spatial resolution of t images. Crucially, interlaces the correlation of th  $i\epsilon$  $\frac{1}{2}$  $\overline{\phantom{a}}$ C<br>alt  $s$ esign<br>and<br>antiis composed of  $\epsilon$ order spectra. It is done using a linear combination of the spectra  $\overline{\phantom{a}}$ Ti<br>a<br>discrimed ruem<br>1. 2014<br>1. 2014 Ir<br>S<br>n the in the structure in the structure in the structure is  $\epsilon$ subtracted along the intervalong columns. (For  $\overline{F}$ e<br>a<br>t<br>C spectra are extracted from the interlaced from the interlaced from the interlaced from the interlaced S141 fr<br>Alternaced G141 frames a<br>P<br>D

![](_page_14_Picture_13.jpeg)

**gravitational lensing helps!** 

![](_page_14_Figure_2.jpeg)

## **Line Morphologies** provide spatially resolved information on ~1kpc scales

![](_page_14_Figure_1.jpeg)

![](_page_15_Picture_1.jpeg)

**Contamination** 

![](_page_15_Picture_3.jpeg)

![](_page_15_Picture_4.jpeg)

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![](_page_15_Picture_8.jpeg)

Nelson et al. 2016

![](_page_16_Picture_1.jpeg)

**Contamination** 

![](_page_16_Picture_3.jpeg)

![](_page_16_Picture_4.jpeg)

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![](_page_16_Picture_8.jpeg)

Nelson et al. 2016

![](_page_17_Picture_1.jpeg)

![](_page_17_Picture_2.jpeg)

![](_page_17_Picture_3.jpeg)

![](_page_17_Picture_6.jpeg)

![](_page_17_Figure_7.jpeg)

Nelson et al. 2016

Kate Whitaker **Astrophysics with WFIRST @ 231st AAS Meeting** January 10, 2018 have a small residual positive background (smaller than the vith WFIRST @ 231st AAS Meeting.  $\qquad \qquad$ dian of all unmasked pixels in the 2 kpc edges of each stamped pixels in the 2 kpc edges of each stamped pixels in the 2 kpc edges of each stamped pixels in the 2 kpc edges of each stamped pixels in the 2 kpc edges of eac

January 10, 2018 for the various systematics described in the remainder of this

We can construct the stacked images by summing normalized, the stacked images by summing normalized, and the s

![](_page_18_Picture_1.jpeg)

![](_page_18_Picture_2.jpeg)

![](_page_18_Picture_3.jpeg)

![](_page_18_Picture_6.jpeg)

![](_page_18_Figure_7.jpeg)

Nelson et al. 2016

Kate Whitaker **Astrophysics with WFIRST @ 231st AAS Meeting** January 10, 2018 have a small residual positive background (smaller than the vith WFIRST @ 231st AAS Meeting.  $\qquad \qquad$ dian of all unmasked pixels in the 2 kpc edges of each stamped pixels in the 2 kpc edges of each stamped pixels in the 2 kpc edges of each stamped pixels in the 2 kpc edges of each stamped pixels in the 2 kpc edges of eac

January 10, 2018 for the various systematics described in the remainder of this

![](_page_18_Picture_11.jpeg)

![](_page_19_Picture_1.jpeg)

![](_page_19_Picture_2.jpeg)

![](_page_19_Picture_3.jpeg)

![](_page_19_Picture_6.jpeg)

![](_page_19_Figure_7.jpeg)

Nelson et al. 2016

Kate Whitaker **Astrophysics with WFIRST @ 231st AAS Meeting** January 10, 2018 have a small residual positive background (smaller than the vith WFIRST @ 231st AAS Meeting.  $\qquad \qquad$ dian of all unmasked pixels in the 2 kpc edges of each stamped pixels in the 2 kpc edges of each stamped pixels in the 2 kpc edges of each stamped pixels in the 2 kpc edges of each stamped pixels in the 2 kpc edges of eac

January 10, 2018 for the various systematics described in the remainder of this

![](_page_19_Picture_11.jpeg)

![](_page_20_Figure_1.jpeg)

![](_page_20_Figure_2.jpeg)

![](_page_20_Picture_3.jpeg)

Nelson et al. 2013, 2015

## **Where do stars form?** The inside-out growth of exponential disks

8 Nelson et al. 1980 et al<br>1980 et al. 1980 et al. 19

8 Nelson et al. 1980 et al<br>1980 et al. 1980 et al. 19

![](_page_21_Figure_2.jpeg)

 $\frac{1}{2}$  for oprigonce with intervent  $\frac{1}{2}$  and  $\frac{1}{2}$  is different to according to action to according to ac

radius (as derived from the *HF*140*<sup>W</sup>* data) they are closer to

![](_page_21_Figure_1.jpeg)

![](_page_21_Picture_7.jpeg)

Nelson et al. 2013, 2015  $N$  . Interpreted the Nation at al. 2013, 2015  $\blacksquare$ 

![](_page_21_Picture_11.jpeg)

#### **When did the stars form?** Bimodality of Galaxy Populations **1.5**

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1.0<br>1.0<br>1.0

![](_page_22_Picture_6.jpeg)

Fumagalli et al. in prep

![](_page_22_Figure_1.jpeg)

# <u>100% |</u>

#### **When did the stars form?** Bimodality of Galaxy Populations **1.5**

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1.0<br>1.0<br>1.0

![](_page_23_Picture_6.jpeg)

Fumagalli et al. in prep

![](_page_23_Figure_1.jpeg)

## **When did the stars form?** Ages of quenched galaxies

![](_page_24_Figure_1.jpeg)

![](_page_24_Picture_5.jpeg)

![](_page_25_Figure_1.jpeg)

![](_page_25_Picture_4.jpeg)

- Hubble beats the cosmic distance record with a best-fit redshift of combined grism spectrum and photometry of  $z = 11.1 \pm 0.1$ 
	- Overall 5.5σ detection at  $\lambda$ >1.47 μm
	- Lyman break factor of  $>3.1$  (2 $\sigma$ , 500Å)
	- Grism + photometric data rule out all plausible lower redshift solutions.

Oesch et al. 2016

![](_page_25_Figure_12.jpeg)

![](_page_25_Picture_13.jpeg)

## Future Prospects

![](_page_26_Picture_1.jpeg)

![](_page_26_Picture_2.jpeg)

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![](_page_27_Figure_2.jpeg)

![](_page_27_Picture_5.jpeg)

Simulation by G. Brammer https://github.com/gbrammer/grizli/

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![](_page_27_Picture_9.jpeg)

## **WFIRST Simulations:** what can we expect?

#### Single 4k WFIRST detector

![](_page_28_Picture_3.jpeg)

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![](_page_28_Picture_6.jpeg)

#### Simulation by G. Brammer https://github.com/gbrammer/grizli/

![](_page_28_Picture_9.jpeg)

![](_page_28_Picture_10.jpeg)

## **WFIRST Simulations:** what can we expect?

### Single 4k WFIRST detector

Dispersed by the HLS grism

![](_page_29_Figure_4.jpeg)

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### Simulation by G. Brammer

https://github.com/gbrammer/grizli/

![](_page_29_Picture_11.jpeg)

![](_page_29_Picture_12.jpeg)

## **WFIRST Simulations:** what can we expect?

### Single 4k WFIRST detector

### Dispersed by the HLS grism

Hα:  $1.1 < z < 1.9$ (full range  $0.5 < z < 1.9$ )

![](_page_30_Figure_4.jpeg)

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![](_page_30_Picture_7.jpeg)

![](_page_30_Picture_10.jpeg)

## **WFIRST Simulations:** what can we expect?

### Single 4k WFIRST detector

### Dispersed by the HLS grism

Hα:  $1.1 < z < 1.9$ (full range  $0.5 < z < 1.9$ )

## **WFIRST Simulations:** what can we expect?

![](_page_31_Figure_1.jpeg)

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![](_page_31_Picture_4.jpeg)

![](_page_31_Picture_7.jpeg)

![](_page_32_Figure_5.jpeg)

![](_page_32_Picture_8.jpeg)

[OIII]+Hβ: 1.9 < z < 2.8 (full range  $1.0 < z < 2.8$ )

Single 4k WFIRST detector

Dispersed by the HLS grism

Hα:  $1.1 < z < 1.9$ (full range  $0.5 < z < 1.9$ )

### Simulation by G. Brammer

https://github.com/gbrammer/grizli/

![](_page_32_Picture_13.jpeg)

![](_page_32_Picture_14.jpeg)

## **WFIRST Simulations:** what can we expect?

- **0.28 deg2** at a shot, **2000 deg2 (!) High Latitude Survey** (*z* for BAO, RSD, public survey)
- **2.4m** telescope (≈HST)
- 1.0–1.9 μm,  **(e.g., just resolves Hα, [NII])**

## **WFIRST:** new capabilities with slitless spectroscopy

#### • **WFIRST GRS grism**

![](_page_33_Picture_5.jpeg)

![](_page_33_Picture_9.jpeg)

#### Simulation by G. Brammer https://github.com/gbrammer/grizli/

Kate Whitaker **Astrophysics with WFIRST @ 231st AAS Meeting** January 10, 2018

![](_page_33_Picture_15.jpeg)

# WFIRST: 0.28 deg<sup>2</sup> / pointing, 2000 deg<sup>2</sup> total

![](_page_34_Figure_1.jpeg)

![](_page_35_Figure_1.jpeg)

# **WFIRST:** 0.28 deg2 / pointing, 2000 deg2 total

![](_page_36_Figure_1.jpeg)

![](_page_36_Figure_4.jpeg)

![](_page_36_Picture_5.jpeg)

## **WFIRST High Latitude Survey** pushes into uncharted parameter space

## WFIRST High Latitude Survey pushes into uncharted parameter space

![](_page_37_Figure_1.jpeg)

![](_page_37_Picture_5.jpeg)

- **2.4m** telescope (≈HST)
- $\cdot$  1.0–1.9 µm
- $\mathbf{R} = 4 \times \mathbf{G}$ **141** (resolves H $\alpha$ , [NII])
- **Star-formation activity** (SFR, Σ<sub>SFR</sub>(r)) Wuyts et al. 2013, Nelson et al. 2016 • **Star-formation history** (H<sup>α</sup> vs. continuum) Nelson et al. 2013, 2015
- 
- **Dust extinction** Price et al. 2014, Nelson et al. 2016
- **Ages** Whitaker et al. 2013, Fumagalli et al. 2016
- **Active Galactic Nuclei** Trump et al. 2011, 2014, Bridge et al. 2016
- **Metallicity gradients** Jones et al. 2014, Wang et al. 2016
- Age gradients Whitaker et al., in prep
- **Cosmic Dawn** Oesch et al. 2016

![](_page_38_Picture_16.jpeg)

![](_page_38_Figure_19.jpeg)

![](_page_38_Picture_20.jpeg)

## **Line Morphologies** provide spatially resolved information on ~1kpc scales

- **Star-formation activity** (SFR, Σ<sub>SFR</sub>(r)) Wuyts et al. 2013, Nelson et al. 2016 • **Star-formation history** (H<sup>α</sup> vs. continuum) Nelson et al. 2013, 2015
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- **Dust extinction** Price et al. 2014, Nelson et al. 2016
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- **Active Galactic Nuclei** Trump et al. 2011, 2014, Bridge et al. 2016
- **Metallicity gradients** Jones et al. 2014, Wang et al. 2016
- **Age gradients** Whitaker et al., in prep
- **Cosmic Dawn** Oesch et al. 2016

![](_page_39_Picture_19.jpeg)

 $F = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$ manust~bUU dalaxies totained by stacking two- $\overline{\phantom{a}}$  spectra of galaxies at 1.35  $\overline{\phantom{a}}$ mass bins. The maps were obtained by starting the stacking continuum of the stacking continuum of the stacking N<sub>3DHST</sub>~600 galaxies total NWFIRST-HLS~**10 million** galaxies total

- **2.4m** telescope (≈HST)
- 1.0–1.9 µm
- $\mathbf{R} = 4 \times \mathbf{G}$ **141** (resolves H $\alpha$ , [NII])

![](_page_39_Figure_5.jpeg)

## Offers amazing number statistics!

![](_page_39_Picture_24.jpeg)

## **Line Morphologies** provide spatially resolved information on ~1kpc scales

- **Star-formation activity** (SFR, Σ<sub>SFR</sub>(r)) Wuyts et al. 2013, Nelson et al. 2016 • **Star-formation history** (H<sup>α</sup> vs. continuum) Nelson et al. 2013, 2015
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- **Dust extinction** Price et al. 2014, Nelson et al. 2016
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![](_page_40_Picture_19.jpeg)

- **2.4m** telescope (≈HST)
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- $\mathbf{R} = 4 \times \mathbf{G}$ 141 (resolves H $\alpha$ , [NII])

N3DHST~200 quiescent galaxies NWFIRST-HLS~**2 million** quiescent galaxies

## Offers amazing number statistics!

![](_page_40_Picture_24.jpeg)

![](_page_40_Figure_5.jpeg)

## **Line Morphologies** provide spatially resolved information on ~1kpc scales

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- **Cosmic Dawn** Oesch et al. 2016

![](_page_41_Picture_18.jpeg)

![](_page_41_Figure_22.jpeg)

![](_page_41_Picture_23.jpeg)

## Wide area + unbiased sample + spectral information = perfect probe of ENVIRONMENT!

- **2.4m** telescope (≈HST)
- 1.0–1.9 µm
- $\mathbf{R} = 4 \times \mathbf{G}$ **141** (resolves H $\alpha$ , [NII])

![](_page_41_Figure_5.jpeg)

## **Line Morphologies** provide spatially resolved information on ~1kpc scales

- **Star-formation activity** (SFR, Σ<sub>SFR</sub>(r)) Wuyts et al. 2013, Nelson et al. 2016
- **Star-formation history** (H<sup>α</sup> vs. continuum) Nelson et al. 2013, 2015
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	- **Ages** Whitaker et al. 2013, Fumagalli et al. 2016
	- **Active Galactic Nuclei** Trump et al. 2011, 2014, Bridge et al. 2016

• **Metallicity gradients** Jones et al. 2014, Wang et al. 2016 **FINDI LANGS US ILUIII ~JU | AL., in prep<br>The LGA AAA recently quenched galaxies at**  $z$ **~2!** 2016

![](_page_42_Figure_19.jpeg)

![](_page_42_Picture_20.jpeg)

## Wide area + unbiased sample + spectral information = perfect probe of ENVIRONMENT!

- **2.4m** telescope (≈HST)
- 1.0–1.9 µm
- $\mathbf{R} = 4 \times \mathbf{G}$ **141** (resolves H $\alpha$ , [NII])

![](_page_42_Figure_5.jpeg)

![](_page_42_Picture_9.jpeg)

## **Line Morphologies** provide spatially resolved information on ~1kpc scales

- **Star-formation activity** (SFR, Σ<sub>SFR</sub>(r)) Wuyts et al. 2013, Nelson et al. 2016
- **Star-formation history** (H<sup>α</sup> vs. continuum) Nelson et al. 2013, 2015
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- **Cosmic Dawn** Oesch et al. 2016

## Wide area + unbiased sample + spectral information = perfect probe of ENVIRONMENT!

• …

![](_page_43_Picture_21.jpeg)

![](_page_43_Figure_24.jpeg)

![](_page_43_Picture_25.jpeg)

- **2.4m** telescope (≈HST)
- $1.0-1.9 \,\mu m$
- $\mathbf{R} = 4 \times \mathbf{G}$ **141** (resolves H $\alpha$ , [NII])
- What role does environment play in star formation efficiency? {
- Does dust attenuation depend on environment?
- Do galaxies quench earlier in denser environments?
- What role do AGN play in quenching?

## **Line Morphologies** provide spatially resolved information on ~1kpc scales

- **Star-formation activity** (SFR, Σ<sub>SFR</sub>(r)) Wuyts et al. 2013, Nelson et al. 2016
- **Star-formation history** (H<sup>α</sup> vs. continuum) Nelson et al. 2013, 2015
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- **Ages** Whitaker et al. 2013, Fumagalli et al. 2016
- **Active Galactic Nuclei** Trump et al. 2011, 2014, Bridge et al. 2016
- **Metallicity gradients** Jones et al. 2014, Wang et al. 2016 Age gradients Whitaker et al., in prep New samples of gravitationally lensed targets!
	- **Cosmic Dawn** Oesch et al. 2016

![](_page_44_Picture_16.jpeg)

# Wide area + unbiased sample + spectral information = perfect probe of ENVIRONMENT!

- **2.4m** telescope (≈HST)
- 1.0–1.9 µm
- $\mathbf{R} = 4 \times \mathbf{G}$ **141** (resolves H $\alpha$ , [NII])

## **Line Morphologies** provide spatially resolved information on ~1kpc scales

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- **Ages** Whitaker et al. 2013, Fumagalli et al. 2016
- **Active Galactic Nuclei** Trump et al. 2011, 2014, Bridge et al. 2016
- **Metallicity gradients** Jones et al. 2014, Wang et al. 2016
- **Age gradients** Whitaker et al., in prep

![](_page_45_Picture_19.jpeg)

**Cosmic Dawn** Oesch et al. 2016

# Wide area + unbiased sample + spectral information = perfect probe of ENVIRONMENT!

### **WFIRST will reveal 100s-1000s of luminous galaxies in the epoch of reionization!**

![](_page_45_Figure_5.jpeg)

## **Line Morphologies** provide spatially resolved information on ~1kpc scales

### • **2000 deg2 (!)**

- **2.4m** telescope (≈HST)
- 1.0–1.9 µm

### •  $\mathbf{R} = 4 \times \mathbf{G}$ **141** (resolves H $\alpha$ , [NII])

# Galaxy Formation & Evolution in the WFIRS Era: From Census to Synthesis of the Lifecycles of Galaxies

- **resource** for galaxy evolution studies
- completeness, spatial resolution)
- the way for upcoming space missions like WFIRST!

## **Kate Whitaker**

Assistant Professor University of Connecticut [www.whitaker.physics.uconn.edu](http://www.whitaker.physics.uconn.edu)

• Slitless grism surveys like 3D-HST offer a highly complete spectroscopic

• The slitless nature of the spectra presents **formidable data analysis challenges**, but with **significant benefits** (e.g., continuum depth,

• Lessons, science, and targets from current HST grism programs will help pave