# CANDELS

## Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey


Co-PIs:

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University of California Santa Cruz

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Space Telescope Science Institute


# CANDELS

## **C**osmic **A**ssembly **N**ear-infrared **D**eep **E**xtragalactic **L**egacy **S**urvey

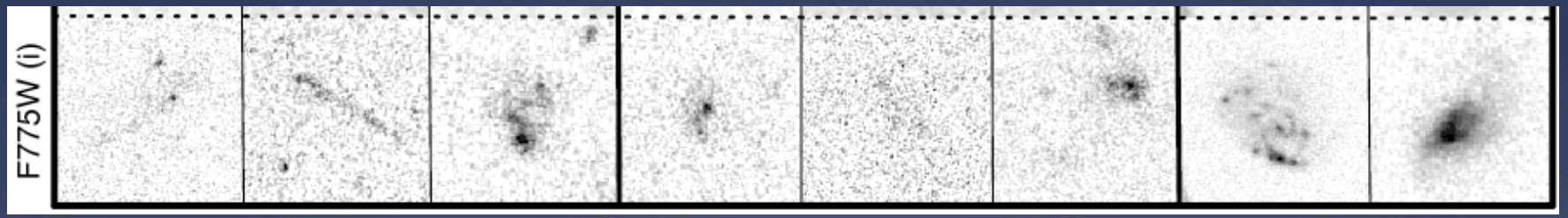
CANDELS Team:

100 scientists

12 countries

Major nodes: UCSC, STScI, ROE, NOAO, UCI, UMich, MPIA

# What WFC3 Can Do



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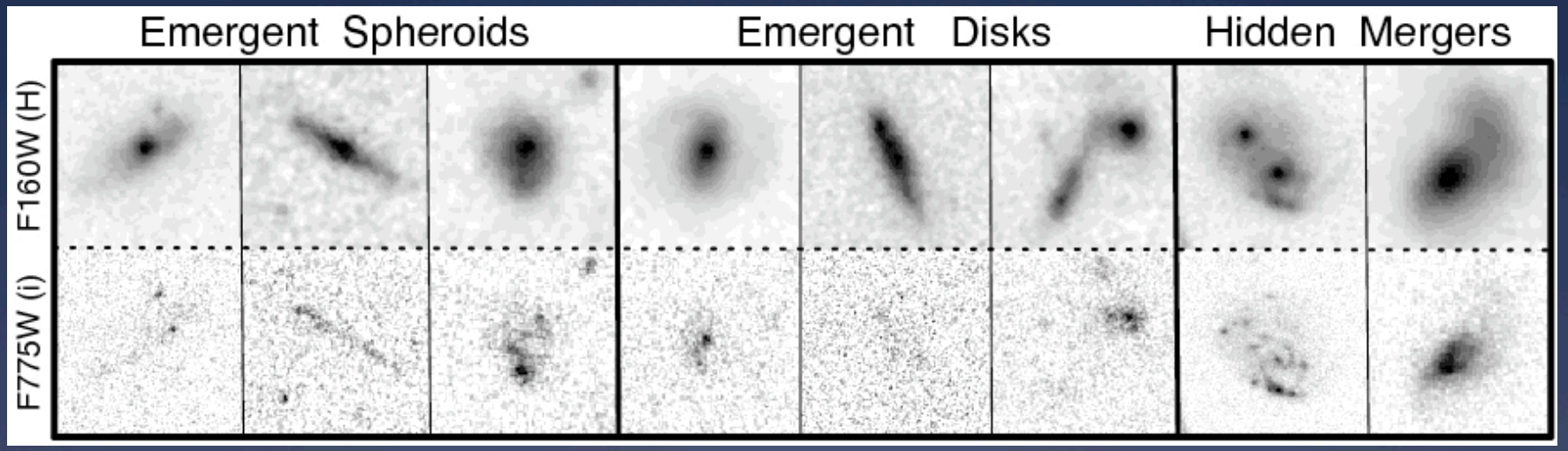
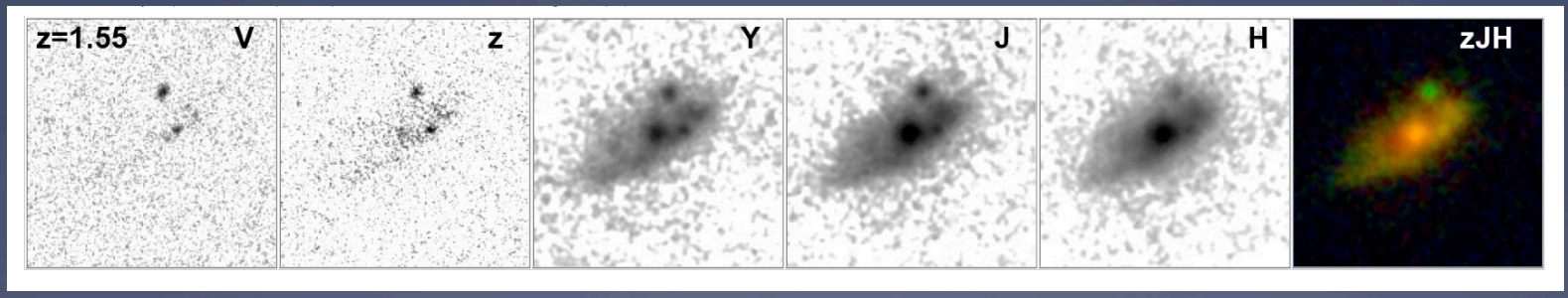
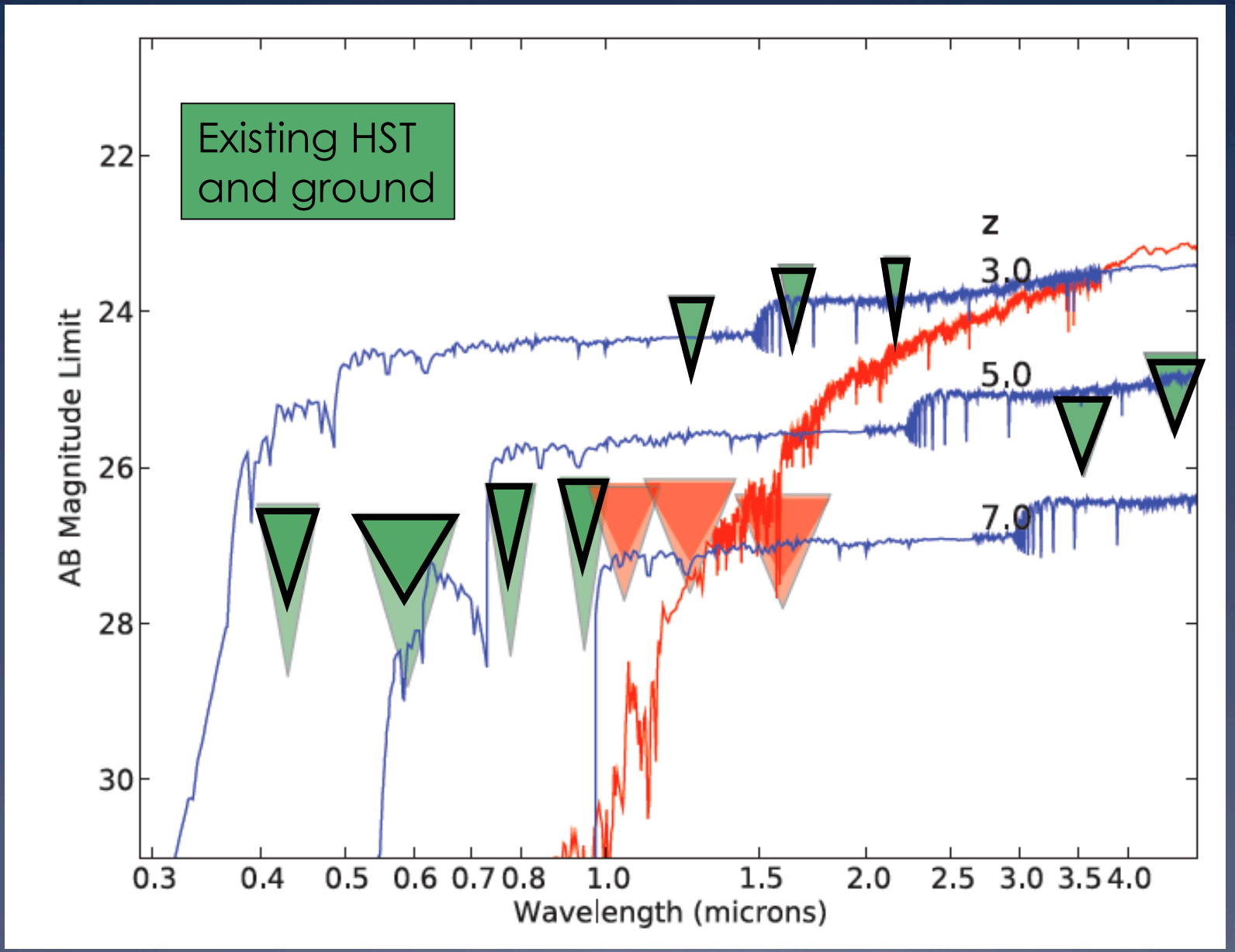



But the WFC3 diffraction limit is 2-3 times softer than ACS

# New YJH photometry limits in GOODS-S Deep region



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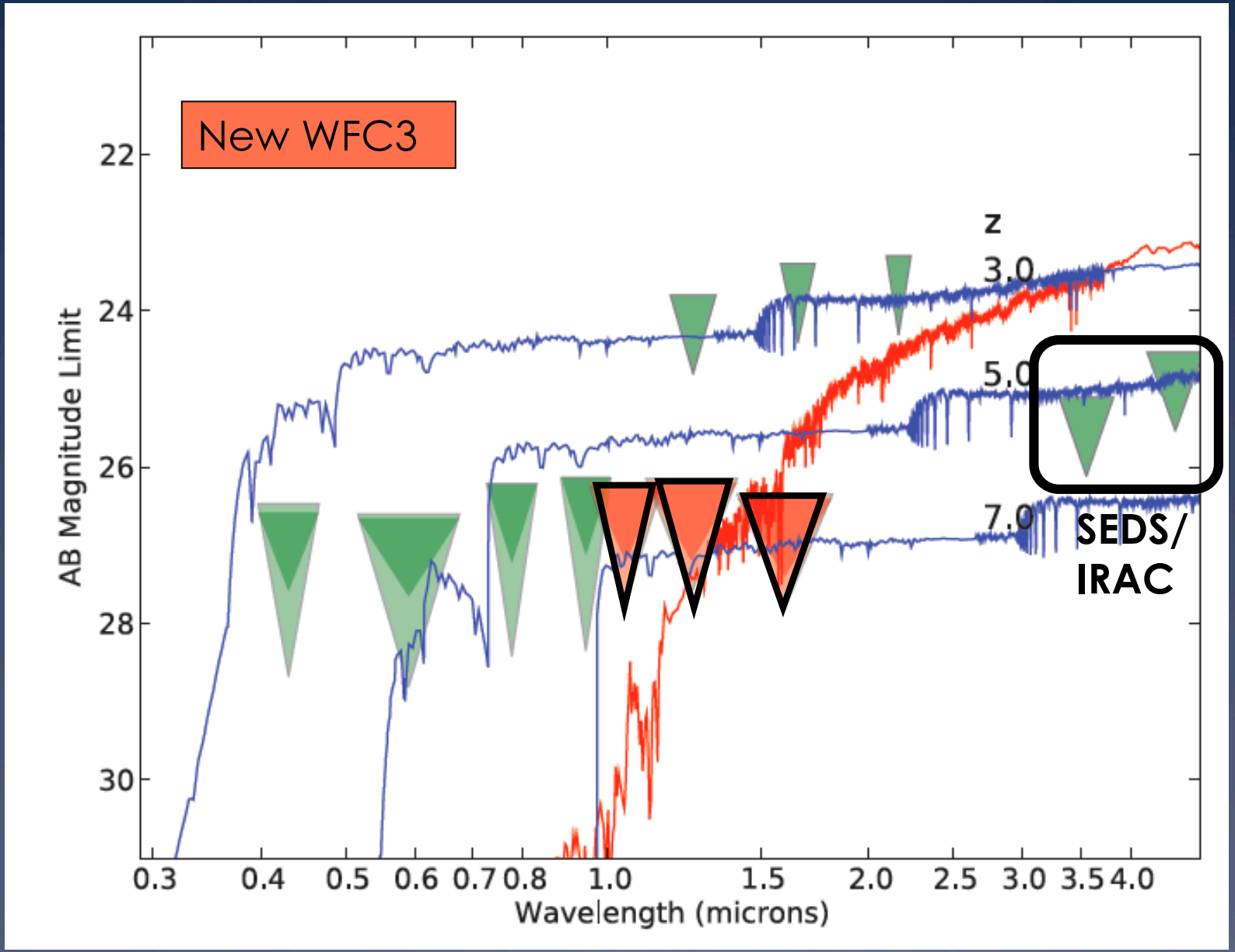


# Exposure Strategy

- "Wedding cake" strategy: three layers of J+H

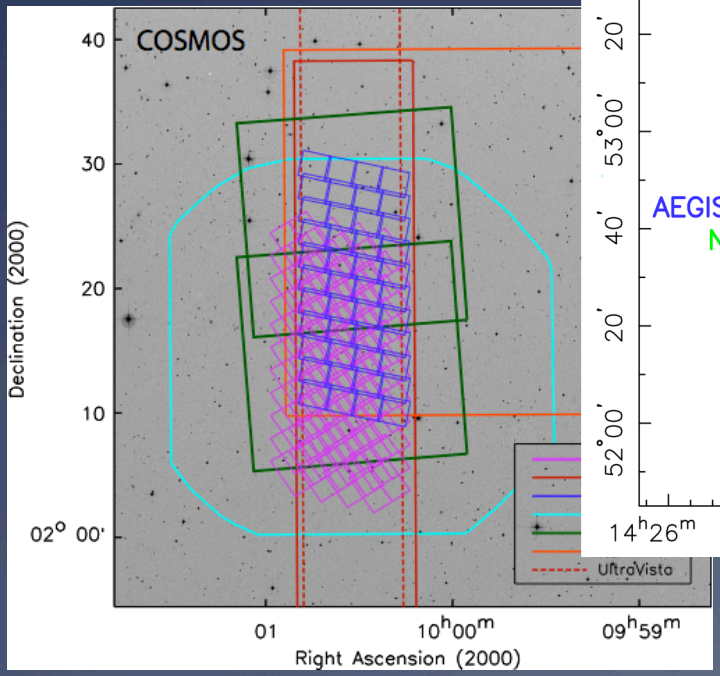
UDFs: 50-100 orbit depth over ~0.004 sq deg

DEEP: 8 orbit depth over ~0.04 sq deg

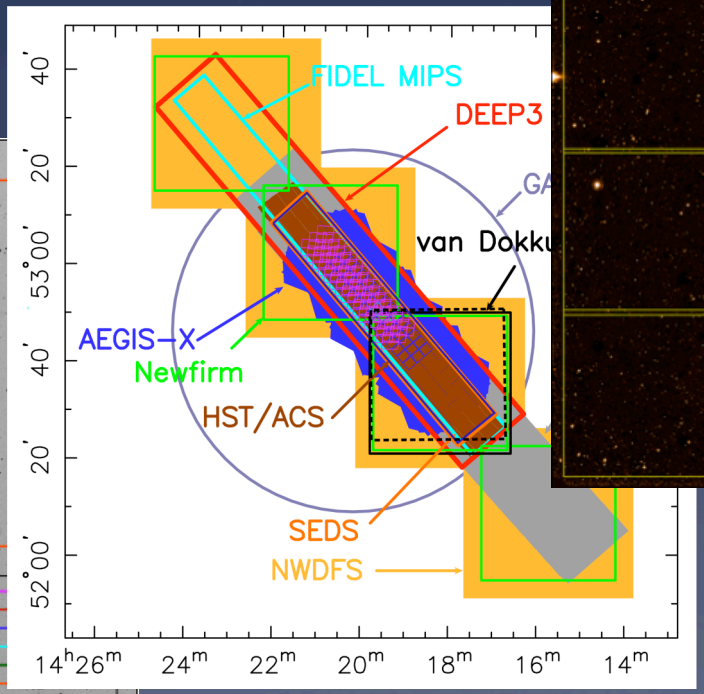
WIDE: 2 orbit depth over ~0.2 sq deg

# Exposure Strategy

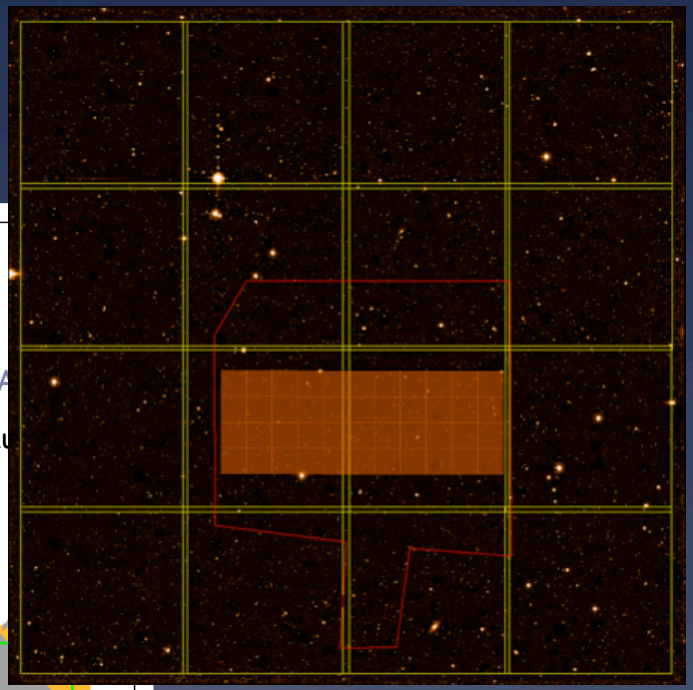
- Five famous fields
  - Wide: COSMOS, EGS, UDS




COSMOS:
$10^h\ 00^m$ +2 deg



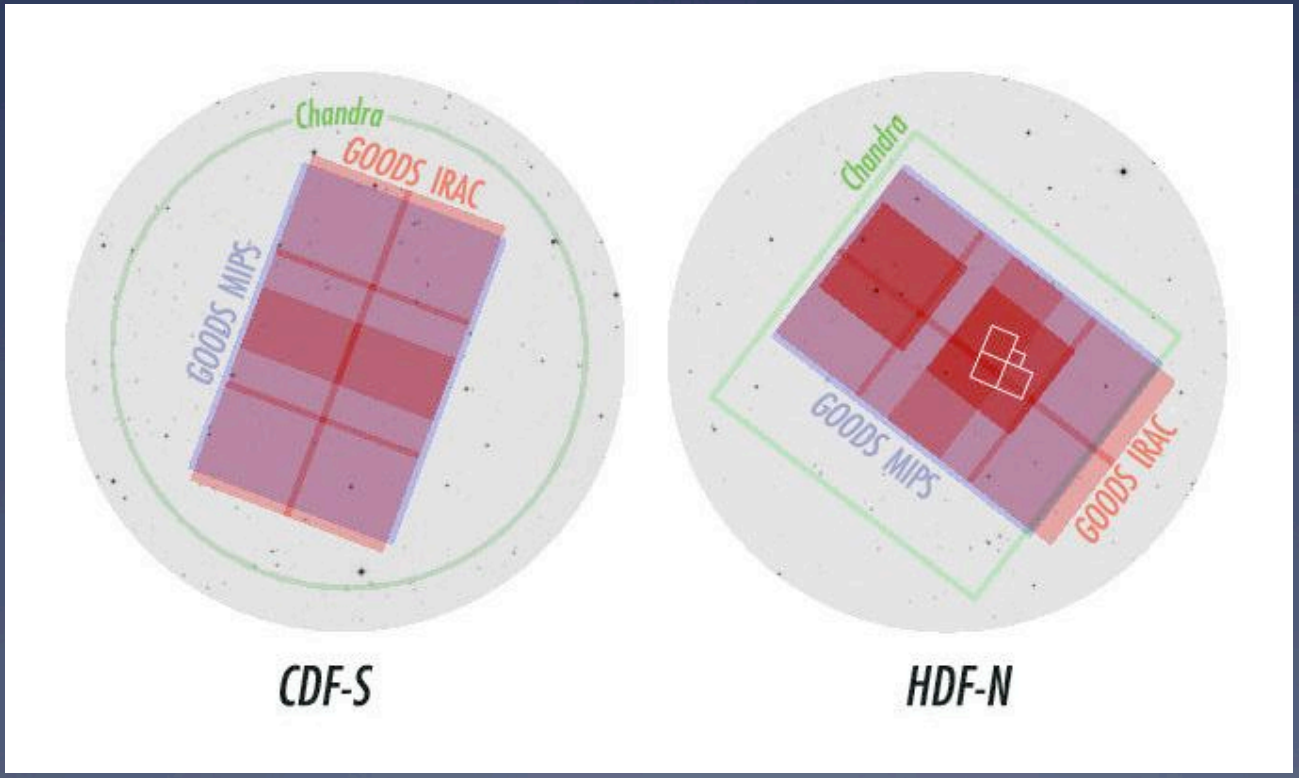

AEGIS:
$14^h\ 18^m$ +53 deg



UDS/UKIDSS/SXDS:
$2^h\ 18^m$ -5 deg

# Overview

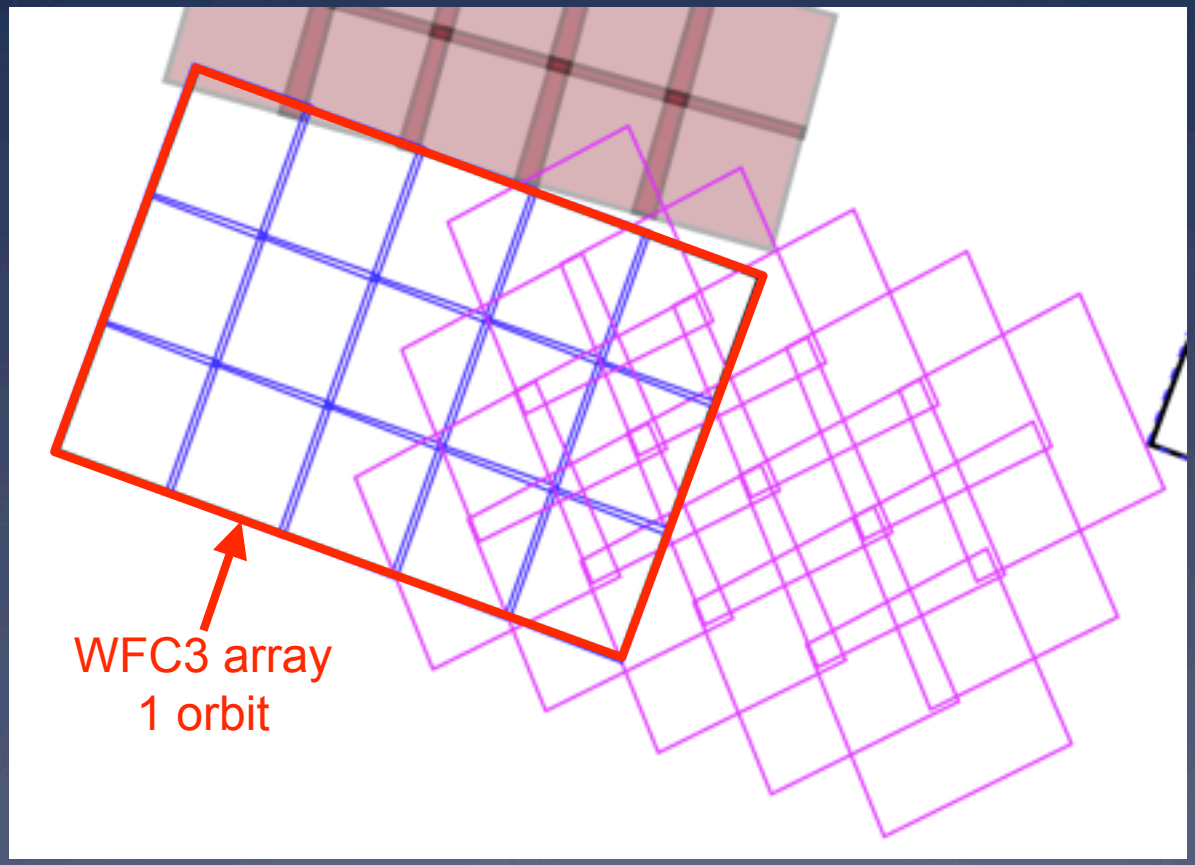
- Five famous fields
  - Deep: GOOD-S, GOODS-N




GOODS-S:
$03^h\ 32^m$ -28 deg

GOODS-N:
$12^h\ 37^m$ +62 deg

# ACS Parallels



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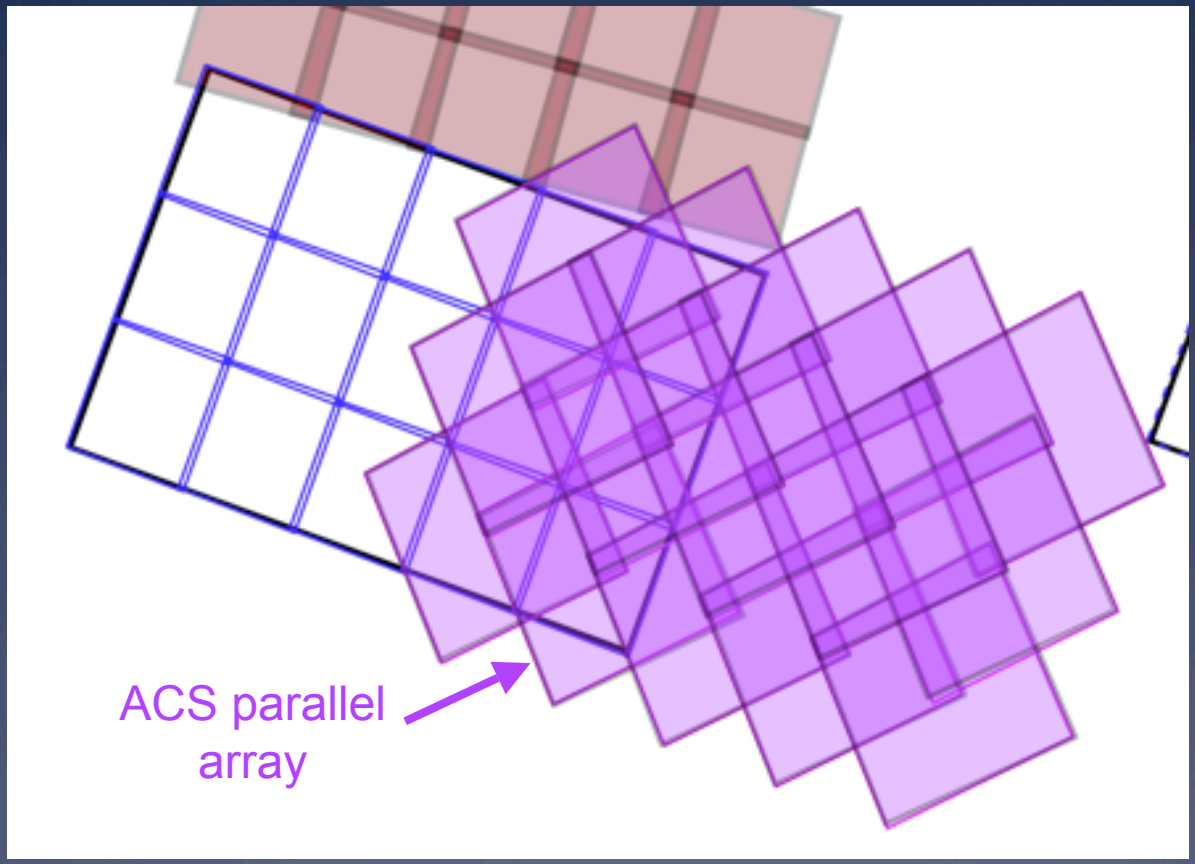

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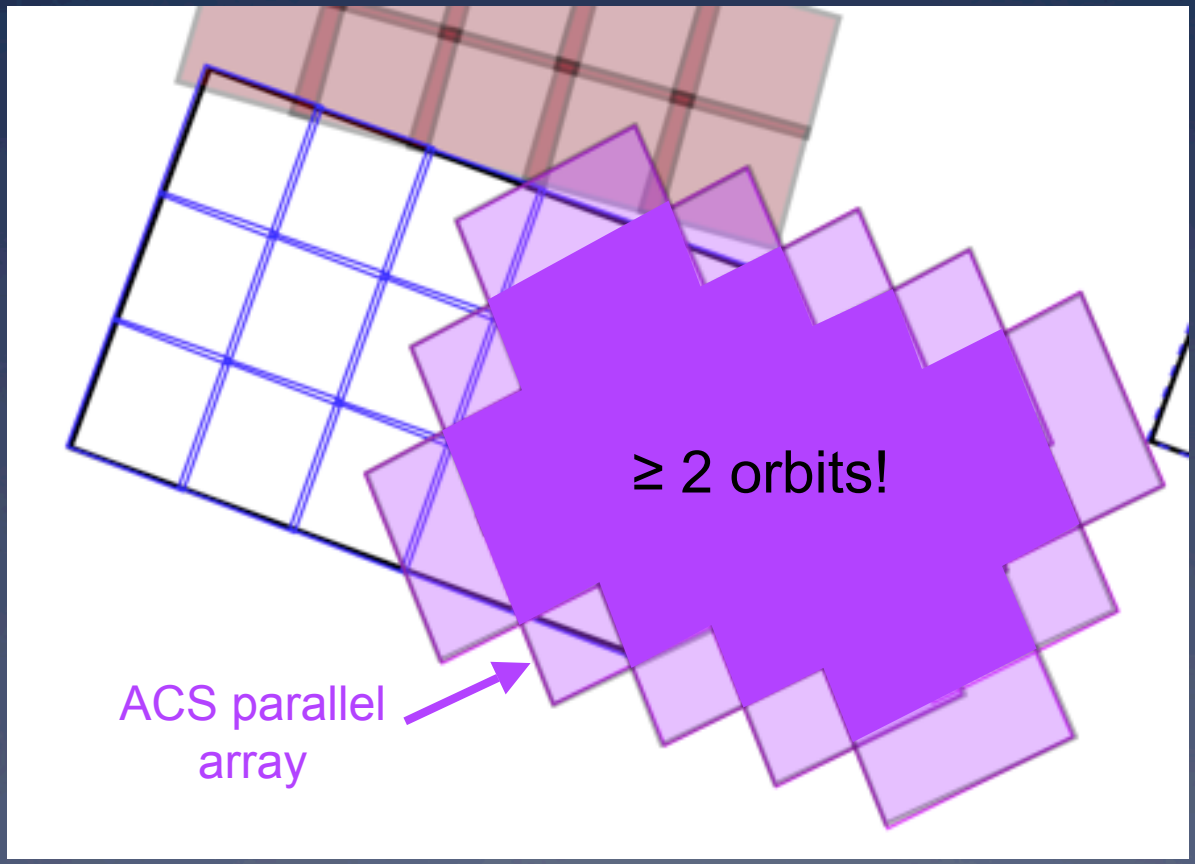
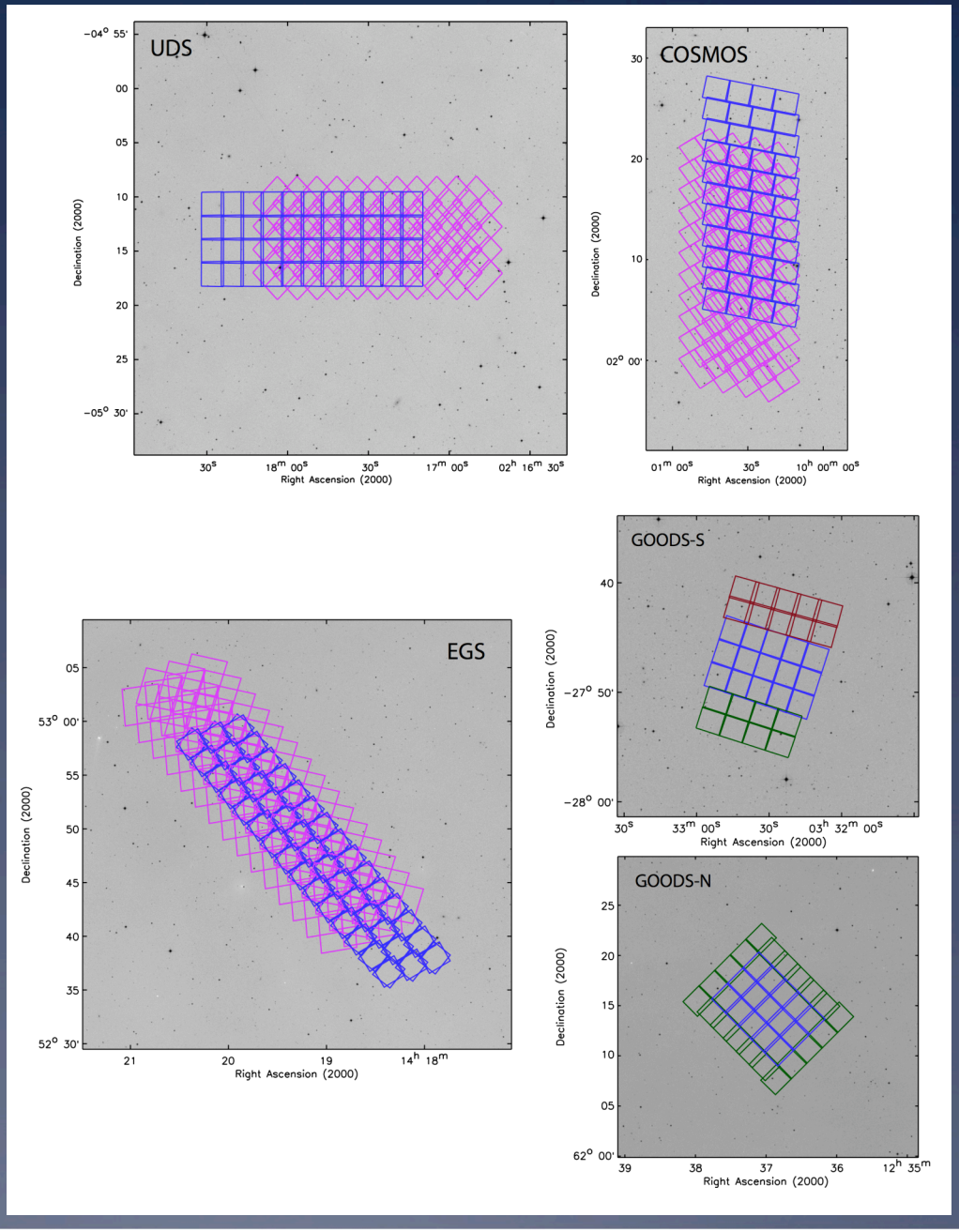


# CANDELS Fields

- Orbit Totals:
  - GOODS: 483
  - EGS: 90
  - UDS: 88
  - COSMOS: 88
  - SNe Follow-up: 152
- Submitted Phase II Files
  - GOODS-S: 12060-12062
  - EGS: 12063
  - UDS: 12064



# Magnitude and Mass Limits

| | Area sq deg | # WFC3 tiles | Exposure, orbits Y | J | H | Eff. Exposure, orbits V | I | z | |
|---|---|---|---|---|---|---|---|---|---|
| Wide | 0.2 | 162 | -- | 2/3 | 4/3 | 4/3 | 8/3 | -- | Plus existing ACS |
| Deep | 0.04 | 30 | 3 | 4 | 4 | >3 | >14 | 5 | Incl existing ACS |
| UDF | 0.004 | 3 | ~40 | ~40 | ~50 | 50+ | 50+ | 50+ | Incl existing ACS |

| | Point source limits | 5-σ AB mag | | | 5-σ AB mag | | | |
|---|---|---|---|---|---|---|---|---|
| Wide | | -- | 27.0 | 7.1 | 28.7 | 28.6 | -- | Plus existing ACS |
| Deep | | 27.8 | 28.0 | 28.0 | >29 | >30 | 29 | Incl existing ACS |
| UDF | | 29.1 | 29.5 | 29.3 | 30+ | 30+ | 29.4+ | Incl existing ACS |

| | Stellar mass @ z~2 | $M_{1500}$, z~7 |
|---|---|---|
| Wide | $10^9\ M_\odot$ | ~ -20 |
| Deep | $4 \times 10^8\ M_\odot$ | ~ -19 |
| UDF | $1.4 \times 10^8\ M_\odot$ | ~ -18 |

$10^9\ M_\odot$

# Highlights/Summary

- Imaging data for 250,000 galaxies from z = 1.5 - 8: Wide and Deep
- WFC3 bridges the Balmer break out to z ~ 2.5
- WFC3 cuts through dust
- Spitzer Extended Deep Survey (SEDS): IRAC 26 AB (5-σ); means stellar masses measured to ~$10^9$ $M_\odot$ to z ~ 7
- Overlapping ACS parallels: panchromatic imaging from V → H; new ACS imaging in UDS, deeper/multicolor ACS imaging in COSMOS and EGS . . . . . *photoz's!*
- UV in GOODS-N: 100 orbits of F275W, F336W
- Every pointing observed at least twice:
  - Search for variable AGN
  - First search for SNe beyond z ~ 1.5

# Science Goals: Supernovae

| | |
|---|---|
| Supernovae | Obtain a direct, explosion-model-independent measure of the evolution of Type Ia supernovae as distance indicators at $z > 1.5$, independent of dark energy. |
| Supernovae | Refine the only constraints we have on the time variation of the cosmic-equation of state parameter *w*, on a path to more than doubling the strength of this crucial test of a cosmological constant by the end of HST's life. |
| Supernovae | Provide the first measurement of the SN Ia rate at $z \approx 2$ to distinguish between prompt and delayed SN Ia production and their corresponding progenitor models. |
| Cosmic Dawn | Constrain star-formation rates, ages, metallicities, stellar-masses, and dust content of galaxies at the end of the reionization era $z \sim 6 - 10$. |
| Cosmic Dawn | Improve the constraints on the bright end of the luminosity function at $z \sim 7$ and 8, and make $z \sim 6$ measurements robust using proper 2-color Lyman break selection. |
| Cosmic Dawn | Measure fluctuations in the near-IR background light, at sensitivities sufficiently faint and angular scales sufficiently large to constrain reionization models. |
| Cosmic Dawn | Greatly improve the estimates of the evolution of stellar mass, dust and metallicity at $z = 4 - 8$ by combining WFC3 data with very deep Spitzer IRAC photometry. |
| Cosmic Dawn | Identify very high-redshift AGN by cross-correlating optical dropouts with deep Chandra observations. Constrain fainter AGN contributions via X-ray stacking. |
| Cosmic Dawn | Use clustering statistics to estimate the dark-halo masses of high-redshift galaxies with triple the area and double the maximum lag of prior HST surveys. |

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| Cosmic Dawn | Constrain star-formation rates, ages, metallicities, stellar-masses, and dust content of galaxies at the end of the reionization era z ~ 6 – 10. |
| Cosmic Dawn | Improve the constraints on the bright end of the luminosity function at z ~ 7 and 8, and make z ~ 6 measurements robust using proper 2-color Lyman break selection. |
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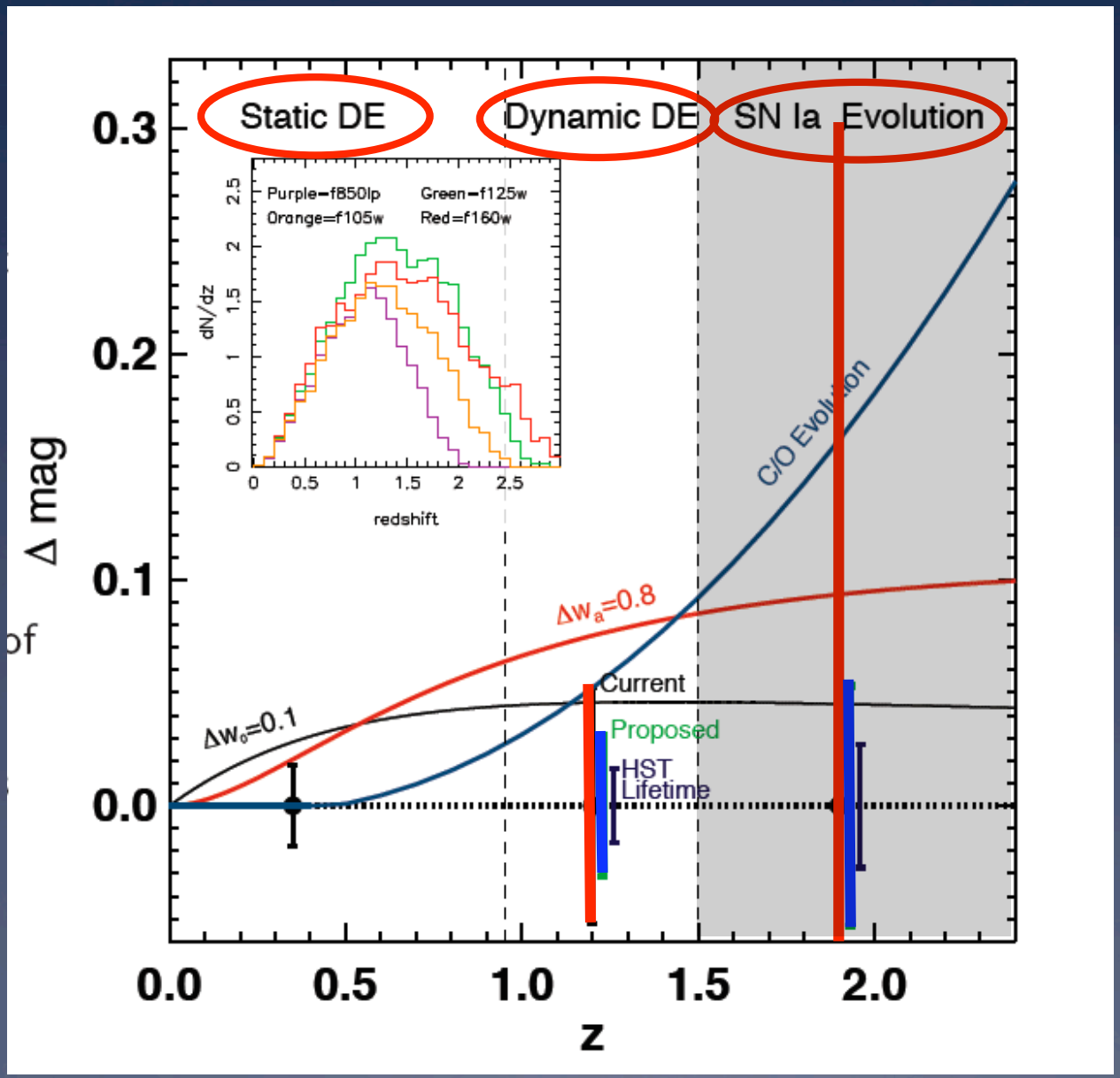
***Type Ia supernovae:***

Detect and measure at least 8 high-z SNe beyond z ~ 1.5

# Supernovae Prospects



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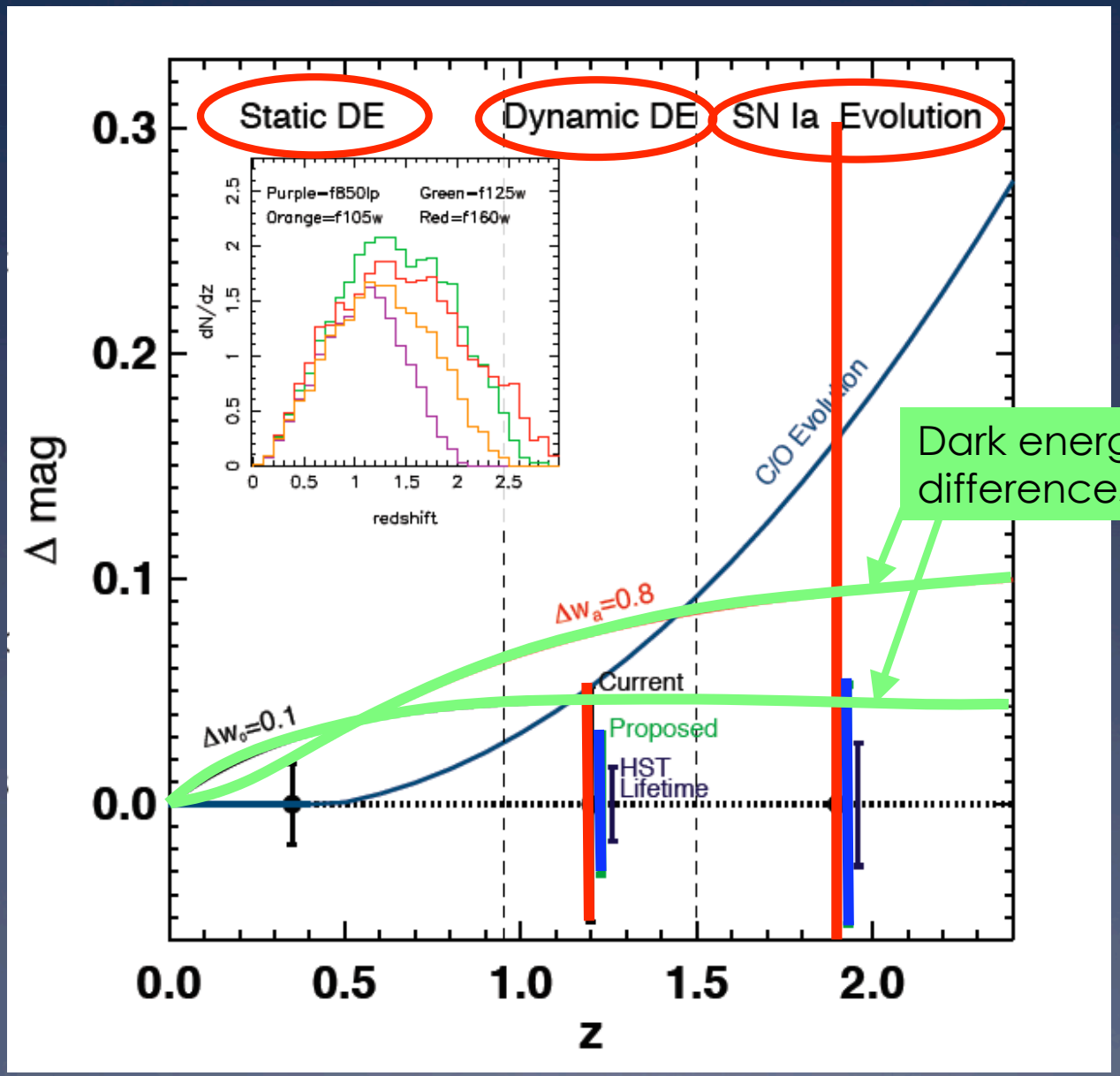

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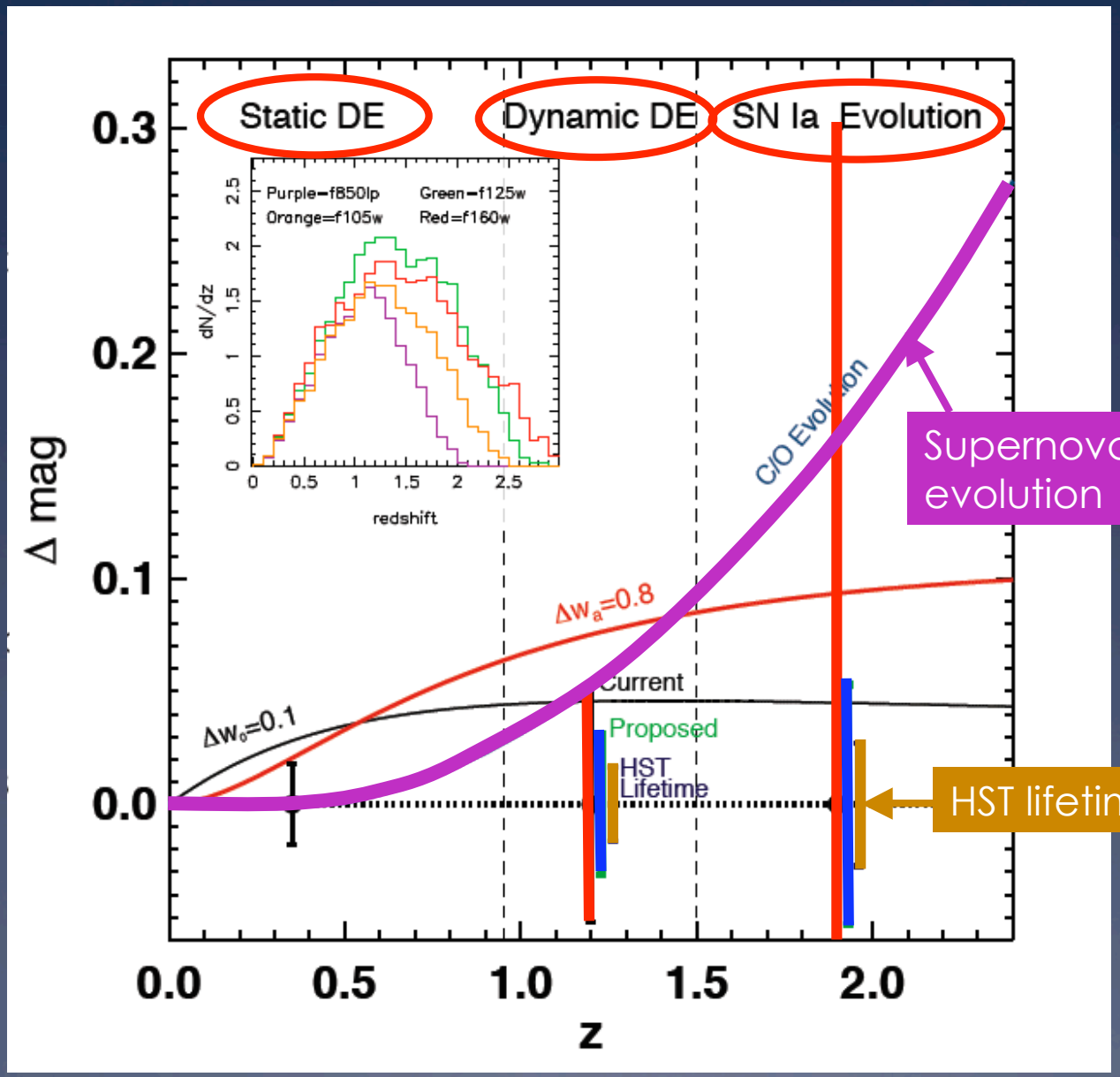

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| Dawn | Chandra observations. Constrain fainter AGN contributions via X-ray stacking. |
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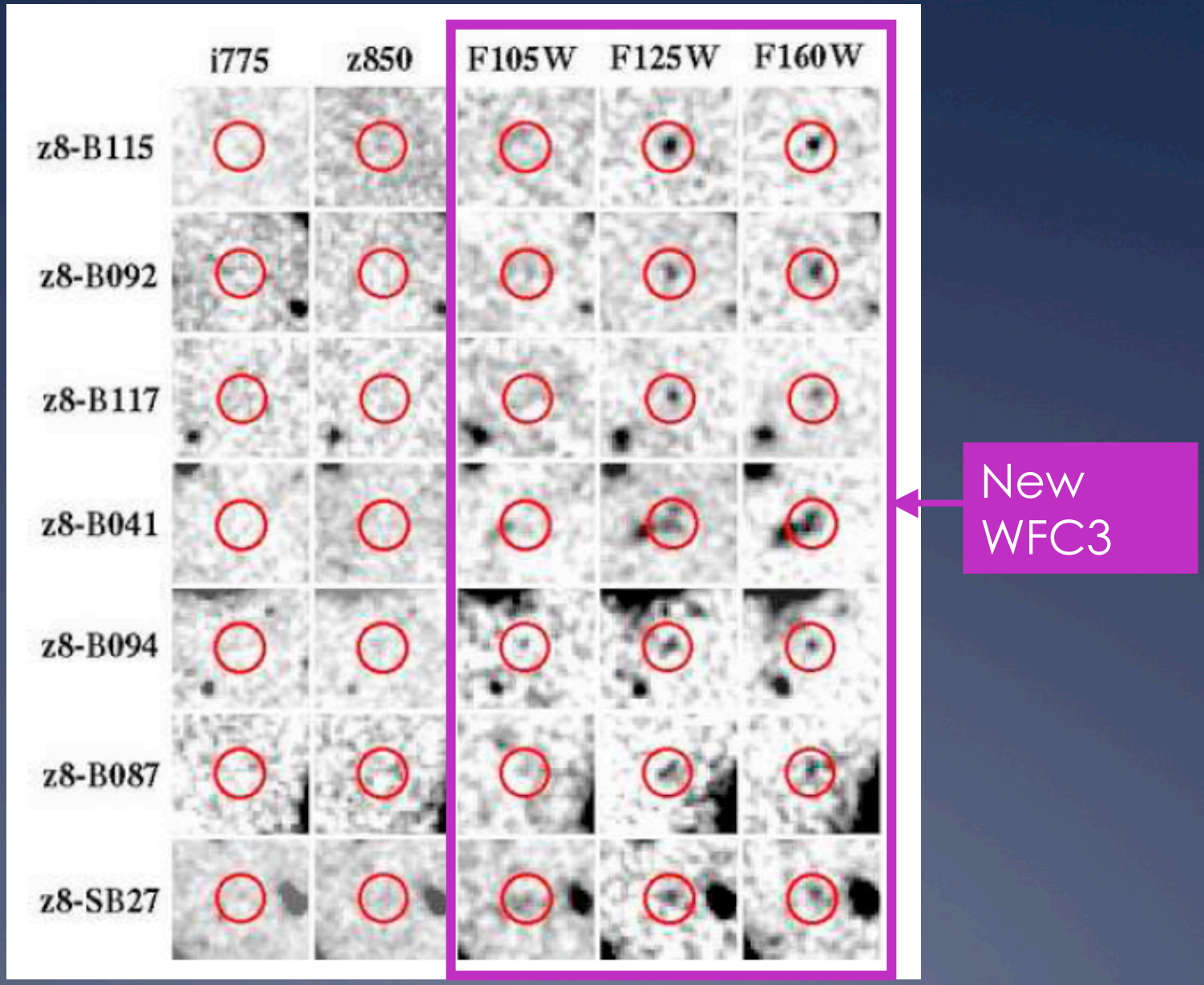
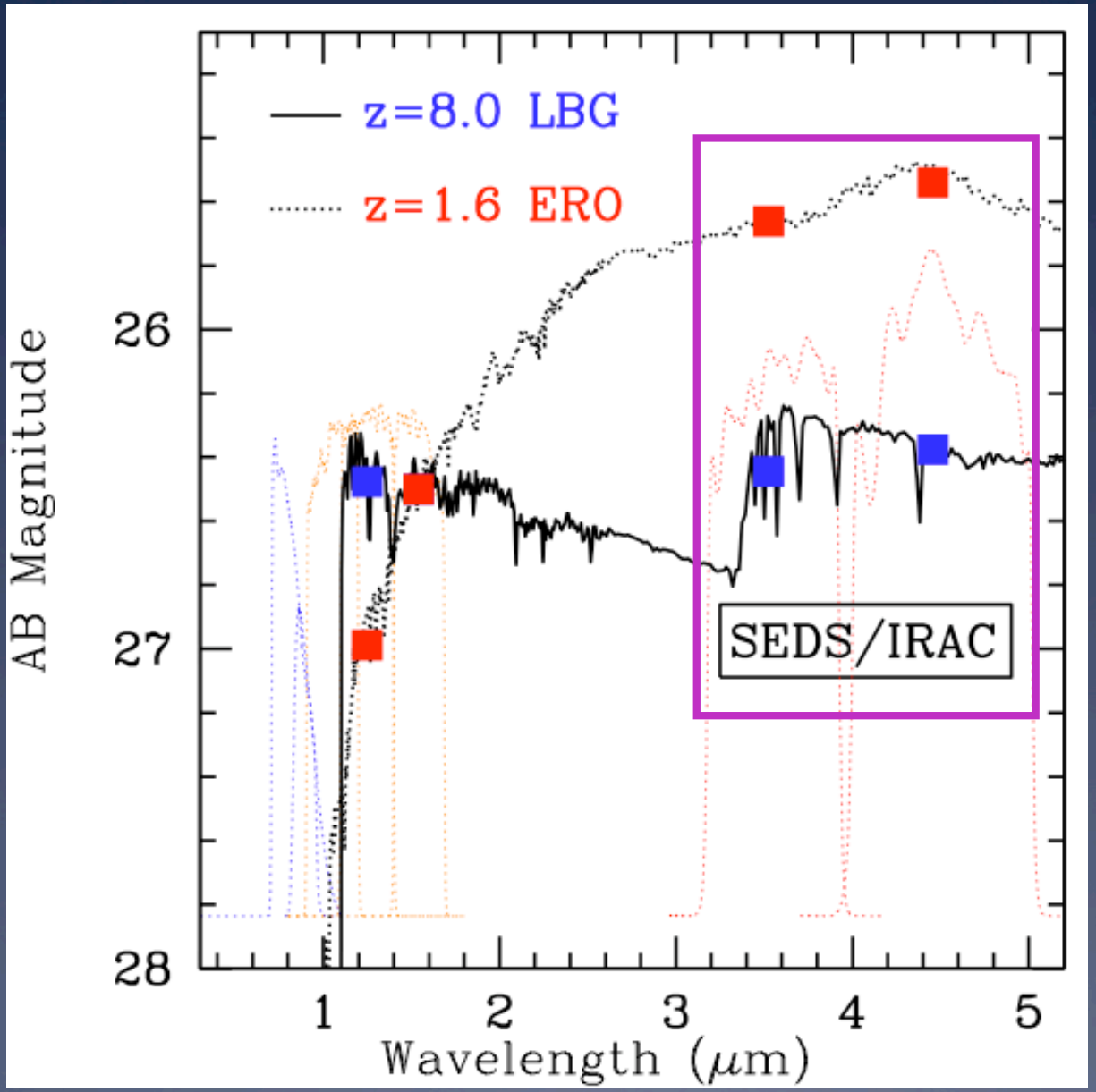
***Cosmic "dawn": z = 7-8***

Stellar masses down to $10^9 M_\odot$, lum functions, mass functions, morphologies, clustering >> halo masses

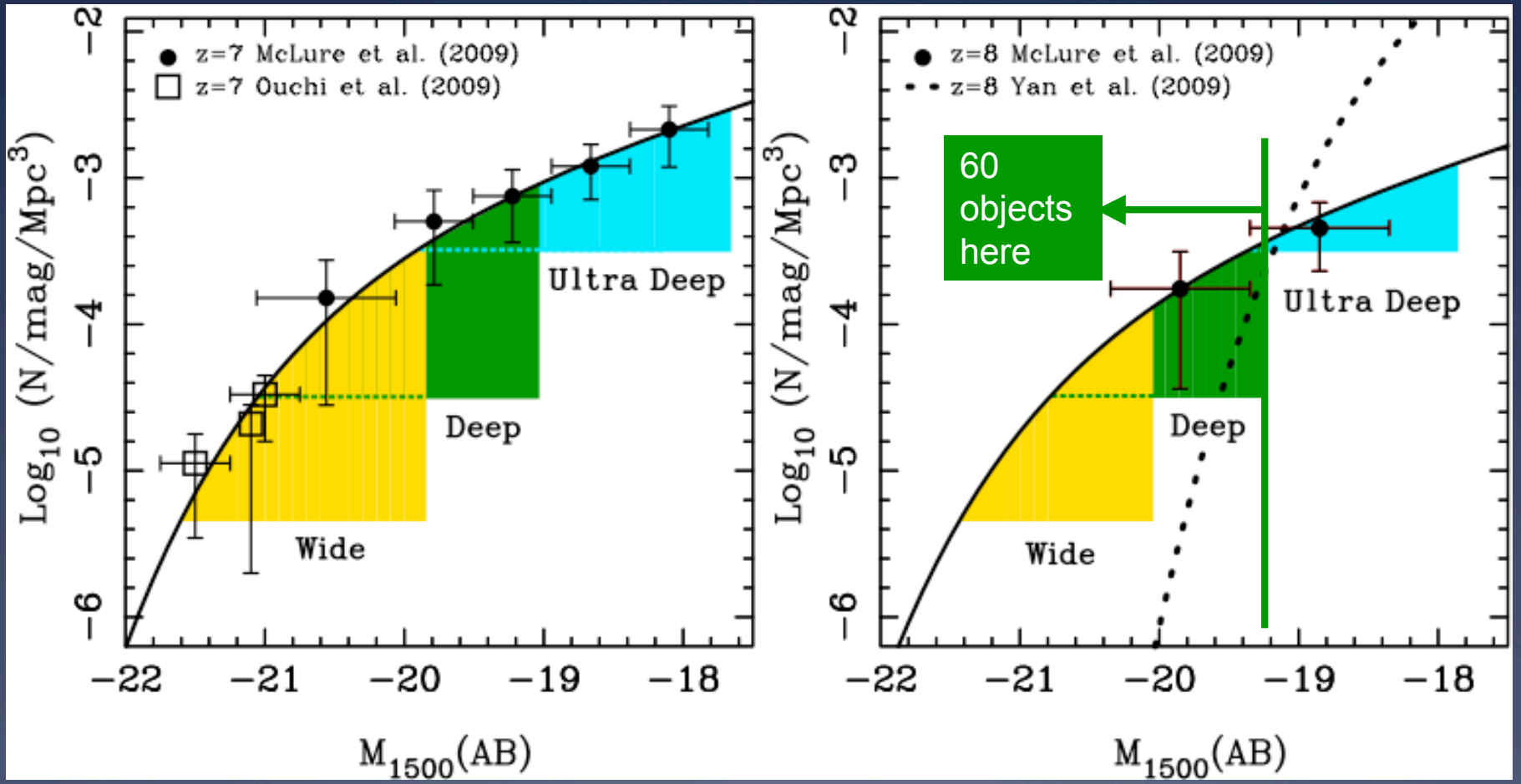
# z ~ 8 galaxies: candidates in UDF from Yan et al. 2009



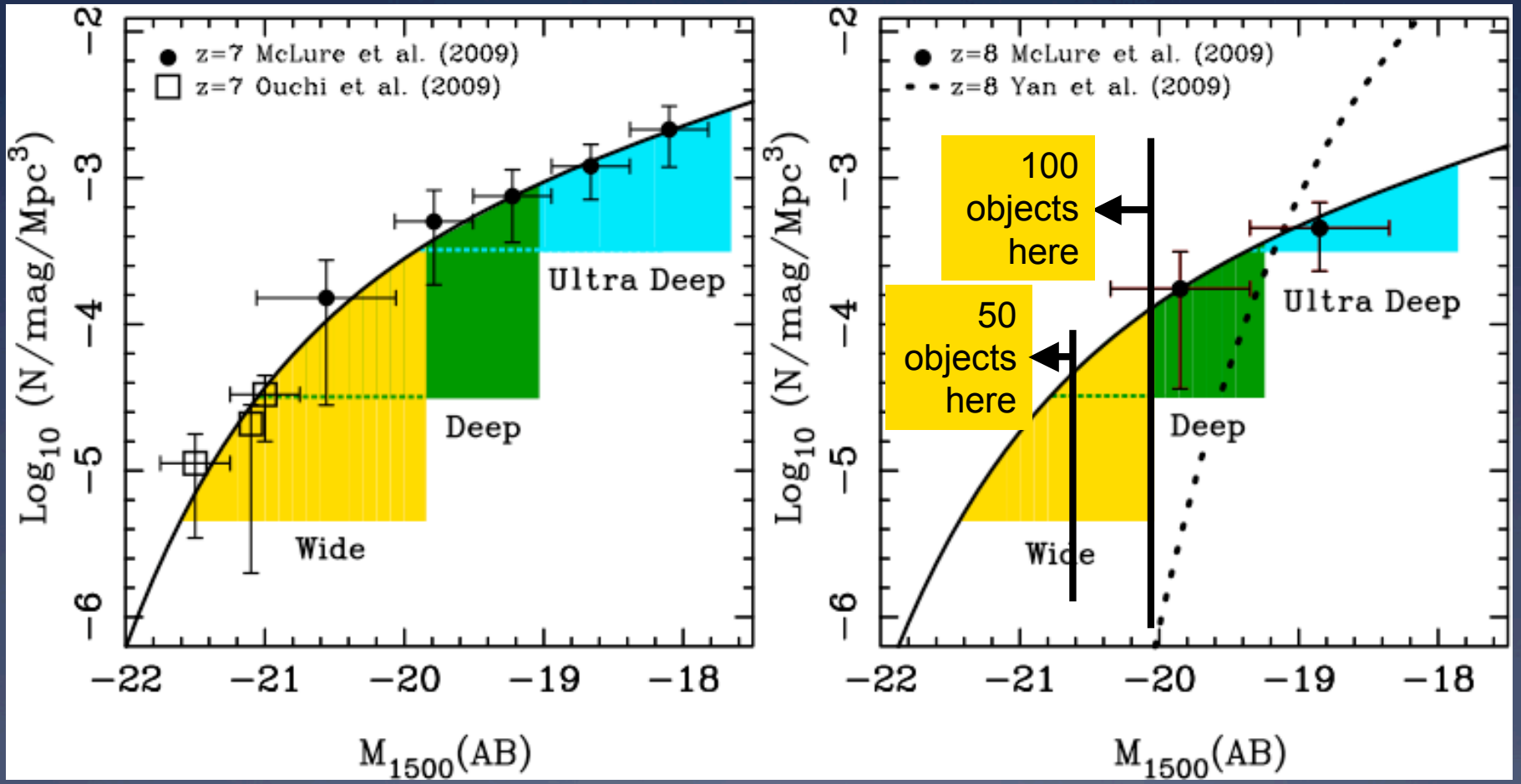
# z ~ 8 galaxies: IRAC/SEDS is crucial for confirming



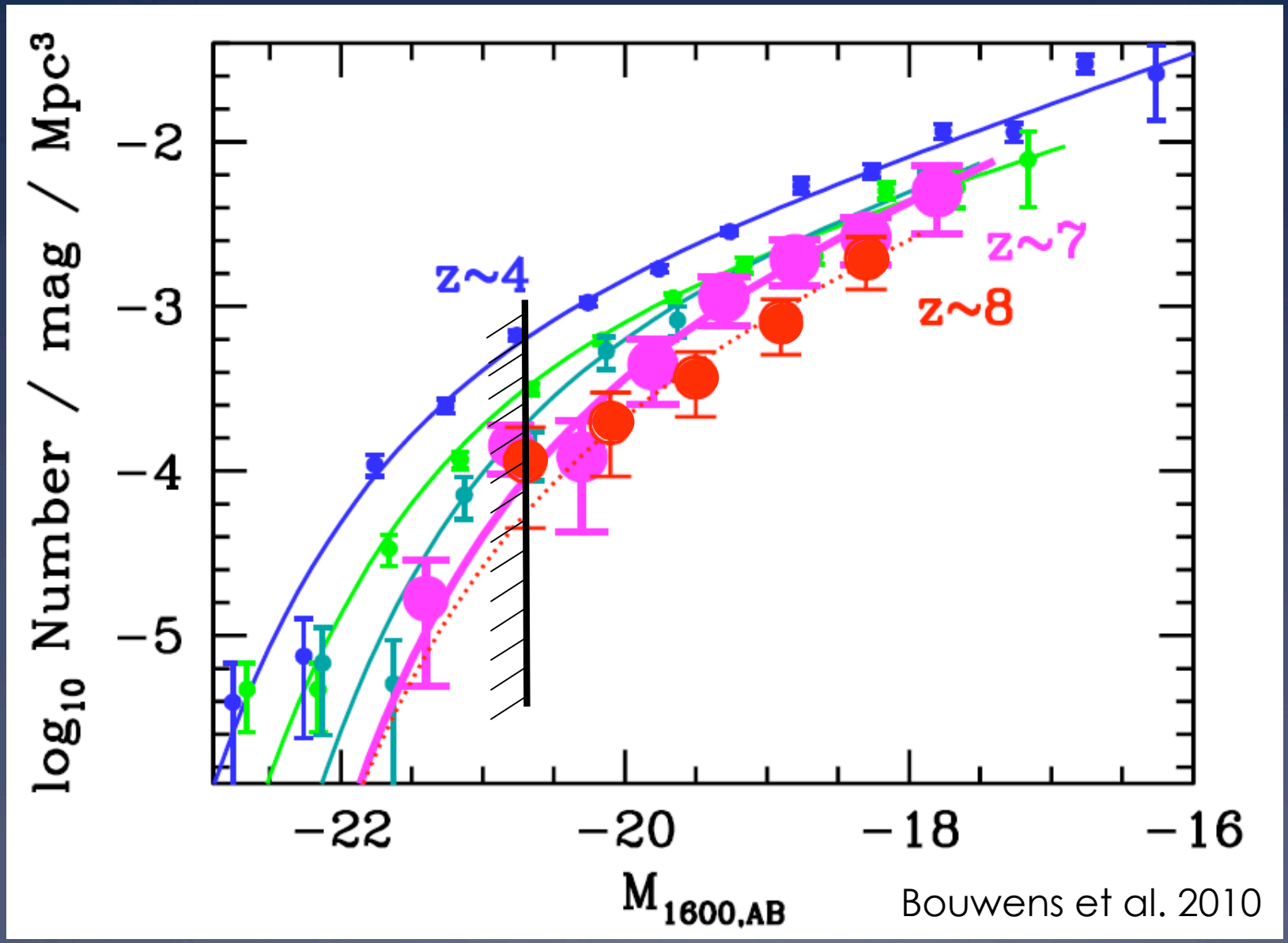
# At z ~ 8: *60 identified galaxies* in Deep



# At z ~ 8: *100 candidate galaxies* in Wide



# Recent high-z luminosity functions




Bouwens et al. 2010

# Survey Comparisons

ERS: 9 WFC3 pointings to J+H depth of 4 orbits

Deep: 30 WFC3 pointings to J+H depth of 8 orbits

Wide: 162 WFC3 pointings to J+H depth of 2 orbits

Deep vs. ERS: 5 times more galaxies, 0.6 mag deeper

Wide vs. ERS: 8 times more galaxies, 0.6 mag shallower

**Wide + Deep will be the prime finding fields for JWST spectroscopy**

# Science Goals: Cosmic "High Noon"

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| Cosmic Noon | Use rest-frame optical observations at $1 < z < 3$ to provide solid estimates of bulge and disk growth, and the evolution spiral arms, bars, and disk instabilities. |
| Cosmic Noon | Test models for the co-evolution of black holes and bulges via the most detailed HST census of interacting pairs, mergers, AGN, and bulges, aided by the most complete and unbiased census of AGN from Herschel, improved Chandra observations, and optical variability. |
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| Cosmic Noon | Determine the rest-frame optical structure of AGN hosts at $z \sim 2$. |
| Cosmic Noon | Identify Compton-thick, optically obscured AGN at $z \sim 2$ and determine their structure. |
| UV | Constrain the Lyman-continuum escape-fraction for galaxies at $z \sim 2.5$. |
| UV | Identify Lyman-break galaxies at $z \sim 2.5$ and compare their properties to higher-z LBG samples. |
| UV | Estimate the star-formation rate in dwarf galaxies to $z > 1$ to test whether dwarf galaxies are "turning on" as the UV background declines at low redshift. |

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***Cosmic "high noon": z ~ 2***

Stellar masses down to $10^9 M_\odot$, counts of massive galaxies and quenched galaxies, radii, morphologies, bulge masses, mergers, AGN hosts

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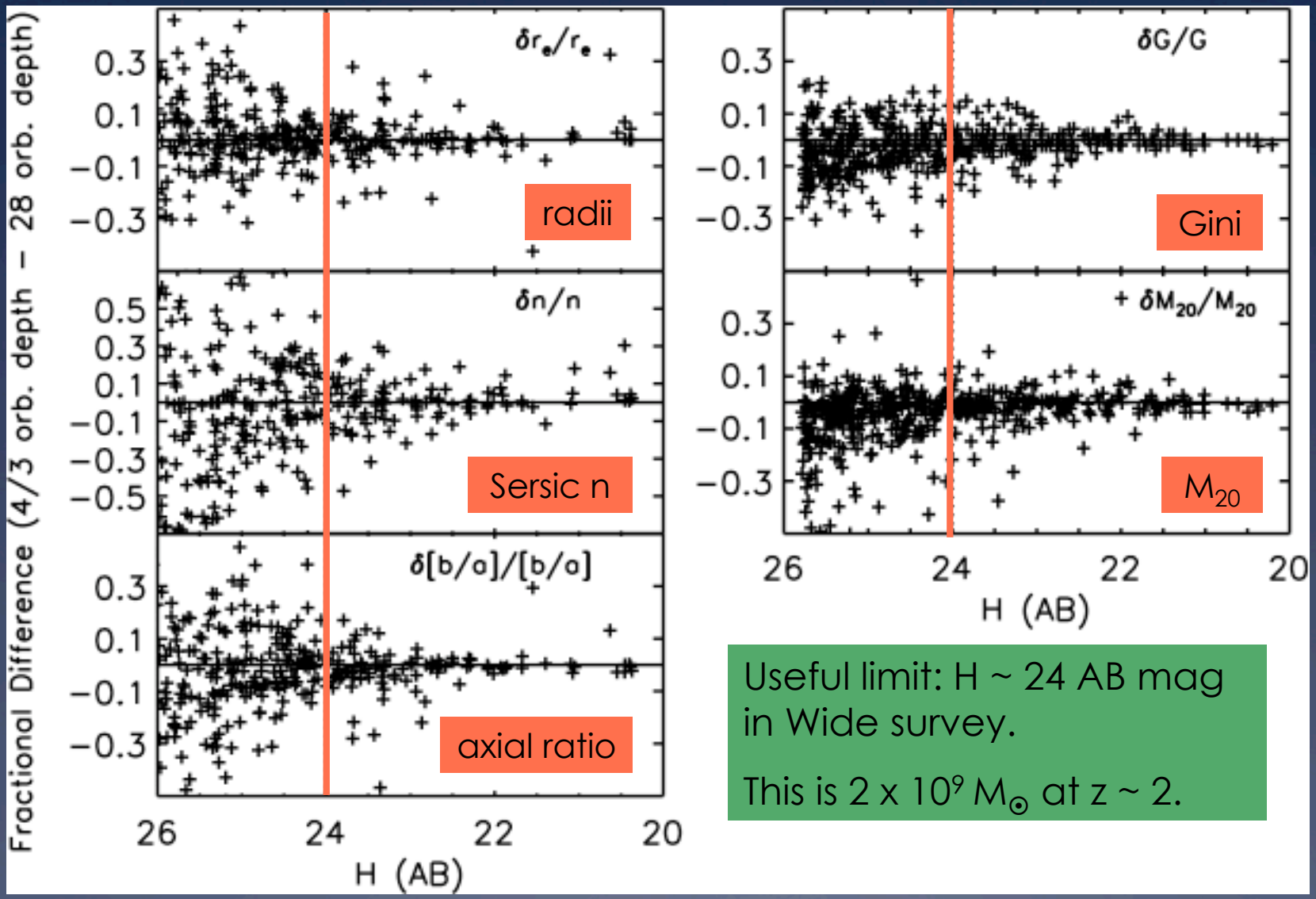
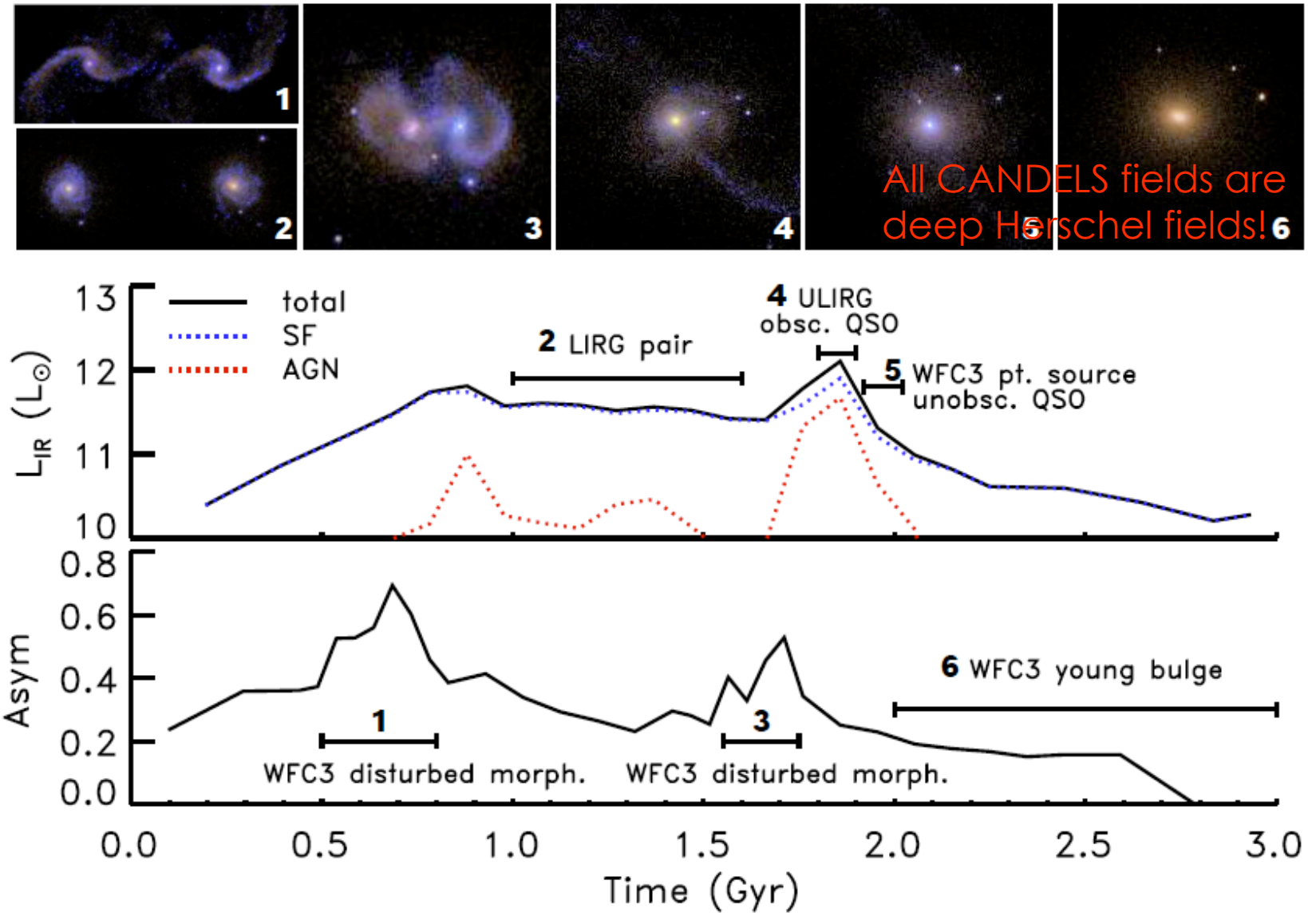
# Structural parameters at z ~ 2: simulated data



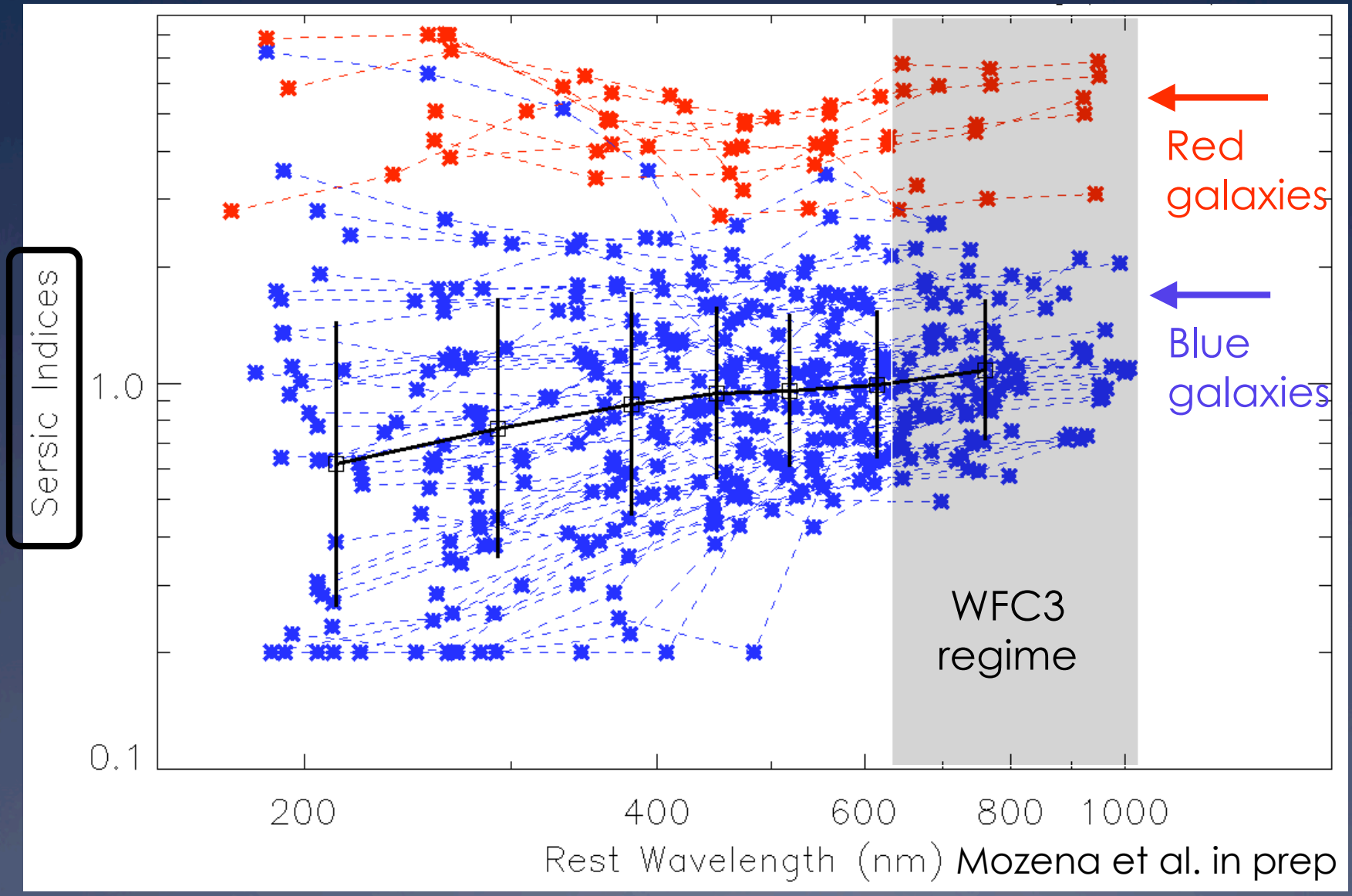

Useful limit: H ~ 24 AB mag in Wide survey.

This is 2 x $10^9$ $M_\odot$ at z ~ 2.

# AGN activity vs. Gini/$M_{20}$ at z ~ 2



# Single Sersic fits: UDF, GIM2D, z ~ 0.5-1.5



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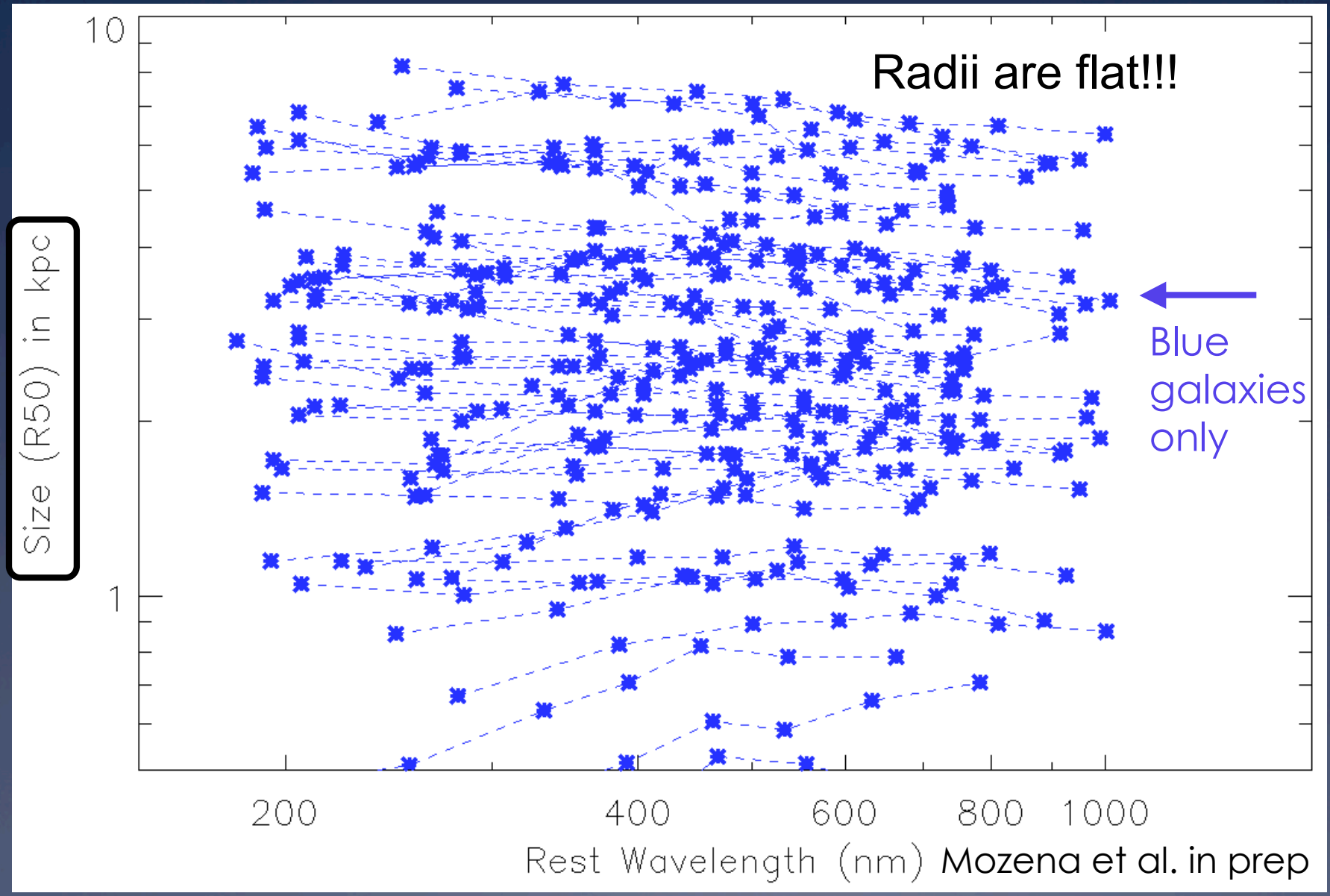

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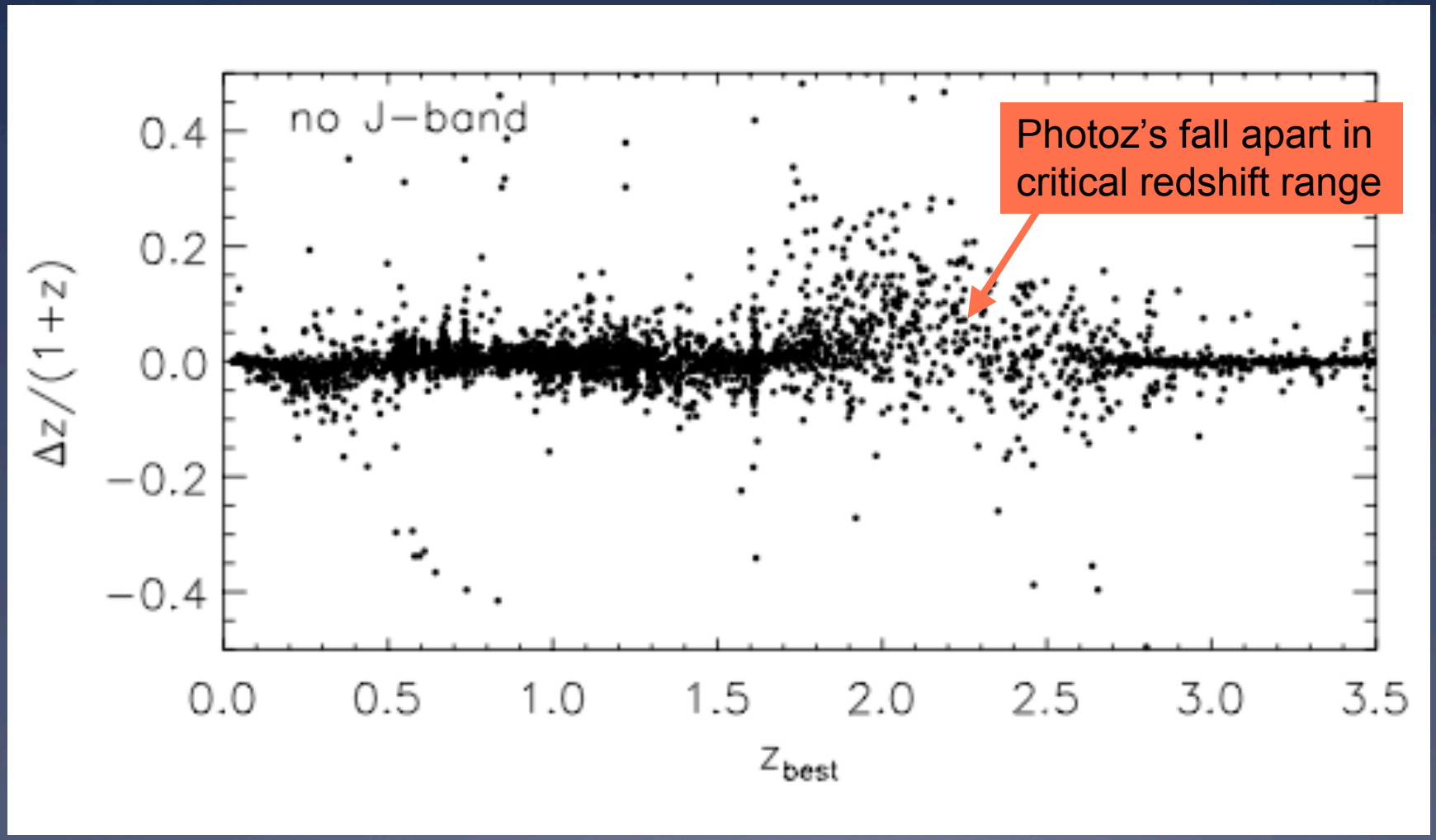
***UV program: CVZ orbits in GOODS-N***

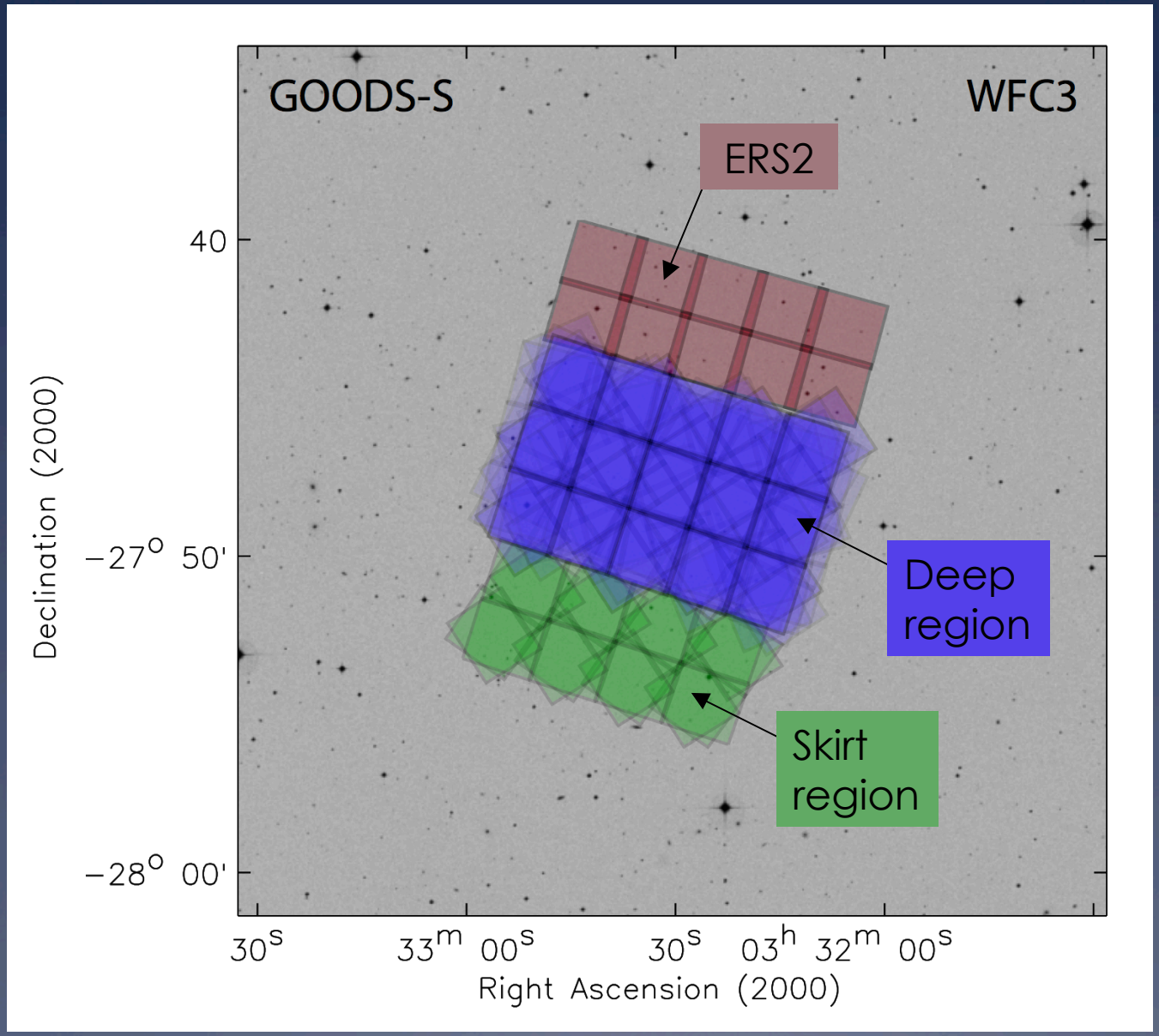
Lyman continuum escape fraction, find LBGs at low z (~2), SFR amount and distribution at z ~ 1

# The importance of the J band for photoz's

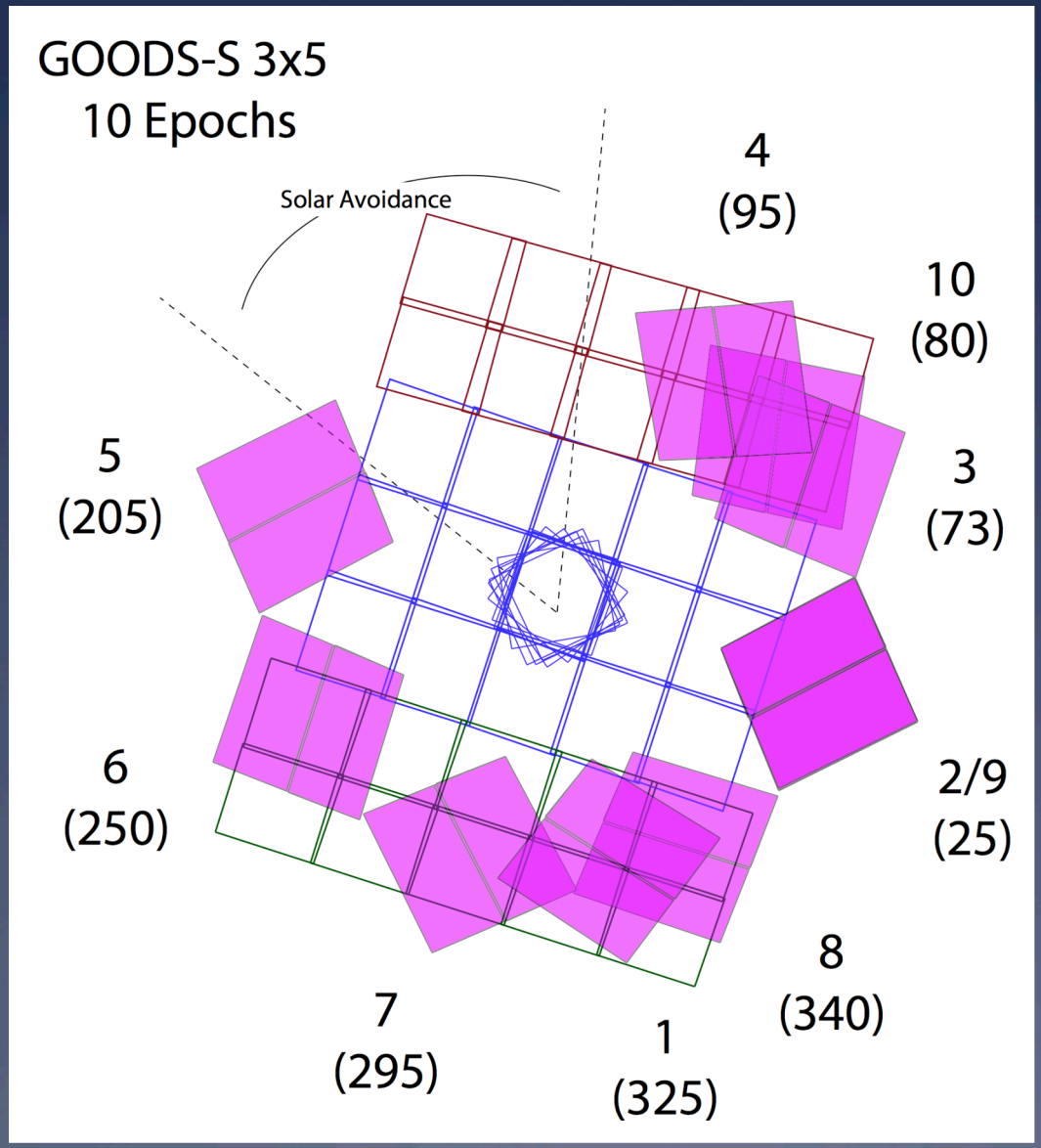
Effect of removing J from the SED: simulated data



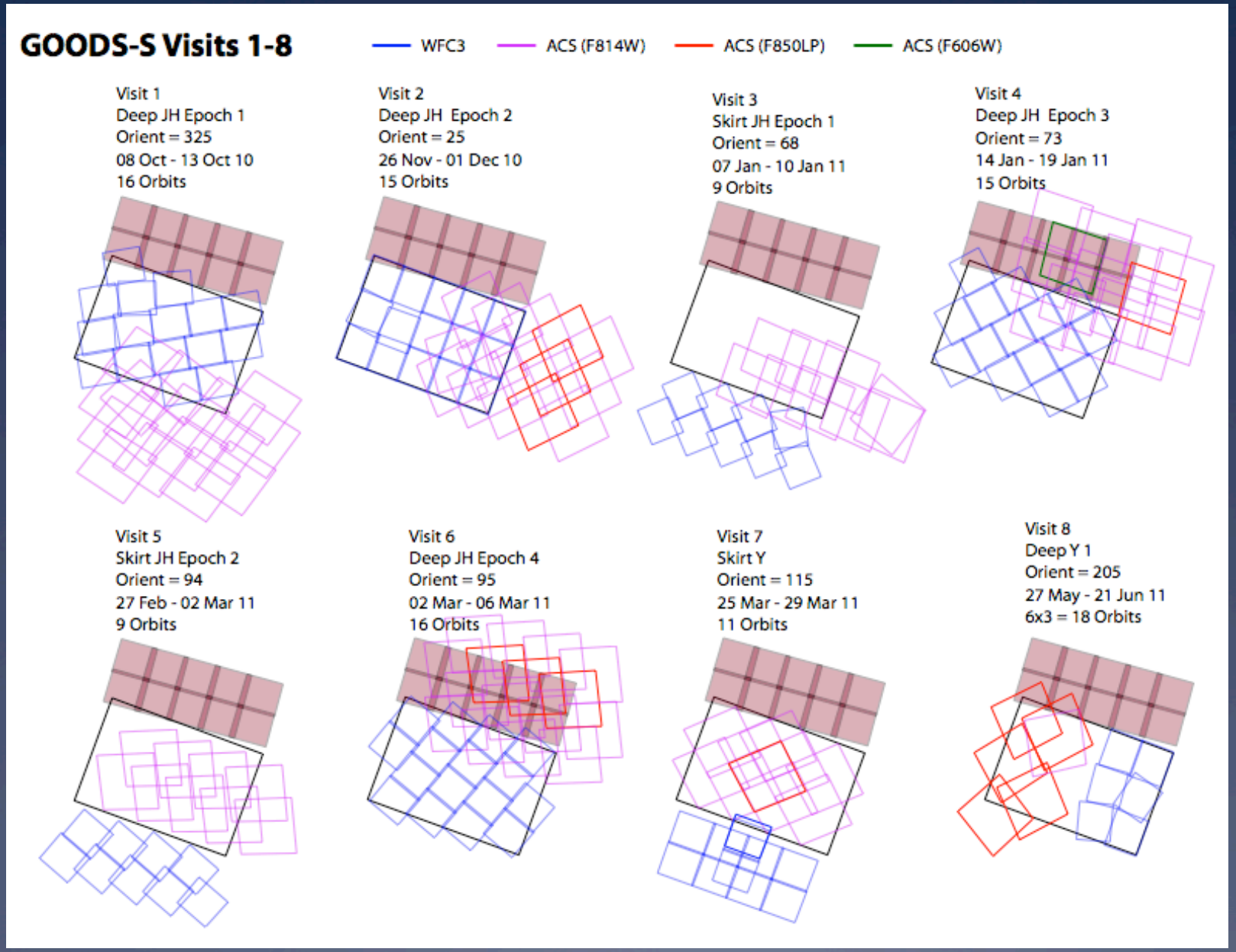
# Deep Strategy: GOODS-S



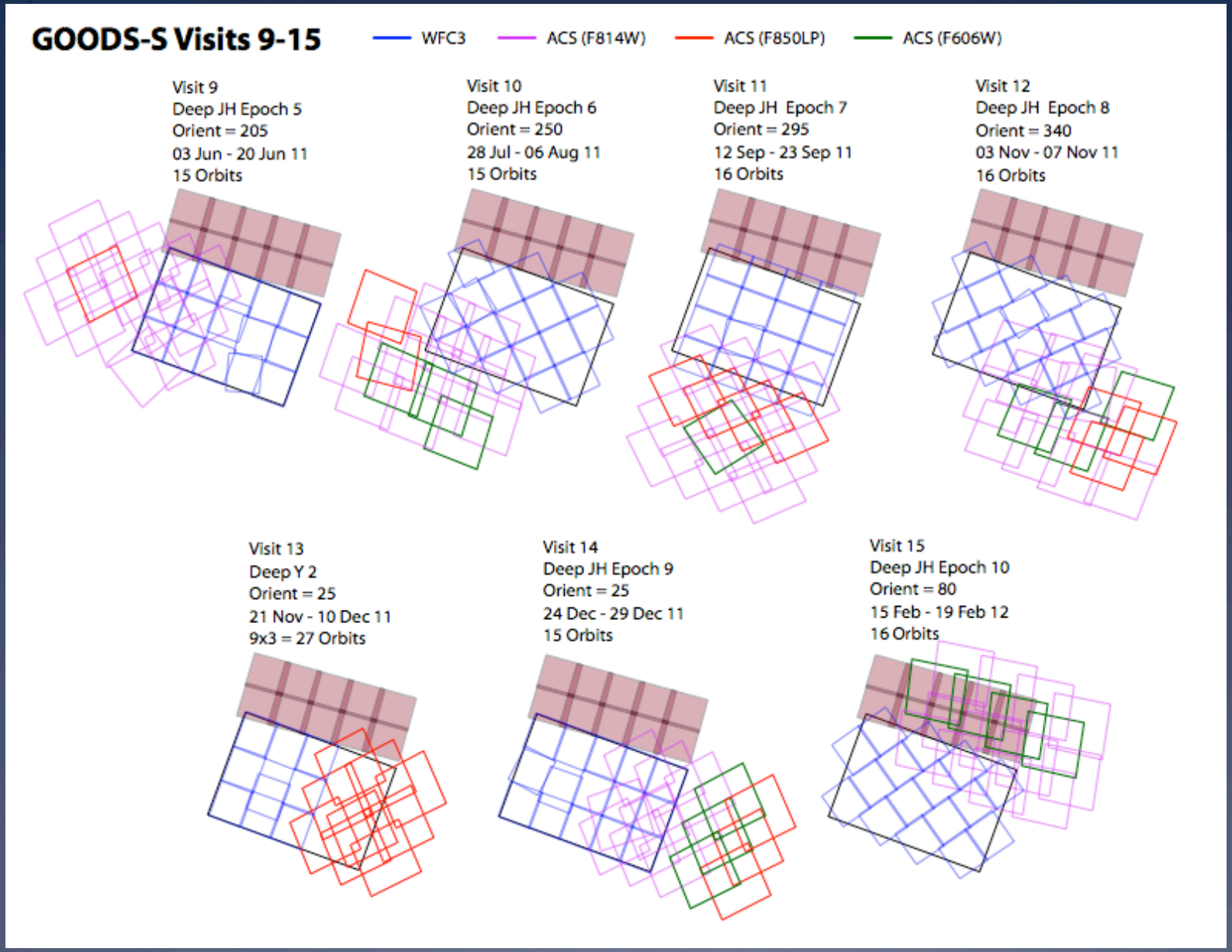
# GOODS-S Deep Strategy: 10 Epochs



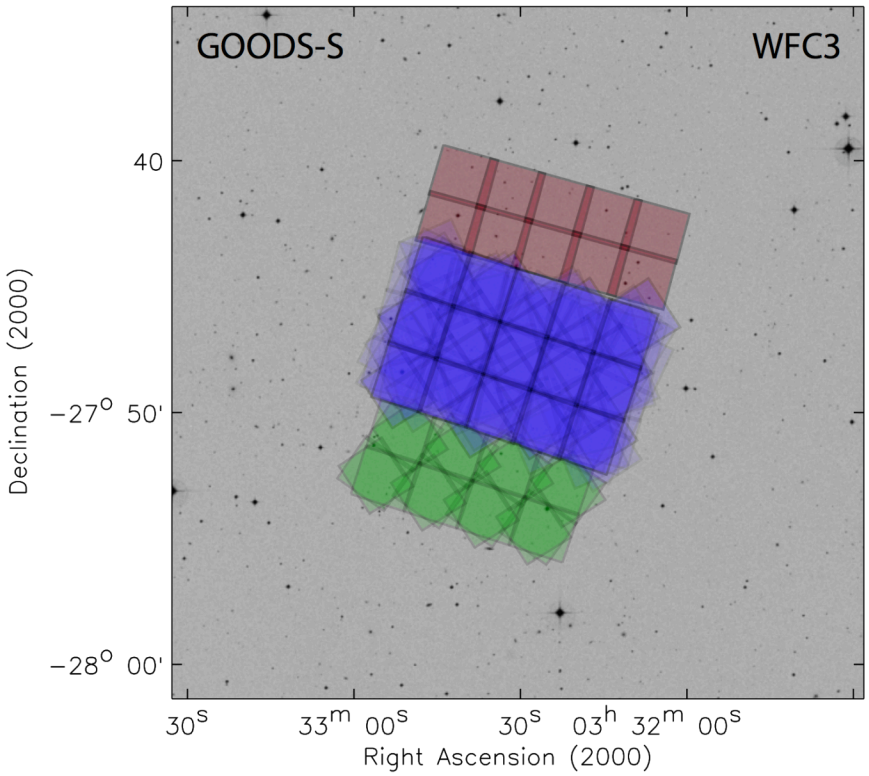
# GOODS-S: WFC3 Tiling and ACS Parallels

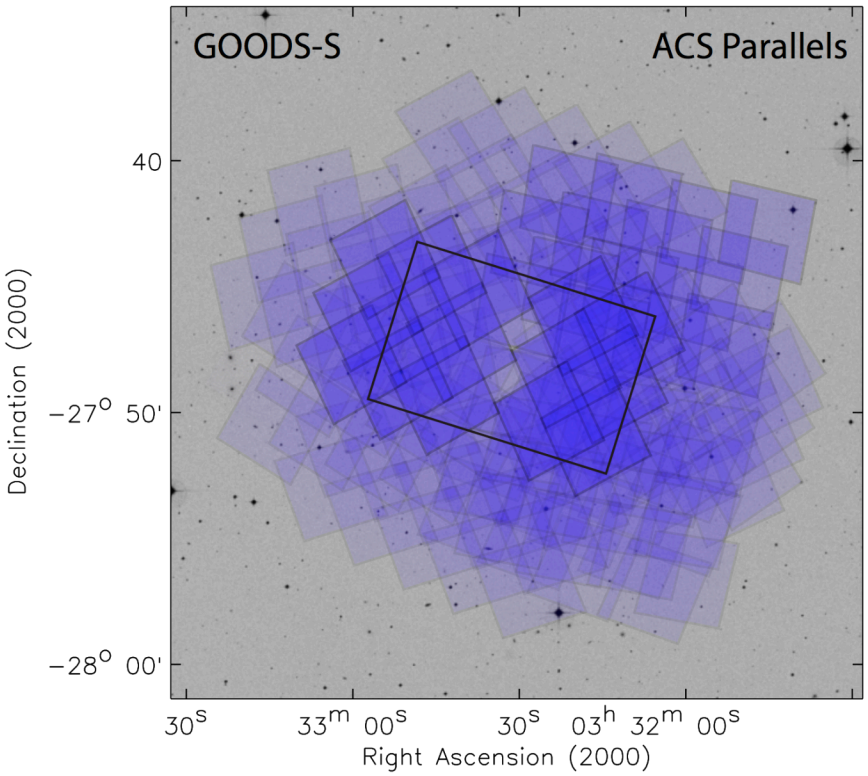


# GOODS-S: WFC3 Tiling and ACS Parallels

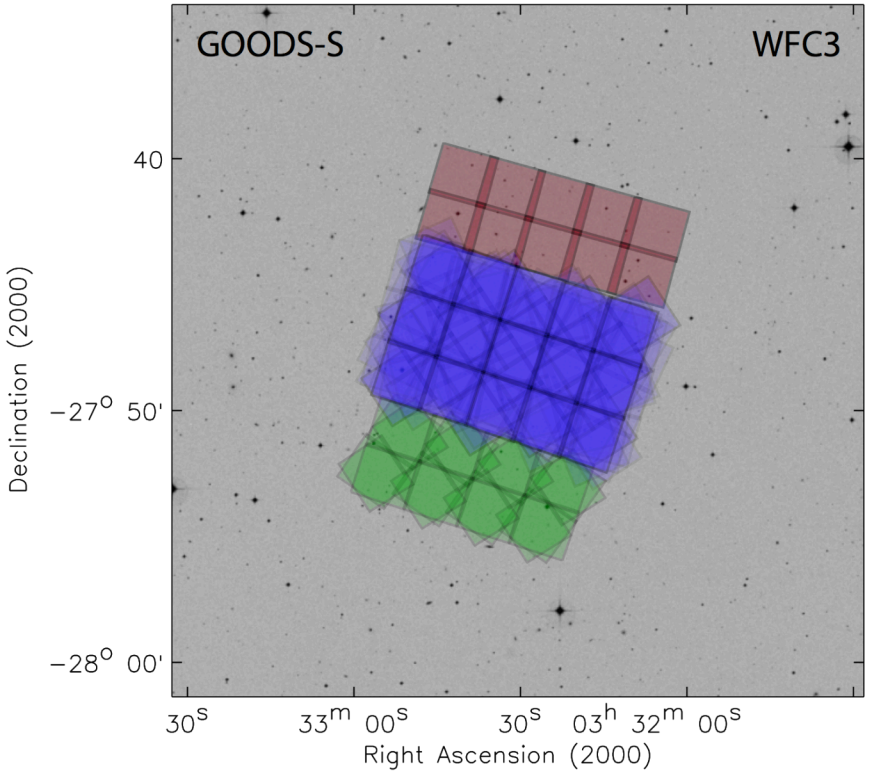


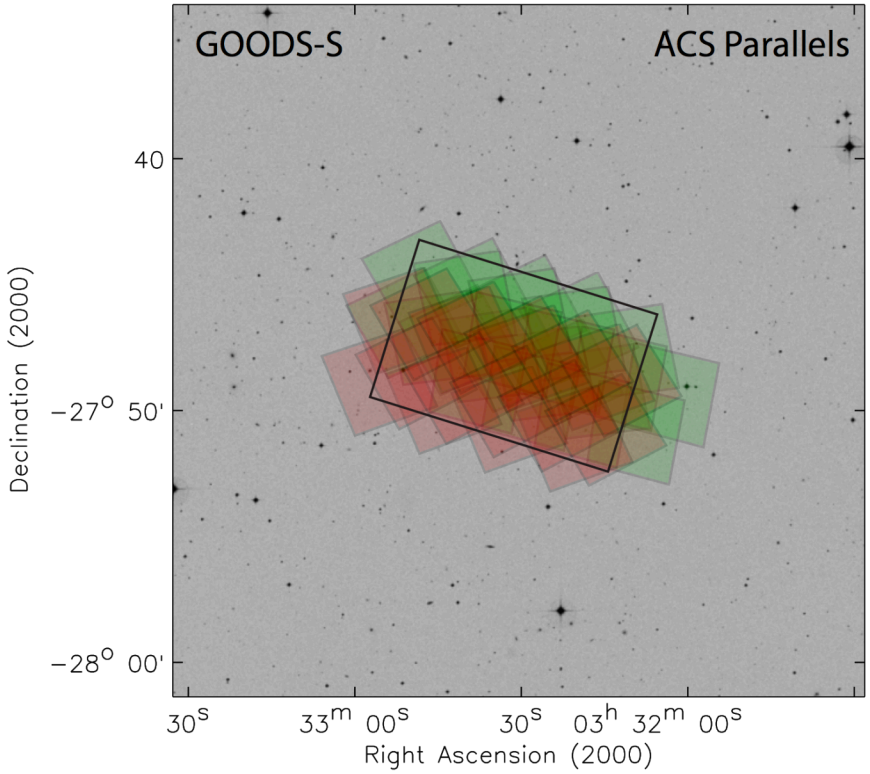
# Deep Strategy: GOODS-S



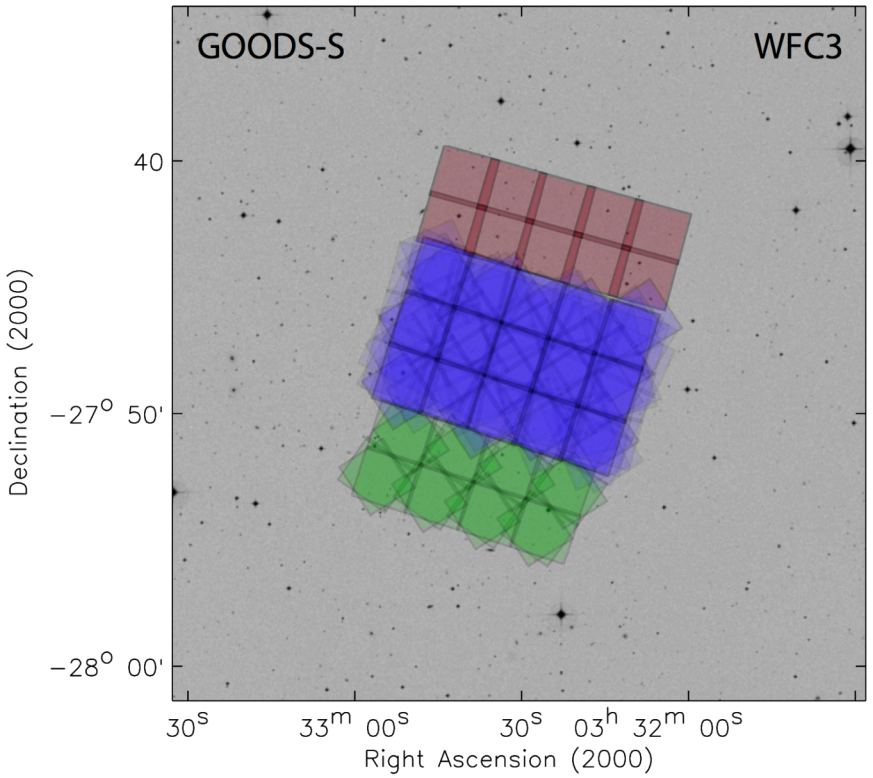



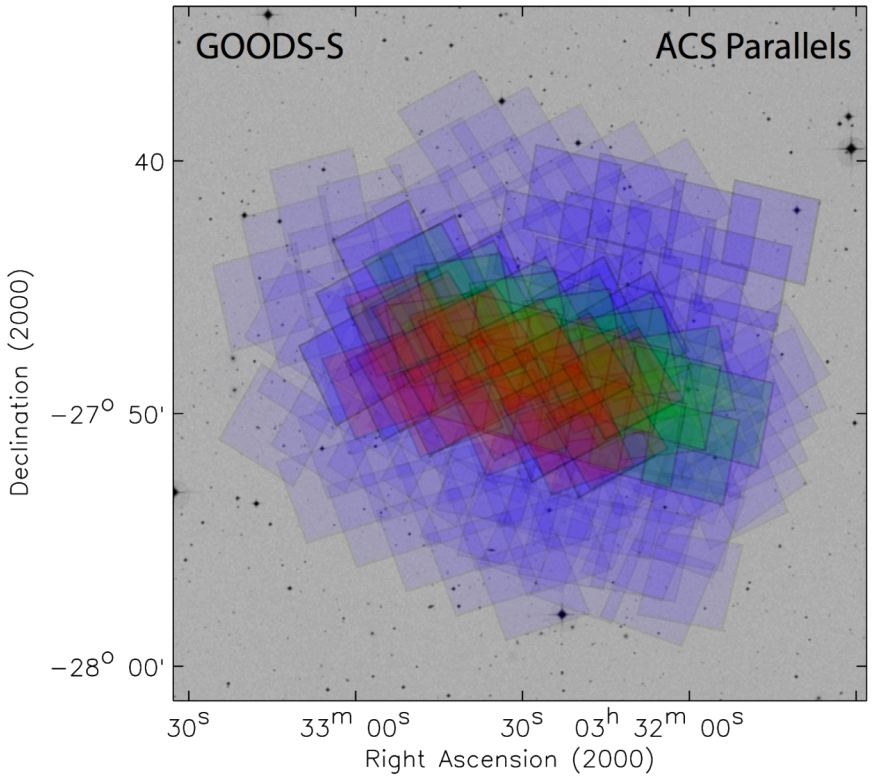
# Deep Strategy: GOODS-S



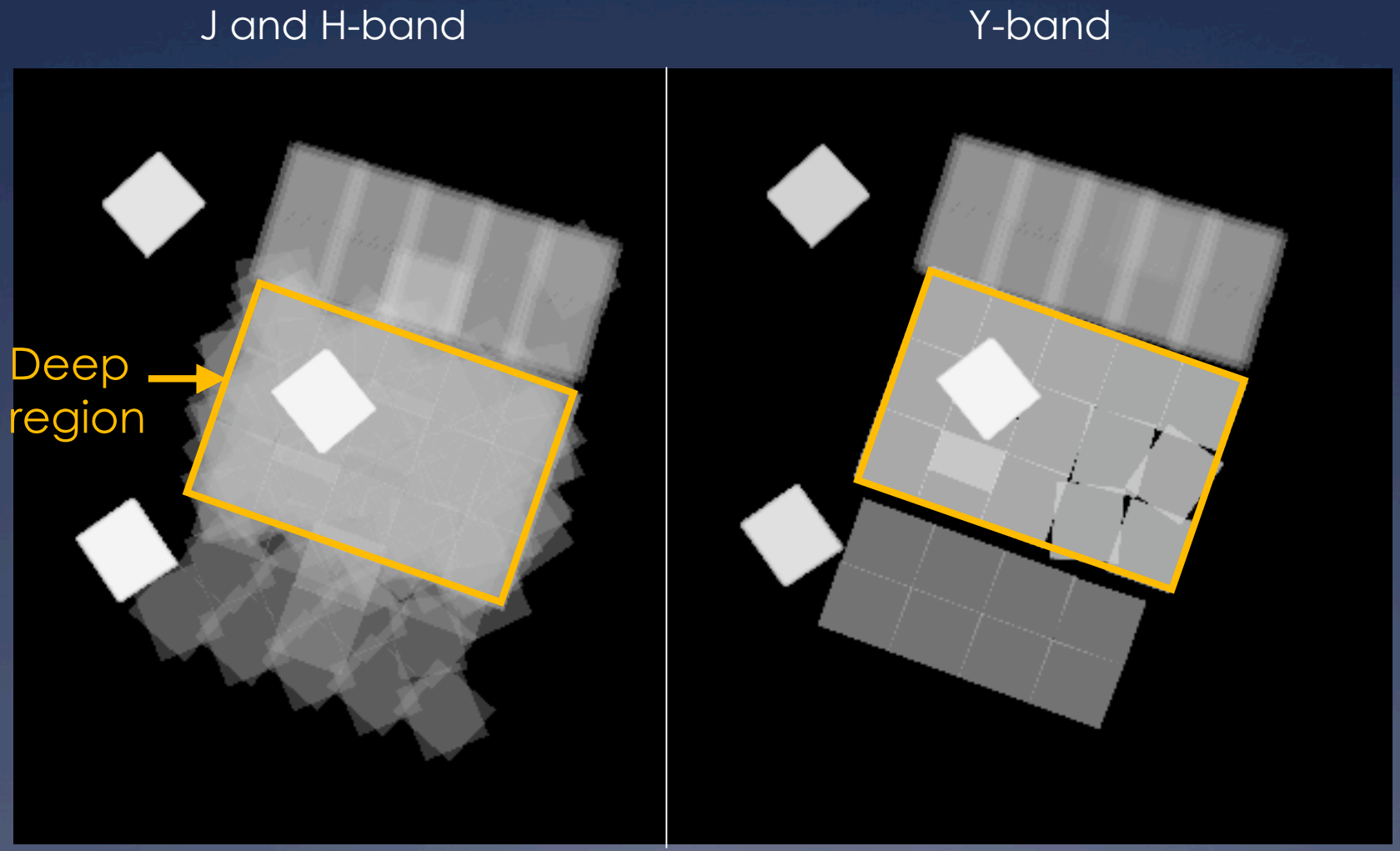



# Deep Strategy: GOODS-S



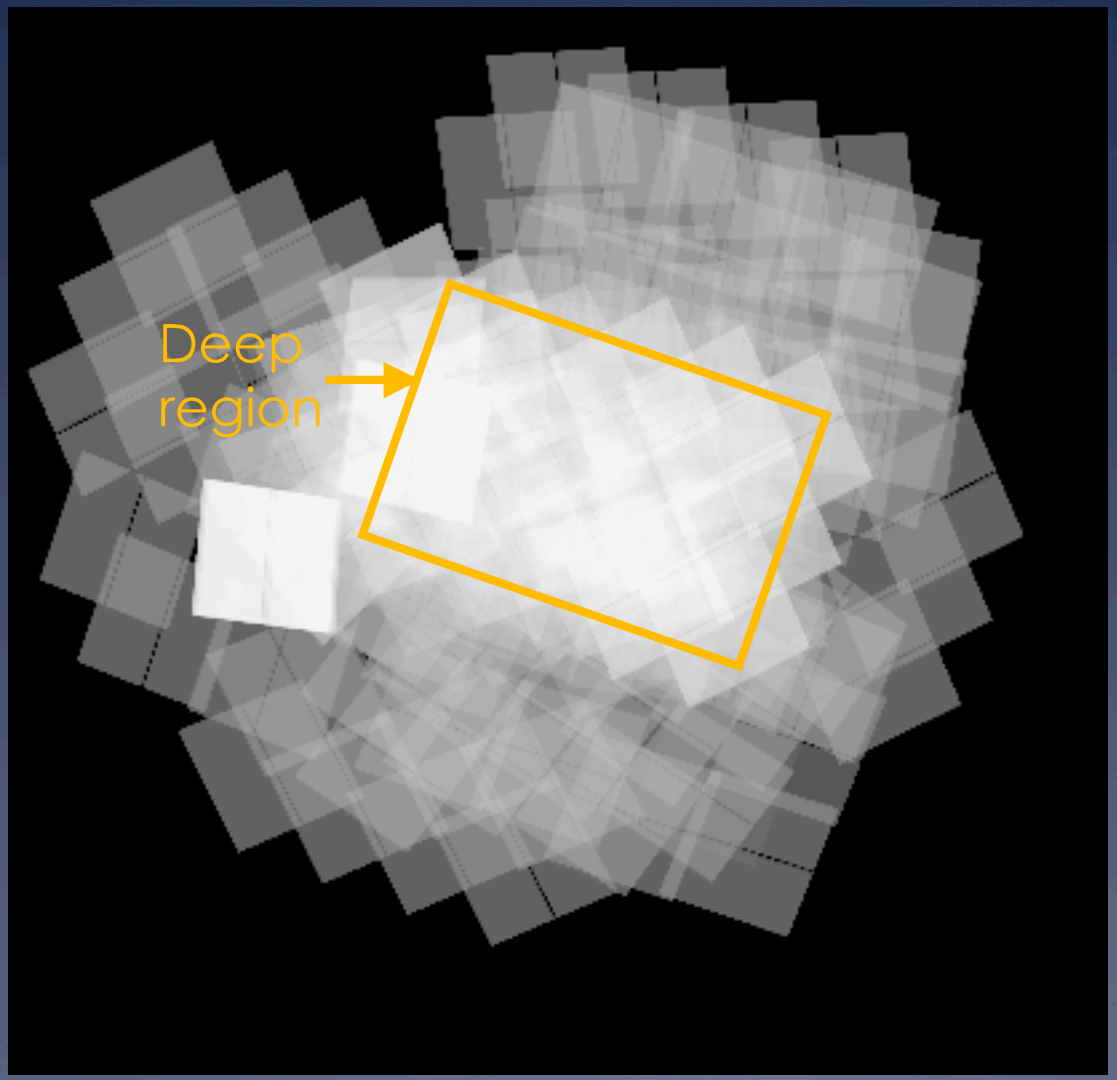



# GOODS-S WFC3 coverage: including all data

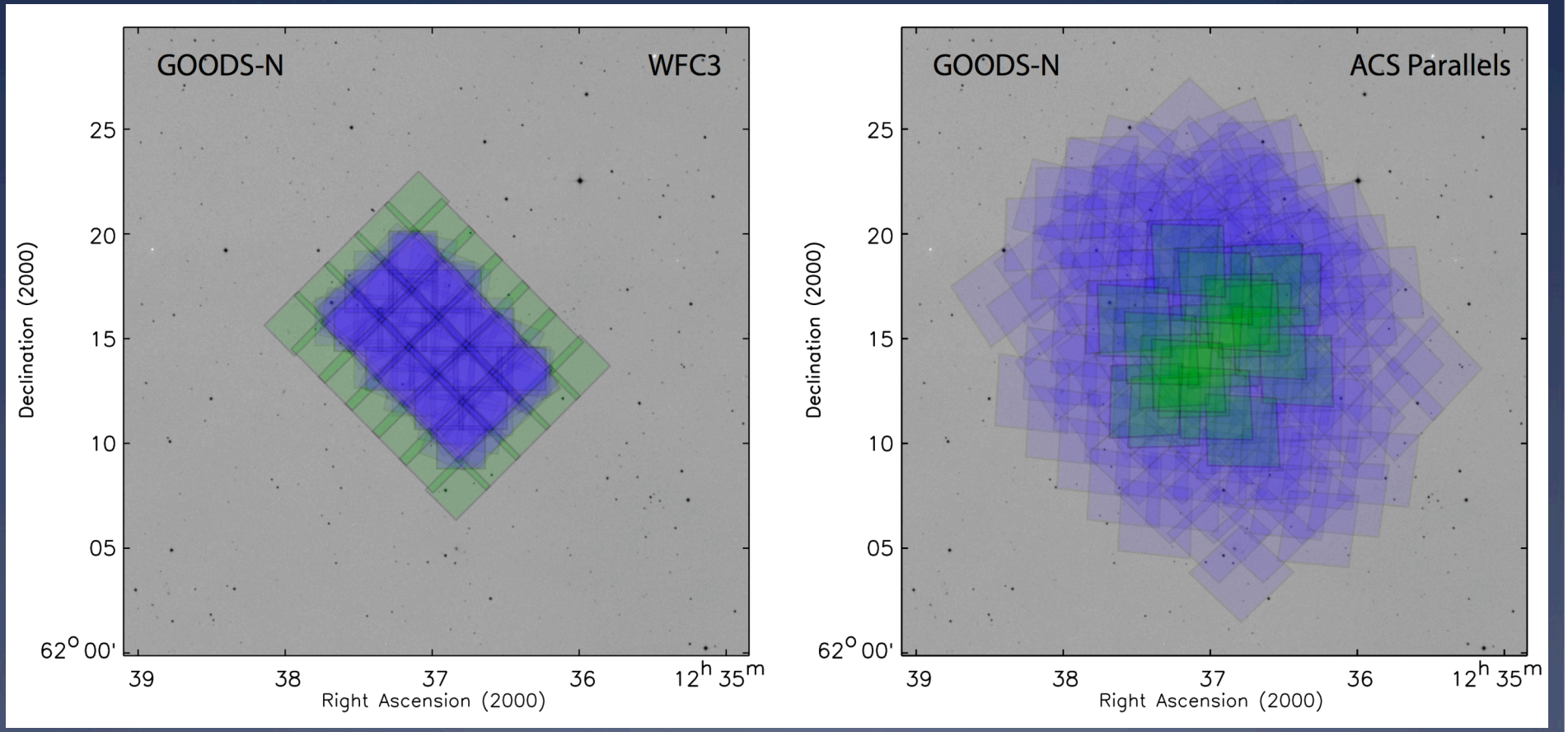


# GOODS-S ACS parallel coverage, final

F814W, I-band: needed to ID high-z galaxies



# Deep Strategy: GOODS-N (preliminary)



# Observing Schedule

| REGION | EPOCH | ORIENT | ORBITS | START DATE | END DATE | Program | Comments |
|---|---|---|---|---|---|---|---|
| STST | - | 255 | 1 | 4-Aug-10 | 10-Aug-10 | | test orbit |
| SD | 1 | 325 | 16 | 8-Oct-10 | 13-Oct-10 | 12061 | Epoch 1 |
| UDS | 1 | 45 | 44 | 6-Nov-10 | 20-Nov-10 | 12064 | |
| SD | 2 | 25 | 15 | 26-Nov-10 | 1-Dec-10 | 12061 | Epoch 2 |
| UDS | 2 | 45 | 44 | 27-Dec-10 | 10-Jan-11 | 12064 | |
| SW | 1 | 68 | 9 | 7-Jan-11 | 10-Jan-11 | 12061 | Skirt |
| SD | 3 | 73 | 15 | 14-Jan-11 | 19-Jan-11 | 12061 | Epoch 3 |
| SW | 2 | 94 | 9 | 27-Feb-11 | 2-Mar-11 | 12061 | Skirt |
| SD | 4 | 95 | 16 | 2-Mar-11 | 6-Mar-11 | 12061 | Epoch 4 |
| SYW | - | 115 | 11 | 25-Mar-11 | 29-Mar-11 | 12060 | Skirt |
| EGSa | 1 | 187.3 | 25 | 2-Apr-11 | 9-Apr-11 | 12063 | |
| EGSa | 2 | 164.9 | 25 | 24-May-11 | 29-May-11 | 12063 | |
| SD | 5 | 205 | 15 | 3-Jun-11 | 20-Jun-11 | 12061 | Epoch 5 |
| SYa | - | 205 | 18 | 27-May-11 | 21-Jun-11 | 12060 | 2x3 array |
| SD | 6 | 250 | 15 | 28-Jul-11 | 6-Aug-11 | 12062 | Epoch 6 |
| SD | 7 | 295 | 16 | 12-Sep-11 | 23-Sep-11 | 12062 | Epoch 7 |
| SD | 8 | 340 | 16 | 3-Nov-11 | 7-Nov-11 | 12062 | Epoch 8 |
| SYb | - | 25 | 27 | 21-Nov-11 | 1-Dec-11 | 12060 | 3x3 array |
| COS | 1 | 307 | 44 | 2-Dec-11 | 15-Dec-11 | | |
| SD | 9 | 25 | 15 | 24-Dec-11 | 29-Dec-11 | 12062 | Epoch 9 |
| COS | 2 | 307 | 44 | 23-Jan-11 | 4-Feb-12 | | |
| SD | 10 | 80 | 16 | 15-Feb-12 | 19-Feb-12 | 12062 | Epoch 10 |
| ND/NWa | 1/1 | 180 | 24 | 31-Mar-12 | 4-Apr-12 | | |
| ND/NWa | 2/2 | 135 | 26 | 23-May-12 | 29-May-12 | | |
| NYa | - | 90 | 18 | 4-Jul-12 | 15-Jul-12 | | |
| ND | 3 | 87 | 15 | 15-Jul-12 | 19-Jul-12 | | |
| ND/NWb | 4/1 | 25 | 25 | 5-Sep-12 | 13-Sep-12 | | |
| NYNE | - | 0 | 8 | 28-Sep-12 | 2-Oct-12 | | |
| ND/NWb | 5/2 | 331 | 25 | 30-Oct-12 | 8-Nov-12 | | |
| ND | 6 | 270 | 15 | 27-Dec-12 | 1-Jan-13 | | |
| NYb | - | 270 | 27 | 2-Jan-13 | 14-Jan-13 | | |
| ND | 7 | 225 | 16 | 20-Feb-13 | 25-Feb-13 | | |
| EGSb | 1 | 187.3 | 20 | 2-Apr-13 | 8-Apr-13 | 12063 | |
| NYSW | - | 180 | 8 | 8-Apr-13 | 10-Apr-13 | | |
| ND | 8 | 180 | 16 | 11-Apr-13 | 16-Apr-13 | | |
| EGSb | 2 | 164.9 | 20 | 23-May-13 | 29-May-13 | 12063 | |
| ND | 9 | 119 | 16 | 7-Jun-13 | 12-Jun-13 | | |
| ND | 10 | 62 | 16 | 5-Aug-13 | 10-Aug-13 | | |

| Legend of region IDs | |
|---|---|
| STST | GOODS-South Test Orbit (IR in ERS2) |
| SD | GOODS-South Deep (3x5 transverse) |
| SW | GOODS-South Wide (2x5 transverse) |
| SYW | GOODS-South Wide (Y-band + JH filler) |
| SYa | Western 3x2 of SD (Y-band only) |
| SYb | Eastern 3x3 of SD (Y-band only) |
| ND | GOODS-North Deep (3x5 transverse) |
| NWa | GOODS-North Wide SW (2x5 transverse) |
| NYSW | GOODS-North Wide SW (Y-band only) |
| NWb | GOODS-North Wide NE (2x5 transverse) |
| NYNE | GOODS-North Wide NE (Y-band only) |
| NYa | Eastern 3x2 of ND (Y-band only) |
| NYb | Western 3x3 of ND (Y-band only) |
| EGSa | Initial five-ninths of EGS |
| EGSb | Remaining four-ninths of EGS |
| UDS | UDS |
| COS | COSMOS |