CANDELS Status

Henry Ferguson & Sandy Faber
8 November 2012
CANDELS
Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey

~175 team members
~45 institutions
12 countries

Builders:
Harry Ferguson, Sandra Faber, Adam Riess, Steve Rodney
Norman Grogin, Dale Kocevski
Anton Koekemoer
Exposure Strategy

- “Wedding cake” strategy: three layers of J+H

  **UDFs:** 50-100 orbit depth over ~10 sq arcmin

  **DEEP:** 8 orbit depth over ~120 sq arcmin

  **WIDE:** 2 orbit depth over ~700 sq arcmin
CANDELS Fields

**Planned Orbit Totals:**
- GOODS: 483
- EGS: 90
- UDS: 88
- COSMOS: 88
- SNe Follow-up: 152

Observations
Complete

Observations
Half complete
The CANDELS fields are the deepest multi-wavelength views of the universe.
HST
0.6, 1.25, 1.6 μm
Chandra

0.5-2, 2-8, 5-8 keV
Spitzer/IRAC
3.6+4.5, 5.6, 8 μm
Spitzer/MIPS + Herschel/PACS
24, 100, 160μm
Herschel/SPIRE
250, 350, 500µm
**Observing Progress**

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**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 filter)
- **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

v0.5 released
Data obtained

UDS v1.0 released; Within a few weeks: COSMOS v1.0
GOODS-S v1.0
Data Release Plans

- **V0.5:**
  - Updated cumulative stacks within 3 months of each epoch

- **V1.0:**
  - Recalibrated, re-aligned stacks within 6 months of final observations on each field.

- **V2.0:**
  - If recalibration is necessary, aim is to release the final version within 1 year of completion of the program.

- **Catalogs:**
  - Generally, release catalogs at the same time as the first publications using the catalogs.

- **Theory component:**
Upcoming catalog releases next ~6 months

- GALFIT morphologies for UDS, GOODS-S, COSMOS
  - Van der Wel et al. accepted
- UDS multi-wavelength photometry
  - Includes photometric redshifts
- GOODS-S multi-wavelength photometry
- GOODS-S photometric redshifts
- GOODS-S Stellar masses
Photz & SED-fitting

- 13 different techniques
- Photz’s trained & tested on different samples
- Photz’s:
  - Smallest uncertainties using the median from different codes.
- Stellar masses:
  - Truth unknown; different codes reveal the systematic uncertainties.

Uncertainties look good over all $z$

Pair counts suggest uncertainties are still good fainter than the training set.

Dahlen+ in prep
Mobasher+ in prep
Complementary Observations
Hawk-I Deep Survey
PI Adriano Fontana

208 hour VLT program
Y and Ks bands

5σ AB=27 at Ks
First 1/3 of the data – seeing 0.38"
Spitzer: SEDS/CANDELS

Pl Giovanni Fazio

$5\sigma$ AB=26.8 at 3.6 μm

Observations finish March 2013
Reprocessing all existing Spitzer data on the fields

![Graph showing 3.6 μm depth vs. area for various fields](image1)

![Map showing SEDS/IRAC UDS Field](image2)
GOODS-N
UDS
GOODS-S
COSMOS

**CANDELS+Herschel**

The deepest far-IR observations at 100 – 500 μm:
Elbaz et al. (GOODS), Dickinson et al. (COSMOS, UDS)

GOODS-Herschel data products now public @ HeDaM

COSMOS+UDS data newly obtained and are now being analyzed together with CANDELS HST data

**CANDELS fields at 160 μm**
HST WFC3 region outlined in red
Other observing

- LBT U band (all but GOODS-S)
  - PI’s Grazian, Windhorst
- Multiple targeted spectroscopy programs
  - Keck/DEIMOS (Mobasher)
  - Keck/MOSFIRE (Faber)
  - GEMINI/GMOS (Papovich)
  - VLT/FORS2 (Fontana)
Science Highlights
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<td>CANDELS: HST Imaging Data Products and Mosaics</td>
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<td>Emission Line Galaxies at z~2: A Mix of Nuclear Activity and Low-Metallicity Star Formation</td>
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<td>Evolution of UV Spectral Slope from z=4-8</td>
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<td>Sizes and Surface Brightness Profiles of Quiescent Galaxies at z ~ 2</td>
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<td>A rest-frame Optical View on z~4 Galaxies I: Color and Age Distributions from Deep IRAC Photometry of the UDF10 and GOODS Surveys</td>
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High-z: evolution of UV slopes

High-mass galaxies already metal-rich

Low-mass galaxies growing dust and metals

Finkelstein+ 2012
High-z galaxy sizes

153 z-band drop-out galaxies in six different fields

Physical sizes are *small*, even accounting for surface-brightness selection.

Luminosity function faint-end slope is not as steep as previously estimated.
Improved constraints UV luminosity density at z=6. Observed galaxies can maintain reionization at z=6 if 30% of the ionizing photons escape.

Finkelstein+ 2012

IGM ionized fraction: Scenario where reionization is <~90% complete at z=7 is consistent with WMAP, QSO absorption lines, Ly-A emitters and Lyman-break galaxies.
Co-evolution of galaxies and supermassive black holes: host galaxies of X-ray selected AGN at z~2

Kocevski+ 2012
Most cited CANDELS science paper
Morphologies of X-ray AGN hosts at z~2

AGN hosts are NOT disturbed.

Kocevski+ 2012
Morphologies of X-ray AGN hosts

AGN hosts are mostly spheroids.

Kocevski+ 2012
Morphologies of X-ray AGN hosts

AGN hosts have many disks.

Kocevski+ 2012
Morphologies of X-ray AGN hosts

The lack of disturbances and high frequency of disks challenges the standard merger-driven AGN paradigm.

AGN demographics at $z \sim 2$ look like those at $z \sim 1 \rightarrow$ internally driven BH growth and AGN triggering.

Coming soon: IR-selected AGN
Donley et al. 2013
Bulge fractions

Massive galaxies $M^* > 10^{11} M_\odot$

- Bulges become dominant in massive galaxies at $z \sim 2$
- Bulges are smaller at fixed mass at $z \sim 2$ than today.
- While most passive galaxies are bulge dominated, a few passive galaxies appear to be pure disks.
  - Implications for quenching models?
- *Era of massive disks at $2 < z < 3$*

Bruce+ 2013
Mortlock + in prep
Massive z~2 galaxies: morphology vs. SFR

Passive (24-μm faint) galaxies tend to be compact spheroidals. Star-forming galaxies tend to be more extended and more disk like.

Also, Bell+ 2012: Passive galaxies at z~2 have high Sersic indices:
- Correlation of star-formation with profile shape is much stronger than with stellar mass.

Wang+ 2012
Correlations of color, mass and morphology

- Passive BzK galaxies tend to be more massive and more compact than star-forming BzK galaxies

Lee+ 2013
The Hubble Sequence at $z \sim 2$

Axial Ratio distributions

Massive galaxies $M^* > 10^{11} M_\odot$

- Passive disks (gray) appear to be flat
- Star-forming disks appear to be prolate or triaxial
- Further studies underway measuring larger samples over a wider mass range.

Bruce+ 2013
Van der Wel+ in prep.
Blue and red “nuggets”

Relative space densities evolve

Densities suggest rapid quenching of blue nuggets (< 1 Gyr)

Barro+ 2013
Spatially resolved stellar populations

Redshift 0.5-1.5:
Off-center star-forming clumps generally disappear from stellar mass maps – contribute up to 20% of integrated SFR but <7% to stellar mass.

Wyuts+ 2012
CANDELS/Theory efforts

Semi-Analytic models
- From the same halo merger trees
- Tuned to the same z=0 stellar mass function
- Different codes, different feedback, different dust, different secondary tuning
- Catalog release in 2013

Lu+ in preparation
High-resolution AMR hydrodynamical simulations
• Drawn from cosmological simulations
• Including dusty radiative transfer (SUNRISE)
• “CANDELized” to HST resolution
• 30 galaxies -> 60+ galaxies
• $M_{\text{halo}} \ 10^{11}-10^{13}$ at $z=1$

SPH zoom simulations
• Variety of feedback recipes
• Davé+ in prep
CANDELS/Theory efforts:
How do galaxies assemble their mass?

Assembly histories extracted from the HART simulations
Tweed+ in prep
Mandelkir+ in prep

Assembly histories reconstructed from (pre-CANDELS) observations
Behroozi+ 2013
Much more in-situ star-formation
CANDELS UV observations

- Observations in GOODS-N during the day side of CVZ orbits
  - Scattered-light avoidance strategy is working well
- 10 epochs March 2013 – August 2014
- Challenging in many ways:
  - Scheduling to make the most of CVZ
  - CTE losses forced a mid-course change of observing strategy
  - Loss of depth; challenging calibration

BIG Thanks to Tricia Royle and the scheduling team!
UV Science goals

- **Morphology**
  - photometric and morphological properties of star-forming clumps
  - spatial differentiation of star formation activity and older stellar populations (e.g., internal color dispersion)
  - Size evolution of passive galaxies

- **Star-Formation in LBGs**
  - Robust selection of dropouts at \( z=2-3 \)
  - Compare UV and optical tracers of star-formation

- **Lyman Continuum Escape Fraction**
  - Resolved LyC if detected;
  - stacking for robust limit if not
<table>
<thead>
<tr>
<th>Field</th>
<th>UV Band(s)</th>
<th>Area (arc')</th>
<th>Depth (orbits)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CANDELS GOODS-N</strong> (day side of deep survey)</td>
<td>F275W</td>
<td>70</td>
<td>about 4</td>
<td>Finish Aug 2013 Binning/post-flash/CTE</td>
</tr>
<tr>
<td><strong>UVUDF</strong></td>
<td>F225W, F275W, F336W</td>
<td>7</td>
<td>30</td>
<td>Data obtained. Binning/post-flash/CTE</td>
</tr>
<tr>
<td><strong>ERS (GOODS-S)</strong></td>
<td>F225W, F275W, F336W</td>
<td>40</td>
<td>2</td>
<td>Mosaics soon Different Y-band</td>
</tr>
</tbody>
</table>

Figure from S. Finkelstein

Figure from Grogin et al. (2011)
Mid-course correction

- Switched from 2x2 binned to unbinned with post-flash (for epochs 4-10).
  - CTE losses were much worse than anticipated
  - So far, unable reach theoretical noise limit of 2x2 binned observations
    - Mostly limited by warm pixels
  - Post flash gives us a formal noise penalty of a factor of ~2, but reduces systematic uncertainties by some difficult-to-estimate factor

- So we opted to switch from a mode that isn’t working as well as expected to a mode that isn’t yet calibrated, but holds more promise.

- Put all remaining orbits into F275W, dropping F336W

BIG Thanks to John Mackenty, Jay Anderson & the WFC3 team!
UV Calibration wish list

• For binned mode, darks with the warm pixels included

• For post-flash mode:
  • High-S/N post-flash background image
    • Post-flash background is not uniform
  • Acid-test of post-flash CTE-corrected galaxy photometry:
    • 2-orbit repeat of a field in the ERS in F275W
    • ERS was observed just after launch.
CANDELS Outreach

- Blog
  - 73 posts
  - 3 per week
  - 24000 views
- Teacher workshop
- Iphone App
  - coming soon
- Galaxy Zoo
  - 500,000 classifications in the first week
Budget cap impacts

• Funded at 72% of our 2011 request

• Cap in 2011 to 76% had the largest impact:
  • Ground-based observing
    • averaging ~4 runs per semester
    • now virtually unsupported by CANDELS funds
  • VAO coordination unsupported
  • Galaxy Zoo science not explicitly supported
  • Shelved:
    • Development of more advanced clump finders
    • Innovative methods for photometric redshifts
  • Severely reduced support for:
    • Extragalactic Background Light measurements
    • Bar fraction evolution
  • V2.0 data release at risk
Budget cap impacts

• Postdocs were hired in 2010 based on projection of original budget – which included a 5-year plan.

• Consequences:
  • Postdoc appointments are now 2.5 instead of 3 years, which necessitates applying for jobs this fall.
  • Timesharing with other grants

• Lesson for future large programs: Stable funding up front will make the teams more productive.
  • Avoid inordinate amounts of time spent preparing and revising budgets
Summary

• CANDELS is going well overall
  • Productive and enthusiastic team working well together.

• Data are supporting a wide variety of science within the collaboration and the greater community

• Significant public outreach & theory components of the project

• For the UV: trying to make the most of what the instrument can offer