CANDELS
Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey

Co-PIs:

Sandra Faber
University of California Santa Cruz

Harry Ferguson
Space Telescope Science Institute
**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 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)
- **NYW**: GOODS-North Wide NE (Y-band only)
- **NYa**: Eastern 3x2 of ND (Y-band only)
- **NYb**: Western 3x3 of ND (Y-band only)
- **EGSSa**: Initial five-ninths of EGS
- **EGSSb**: Remaining four-ninths of EGS
- **UDS**: UDS
- **COS**: COSMOS
Science: High-level Summary

- Spheroid formation is crucial for the growth of black holes and for the quenching SFR in massive galaxies.
- Some processes were expected to be different at $z \sim 2$ from lower redshifts but actually turn out to be the same.
- Two surprises for small/dwarf galaxies.
- Supernovae on track.
- Thirteen submitted papers, four in press.
Spheroids, quenching, and AGN activity at $z \sim 2$
Massive $z \sim 2$ galaxies: morphology vs. SFR

The GINI-M20 diagram sorts galaxies quantitatively by morphology.

Wang et al., in prep.
Massive z~2 galaxies: morphology vs. SFR

SFR are low surface b’ness and disky

Quenched are high surface b’ness and spheroidal

Wang et al., in prep.
Massive z~2 galaxies: morphology vs. SFR

Question:
By z ~ 1, all the SFR disky galaxies shown here will have stopped SFR and morphed into spheroids. How will this happen?

SFR are low surface b’ness and disky

Wang et al., in prep.
Same cluster: Size vs. redshift for spheroids

Cluster galaxies are larger at fixed redshift.
Dry mergers go faster in clusters than in field.
Cluster evolution is faster than field evolution.

Papovich et al., submitted.
Morphologies of X-ray AGN hosts at $z \sim 2$

Kocevski et al., submitted
Morphologies of X-ray AGN hosts at $z \sim 2$

Kocevski et al., submitted

AGN hosts are NOT disturbed.

Kocevski et al., in press
Morphologies of X-ray AGN hosts

AGN hosts are mostly spheroids.

Kocevski et al., submitted
Morphologies of X-ray AGN hosts

AGN hosts have many disks.
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 $z \sim 1$ \textcolor{red}{internally driven} BH growth and AGN triggering.

Kocevski et al., submitted
Star-forming galaxies at $z \sim 2$
Bursting dwarfs at $z \sim 1.7$?

J-band excess due to $\text{H}\alpha$ emission; EW up to 1000 A.

van der Wel et al., in press
Bursting dwarfs at $z \sim 1.7$?

van der Wel et al., in press
Bursting dwarfs at $z \sim 1.7$?

- Ubiquitous low-metallicity extreme starbursts.
- Can produce most of stellar mass in today’s $10^8 - 10^9 \, M_\odot$ dwarfs in only 4 Gyr.

van der Wel et al., in press
High redshift galaxies at $z > 4$: UV slopes
UV slope reflects dust reddening, metallicity.
UV slope reflects dust reddening, metallicity

Finkelstein et al., submitted
UV slope reflects dust reddening, metallicity

High-mass galaxies already metal-rich

Low-mass galaxies growing dust and metals

Finkelstein et al., submitted
UV slope reflects dust reddening, metallicity

High-mass galaxies already metal-rich

Low-mass galaxies growing dust and metals

The roots of the mass-metallicity relation at high $z$?
### Papers from other groups

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<td>22</td>
<td>10/2011</td>
<td>Newman, Andrew B.; Ellis, Richard S.; Bundy, Kevin; Treu, Tommaso</td>
<td>Can Minor Merging Account for the Size Growth of Quiescent Galaxies? New Results from the CANDELS Survey</td>
<td>Yes at z&lt;1; No at z&gt;1</td>
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<td>Bouwens, R. J.; Illingworth, G. D.; Oesch, P. A.; Franx, M.; Labbe, I.; Trenti, M.; van Dokkum, P.; Carollo, C. M.; Gonzalez, V.; Magee, D.</td>
<td>UV-continuum slopes at z~4-7 from the HUDF09+ERS+CANDELS observations: Discovery of a well-defined UV-color magnitude relationship for z&gt;=4 star-forming galaxies</td>
<td>Disagrees with CANDELS (Finkelstein &amp; Castellano): -- Finds a correlation between UV slope &amp; UV luminosity</td>
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<td>Oesch, P. A.; Bouwens, R. J.; Illingworth, G. D.; Labbe, I.; Trenti, M.; Gonzalez, V.; Carollo, C. M.; Franx, M.; van Dokkum, P. G.; Magee, D.</td>
<td>Expanded Search for z~10 Galaxies from HUDF09, ERS, and CANDELS Data: Evidence for Accelerated Evolution at z&gt;8?</td>
<td>Surprisingly few good candidates at z~10</td>
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<td>DeGraf, Colin; Di Matteo, Tiziana; Khandai, Nishikanta; Croft, Rupert; Lopez, Julio; Springel, Volker</td>
<td>Early Black Holes in Cosmological Simulations: Luminosity Functions and Clustering Behaviour</td>
<td>Predict CANDELS quasar numbers at z=5-6, 6-7, 7-8: WIDE: 119, 19, 1.7 DEEP: 87, 18, 1.5</td>
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Theory efforts

• Recent theory workshop, Stanford, Nov 9-11
• Three groups doing semi-analytic or halo-based models
• Two groups doing full hydrodynamic models, cosmologically embedded, with dusty radiative transfer
  • focus on disk and clump formation at $z > 2$
• Very high-resolution hydrodynamic models of disk galaxies with outflows at $z > 4$
• Mock catalogs and images
AAS Special Session: Austin, Jan. 12, 2012

- Double session, 12 talks

- Speakers and titles
  - S. Faber, “Introduction to CANDELS”
  - J. Kartaltepe, “CANDELS morphological classifications”
  - E. Bell, “Why did SFR shut down in massive galaxies?”
  - M. Mozena, “Morphologies at $z \sim 2$”
  - D. Kocevski, “Morphology and structure of $z \sim 2$ AGNs”
  - S. Ravindranath, “Clumps in galaxies and their evolution”
  - B. Weiner, “Results from CANDELS grism data”
  - A. Rodney, “Type Ia SNe rates at $z > 1.5$ from CANDELS”
  - A. Koekemoer, “High-redshift AGN”
  - H. Yan, “Census of luminous galaxies at $z > 6$”
  - S. Finkelstein, “Stellar populations at $z \sim 6$”
  - R. Wechslser, “CANDELS theory: SAM models”
  - P. Madau, “CANDELS theory: hydro simulations”
### CANDELS+CLASH Supernova Status

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### HST Follow-up: 88 of 202 orbits used
- WFC3 Grism: 3 SNe, 28.5 orbits
- ACS Grism: 2 SNe, 4 orbits
- ACS/WFC3 imaging: 10 SNe, 55.5 orbits

### Target of Opportunity Interruptions:
- Disruptive Triggers: 4
- Non-disruptive Triggers: 9+
- Commandeering CLASH Parallels: 2

### Ground Facilities:
- Spectroscopy: 12 SNe (Keck,VLT,Gemini)
- Imaging: 1 SN (Magellan)
Supernova MCT Follow-up Program for CANDELS

A TYPE IA SUPERNOVA AT REDSHIFT 1.55 IN THE INFRARED FROM THE CANDELS HUBBLE SPACE TELESCOPE TREASURY PROGRAM

Steven A. Rodney¹, Adam G. Riess²,³, Tomas Dahlen⁴, Louis-Gregory Strolger¹, Henry C. Ferguson⁵, Jens Hjorth⁶, Teddy F. Frederiksen⁷, Benjamin J. Weiner⁸, Bahram Mobasher⁹, Stefano Casertano¹⁰, David O. Jones¹¹, Peter Challis¹², S. M. Faber¹³, Alexei V. Filippenko¹⁴, Peter Garnavich¹⁵, Ofer Graur¹⁶, Norman A. Grogin¹⁷, Brian Hayden¹⁸, Saurabh Jha¹⁹, Robert P. Kirshner²⁰, Dale Kocevski²¹, Anton Koekemoer²², Curtis McCully²³, Brandon Patel²⁴, Abhijit Rajan²⁵, Claudia Scarlata²⁶

Catalogs

• HST photometry
  • H-selected Sextractor (and J+H selected)

• Multi-wavelength
  • TFIT for 0.3-8 $\mu$m
  • PSF-fitting photometry at longer $\lambda$ with positional priors from 8 and 24 $\mu$m
  • Position matching for radio & X-ray

• UDS photometry paper in preparation
  • Catalog release with paper publication.
TFIT: tests indicate much better photometry reductions

Demonstrably works well on simulated data.

Devilishly hard to validate on real data.

Lee et al. 2011
Catalogs, continued

- **Morphology**
  - Non-parametric CAS, GINI/M20
  - Parametric Sersic & Bulge+disk fits with Galfit & GIM2D

- **Photometric redshifts, ages, stellar masses, dust, star-formation histories**
  - Comparison of 12 independent estimates with different underlying assumptions
Impact if ACS were lost

• Most of the rest of the survey would use F350LP instead of ACS for low-z supernova rejection
  • Results in ~20% loss for IR science

• High-z galaxy search would need F814W with WFC3 UVIS
  • ~270 orbits per GOODS field for comparable depth and area.
  • ~300 orbits per wide field.
  • We would need to consider trades in detail depending on when ACS is lost.
Support

• Extra attention to GOODS-N scheduling
  • Need to begin running some test schedules

• Consultation with WFC3 experts on predicting scattered light for GOODS-N.
  • Marc Rafelski visiting STScI this week to work on this.

• Consultation on WFC3 UVIS CTE and charge injection.
  • Brian Siana working on this for CANDELS.

• DGO files for WFC3 UVIS will be needed for GOODS-N

• ACS CTE
  • Consultation on “forward model” to estimate flux upper limits.
  • ACS team preparing de-trailed darks for to allow CTE correction on archival ACS data.
Lessons Learned

- Make sure your wiki is doubly backed up!
  - Multiple failures on raid at UCSC resulted in a month without the wiki, and costly forensic data recovery.

- Need to be very alert to visibility changes between phase-2 submission and actual scheduling:
  - Especially on high ecliptic-latitude fields (GOODS-N and EGS).
Lessons Learned 2

- Budget process is complicated and evolving
  - Spent a lot of time on month-by-month spending plans; Unclear how these are to be used.
  - We submitted a long memo with suggestions.
  - We still don’t know for certain our final budget.
  - Difficult to plan if students & postdocs might evaporate next year.
Projected Scientific Impact

- Projected impact as outlined in our proposals is basically on track, e.g:
  - Evolution of galaxies at the end of reionization
  - Evolution of massive galaxies and AGN at z~2
    - CANDELS Spitzer observations underway to bring all fields to 26.8 AB at 3.6 μm.
  - SNe evolution; improved DE constraints

- Challenges to some goals:
  - ACS and WFC3 UVIS CTE degradation
    - Affects identification of z~7 dropouts
    - Affects measurements of escaping Ly continuum at z~2
  - WFC3 flatfields & scattered light
    - Affects large-angle EBL measurements
Concerns

• **Scheduling:**
  • GOODS-N is challenging: using the day side of CVZ orbits for UV observations.
  • Need to be very careful about scattered light in the IR for the CVZ and the near-CVZ orbits.

• **Funding:**
  • The full survey won’t be available until the end of cycle 20, which is the nominal end of our funding.
  • Funding to date has been adequate, but it would be a disaster if the cycle 20 funding allocation ignores the fact that science support will be required until 2015.