Probing SN progenitor evolution with Hubble diagram at z>1.5 :
A Hubble Survey to Study the Dark Universe

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Why is the expansion of the universe accelerating?
- Is it something other than $\Lambda$?
- What are the parameters of the dark energy equation of state?
- What is the time derivative of the equation of state?
- How standard are our “standard” candles (cosmic distance indicators)? Need better measurements of systematic effects at large lookback times.

$w = \frac{P}{\rho c^2}$
$w = -1$ for $\Lambda = \text{const}$

$w \neq -1$?
Possible for other models (e.g. Quintessence, k-essence)

Is $w$ a $f(z)$?
$w(z) = w_o + w_a \frac{z}{1+z}$
(see Linder 2003)
CLASH: Cluster Lensing And Supernova survey with Hubble

An Hubble Space Telescope Multi-Cycle Treasury Program designed to place new constraints on the fundamental components of the cosmos: dark matter, dark energy, and baryons.

To accomplish this, we will use galaxy clusters as cosmic lenses to reveal dark matter and magnify distant galaxies.

The galaxy clusters are chosen based on their smooth and symmetric x-ray surface brightness profiles: “simpler” lenses to model and minimizes lensing bias. All clusters have masses ranging from $\sim5$ to $\sim30 \times 10^{14} \text{ M}_\text{SUN}$. Redshift range covered: $0.18 < z < 0.90$ ($11.3 \text{ Gyr} > t_u > 6.3 \text{ Gyr}$).

Multiple epochs enable a $z > 1$ SN search in the surrounding field (where lensing magnification is low). This will allow us to improve the constraints on both the time dependence of the dark energy equation of state and on the amplitude of systematic errors in cosmological parameters.
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CLASH: An HST Multi-Cycle Treasury Program


Footprint of our 2 ORIENT survey: The area of the complete 14-band coverage in the cluster center is 4.07 square arcminutes (88% of the WFC3/IR FOV).

SN search cadence: 10d–14d, 4 epochs per orient

Lensing amplification small at these radii
Constraining Dark Energy by measuring the change in the cosmic scale factor with time

White Dwarf in binary system. Progenitor of a “Type 1a” supernova.

Accretion of material onto the white dwarf (WD) leads to increase in temperature of WD core. This leads to a runaway thermonuclear deflagration front of Carbon and, eventually, Oxygen burning. WDs are susceptible to runaway fusion as degeneracy pressure is independent of temperature.

The star ultimately explodes when Chandrasekhar mass limit is approached. Homogeneous (few %) explosion mass produces a nearly constant amount of light. Since we know the intrinsic luminosity, distance to the SN (and its host galaxy) can be accurately computed.
Discovering Type Ia SNe at z>1 with HST:

**Step 1: Detection:**
- Pre-explosion image
- SN Detection image
- Difference image

**Step 2: Winnowing**
- SN Ia are red in UV

**Step 3: Identification, redshift**
- Obtain HST grism spectrum:
  - SN Ia, z=1.3
- Ground has never measured redshift this high

**Step 4: Follow-up, near-IR**
- Light Curve
- NICMOS:
  - Peak and shape yields distance
New HST NIR Camera – 16 orbits

Slide credit: Garth Illingworth, UCSC, Lick Observatory
Higher-z SNe Ia from ACS

<table>
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<th>Z=1.39</th>
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<td>HST04Zwi</td>
<td>HST05Lan</td>
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Host Galaxies of Distant Supernovae

*Hubble Space Telescope • Advanced Camera for Surveys*
HST: 23 SNe Ia at z>1 Find Past Deceleration, Confirms Dark Energy+Dark Matter Model

Riess et al. 2004, 2007
Current Observational Constraints

Kowalski et al. 2008: \( w = -0.969^{+0.063}_{-0.066} \) (stat) (sys)

SN data: SNLS, ESSENCE, high-z HST SNe, plus a few other datasets
BAO: SDSS (Eisenstein et al. 2005)
CMB: WMAP 5-year data release (Dunkley et al. 2009)
We expect to double the number of Type Ia supernovae at $z > 1$.

Depending on SN delay time, expect to find $10 - 20$ SNe at $z > 1$; at least 5 with $z > 1.5$.
Two MCT HST programs (CLASH + CANDELS) will detect SNe Ia at 1.0 < z < 2.5. They will provide a direct test of systematics in matter-dominated universe (e.g., Riess & Livio 2006).
The Future of Dark Energy Measurements

Present=Planck CMB priors, SDSS II BAO, SN World compilation, 5% $H_0$ prior

Dark Energy Metrics

- or -

JDE+LSST (BAO, lensing, SN Ia)
+HST 100 z>1 SN Ia + SDSS III-LRG BAO z<0.7'

Present (CMB+BAO+SNe)

Odds to reject $\Lambda$ in unit phase w/w' space

68% 90% 97% 99% 99.7% 99.9%
Science Goals: SN Rates

Predicted SNIa Yield:
\( z > 1 : 10 - 30 \)
\( z > 2 : 0 - 4 \)
Science Goals:

SN Rates

Or Graur
Dan Maoz
Steve Rodney
Tomas Dahlen
Lou Strolger
SN Discoveries:

Abell 383

SN Caligula, $z=1.7$

SN Tiberius, $z=1.1$

SN Nero, $z=0.7$

SN Galba, $z=0.28$
SN Discoveries:

MACS1149+22

SN Otho,

SN Scarlet,
Follow-up:

Otho+Scarlet:
Ground-based spectroscopy confirms the photo-z estimates
Follow-up: Caligula

$z \sim 1.7$, possible SNIa
Follow-up: Caligula $z \sim 1.7$, possible SNIa

ToO completed: 1 additional epoch F160W, F814W
ToO Pending: 1 orbit WFC3 F105W, F814W in December 2011

SNIIa template at $z=1.65$