Next Generation IR Standard Stars
Perfect Black Body Stars in the Sky

• Report on Intensive Program 2005-6 by Doi et al.
  a) Morokuma et al. 2010 (PASJ, 62, 19)

• Re-Calibration of SDF/SXDF Zeropoints
  c) Yagi et al. 2013 (PASJ, 65, 22)

• Next Generation IR Standard Stars

  Need for IR Standards

Nao Suzuki (LBNL=>Kavli IPMU)
SN Factory, Palomar Transient Factory (PTF), SuperNovaLegacySurvey (SNLS), Supernova Cosmology Project (SCP)
HST Cluster Supernova Survey

1. Keck AO Photometry of $z=1.3$ SNIa (Melbourne et al. 2007)
2. IRAC Shallow Survey (Eisenhardt et al. 2008)
3. Color Magnitude at $z=1$ Cluster (Santos et al. 2009)
4. XMMXCS J2215.9-1738 at $z=1.457$ (Hilton et al. 2007)
5. Unusual Transient, SCP05-F006 (Barbary et al. 2009)
6. Multiply Imaged Lensed System (Huang et al. 2009)
7. X-ray from IRAC $z=1.4$ Cluster (Brodwin et al. 2011)
8. Weak Lensing Studies + Scaling Relation (Jee et al. 2011)

XMMU J2235-2557 $z=1.4$
9. Weak Lensing Study (Jee et al. 2009)
10. Multi-Wavelength Study (Rosati et al. 2009)
11. Galaxies Properties (Strazzullo et al. 2011)
HST Cluster SN Survey

HST  Keck  VLT  Subaru

SCP06K0  SCP06G4  SCP05D6  SCP06H5
z=1.415  z=1.349  z=1.315  z=1.231

SCP06R12  SCP06A4  SCP06N33  SCP06F12
z=1.212  z=1.192  z=1.188  z=1.110

SCP06C0  SCP06U4  SCP06E12  SCP05D0
z=1.092  z=1.050  z=1.030  z=1.014

SCP06C1  SCP06H3  SCP05P9  SCP06Z5
z=0.980  z=0.850  z=0.821  z=0.623

Nao Suzuki & SCP
PI: Saul Perlmutter
Unusual Transient SCP06-F6
Barbary et al. 2009 z=1.2 Superluminous Supernova by Quimby
A $z=3.9$ Galaxy Lensed Twice

Xiaosheng Huang et al. 2011

WARPS J1415.1+3612 : $z=1.026$

Cluster Mass Profile : NFW

Spectroscopic Follow-up

Spectra from Subaru FOCAS

WARPS J1415.1+3612 : $z=1.026$

BCG (#15)

N

E

A

B

C

D

E

Lensing Galaxy (#13)

F

10 kpc

1.24"
THE HUBBLE SPACE TELESCOPE CLUSTER SUPERNOVA SURVEY. V. IMPROVING THE DARK-ENERGY CONSTRAINTS ABOVE z > 1 AND BUILDING AN EARLY-TYPE-HOSTED SUPERNOVA SAMPLE


( THE SUPERNOVA COSMOLOGY PROJECT)

( THE SUPERNOVA COSMOLOGY PROJECT)

Astronomy Department, University of Washington, Seattle, WA 98195, USA

We present Advanced Camera for Surveys, NICMOS, and Keck adaptive-optics-assisted photometry of 20 Type Ia supernovae (SNe Ia) from the Hubble Space Telescope (HST) Cluster Supernova Survey. The SNe Ia were discovered over the redshift interval 0.623 < z < 1.415. Of these SNe Ia, 14 pass our strict selection cuts and are used in combination with the world’s sample of SNe Ia to derive the best current constraints on dark energy. Of our new SNe Ia, 10 are beyond redshift z = 1, thereby nearly doubling the statistical weight of HST-discovered SNe Ia beyond this redshift. Our detailed analysis corrects for the recently identified correlation between SN Ia homogeneity and host galaxy mass and corrects the NICMOS zero point at the count statistics weight for very distant SNe Ia. Adding these SNe improves the best combined constraint on dark-energy density, $\rho_{\text{DE}}(z)$, at redshifts 1.0 < z < 1.6 by 18% (including systematic errors). For a flat LCDM universe, we find $\Omega_{\Lambda} = 0.729 \pm 0.014$ (68% confidence level) including systematic errors. For a flat $\omega$CDM model, we measure a constant dark-energy equation-of-state parameter $w = -1.013^{+0.068}_{-0.073}$ (68% CL). Curvature is constrained to -0.7% in the $\omega$CDM model and to -2% in a
ACS Image Reduction v125
\( \Lambda \) Today

Combination of SNe with:
- BAO (Percival et. al., 2010)
- CMB (WMAP data, 2011)

For a flat Universe:

**LCDM:**
\[ \Omega_m = 0.271 \pm 0.012\text{(stat)} \pm 0.014\text{(sys)} \]

with curvature:

**oLCDM:**
\[ \Omega_k = 0.002 \pm 0.005\text{(stat)} \pm 0.005\text{(sys)} \]
Accelerating Universe

Expansion History of the Universe


- Scale of the Universe Relative to Today's Scale
- After inflation, the expansion either...
- first decelerated, then accelerated
- expands forever
- collapses

Billions of Years
$w = P/\rho$ : equation of state

Q. Is $w = -1$?

$w_{\text{CDM}}$:

$w = -1.008 \pm 0.052 \text{(stat)}$

$-1.013 \pm 0.070 \text{(sys)}$

$\text{SNe} + \text{BAO} + \text{CMB}$

.. and allowing for curvature: $ow_{\text{CDM}}$

$w = -1.006 \pm 0.058 \text{(stat)}$

$-1.003 \pm 0.093 \text{(sys)}$

*with systematics*

- $w = -1$ : cosmological constant
- $w = 0$ : matter
- $w = 1/3$ : radiation

\[ E \propto a^{-3(1+w)} \]
Systematic Error Limits
the Precision Cosmology Today
Stat Err \sim 5\%, Systematic Err \sim 5\%

Suzuki et al 2012 (Supernova Cosmology Project)
Re-Calibration of SDF/SXDS Photometric Catalogs of Suprime-Cam with SDSS Data Release 8

Masafumi YAGI,¹ Nao SUZUKI,² Hitomi YAMANOI,¹ Hisanori FURUSAWA,³ Fumiaki NAKATA,⁴ and Yutaka ISHIHARA

¹ Optical and Infrared Astronomy Division, National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan
  yagi.masafumi@nao.ac.jp

² E.O. Lawrence Berkeley National Lab, 1 Cyclotron Rd., Berkeley, CA 94720, USA

³ Astronomy Data Center, National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan

⁴ Subaru Telescope, 650 North A'ohoku Place, Hilo, Hawaii 96720, USA

\( dm = 0.10 \) for \( i \)

\( dm = 0.15 \) for \( z \)
Cosmology in 10 years

SSP

6hr Exp

Deep Space Program
None of standard stars from SNF will be used for HSC and others

- They are too bright (HSC/LSST saturates at 17-18th mag)
- No accurate IR coverage

### A NEW SYSTEM OF FAINT NEAR-INFRARED STANDARD STARS

**S. E. Persson,1 D. C. Murphy,1 W. Krzeminski,1 M. Roth,1 AND M. J. Rieke2**

*Received 1998 June 3; revised 1998 July 28*

**ABSTRACT**

A new grid of 65 faint near-infrared standard stars is presented. They are spread around the sky, lie between 10th and 12th magnitude at $K$, and are measured in most cases to precisions better than 0.001 mag in the $J$, $H$, $K$, and $K_s$ bands; the latter is a medium-band modified $K$. A secondary list of red stars suitable for determining color transformations between photometric systems is also presented.

**Key words:** infrared radiation — stars: general — techniques: photometric

---

**TABLE 2**

<table>
<thead>
<tr>
<th>No.</th>
<th>HST</th>
<th>R.A. (J2000.0)</th>
<th>Decl. (J2000.0)</th>
<th>$J$</th>
<th>$J_{\sigma_m}$</th>
<th>$N$</th>
<th>$H$</th>
<th>$H_{\sigma_m}$</th>
<th>$N$</th>
<th>$K$</th>
<th>$K_{\sigma_m}$</th>
<th>$N$</th>
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<td>9101</td>
<td>P525-E</td>
<td>00 24 28.3</td>
<td>07 49 02</td>
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<td>16</td>
<td>11.298</td>
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<td>16</td>
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<td>00 33 15.2</td>
<td>-39 24 10</td>
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<td>0.006</td>
<td>15</td>
<td>10.657</td>
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<td>0.005</td>
<td>17</td>
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<td>0.005</td>
<td>16</td>
<td>10.693</td>
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<td>10.695</td>
<td>0.005</td>
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<tr>
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<td>06 25 38</td>
<td>11.309</td>
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<td>8</td>
<td>10.975</td>
<td>0.006</td>
<td>8</td>
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<td>9106</td>
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<td>11.842</td>
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<td>9107</td>
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<td>03 32 03.0</td>
<td>37 20 40</td>
<td>11.934</td>
<td>0.005</td>
<td>16</td>
<td>11.610</td>
<td>0.004</td>
<td>18</td>
<td>11.492</td>
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<td>11.503</td>
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## Top 10 Subaru Papers

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<tr>
<th>#</th>
<th>Bibcode Authors</th>
<th>Cites</th>
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<th>Date</th>
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<tbody>
<tr>
<td>1</td>
<td>2010ApJ...716...712</td>
<td>652.000</td>
<td>Spectral and Hubble Space Telescope Light Curves of Six Type Ia Supernovae at $0.511 &lt; z &lt; 1.12$ and the Union2 Compilation</td>
<td>06/2010</td>
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<td>4</td>
<td>2009ApJ...690.1236</td>
<td>411.000</td>
<td>Cosmos Photometric Redshifts with 30-Bands for 2-deg^2</td>
<td>01/2009</td>
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<tr>
<td>5</td>
<td>2002PASJ...54...33</td>
<td>398.000</td>
<td>Subaru Prime Focus Camera -- Suprime-Cam</td>
<td>12/2002</td>
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<tr>
<td>6</td>
<td>2007ApJS..172...70</td>
<td>368.000</td>
<td>zCOSMOS: A Large VLT/VIMOS Redshift Survey Covering $0 &lt; z &lt; 3$ in the COSMOS Field</td>
<td>09/2007</td>
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<tr>
<td>7</td>
<td>2005Natur.434..871</td>
<td>313.000</td>
<td>Nucleosynthetic signatures of the first stars</td>
<td>04/2005</td>
</tr>
<tr>
<td>9</td>
<td>2002ApJ...568L..75</td>
<td>283.000</td>
<td>A Redshift $z=6.56$ Galaxy behind the Cluster Abell 370</td>
<td>04/2002</td>
</tr>
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</table>

**SN1a : Dark Energy**

**COSMOS**

**SuprimeCam**

**HDS : Metal Poor Star**

**SDF**

<table>
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<tr>
<th>#</th>
<th>Bibcode</th>
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<th>Title</th>
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<tr>
<td>3</td>
<td>2012MNRAS.427.3435A</td>
<td>Anderson, Laurens; Aubourg, Eric; Bailey, Stephen; Bizyaev, Dmitry; Blanton, Michael; Bolton, Adam S.; Brinkmann, J.; Brownstein, Joel R.; Burden, Angela; Cuesta, Antonio J.; and 267 coauthors</td>
<td>233,000</td>
<td>The clustering of galaxies in the SDSS-III Baryon Oscillation Spectroscopic Survey: baryon acoustic oscillations in the Data Release 9 spectroscopic sample</td>
<td>12/12</td>
<td>A E F X D R C S U</td>
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<tr>
<td>4</td>
<td>2012ApJS..203..21A</td>
<td>Ahn, Christopher P.; Alexandroff, Rachael; Allende Prieto, Carlos; Anderson, Scott F.; Anderton, Timothy; Andrews, Brett H.; Aubourg, Eric; Bailey, Stephen; Balbinot, Eduardo; Barnes, Rory; and 226 coauthors</td>
<td>206,000</td>
<td>The Ninth Data Release of the Sloan Digital Sky Survey: First Spectroscopic Data from the SDSS-III Baryon Oscillation Spectroscopic Survey</td>
<td>12/12</td>
<td>A E F X D R C O U</td>
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<td>5</td>
<td>2012JCAP...08..007W</td>
<td>Weniger, Christoph</td>
<td>206,000</td>
<td>A tentative gamma-ray line from Dark Matter annihilation at the Fermi Large Area Telescope</td>
<td>08/12</td>
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<td>6</td>
<td>2012A&amp;A...537A.146E</td>
<td>Howard, Andrew W.; Marcy, Geoffrey W.; Bryson, Stephen T.; Jenkins, Jon M.; Rowe, Jason F.; Batalha, Natalie M.; Borucki, William J.; Koch, David G.; Dunham, Edward W.; Gautier, Thomas N.; III; and 57 coauthors</td>
<td>183,000</td>
<td>Planet Occurrence within 0.25 AU of Solar-type Stars from Kepler</td>
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<td>7</td>
<td>2012A&amp;A...537A.146E</td>
<td>Ekstrom, S.; Georgy, C.; Eggenberger, P.; Meynet, G.; Mowlavi, N.; Wytenbach, A.; Granada, A.; Decressin, T.; Hirschi, R.; Frischknecht, U.; and 23 coauthors</td>
<td>175,000</td>
<td>Grids of stellar models with rotation. I. Models from 0.8 to 120 $M_\odot$ at solar metallicity (Z = 0.014)</td>
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<td>8</td>
<td>2012JCAP...07..054B</td>
<td>Bringmann, Torsten; Huang, Xiaoyuan; Ibarra, Alejandro; Vogel, Stefan; Weniger, Christoph</td>
<td>173,000</td>
<td>Fermi LAT search for internal bremsstrahlung signatures from dark matter annihilation</td>
<td>07/12</td>
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<td>9</td>
<td>2012MNRAS.422.1203B</td>
<td>Boylan-Kolchin, Michael; Bullock, James S.; Kaplinghat, Manoj</td>
<td>144,000</td>
<td>The Milky Way’s bright satellites as an apparent failure of ACDM</td>
<td>05/12</td>
<td>A E F X D R C S U</td>
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<td>10</td>
<td>2012MNRAS.427.2132P</td>
<td>Padmanabhan, Nikhil; Xu, Xiaoying; Eisenstein, Daniel J.; Scalzo, Richard; Cuesta, Antonio J.; Mehta, Kushal T.; Kazin, Eyal</td>
<td>138,000</td>
<td>A 2 per cent distance to $z = 0.35$ by reconstructing baryon acoustic oscillations - I. Methods and applications to the Sloan Digital Sky Survey</td>
<td>12/12</td>
<td>A E F X D R C U</td>
</tr>
</tbody>
</table>
Mostly Astro Community

Ouchi et al 2004

- ApJ: 46%
- AA: 10%
- AJ: 4%
- MNRAS: 26%
- PASP: 0%
- PhRv: 0%
- PhLB: 4%
- GReGr: 10%
- CQGra: Others

Only 37% from Astro Community

Suzuki et al 2012 (SCP)

- ApJ: 12%
- AA: 3%
- AJ: 1%
- MNRAS: 11%
- PASP: 15%
- PhRv: 12%
- PhLB: 0%
- GReGr: 1%
- CQGra: 1%
- MPL: 0%
- Others: 39%
Precision Cosmology Requirements

- Precise Estimate of Errors
- Covariance Matrix
- Cross Calibrations & Cross Checks
- Reproducibility
The Origins of Systematic Errors Today

- I: Zero Point is not accurate enough
- II: Standard Star Calibration (HST CALSPEC) is not accurate enough
BD17: SDSS mag Definition
SDSS vs HST
Figure 8. Ratio between the CALSPEC fluxes and those calculated here using redetermined atmospheric parameters for the HST primary standards. The zero point of the flux scale of the CALSPEC fluxes is given by Landolt $V$-band photometry, while here it is set by SDSS PT $ugr$ photometry (but see text for an exception for GD 153). The two scales are inconsistent by 1.5% for GD 71.
CALSPEC 2010: Model vs. STIS obs.
CALSPEC Model 2010 / STIS 2010

Looks ok, but I don't forget what you've done to me
CALSPEC 2003-10: Model vs. STIS obs.
CALSPEC : STIS 2003 / STIS 2010

I don’t trust STIS data in 1% Level

STIS Calibration moves
CALSPEC Model 2003 / Model 2010

Model Spectrum moves

I don’t trust WD Models in 1% Level
Model Uncertainties

<table>
<thead>
<tr>
<th></th>
<th>V</th>
<th>B - V</th>
<th>$T_{\text{eff}}$ [K]</th>
<th>log g</th>
<th>spectral type</th>
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<tbody>
<tr>
<td>G191-B2B</td>
<td>11.781</td>
<td>-0.33</td>
<td>61193 (241)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.492 (0.012)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>DAO</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>60929 (993)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.55 (0.05)&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
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<tr>
<td>GD 153</td>
<td>13.346</td>
<td>-0.29</td>
<td>38686 (152)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.662 (0.024)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>DA1</td>
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<td>40320 (626)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.93 (0.05)&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>GD 71</td>
<td>13.032</td>
<td>-0.25</td>
<td>32747 (92)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.683 (0.023)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>DA1</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>33590 (483)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.93 (0.05)&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> (Finley et al., 1997)

<sup>b</sup> (Gianninas et al., 2011)
Figure 2.1.: Comparison between the Tübingen model (TMAW) and the Bergeron model for star GD 71. Both models were computed for pure hydrogen atmosphere, with $T_{\text{eff}} = 33590 K$ and $\log g = 7.93$. Upper panel: model spectra (shifted, to distinguish them). Lower panel: ratio.
Trust No One

- I don’t Trust CALSPEC!
- I don’t Trust HST/STIS!
- I don’t Trust White Dwarf Models!
RA=23:02:40.032  DEC=−00:30:21.59

\[ u = 17.968 \pm 0.021 \]
\[ g = 17.804 \pm 0.017 \]
\[ r = 17.898 \pm 0.017 \]
\[ i = 18.025 \pm 0.020 \]
\[ z = 18.246 \pm 0.025 \]

\[ T_{\text{eff}} = 10467.3 \pm 21.1 \]
\[ \chi^2/\text{dof} = 1.031 \]
DR8 Plate 380 MJD 51792 Fiber 104 : 2000-09-05

RA=23:02:40.032  DEC=-00:30:21.59

SDSS

GALEX

$T_{\text{eff}}=10478.4 \pm 42.1$

$\chi^2$/dof=1.367
Discovery of Perfect Black Body Spectra: found as a Quasar Target

Only 20 stars out of a million stars

- DR8: 605,772 stars => 5 stars
- DR9: 110,929 stars => 9 stars
- DR10: 81,892 stars => 10 stars
Looking at the Future with JWST today 0.3%, but we can do 0.1%
Magnitude Errors are Correlated

\[ \text{u mag} \]

\[ \text{g mag} \]
Near Future plan:

- Dec 2013 : 8m-Subaru Time (approved)
- We will observe these stars with Subaru (MOIRCS) in K-band (2.2 micron)
- UH88 (approved) will have S/N=100 data
- Aim to Publish Discovery Paper in 2014
- If no IR excess is detected, we will write a discovery paper and send it to HST (cycle 22 proposal)
- We aim to re-calibrate SDSS photometry at 20th mag with 4 decimal numbers with 0.1% accuracy
- GAIA (2013-2020) will measure the distances to these stars
What I will do:
with M. Fukugita, Tim Beers and SDSS collaboration

• Step I : Replace BD17 by perfect black body spectra
• Step II : Re-establish SDSS mag in AB
• Step III : Re-measure zpt offset in covariance matrix form using 5-band SDSS photometry, 2-band GALEX photometry, and SDSS-I/II/III spectra for 320,751 F-stars
• Publish model spectra and synthetic mag of 320,751 F-stars (=20 stars / square degree)
New Observations
Collaborators

- UH88 Fall 2013 (Postponed) : 1 night
- Subaru MOIRCS (H-, K-band) in Dec 2013
- HST/WFC3 Cycle 22 Proposal
- Establish F-Star Spectra Network
- M. Fukugita (IPMU), R. Bohlin, S. Deustua (STScI), T. Beers (NOAO), N. Regnault (LPNHE), A. Conley (Colorado), SDSS Friends, Your Name here
Let’s think outside the Box
“In 2020, which standard stars do we use?”

- JWST is coming in 5 years
- Imagine HyperSuprimeCam + JWST SNIa Survey at $z = 2.0$ & Discovering PopIII
- GAIA (successful launch) will give us an excellent new stellar photometry and distances
Backup Slides
HST Cluster Supernova Survey

I. Survey Overview (Dawson et al. 2009)
II. SNIa Cluster Rates (Barbary et al. 2012)
III. SNIa Host Galaxy Studies (Meyers et al. 2012)
IV. NICMOS Non-Linearity (Ripoche et al. 2012)
V. SNIa Photometry & Cosmology (Suzuki et al. 2012)
VI. SNIa Field Rates (Barbary et al. 2012)

Spectroscopic Follow-up (Morokuma et al. 2010)
NICMOS Calibration (Hsiao et al. 2011)
Joshua Meyers et al. 2012

OII Line Detection by Subaru, VLT, Keck
Light Curve Width Distribution depends on the host type.
AB Magnitude Definition

\[ ABmag = -2.5 \log_{10} \frac{\int R \frac{f_\nu}{\nu} d\nu}{\int \frac{R}{\nu} d\nu} - 48.6 \]

\[ ABmag = -2.5 \log_{10} \frac{\int \lambda R f_\lambda d\lambda}{\int \frac{R}{\lambda} d\lambda} - 2.407948 \]
AB Mag \neq \text{SDSS Mag}

\[
AB_{\text{mag}}(u) = -2.5 \log_{10} \frac{\int \lambda R f_\lambda d\lambda}{\int \frac{R}{\lambda} d\lambda} - 2.407948 - 0.042
\]

\[
AB_{\text{mag}}(g) = -2.5 \log_{10} \frac{\int \lambda R f_\lambda d\lambda}{\int \frac{R}{\lambda} d\lambda} - 2.407948 + 0.036
\]

\[
AB_{\text{mag}}(r) = -2.5 \log_{10} \frac{\int \lambda R f_\lambda d\lambda}{\int \frac{R}{\lambda} d\lambda} - 2.407948 + 0.015
\]

\[
AB_{\text{mag}}(i) = -2.5 \log_{10} \frac{\int \lambda R f_\lambda d\lambda}{\int \frac{R}{\lambda} d\lambda} - 2.407948 + 0.013
\]

\[
AB_{\text{mag}}(z) = -2.5 \log_{10} \frac{\int \lambda R f_\lambda d\lambda}{\int \frac{R}{\lambda} d\lambda} - 2.407948 - 0.002
\]