SN IA in the IR = RAISIN

Robert Kirshner
Harvard University
investigators:

AWARDED 100 Orbits Cycle 20/21

<table>
<thead>
<tr>
<th>Investigator</th>
<th>Institution</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>Prof. Robert P. Kirshner</td>
<td>USA/MA</td>
</tr>
<tr>
<td>CoI</td>
<td>Mr. Peter Challis</td>
<td>USA/MA</td>
</tr>
<tr>
<td>CoI</td>
<td>Dr. Ryan Chornock</td>
<td>USA/MA</td>
</tr>
<tr>
<td>CoI</td>
<td>Dr. Wendy L. Freedman</td>
<td>USA/DC</td>
</tr>
<tr>
<td>CoI</td>
<td>Dr. Peter Garnavich</td>
<td>USA/IN</td>
</tr>
<tr>
<td>CoI</td>
<td>Dr. Ryan Foley</td>
<td>USA/MA</td>
</tr>
<tr>
<td>CoI</td>
<td>Dr. Joshua Frieman</td>
<td>USA/IL</td>
</tr>
<tr>
<td>CoI</td>
<td>Dr. Andrew Friedman</td>
<td>USA/MA</td>
</tr>
<tr>
<td>CoI</td>
<td>Dr. Eric Hsiao</td>
<td>USA/DC</td>
</tr>
<tr>
<td>CoI</td>
<td>Dr. Mark E. Huber</td>
<td>USA/HI</td>
</tr>
<tr>
<td>CoI</td>
<td>Mr. David Oscar Jones</td>
<td>USA/MD</td>
</tr>
<tr>
<td>CoI</td>
<td>Dr. G. H. Marion</td>
<td>USA/MA</td>
</tr>
<tr>
<td>CoI*</td>
<td>Dr. Kaisey Mandel</td>
<td>GBR</td>
</tr>
<tr>
<td>CoI</td>
<td>Mr. Gautham Narayan</td>
<td>USA/MA</td>
</tr>
<tr>
<td>CoI*</td>
<td>Prof. Bob Nichol</td>
<td>GBR</td>
</tr>
<tr>
<td>CoI</td>
<td>Dr. Mark M. Phillips</td>
<td>USA/DC</td>
</tr>
<tr>
<td>CoI</td>
<td>Dr. Adam Riess</td>
<td>USA/MD</td>
</tr>
<tr>
<td>CoI</td>
<td>Dr. Steven A. Rodney</td>
<td>USA/MD</td>
</tr>
<tr>
<td>CoI</td>
<td>Dr. Armin Rest</td>
<td>USA/MD</td>
</tr>
<tr>
<td>CoI</td>
<td>Prof. Masao Sako</td>
<td>USA/PA</td>
</tr>
<tr>
<td>CoI</td>
<td>Prof. Christopher W. Stubbs</td>
<td>USA/MA</td>
</tr>
<tr>
<td>CoI</td>
<td>Dr. John L. Tonry</td>
<td>USA/HI</td>
</tr>
<tr>
<td>CoI</td>
<td>Prof. Michael Wood-Vasey</td>
<td>USA/PA</td>
</tr>
</tbody>
</table>

Number of investigators: 23
Today’s nearby Hubble diagram for Supernovae
Today’s Sample ~913 SN Ia

Pan-STARRS 2013
Low-z 2013

Hamuy 1996
Riess 1999
Jha 2006
Hicken 2009
Kowalski 2008
Contreras 2010
Holtzman 2008
Riess & HZT 1998
\(\Delta\) Perlmutter 1999
Barris 2004

Amanullah 2008
Knop 2003
Tonry 2003
Astier 2006
Kosciucu 2005
Miknaitis 2007
Riess 2007
Amanullah 2010
Suzuki 2012
Looks easy now!

Figure from Ariel Goobar

\[ \Omega_\Lambda = 0.00 \]

\[ \text{Dashed: } \Omega_\Lambda = 0.73 \]
Galileo wrote, “All truths are easy to understand once they are discovered; the point is to discover them.”
Is the Dark Energy the Cosmological Constant?

\[ m_p \sim 120 \text{ GeV} \]

HST Roma
“Everything happens as though the energy in vacuo would be different from zero...we associate a pressure $p = -\rho c^2$ to the density of energy $\rho c^2$ of vacuum. This is essentially the meaning of the cosmical constant $\lambda$."

PNAS 20, 12 (1934)

From Sullivan et al. 2011 (SNLS results)

\[ 1 + w = -0.06 \pm 0.07 \] (statistical + systematic)
Figure 15. The cosmological constraints using PS1-lz, Planck, BAO and H0 measurements. Here the statistical and systematic uncertainties are propagated.

Left: Constraints on $\Omega_M$ and $\Omega_{\Lambda}$ assuming a cosmological constant ($w = 1$).

Right: Constraints on $\Omega_M$ and $w$ assuming a constant dark energy equation of state and flatness.

Table 6 - Cosmological Parameter Constraints Using different Cosmological Probe Combinations

<table>
<thead>
<tr>
<th>Sample</th>
<th>$\Omega_M$ (Planck only)</th>
<th>$\Omega_M$ (Planck + PS1-lz, stat. only)</th>
<th>$\Omega_M$ (Planck + PS1-lz, sys. &amp; stat.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNe+BAO+H0</td>
<td>0.287 ± 0.021</td>
<td>0.289 ± 0.020</td>
<td>0.287 ± 0.020</td>
</tr>
<tr>
<td>SNe+BAO+H0</td>
<td>0.287 ± 0.021</td>
<td>0.289 ± 0.020</td>
<td>0.287 ± 0.020</td>
</tr>
</tbody>
</table>

Note: Comparison of the $\Omega_M$ and $w$ constraints using different variations of external constraints Planck (Collaboration et al. 2013), BAO (Blake et al. 2011), and H0 (Riess et al. 2011).
w is Harder!

\[ w = \frac{p}{\rho} \]

\[ w = -1 \text{ for Cosmo const } \]

\[ (1 + w = 0) \]

Dashed: \( w_0 = -1.0 \)

\( w_0 = -1.50 \)
Dust both dims and reddens: Adam Riess showed how to account for this.
In the IR SN IA really are standard candles!
And there’s less trouble with dust.
Seeing through the dirt

HST Roma
Seeing through the dirt

HST Roma
The payoff for nearby supernovae
Could we get this advantage for the high-z supernovae?

RAISIN

![Histograms showing the number of supernovae with optical and optical plus near-infrared observations, with estimated distance modulus uncertainty.](image)
Only in space!

Rest frame IR measurements of z~1 supernovae are not possible from the ground

Go as far into the IR as technically feasible!

Sky is very bright in NIR: >100x brighter than in space
Sky is not transparent in NIR: absorption due to water is very strong and extremely variable
SN Ia in the IR with Pan-STARRS1

Medium-Deep Fields

Good light curves at $z \sim 0.4$
Every 4 days griz
7 square degrees 0.26 "/pixel
Dozens of supernova candidates every month!
Find SN with Pan-STARRS
Get spectrum with MMT (or Magellan, Gemini or Keck)

Input: j440162.txt
No. 1: sn02er (la-norm; −4); z = 0.431±0.008
Use the infrared camera on HST to get rest frame IR of cosmological SN Ia!

SN IA in the IR = RAISIN 100 orbits in Cycle 20
Get IR with WFC3

Goal: better knowledge of dark energy by avoiding systematic errors
Mean Absolute Intrinsic BVrYJH 15(B) = 1.1 Normal SN Ia
HST/WFC3–IR  F125W 0.4 orbits F160W 0.6 orbits PS1C490037 z=0.422
HST/WFC3–IR F160W 1 orbit PS1 520107 $z=0.5$

Epoch 1

Epoch 2

Epoch 3

Template

Subtractions

HST Roma
Marginal Probability Density

$\mu(z=0.43, \text{LCDM, } h=0.72)$

$\mu = 0.183$

$\sigma_\mu = 0.116$

PS1 Optical (68%, 95%)

PS1 Optical + HST NIR

$A_V$ (mag)

$\mu$ (mag)
$h = 0.72$

- 25 SN @ $z=0.35$, Optical
- 25 SN @ $z=0.35$, Opt+NIR
- 25 SN @ $z=0.35 + 20$ SN @ $z=0.50$, Opt+NIR
- BAO
RAISIN Scorecard

23 PanSTARRS targets

3 epochs of IR with HST in two near-IR bands

Images without the supernovae will be complete by autumn-2014

HST Roma
Observations for 13046 on 140697C3 are being archived

archive@stsci.edu <archive@stsci.edu>
Reply-To: archive@stsci.edu
To: kirshner@cfa.harvard.edu, pchallis@cfa.harvard.edu, rodney@jhu.edu

Dr. Kirshner,

The purpose of this email is to inform you that observations for proposal 13046 on SMS 140697C3 have begun to be stored in the HST Archive. Visit(s) included on this SMS are:

K5

HST Roma
The Future

HST Roma
Dark Energy Survey

HST Roma
More RAISINS, please

$w = 0.72$

- 25 SN @ $z=0.35$, Optical
- 25 SN @ $z=0.35$, Opt+NIR
- 25 SN @ $z=0.35 + 20$ SN @ $z=0.50$, Opt+NIR
- BAO
Kaisey Mandel
Won Savage Award from International Society of Bayesian Analysis!
US: WFIRST/AFTA
(to measure w, first, do other topics after)

Optical systems for looking down transferred to NASA

Gift Horse Optical System Telescope GHOST (can pass through walls from the dark side)

- Two 2.4-m telescopes have been transferred to NASA:
  - Designed as a TMA system but tertiary mirror is not applicable for science mission
  - Primary mirror is f/1.2, on-axis system
  - Compact design is similar to the dynamic test unit shown here
  - Thermal control heaters are already on the shell
  - 6 struts position the secondary mirror
    - 6 actuators at the base of the SM struts
    - 1 focus actuator on the SMA for fine focus
  - Long struts to spacecraft bus provide approximately 1.5m of available space for aft optics, instruments, etc.