PI Name: Isobel Hook

Title: Cosmology with High-Redshift Type Ia Supernovae

Semester:	2001A
Observing Mode:	queue
Partner Reference Number:	
Partner Ranking:	
Partner Received Date:	Sep 19, 2000
Partner Recommended Time:	0.0 nights

Abstract: *We now have the opportunity to obtain a Hubble diagram of Type Ia supernovae (SNeIa) that will be of longlasting value as a record of the expansion history of the universe. This record, based on SNeIa used as calibrated standard candles, directly constrains the cosmological parameters. NIRI on Gemini is capable of providing crucial near-IR data (rest-frame V band) for the highest redshift supernovae. Combined with coordinated optical observations at other observatories, in particular HST, these will provide powerful constraints on SNIa evolution and abnormal dust within or between galaxies. Accurate measurement of these high redshift SNe will dramatically shrink the major-axis of the error ellipse in the Omega_M--Lambda plane, decoupling the measurements of Omega_M and Omega_Lambda. This will provide the first check on the CMB measurements of a spatially flat universe, and unambiguously determine whether the universe contains vacuum energy. The Hubble diagram in this redshift range is the only currently feasible way to begin constraining the physics of the ‘‘dark energy’’ that is accelerating the universe’s expansion.*

Proposal Contents

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Science Justification

The Hubble diagram for Type Ia supernovae (SNe Ia), extended to redshifts well beyond z=0.25 (Fig. 1), provides perhaps the most direct current measurement of the expansion history of the universe - and hence the most direct evidence for an accelerating expansion. The Supernova Cosmology Project developed an approach to this measurement (Perlmutter et al 1997, 1998, 1999) that resulted in a determination, based on 42 SNe with redshifts between 0.18 and 0.83, of Omega_M=0.28 (+0.09,-0.08) for a flat universe (Perlmutter et al 1999; see also Riess et al 1998).

This evidence has been increasingly strengthened, both by improvements of the SN measurements and by independent, cross-cutting cosmological measurements. In particular the recent balloon-based CMB measurements (Jaffe et al 2000) have strongly indicated that the geometry of the universe is flat, reinforcing evidence for an accelerating universe by eliminating the possibility of a low-density open universe (see Fig.2a). There are now two important directions to pursue with the SN Ia cosmology work: (a) filling in the SN Ia Hubble diagram to obtain a more complete and detailed expansion history of the universe and (b) refining and further testing the SNe Ia as tools for cosmological measurements.

(a) EXPLOITING A COSMOLOGY TOOL: FILLING A SN IA HUBBLE DIAGRAM TO z=1.2

Significant improvements are being made in the systematic uncertainties in SN measurements (see later in this proposal) and it is therefore now appropriate to reduce the statistical uncertainty by almost a factor of two - that is, by studying an additional 100 SNe Ia in the redshift range 0.5 - 1.3. This number could reasonably be expected to be found and spectroscopically confirmed with ground-based telescopes, and followed with accurate space-based optical photometry over the remaining lifetime of the HST. The study of these SNe is a key task to complete and we are therefore proposing a concerted effort in Semester 2001A to discover and study 15 SNe Ia, with the most distant to be followed with Gemini and 76 HST awarded orbits.

The supernovae at the high end of this redshift range (z>1) are the most challenging to study, but also have the largest scientific impact. First they allow a determination of the curvature of the universe and decoupled measurements of Omega_M and Omega_Lambda. While additional SNe Ia over the z~0.85 range of the current datasets will improve the current statistical uncertainty by square-root(N), additional SNe Ia beyond z=0.85 can dramatically shorten the major-axis of the current Omega_M-Omega_Lambda error ellipse (Goobar & Perlmutter 1995 and Fig. 2). After our proposed observations in semester 2001A, Lambda=0 could be ruled out at better than 3sigma. For a flat universe, Omega_M and Omega_Lambda could be constrained to about 7%. The resulting estimate of Omega_M, for any Omega_Lambda, is still accurate to +/-0.2 in this simulation and would be a first check on the CMB measurements that indicate a flat geometry.

Second, the Hubble diagram out to redshifts above 1 provides one of the only known ways to constrain the physics of the ‘‘dark energy’’ that apparently is accelerating the universe’s expansion. The current constraints on the effective equation of state ratio (w=p/rho) are consistent with a very wide range of dark energy theories, including Einstein’s Cosmological Constant (for which w=-1) (Perlmutter et al 1999, Garnavich et al 1998). The proposed data set, together with data now being analyzed can tighten these constraints by 40%, potentially ruling out several contending theories.

(b) REFINING AND TESTING A COSMOLOGY TOOL: SNE IA SYSTEMATIC UNCERTAINTIES

Perlmutter et al (1997, 1999) provide extensive discussion of possible systematics in the measurement of Omega_M,Omega_Lambda; we find that uncertainties due to K-corrections, gravitational lensing amplification, and Malmquist bias are quite small compared to the statistical error. Remaining sources of systematic uncertainty that we showed are unlikely, but possible, are SNIa evolution and abnormal dust within, or even between, galaxies. Well-measured SNeIa at z>1 will provide a direct test for such possible systematics. As shown in Fig.1, the form of the Hubble diagram at high-z expected for a Lambda-dominated universe would be hard to mimic by systematic effects such as intergalactic gray dust or evolution in SNIa peak magnitudes.

THIS PROPOSAL

To use SNe at z>1 for cosmological purposes, near-IR photometry is crucial since the rest frame B- and V-bands, where SNeIa are good calibrated standard candles, shift to the near-infrared. Our intention is to use Gemini J-band photometry, combined with data from other observatories to accurately determine the rest-frame B-V color for two z>1 supernovae (see technical case). This in turn determines any reddening so that corrected rest-frame peak B and V magnitudes may be placed on the Hubble diagram and used for cosmology. Without near-IR photometry, our highest redshift HST-observed SNe cannot be corrected for host galaxy extinction.

In summary, well measured SNeIa at z>1 are crucial for addressing the questions of the cosmological parameters, the curvature, and the identity of dark energy. The same SNe can serve double-duty by refining our checks on systematic effects such as dust and evolution.

Attachments:

Name	Source	Type
Figures	figpage.ps	PS

Keywords

Keyword Category: **Extra Galactic**

- Cosmological distance scale

Resources

- Facility
  - Gemini North
- Instrument
  - NIRI
    - Camera
      - f/6 (0.12 arcsec)
    - Filter
      - Broad-Band
        - J (1.25 um)

Scheduling Information

Minimum useful allocation: 17.5 hours
Future required allocation: 35.0 hours
Synchronous observing dates:

- 2001/4/26-2001/5/15
- 2001/5/26-2001/6/15

Sychronous observing comment: Observations will be synchronised with supernova searches at CFHT and CTIO (dates not yet scheduled) and follow-up spectroscopy at Keck (also not yet scheduled). Here we give two possible scenarios for the Gemini follow-up schedule but PLEASE CONTACT US BEFORE SCHEDULING OUR REQUESTED GEMINI OBSERVATIONS.

Requirements

Staff Support: None

Observations

Name	Ra	Dec	Type	Brightness	d' (arcmin)	Exp Time	Condition
SN1 (science)	13 00 00	00 00 00	J2000	J=23.8 (dummy target)		17.5 hours	SN constraints
GSC0029801079 (wfs)	13:00:15.79	0:04:08.11	J2000	13.43 mag	5.72		
SN2 (science)	13 10 00	01 00 00	J2000	J=23.8 (dummy target)		17.5 hours	SN constraints
GSC0029800939 (wfs)	13:09:33.312	0:59:15.76	J2000	10.77 mag	6.71		

Observing Conditions

Name	Image Quality	Sky Background	Water Vapor	Cloud Cover
SN constraints	50%	Any	80%	50%

Proposal Support

Publications:

- Aldering G, Knop R., Nugent P., (2000) "The rise times of High- and Low- redshift Type Ia Supernovae are consistent", AJ, 119, 2110
- Perlmutter S. et al (1999) "Measurements of Omega and Lambda from 42 High-z Supernovae", ApJ, 517, 565
- Perlmutter S. et al, (1998) "Discovery of a supernova explosion at half the age of the Universe and its cosmological implications", Nature 391, 51.
- Pain R. et al (1996) "The Type Ia supernova rate at z~0.4", ApJ, 473, 356
- Kim A. et al (1996) "Implications for the Hubble constant from the first seven supernovae of z>0.35", ApJ, 473, 356
- Perlmutter S. et al (1997) "Measurement of the cosmological parameters Omega and Lambda from the first 7 supernovae at z>0.35", ApJ, 483, 565

Technical Justification

We intend to use NIRI to observe two supernovae close to peak brightness in the J band, which roughly corresponds to rest-frame V band at the redshift of the supernovae (1.0 - 1.4). Meanwhile rest-frame B-band data, also at peak, will be obtained using HST 850LP observations (and possibly Z-band observations at VLT), so that combining these will determine the rest-frame B-V colour. In addition the full rest-frame U-band light curve will be obtained using HST 814W (76 HST orbits are already allocated for this project). This will be used to determine the shape and time-of-maximum of the lightcurve. By combining these datasets we have all the information necessary to use the supernovae for cosmology.

INSTRUMENT SETUP: NIRI f/6 camera, J-band filter. (The larger field of the f/6 camera gives a better chance of using other objects in the field for relative photometry).

EXPOSURE TIMES: We need to determine the rest-frame B-V colour with signal-to-noise ratio of 10. The noise will be dominated by the J-band (rest-frame V) measurement, and since this will involve subtracting a final J-band reference frame (to be obtained in a future semester) from the at-peak J-band data requested here, the current J-band data must reach a S/N of 14. (Restframe B will be determined to S/N > 20 from HST 850LP and/or VLT Z-band, as mentioned above).

In the J-band, supernovae in the redshift range of interest are predicted to have peak magnitude of J=23.8. To estimate the required exposure time we have used the NIRI ITC with the following assumptions: median image quality (using the PWFS but not the OIWFS since we are using the f/6 camera), median sky transparency, 80%-ile water vapour and sky background, airmass < 1.2. This gives an exposure time of 43800s. Two SNe will therefore require 87600s= 24.3hrs on target.

We request photometric conditions (median sky transparency or better).

OVERHEADS: Following the guidelines on the NIRI web page of 15 mins per new target plus 25% of elapsed time used for offsetting etc, the overheads are 8.6hrs. We include a further 2 hours total to obtain photometric standards to obtain photometric calibration for the two SN fields. Suitable standards will be chosen once the target positions are known. At this stage we include photometric calibration time as an overhead on top of the target exposure times. The total request is therefore 35hrs.

FUTURE TIME: An approximately equal amount of time will be needed in a future semester (2002A) to obtain ‘reference’ images once the SNe have faded. These are necessary for subtraction of the host galaxy light from the supernova photometry. To maximise the effectiveness of our supernova search and follow-up campaigns, we are planning concerted efforts once per year, and will not be applying for Gemini time for this program next semester.

DIVISION OF TIME BETWEEN TACS: This proposal is being submitted on behalf of the Supernova Cosmology Project, and we are also applying for Gemini time for this program via the U.S. TAC (see proposal of Perlmutter et al "Cosmology with High-Redshift Type Ia Supernovae"). We request that the time be divided between the U.K and U.S. allocations in approximately the proportion of partner shares, i.e. 23hrs (US) and 12hrs (UK).

TARGETS: The targets will be discovered using the following procedure. We will obtain reference images just after new moon using the 12x8k camera on the CFHT telescope and the Mosaic camera on the CTIO 4m telescope. Just before the next new moon, we will observe the same fields again, and examine the tens of thousands of high redshift galaxies (z~ 0.3-1.5) to find those showing the new light o a SN that was not there on the previous observation. The search procedure will detect SNe to I=25.2. We have developed extensive software to find and identify these supernova candidates within hours of the observations, so that the photometric and spectroscopic follow-up may begin immediately. We will determine redshifts for around 15 of the faint (likely high-redshift) candidates using the Keck, and from this will select 2 $z>1$ SNe for detailed follow up.

We have regularly demonstrated our ability to find and follow distant supernovae in this way over the last several years (See International Astronomical Union Telegrams and Circulars by the Supernova Cosmology Project in which we have reported more than 100 discoveries of supernovae), including those at the highest redshifts (e.g. sn1998eq at $z=1.2$).

The targets will be found in search fields with declination around 0 degrees, so that they can be observed by telescopes in both hemispheres, and avoiding regions of high galactic extinction. The final selection of fields depends on the dates scheduled for searching.