Advanced Dark Energy Physics Telescope (ADEPT)

Warren Moos, JHU

Daniel Eisenstein, U. of Arizona

January 30, 2007

ADEPT Science Team

Jon Bagger, JHU
Chuck Bennett (PI), JHU
Chris Blake, Swinburne
Dan Eisenstein, Arizona
Harry Ferguson, STScI
Holland Ford, JHU
Karl Glazebrook, Swinburne
Catherine Heymans, UBC
Gary Hinshaw, GSFC
Chris Hirata, Princeton
Warren Moos, JHU
Harvey Mosley, GSFC
Bill Oegerle, GSFC
Adam Riess, JHU
David Spergel, Princeton
John Tonry, Hawaii
Licia Verde, Penn

Overview

- Dark Energy is a scientific mystery that urgently needs better experimental data.
- We will describe the scope of a satellite (ADEPT) that can make major advances in addressing this mystery.

The Dark Energy Puzzle: What is the Nature of Dark Energy?

- **"Is it the unvarying vacuum energy density implied by Einstein's cosmological constant, Λ, introduced to avoid gravitational collapse of the Universe and later discarded when the Hubble expansion was discovered?**

  Or is it a more dynamic energy, changing with time as some cosmic scalar field slowly settles into an equilibrium configuration?"

  Adapted from Physics Today Jan '07 pg 21
- **"To date, attempts to unify General Relativity and Quantum Mechanics have failed. Should one or both be modified? Understanding DE may cut the Gordian knot."**

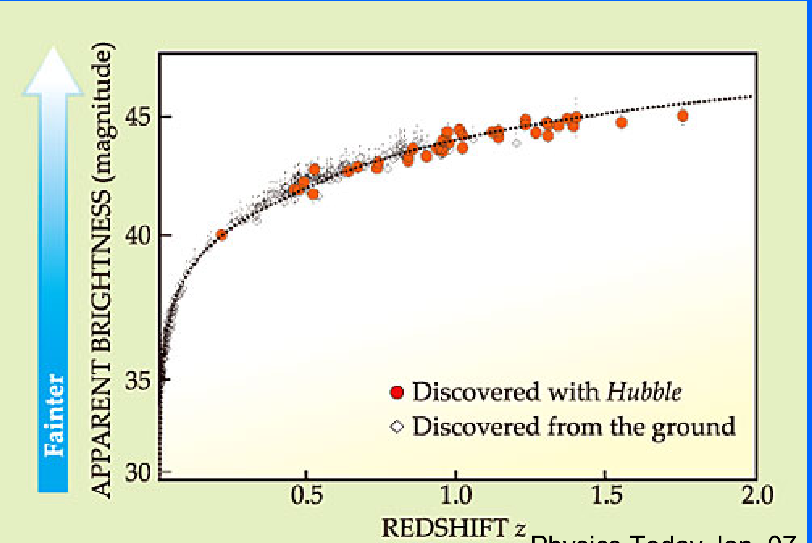
  \- Jonathan Bagger

Dark Energy

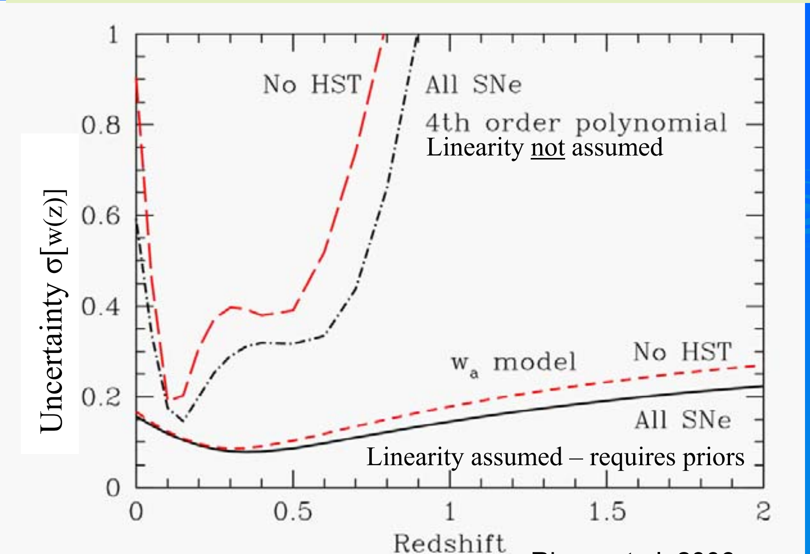
- Dark energy equation of state: $P = w\rho$
- Options have HUGE implications for fundamental physics
  - w=-1 (cosmological constant)?
  - $w = w_0$ (constant)?
  - $w = w(z)$ (not constant) ?
  - *w* is irrelevant, because GR is wrong ?
- Parameterization $w=w_o+w_a(1-a)$ is too simplistic.
- Philosophy
  - We recognize that <u>complementary</u> space-based and ground-based measurements are <u>both</u> needed
  - ADEPT is designed to do from space what needs to be done from space – <u>controls cost</u>

Present Experimental Data Woefully Inadequate

- Fig 1 presents most recent HST data (Riess et al. 2006). Note the importance of high-z points that can ONLY be obtained from space.
- Fig 2. For polynomial fit, **HST=> ~40% improvement, z>0.7**. Even this wonderful data is too limited (only 23 SNe Ia at z>1) to constrain changes in w(z) with z in an important way.

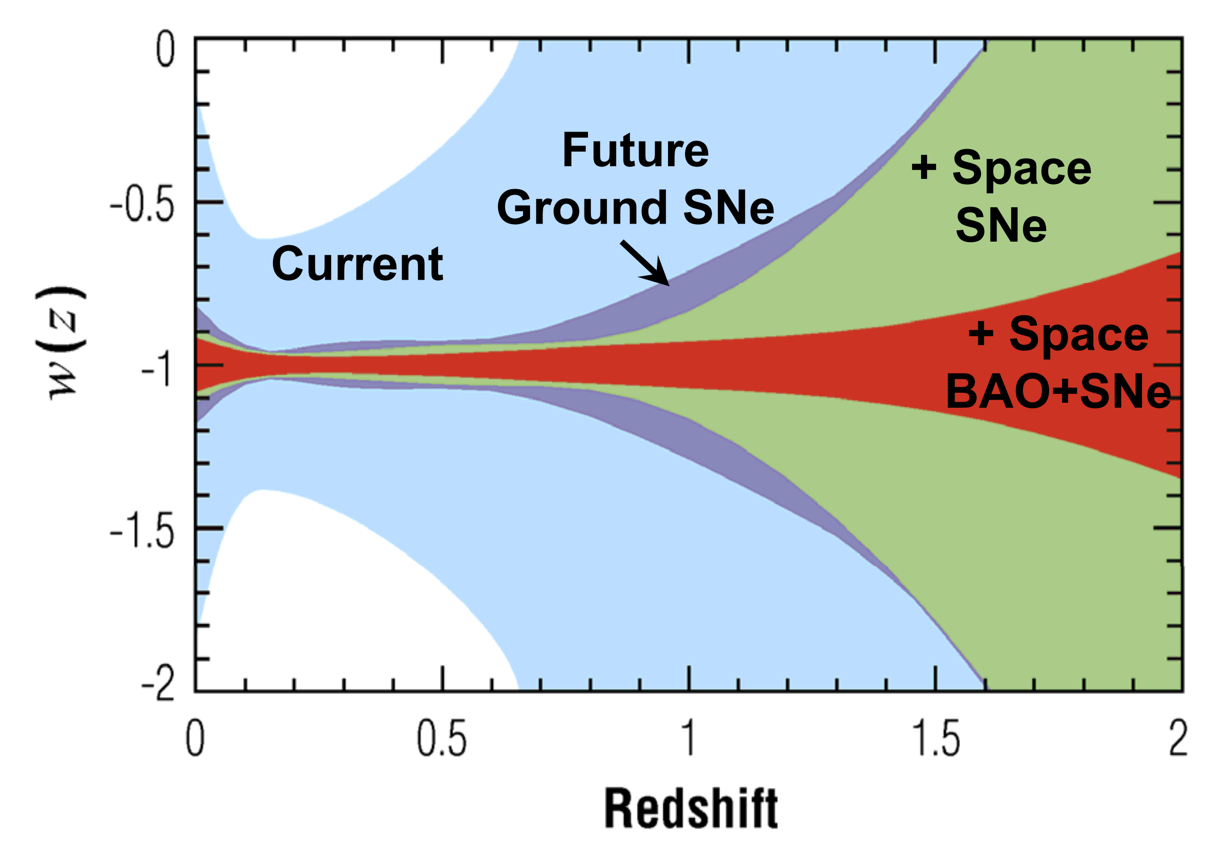


Physics Today Jan. 07



Riess et al. 2006

Limits on *w(z)*



- Markov chains are run with w(z) represented in a 5 parameter quartic polynomial in ln(1 + *z*).

- Ω_m, h, Ω_k, and *w(z)* free to vary, with priors set on $\Omega_m h^2$ (1% precision) and the CMB angular size of the acoustic scale at *z* = 1100.

- Assumes 0.5% SNe distance calibration per Δ z = 0.1 redshift bin.

Baryon Acoustic Oscillation Surveys: Current Results and Future Prospects

Survey[a]	Redshift Range	Sky Area (deg^2)	Millions of Galaxies	Effective Volume[b] (Gpc^3) [c]
ADEPT	$1 < z < 2$	28,600	~100	180
SDSS DR4 Main+2dF	$z < 0.3$	7,000	0.7	0.50
SDSS LRG	$0.16 < z < 0.47$	3,800	0.047	0.52
SDSS-II 8-yr LRG	$0.16 < z < 0.47$	7,600	0.094	1.0
WiggleZ/AAT (220 nights)	$0.5 < z < 1.0$	1,000	0.4	0.64
APO-LSS	$0.2 < z < 0.8$	10,000	1.5	10
FMOS/Subaru (200 nights)	$1.4 < z < 1.7$	300	0.6	0.7
HETDEX	$1.8 < z < 3.8$	250	1.0	2.0
WFMOS/Subaru (150 nights)	$0.5 < z < 1.3$	2,000	2.	3.8
WFMOS/Subaru (150 nights)	$2.3 < z < 3.3$	300	0.6	1.2

Notes to the Table: a. The SDSS surveys in the 2nd and 3rd rows are the only ones completed; the rest are planned or proposed. They are all spectral line surveys. LSST plans a large (~10,000 deg^2) photometric redshift survey, perhaps observing $>10^9$ galaxies at $0.5 < z < 3.5$. The photometric redshift errors would degrade the equivalent effective volume of the LSST survey to < 25 Gpc^3. **b.** Effective volume accounts for the limited sampling of the survey volume due to the discrete number of galaxies as a function of redshift. It is evaluated at the scale of the BAO, $k = 0.15h$ Mpc^{-1}. **c.** Assumes $h = 0.7$.

ADEPT & Ground-Based Measurements

- JDEM is intended to probe dark energy at z>1 with high precision.
- Dark energy is so poorly understood that multiple techniques are mandatory.
  - This drives us to the near-IR
- ADEPT is complementary with LSST.
  - 10^8 spectra are fundamentally different data then 10^9 galaxy shapes.
- The optimistic forecasts for LSST do not reduce our enthusiasm for ADEPT and in fact increase it.

THE ADEPT APPROACH TO PROBING DARK ENERGY

- Use Near Infrared to obtain redshift leverage.

- Baryon Acoustic Oscillations (BAO) measured by a Redshift survey of 100 million galaxies $1 \leq z \leq 2$
  - Slitless spectroscopy 1.3-2.0 μm Hα
  - Nearly cosmic variance limited over ~3/4 of the full sky (28,600 deg^2)
  - Final generation $1 \leq z \leq 2$ BAO measurement

- Obtain Type Ia Supernovae (SNe Ia) for measurements of this standard candle versus red shift.
  - ~1000 SNe Ia $0.8 \leq z \leq 1.3$ with no additional hardware or operating modes

- **This requires a satellite carrying a 1.3 m telescope, and a camera with low resolution dispersion of the image.**

The Power of the ADEPT Approach

- Precision Cosmology Experiment for z>1with a dedicated facility in the spirit of WMAP.
- Deep near IR survey requires the low background of space.
- Stability of the instrument and observing conditions are critical for precision measurements.
- Covers all of the available extragalactic sky. Minimizes cosmic variance.
- A precise slitless spectroscopic redshift survey will measure the acoustic scale transverse and along the line of sight.
  - Cross checking the two allows a built-in cosmological and systematic error check.
  - The slitless approach is the only way to measure so many galaxies and is only possible in the low sky background of space.

Detailed information on ADEPT's science, spacecraft, instrument, and mission design is not releasable given the competitive nature of the JDEM program, proprietary data considerations, non-disclosure agreements, and Federal ITAR restrictions.

An Adequate and Insightful Approach

Characterize missions by approximate Cost and Technical Readiness (TR).

Cost / Technical Readiness Matrix

Cost / Technical Readiness Matrix	High TR	Moderate TR	Low TR
Low Cost < $1B	ADEPT		
Moderate $2B<Cost<$1B			
Hi Cost >$2B			

ADEPT

LAUNCH

- Could launch on Delta II, but it will likely be unavailable >2010
- Current study configuration uses an Atlas V 401 with XEPF fairing
- Mass-to-orbit capability exceeds requirements by factor of ~200%.
  - This eliminates any concerns with regard to LV mass margin.
- Atlas V 401 has a softer ride than Delta II
- A liquid propulsion system not required, avoiding possible jitter from propellant slosh.

ADEPT

LOW EARTH ORBIT

- Circular Sun-synchronous low Earth orbit
- Descending node 6 am local time
- LEO greatly simplifies mission design, comm, and operations
- Eclipse season is very short
  - Single two-month eclipse season per year
  - ADEPT operates through eclipses
- Observatory continuously collects spectroscopic images in multiple pre-determined fields each orbit with inertially-fixed integration times
- Observatory pointing restricted to a cone about the local Earth zenith. Angle between the boresight and the sun vector is also restricted.

ADEPT

OPERATIONS

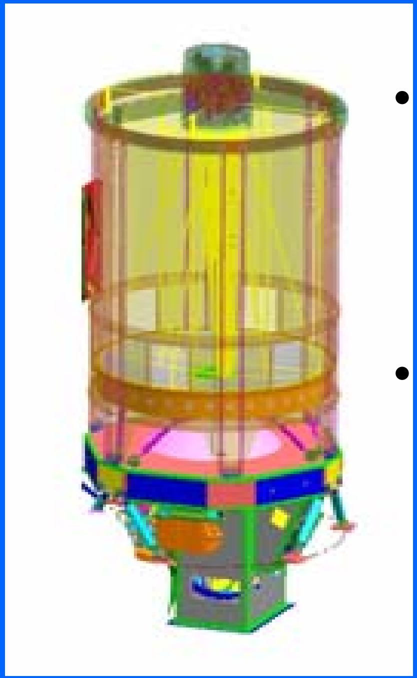
- **Extremely simple**
- Repeated pre-determined observations
  - Command uploads (observation pattern) **only once per week**
  - No real-time observation requirements
  - No need for ad hoc mission planning
  - Many fields observed per orbit with slew (reorientation) between fields
- Two contacts per orbit with polar ground stations for science data return
- Loose requirements on data latency or timing precision
- Ephemeris knowledge accuracy requirement is coarse; only needed for timing ground contacts
- No unusual operations constraints, tracking, or real-time ground support requirements.

ADEPT

READINESS / MATURITY

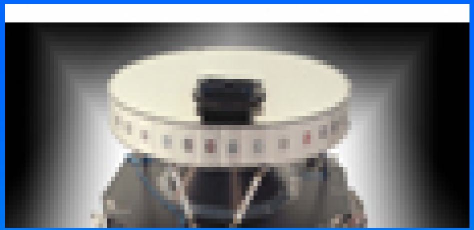
- Highly mature
- No technology development required
  - Almost all components have already been qualified for spaceflight
  - Most have significant space flight heritage
- Designed to be very low risk (technical, schedule, and cost)
- ADEPT slewing and pointing requirements are readily achieved through the use of commercial actuators (wheels), star trackers and inertial reference unit (IRU) with the payload fine error sensor.
- New development items have been avoided as a mission design requirement
- Strong heritage to the GeoEye-1, SWIFT and GLAST designs and JWST detectors.

ITT Leverages GeoEye-1 Payload for ADEPT



ITT GeoEye-1 Payload

- ITT Space Systems Division GeoEye-1 Payload
  - 1.1m Aperture, f/12 System
  - Visible, MSI Imaging Sensor & Electronics
  - 30 Month Design & Manufacturing Cycle
- ITT ADEPT Design Leverages GeoEye-1 Payload
  - 1.3 m Aperture Sharing Similar Design & Components
  - High Stability Optics & Structures
  - Low Technical, Cost, Schedule Risk



ITT GeoEye-1 Mirror Assembly

ITT GeoEye-1 Focal Plane Electronics

ITT GeoEye-1 Structure

TRL 8 Camera Successfully Delivered January 2007

GeoEye-1 (1 of 3)

Expected to Launch in 2007

Delta II 7420-10 from Vandenberg AFB

General Dynamics High-Resolution Earth Imagery Satellite

contract award for S/C and telescope/camera **~ $209 million**

Camera and optical telescope assembly

developed by ITT Corporation (Rochester, NY)

Three-mirror anastigmat telescope with two fold-mirrors

1.1 m clear aperture; 13.3 m focal length

Field of View: > 1.28°

I&T began 1/23/07 with all major components in hand. Launch 3rd quarter '07

Since the GeoEye-1 development is nearing completion, the mission cost is well understood, forming a sound basis for estimating the ADEPT satellite cost.

GeoEye-1 (2 of 3)

- Design lifetime: 7 years in orbit
  - Fully redundant
- Launch Mass: 1955 kg (4310 lbm)
  - Bus Mass: 1260 kg (2778 lbm)
- Orbit: 684 km (369 naut mi) Polar, Sun Synchronous
- Solar Array: Deployable, 7-panel, GaAs, 3862 W EOL
- Data Downlink: 150 or 740 Mbps, X-Band
- Battery: 160 amp-hr NiH2 CPV
- Standard cPCI backplane/bus, RAD750 CPU
  - MIL-STD-1553B data bus
  - 1000 Gbit (1 Tbit) bulk storage for image data, ancillary data, and stored SOH data

GeoEye-1 (3 of 3)

- Attitude control system provides…
  - highly stable pointing
  - highly agile imaging platform
- 3-axis stabilized, (8) high-performance Reaction Wheel Assemblies with Zero Momentum Bias.
- Slewing: to 2.4 deg/sec with acceleration to 0.16 deg/sec2
- Components
  - Dual-head star tracker
  - Scaleable space IRU
  - 10-cell coarse sun sensor
  - (2) GPS receivers
  - (3) EM torque rods, and a TAM
  - Bi-axial gimbal drive for antenna pointing
- Pointing
  - Accuracy (3σ): 75 arcsec
  - Knowledge (3σ): 0.4 arcsec
  - Attitude Jitter: 0.007 arcsec/sec rms (25 - 2000 Hz)

Swift Gamma-Ray Observatory

Launched November 20, 2004
- from Cape Canaveral Air Force Station
- Delta 7320-10
- 3-year lifetime design, 5-year goal
- fully-redundant S/C

General Dynamics designed and manufactured
- ~$40 million contract: spacecraft, Observatory I&T (with GSFC participation), and pre and post launch support through IOC.

Features
- Rapid slew and settle
- 1467 kg (3234 lbm) at Launch
- 2132 W EOL, via two, 3-Panel, Deployed Solar Arrays
- 600 km (324 naut mi) Circular Orbit @ 20.5° Inclination
- Attitude Jitter at Burst Alert Telescope
  - < 0.3 arcsec/sec rms in Pitch & Yaw (10 sec avg)
  - 32 Gbit Solid State Recorder for Science Data Storage

SUMMARY

- Space-based measurements are urgently needed for a better understanding of Dark Energy.
- The ADEPT approach to obtaining this data is low cost with high technical readiness.

Cost / Technical Readiness Matrix	High TR	Moderate TR	Low TR
Low Cost < $1B	ADEPT		
Moderate $2B<Cost<$1B			
Hi Cost >$2B			