DESTINY
Dark Energy
Space Telescope

Dominic Benford
NASA / GSFC
Content of the Universe

- **73%** Dark Energy
- **23%** Dark Matter
- **3.6%** Intergalactic Gas
- **0.4%** Stars, etc.
How Important Is This?

Science's Top Question:

“What is the universe made of? ... what is dark energy? This question, which wouldn't even have been asked a decade ago, seems to transcend known physics more than any other phenomenon yet observed.”
Dark Energy 70% of Universe

Supernova Cosmology Project

Knop et al. (2003)
Spergel et al. (2003)
Allen et al. (2002)

Supernovae

Clusters

No Big Bang

CMB

expands forever
recollapses eventually

flat
closed
open

$\Omega_\Lambda$

$\Omega_M$

0 1 2 3 0

4
Evolution of the Universe

Average Density of the Universe

- **Matter**
- **Cosmological constant**

Density (grams per cubic centimeter)

<table>
<thead>
<tr>
<th>Age (billions of years)</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>First galaxies formed</td>
<td>$10^{-30}$</td>
</tr>
<tr>
<td>Solar system formed</td>
<td>$10^{-29}$</td>
</tr>
<tr>
<td>Now</td>
<td>$10^{-29}$</td>
</tr>
<tr>
<td>Our sun dies</td>
<td>$10^{-29}$</td>
</tr>
</tbody>
</table>
Current Destiny Status

- Awarded JDEM concept study by NASA 8/06
- Pursuing DOE grant to augment NASA grant activities

Teams in place:
- Technical people at Goddard hard at work.
- Science team working on calibration, survey definitions, etc.

Working with industry:
- LMCO for spacecraft
- Goodrich for telescope
- Teledyne for detectors

Target mid-2008 for high-fidelity definition
- Prepared for AO to flight late 2008
DESTINY Facts & Design

• **1.65m telescope at L2**
• **SN1a survey over 3°² - first two years**
• **Imaging Spectrograph with \( \lambda/\delta\lambda \sim 75 \). Over 0.85\( \mu \)m < \( \lambda \) < 1.7\( \mu \)m**
• **WL survey 1000°² - third year**
• **R~5 IR filters for WL survey**
• **Goal of \( w_0 \) to 0.05 and \( w_a \) to 0.20**

• **Heritage: no technology development**
• **Spacecraft, instrument, Cost defined in two independent studies (GSFC & LMCO)**
• **Scientifically unique configuration of proven technology**
Destiny Philosophy

• Do only in space what must be done in space - leverage ground based observations.

• Use the minimal instrument required – maintain high heritage.

• Highly automated survey - no time critical operations.

• All spectra all the time. Complete spectro-photometric time series on all SN events.
# Destiny Science Team

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- **Mike Warren (LANL)**
- **Rogier Windhorst (ASU)**
- **Robert Woodruff (LMCO)**
- **Ann Zabludoff (Arizona)**
DETF Findings

“A mix of techniques is essential for a fully effective [Dark Energy] program.”
**Supernova Hubble Diagram**

**Destiny’s primary survey will leverage the maturity of the supernova standard candle technique (with data from existing supernova studies) to precisely determine the dark energy equation of state.**
Hubble Diagram (diff.)

Relative to Empty ($\Omega=0$) Universe

Relative to Coasting ($q(z)=0$) Universe

$\Omega_M=0.27$, $\Omega_\Lambda=0.73$

"replenishing" gray Dust

$\Omega_M=1.0$, $\Omega_\Lambda=0.0$

High-z gray dust ($+\Omega_M=1.0$)

Evolution $\sim z$, ($+\Omega_M=1.0$)

Constant Acceleration, $q_0=-$, $dq/dz=0$ ($j_0=0$)

Constant Deceleration, $q_0=+$, $dg/dz=0$ ($j_0=0$)

Acceleration+Deceleration, $q_0=-$, $dq/dz=+$

Acceleration+Jerk, $q_0=-$, $j_0=+$

$\Delta(m-M)$ (mag)

$\Delta(m-M)$ (mag)

$0.0$ to $2.0$

$0.0$ to $2.0$

$0.0$ to $2.0$

$0.0$ to $2.0$

$0.0$ to $2.0$

$0.0$ to $2.0$

$0.0$ to $2.0$

$0.0$ to $2.0$

$0.0$ to $2.0$
SN light curves required for “standard candle” use

V Band

-20
-19
-18
-17
-20 0 20 40 60 days

Calan/Tololo SNe Ia

light-curve timescale “stretch-factor” corrected

as measured
Spectra needed for SN redshifts & classification

Spectra of SNe near maximum light (~1 week)

SN 1994D (Ia)

SN 1992H (II)

SN 1994I (Ic)

SN 1998dt (Ib)
Why go to high redshifts?

Dark energy has been well detected at \( z < 0.5 \). To determine what it is – and not just that it is – demands measurements at earlier epochs.
NIR AVAILABLE ONLY IN SPACE

Crucial near-infrared observations are impossible from the ground for the required photometric accuracy

- Sky is very bright in NIR: >100x brighter than in visible
- Sky is not transparent in NIR: absorption due to water is very strong and extremely variable

Data from Gemini Observatory & ATRAN: Lord (1992)
ACS Grism Images of SN2002FW (z = 1.30)

Riess et al. (2004)
Riess et al. (2004)
ACS grism spectra of
z ~ 1.3 SN Ia
Supernova Observations

1. Broadband: locate SN & host galaxy
2. Dispersed: spectral time series
3. Difference & extract SN spectrophotometry
Survey area is a contiguous Mosaic of Destiny FOVs. Orientation rolls by 90° every 3 months. Dithering will fill in chip gaps and ensure Nyquist sampling.
**Sn Photometric Calibration**

- Obtain high fidelity external and internal flats in ground tests.
- Monitor with internal flats on orbit, plus field stars.
- Absolute photometric calibration with DA white Dwarfs.
- Sn spectra isolated with differencing. Ad hoc spectral flat extracted from data cube of monochromatic flats.
**Supernova Spectra**

- **Simultaneous spectrum & photometry = redshift & brightness**
- **Redshift from 615nm SiII line**
- **Equal precision & more accuracy than broadband filters alone**
Supernova Light Curves

- **Always get photometry around maximum light**
- **Sample every 5 days**
- **SN Ia are “most direct & precise approach” to study Dark Energy**
Supernova Survey

- Present day & ongoing surveys find hundreds
Supernova Survey

- Present day & ongoing surveys find hundreds
- Destiny will find >3000 SN in 2 yrs.
- Most at z~1; requires 3.2 deg² survey area
- Destiny does 0.4 < z < 1.7 - combine with ground over 0 < z < 0.8
- Goal: 100 SN Ia in each Δz = 0.1 bin
What IS Weak Lensing?

In weak lensing, we measure the shapes of galaxies.

Dominant noise source is the random intrinsic shape of galaxies.

Large-N statistics extract lensing influence ("shear") from intrinsic noise.
Dark Energy and Weak Lensing

Dark Energy equation of state:
\[ w = \frac{p}{\rho} \quad (w = -1 \text{ for } \Lambda) \]

Modifies:
- Angular-diameter distance
- Growth rate of structure
- Power spectrum on large scales

\[ \rightarrow w \text{ can be measured from the lensing power spectrum} \]
Destiny Performance
Ongoing Work Continues to Refine DE & Cosmological Parameters

Preliminary results from ESSENCE are Consistent with $w = -1$
Understanding Dark Energy

![Graph showing various dark energy models with different values of \( \Omega_N = 0.8 \), \( \Omega_N = 0.6 \), \( \Omega_M = 1 \), and \( \text{SUGRA potential} \). The graph compares the magnitude difference from a flat, \( \Omega_N = 0.7 \) model with various potential models such as Albrecht & Skordis potential, exponential tracker potential, two D3-Brane potential, double exponential potential, pure exponential (fine tuned), periodic potential, inverse tracker potential, and Pseudo-Nambu-Goldstone Boson (example). The graph is based on Weller & Albrecht (2001).]
Destiny will conduct a Weak Lensing survey as an independent, complementary technique for increased accuracy and precision on the determination of the dark energy equation of state.
Predicted Survey Results

Assuming a Flat Universe
Predicted Survey Results

Not Assuming a Flat Universe

See Knox, Song & Zhan 2006
Destiny Design
**Science Goals**

- **To Characterize and Constrain the Nature of Dark Energy**
  - Determine the expansion history of the Universe to 1% accuracy over the past 10 billion years of cosmic history, constraining the equation of state constant term $w_{\text{de}}$ to within 0.05 and its time derivative $\dot{w}_{\text{de}}$ to within 0.20.
  - Obtain precise photometric light curves and redshifts of $>3000$ Type Ia supernovae to provide luminosity distances with sufficient statistics ($>100$ SN) in each $\Delta z\sim 0.1$ bin over the redshift range $0.4 < z < 1.7$.
  - Combine Destiny constraints with results from other ground-based and space-based techniques.

**Science Investigation**

- Measure photometry of SN Ia in four $R$–$5$ band-passes with S/N $>7$ to 20 days (rest frame) after maximum. Each point on light curve from 8 hrs or less of exposure time.
- Measure redshifts of the SN to an accuracy of $\Delta z\sim 0.005$.
- SN Ia occur at the rate of $1.5\times10^4$ Mpc$^{-3}$ yr$^{-1}$ at $z \sim 1$. Repeatedly monitor $\sim 3$ sq-deg with $\sim 5$-day cadence to detect SNe and measure their light curves and redshifts. The 3 sq-deg survey is split into two sky regions of $\sim 1.5$ sq-deg near the NEP and SEP.
- Use 1 broadband imaging filter and grism to obtain precise positions, photometry, galaxy morphology, redshifts, and SN type.

**Measurement Capabilities**

- **Primary Mirror $\sim 1.65$ m**
  - **Field of View and Image Scale:**
    - Angular Resolution
      - Diffraction-Limited at $1\mu$m to $1.2\lambda/D = 0.15$ arcsec
    - **Image Scale**
      - $0.15$ arcsec/pixel
    - **Science Field of View**
      - $0.12$ square-degrees
    - **Fine Guidance FoV**
      - $100$ square-arcmins with $0.15$ arcsec/pixel scale
  - **Broadband Near-IR Imaging Filter:**
    - $R \equiv \frac{\lambda}{\Delta \lambda} = 5$
    - J-Band Filter centered at 1250 nm
  - **Low-resolution Near-IR Spectroscopy:**
    - Spectral Resolving Power $R = 75$ at $1.2\mu$m
  - **Minimum Wavelength Coverage**
    - 850–1700 nm

**Implementation**

- **Optics**
  - 1.65 m monolithic PM
  - Three-mirror anastigmatic Telescope
  - High reflectance coatings (e.g., protected Ag or Au)
  - High throughput imaging filter and grism/prism
  - Low scatter dispersive optic
- **Detectors**
  - 16.2kx2k format 1.7 $\mu$m cut-off HgCdTe detectors
  - 3- or 4-edge buttable
  - $>80\%$ QE over bandpass, optimized AR coatings
  - $>20$ krad radiation tolerance
- **Miscellaneous**
  - Mission lifetime: 3 years
  - Fine pointing/correction 10 mas (1\sigma), using guide camera 10 Hz feedback
  - 37 GBytes/day raw data, 1:8:1 compression, Ka-band downlink
**Science and Instrumentation**

- **Destiny SN survey** motivated by unique role of an NIR space telescope for observing SN Ia at $z > 0.8$.
- **All spectra all the time** gives a rich data set that allows for future developments of SN Ia’s as standard candles. Minimizes mission complexity.
- **WL survey** uses sharp and stable PSF; NIR for depth.
- **Instrument follows from HST/WFC3, JWST/NIRCAM.** Its unique aspect is the large mosaic of H-2RG SCAs.
- **Analysis techniques** well understood for both SN and WL observations.
- **Absolute Photometric calibration of SN survey data** is a challenge and a major part of our present study.
Mission Design / Operations

- **SN and WL survey fields located near both ecliptic poles. No targeting or acquisition of specific objects.** Highly automated and repetitive “blank sky” surveys.

- **No real-time or time-critical operations required as part of SN or WL surveys.**

- **Steady-state operations mainly comprises monitoring of data stream, spacecraft health, occasional maintenance (angular momentum dumps, orbit stabilization).**

- **Location at Sun-Earth L2 gives stable spacecraft and simple operations.**

- **Delivery to L2 can be done with Atlas V (401) with ample mass margins.**
Performance Requirements

- **Survey time:**
  SN: 2 yrs; WL: 1 yr

- **Survey areas:**
  SN: 3.2 deg²; WL: 1000 deg²

- **Science FOV:**
  0.18° x 0.72°

- **0.85μm < λ < 1.7μm**
  \( \therefore 0.4 \leq z \leq 1.7 \)

- **\( \lambda / \Delta \lambda = 75; R = 5 \) NIR broadband filters**

- **Resolution:** 0.13″

- **Pointing:** 0.01″

- **Stability:** 0.01″ / 900s

- **13 GB / day**

- **Thermal control:**
  passive; FPA 150K
PAYLOAD LAYOUT

DESTINY PHILOSOPHY: TECHNICAL FEASIBILITY AND A SIMPLE, LOW-COST APPROACH WITH HIGH HERITAGE.
Optical Design

- **1.65m primary, ULE glass**
- **Three-mirror anastigmat**
- **Movable secondary**
- **FOV for surveys is 0.72°x0.18°; well-corrected diameter of 1.15°**
- **Filter wheel with disperser & broadband filters**
Focal Plane Layout

- **Science FPAs:**
  - 2k x 2k arrays,
  - 2 x 8 mosaic

- **Guide FPAs:**
  - 2k x 2k arrays,
  - 2 x 2 sparse mosaic
## Detector Arrays

Existing technology can meet requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rockwell H2RG</th>
<th>Raytheon VIRGO</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{\text{dark}}$ ($\lambda_C=1.7,\mu m$)</td>
<td>0.1 e$^-$/s at 145K</td>
<td>0.1 e$^-$/s at 139K</td>
</tr>
<tr>
<td>Read noise, CDS</td>
<td>15 e$^-$ (Loose et al. 2003)</td>
<td>15 e$^-$ (McMurtry et al. 2005)</td>
</tr>
</tbody>
</table>
Mission Parameters

- Mass: 1972 kg (wet)
- Power: 785W
- Size: 4.4m x 2.5m
- Data: ~13 GB/day
- Launch: Atlas V 401
- Location: L2
- Timeline: 2013
Spacecraft Implementation

• **Two independent Design studies: 1) GSFC/IMDC 2) LMCO; derive similar spacecraft parameters and cost**

• **High maturity, high Heritage, TRL 7 or greater for all subsystems**

• **No significant risks**

• **No new spacecraft technology**

• **High stability is demanded --> Precise pointing control.**
Launch Around 2013

~1,500,000 km

~340,000 km

-1,500,000 km
Mission Operations / Data Flow

50 Mbps Ka-Band,
2 kbps S-Band TLM
2 kbps S-Band CMD
S-band ranging

Deep Space Network
34M

50 Mbps Ka-Band
Science & HK
CMD (S-Band Ranging)

DESTINY S/C

TDRSS

SSA
2 kbps TLM
1 kbps CMD
Launch & Early Orbit Operations Only

Mission Ops Center

White Sands Complex

Science Ops Center (STScI)

Destiny Science Analysis Center (LANL)

Astronomical Community

HK = House Keeping Data
CMD = Commanding
TLM = Telemetry
LANL = Los Alamos National Lab
STScI = Space Telescope Science Institute

(HK & Science) 6.2 Mbps
(4 T1 Lines)
CMD (Real-Time & Stored)

Level 0 Data
Coordination

Level 2 Data
Level 3 Data

CMD
HK
Closing Remarks

• Team is engaged in advancing Destiny as a lost-cost but realistic JDEM.

• Current tasks:
  – Serious engineering work
  – Refined science simulations

• Making substantial progress.
DESTINY