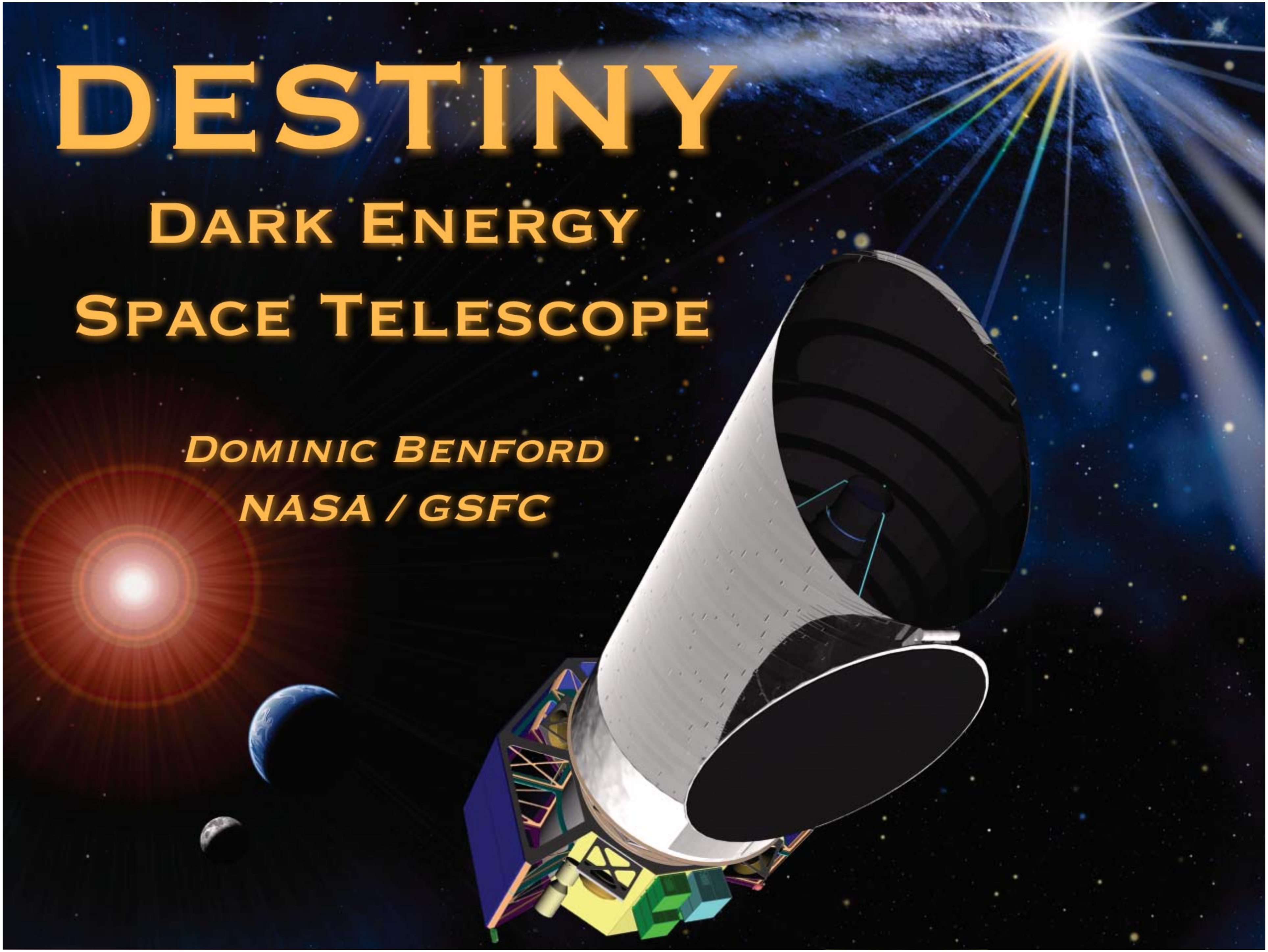
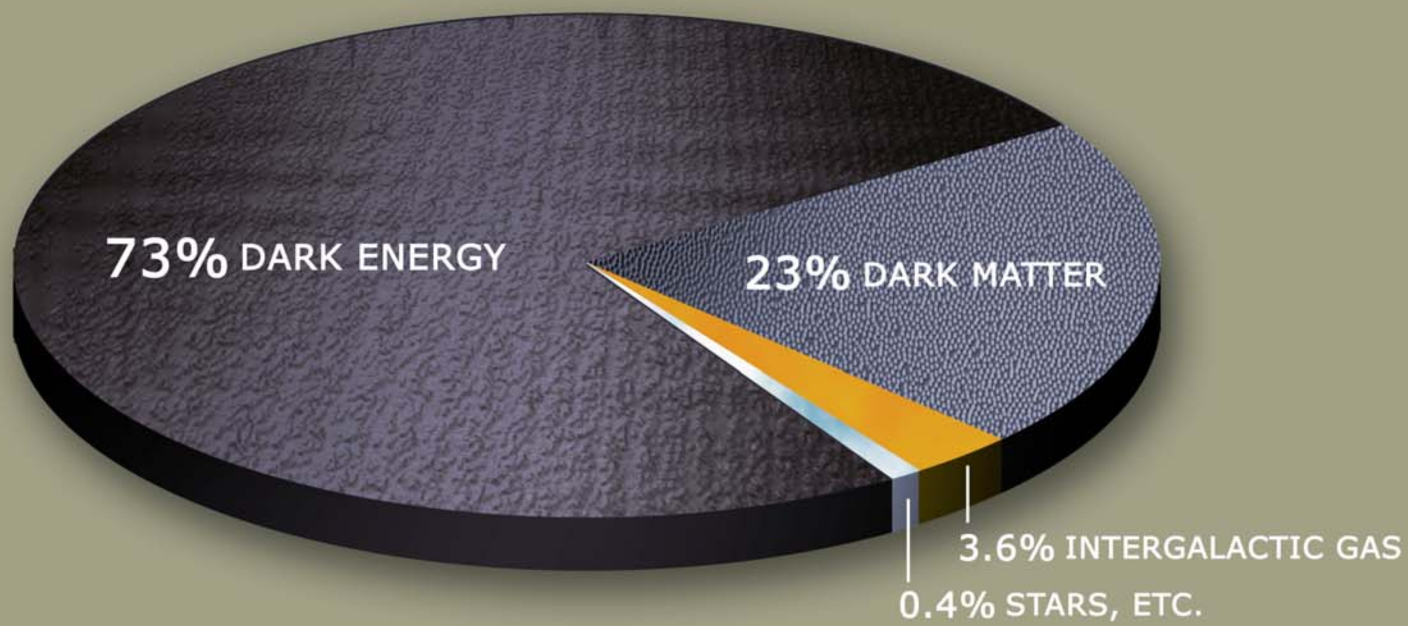
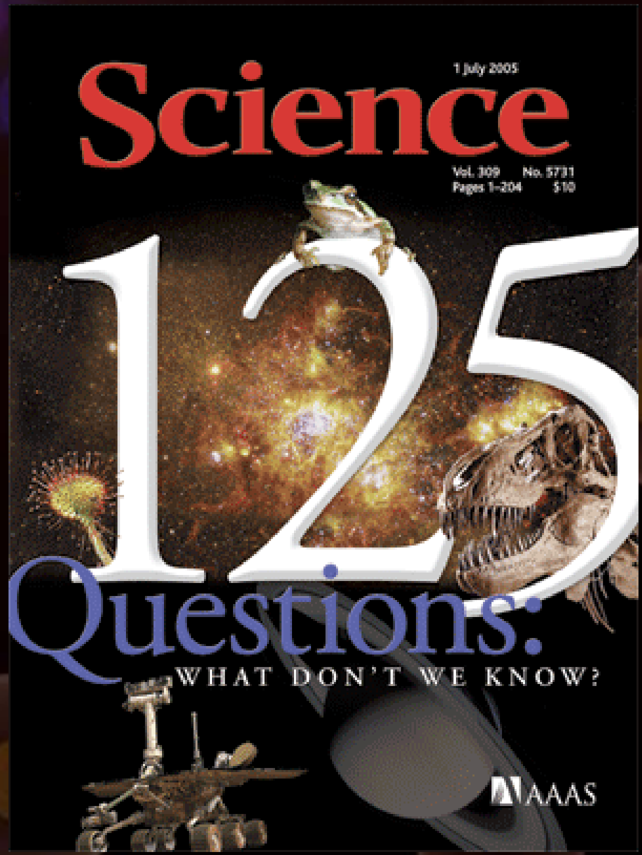

DESTINY
Dark Energy
Space Telescope
Dominic Benford
NASA / GSFC

Content of the Universe



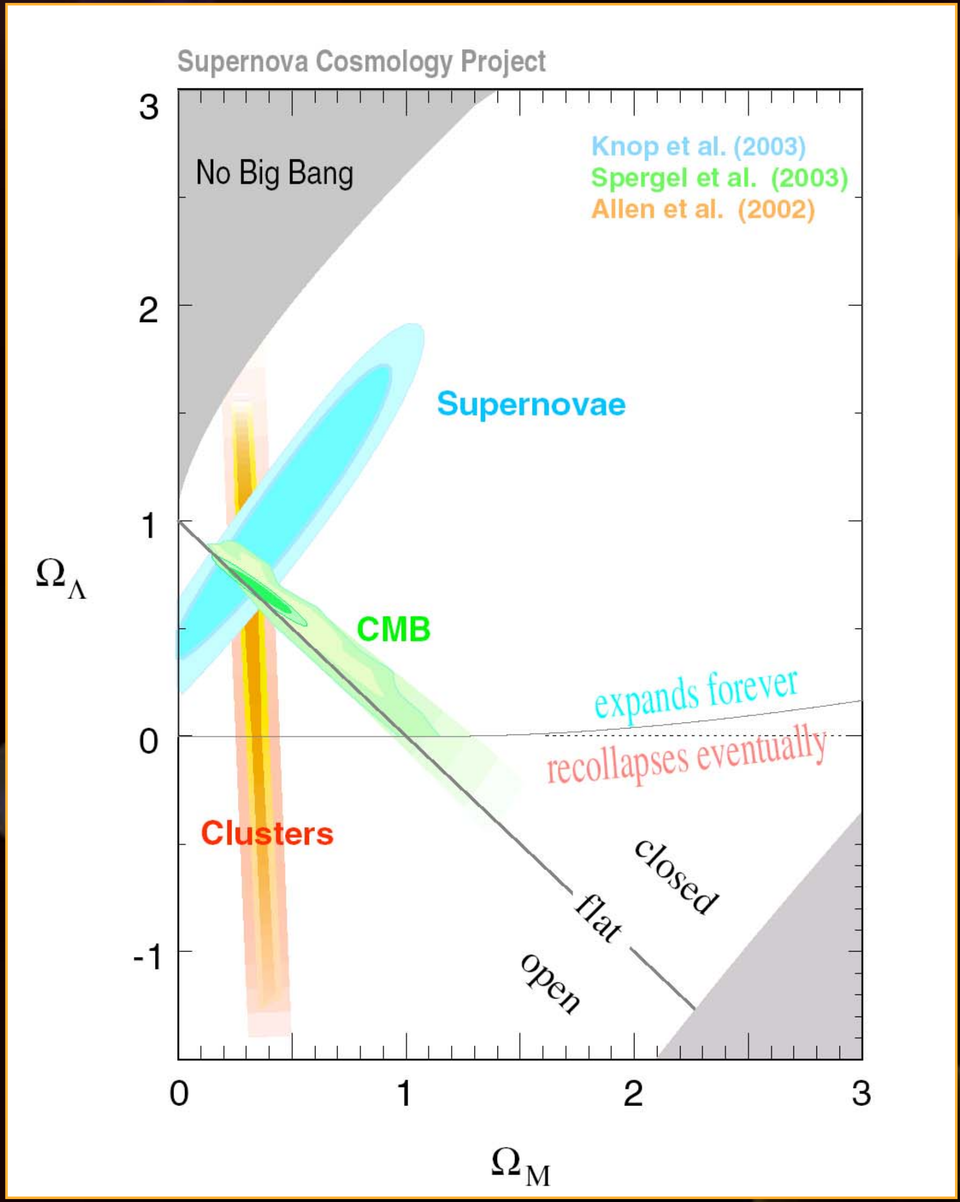
How Important Is This?



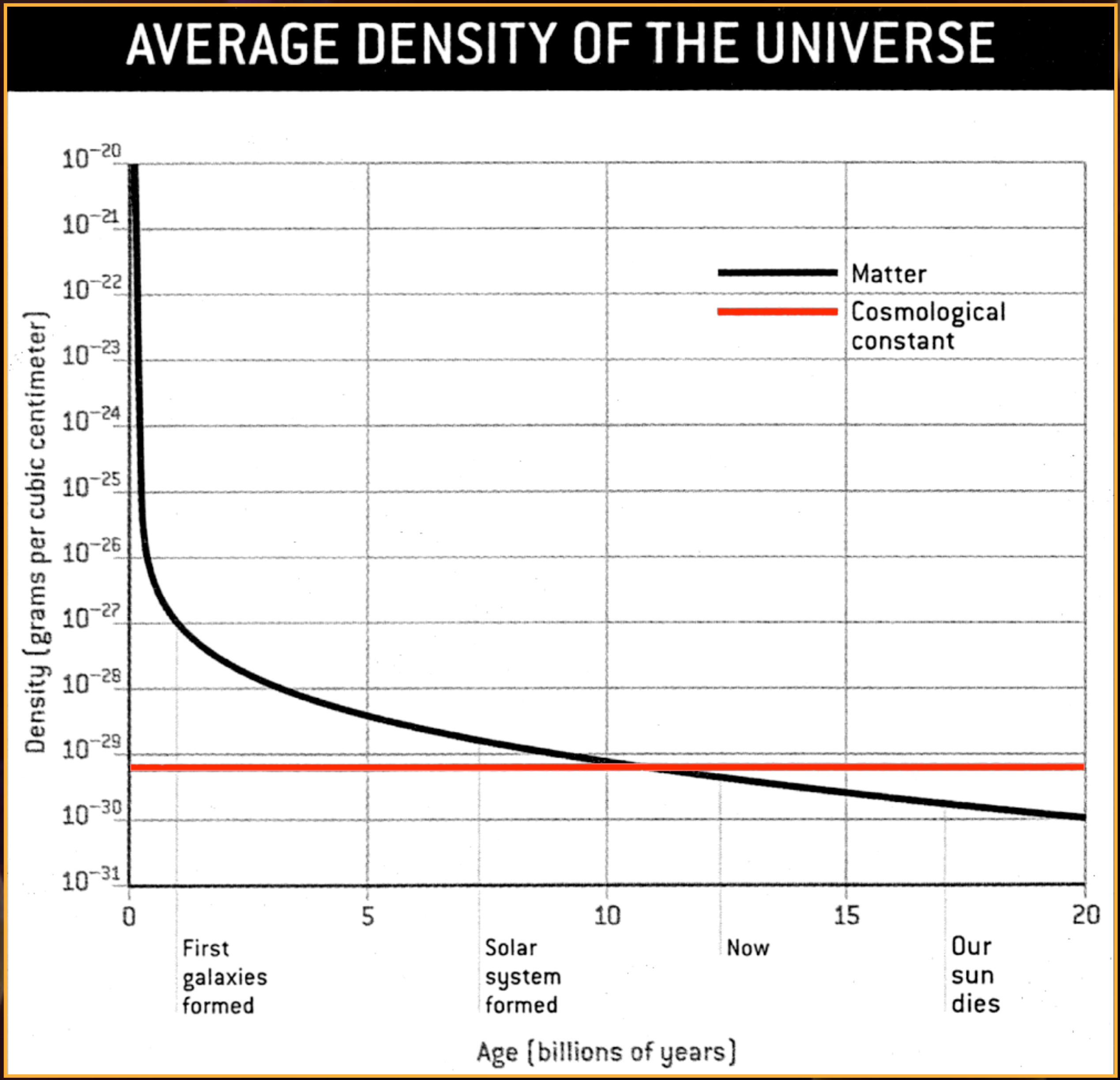
Science's Top Question:

"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



Evolution of the Universe



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

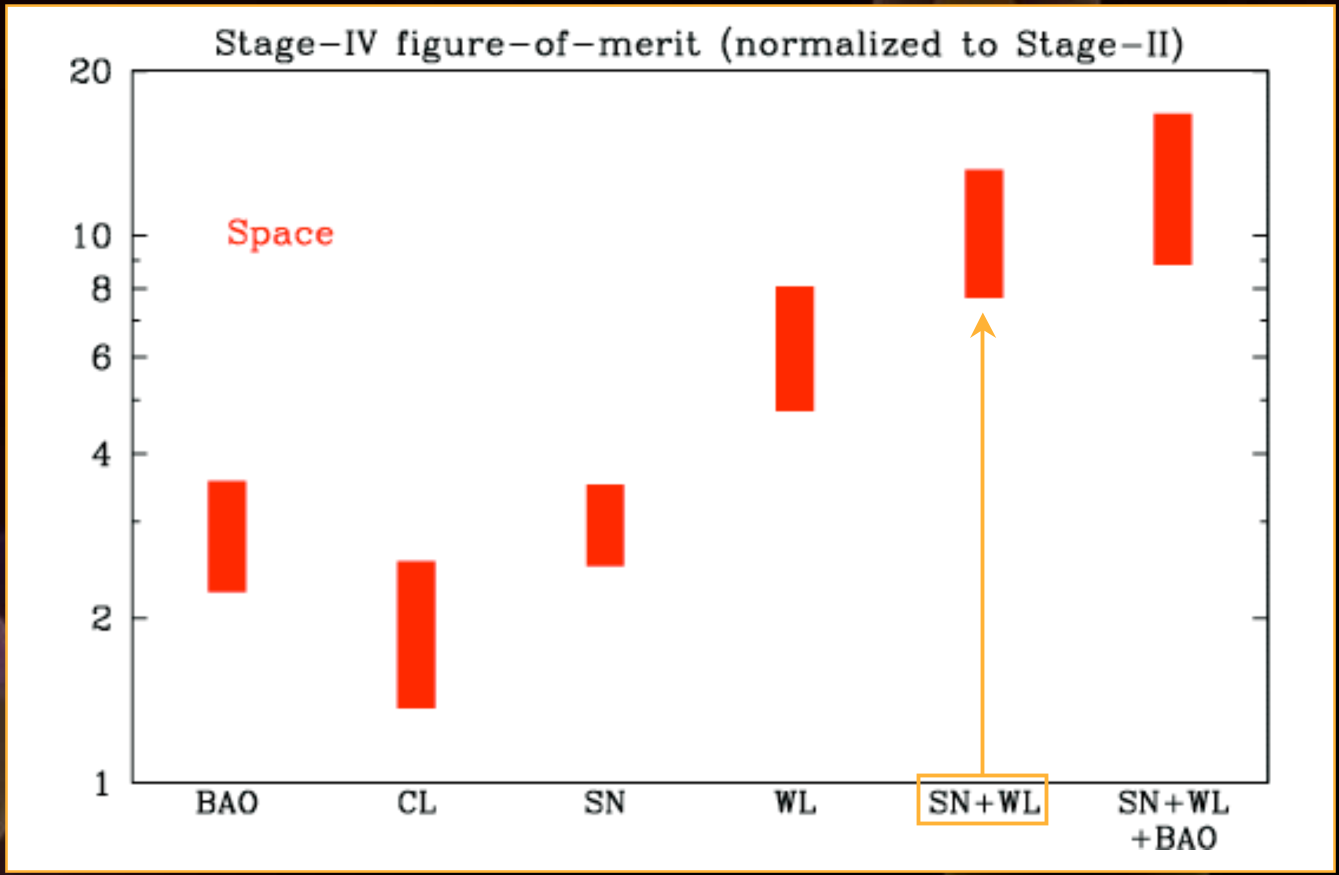
PI: Tod R. Lauer (*NOAO*)

Deputy PI: Dominic Benford (*GSFC*)

Matthew Beasley (*Colorado*)
Chris Burns (*OCIW*)
Kenneth Carpenter (*GSFC*)
Doug Clowe (*Ohio U*)
Ian Dellantonio (*Brown*)
Megan Donahue (*MSU*)
Chris Fassnacht (*UC Davis*)
Wendy Freedman (*OCIW*)
Chris Fryer (*LANL*)
Jay Holberg (*Arizona*)
Aimee Hungerford (*LANL*)
Robert Kirshner (*Harvard*)
Lloyd Knox (*UC Davis*)
Lori Lubin (*UC Davis*)
Sangeeta Malhotra (*ASU*)
Tom Matheson (*NOAO*)
Phillip Pinto (*Arizona*)
Marc Postman (*STScI*)
James Rhoads (*ASU*)
Yong-Seon Song (*Chicago*)
George Sonneborn (*GSFC*)
Sumner Starrfield (*ASU*)
Nicholas Suntzeff (*TAMU*)
Frank Timmes (*LANL*)
Thomas Vestrand (*LANL*)
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."




SUPERNOVAE
Ia
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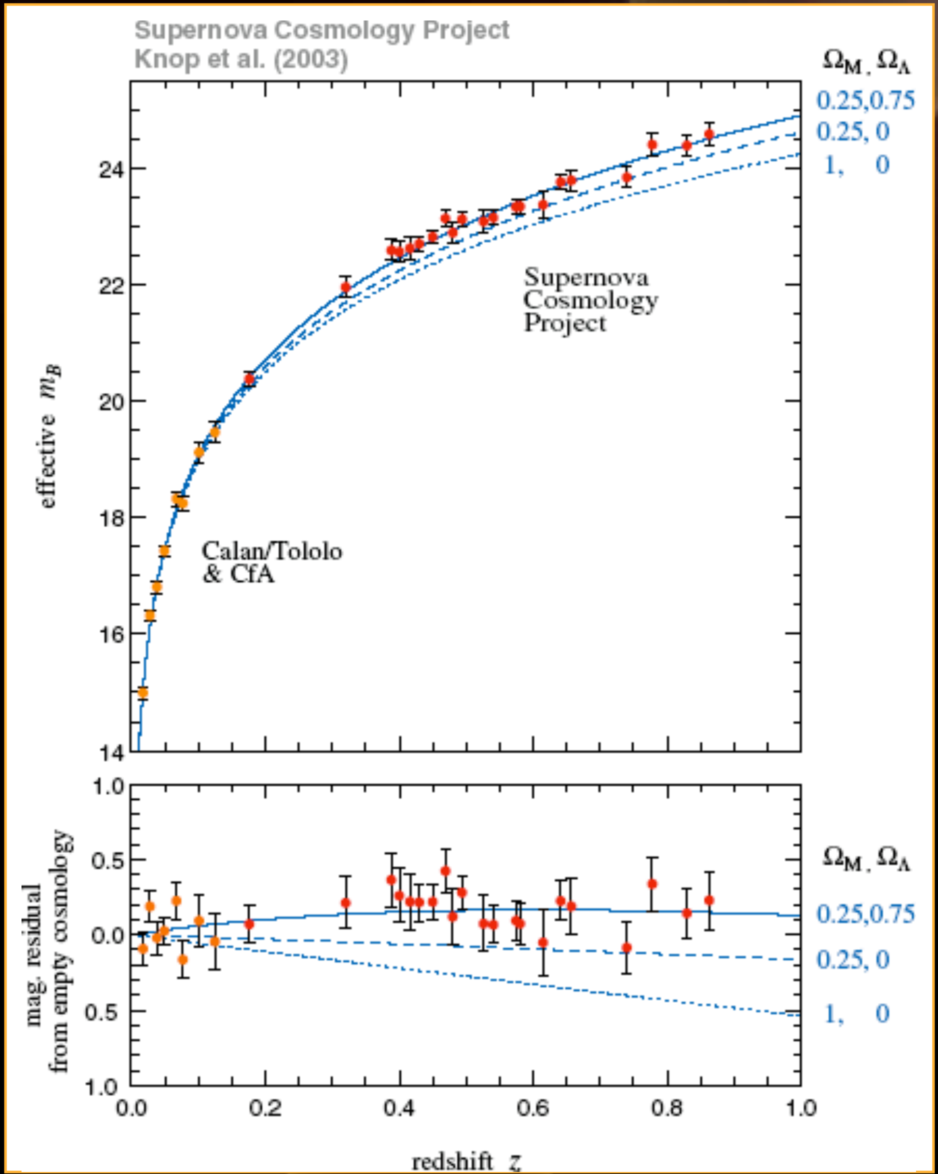
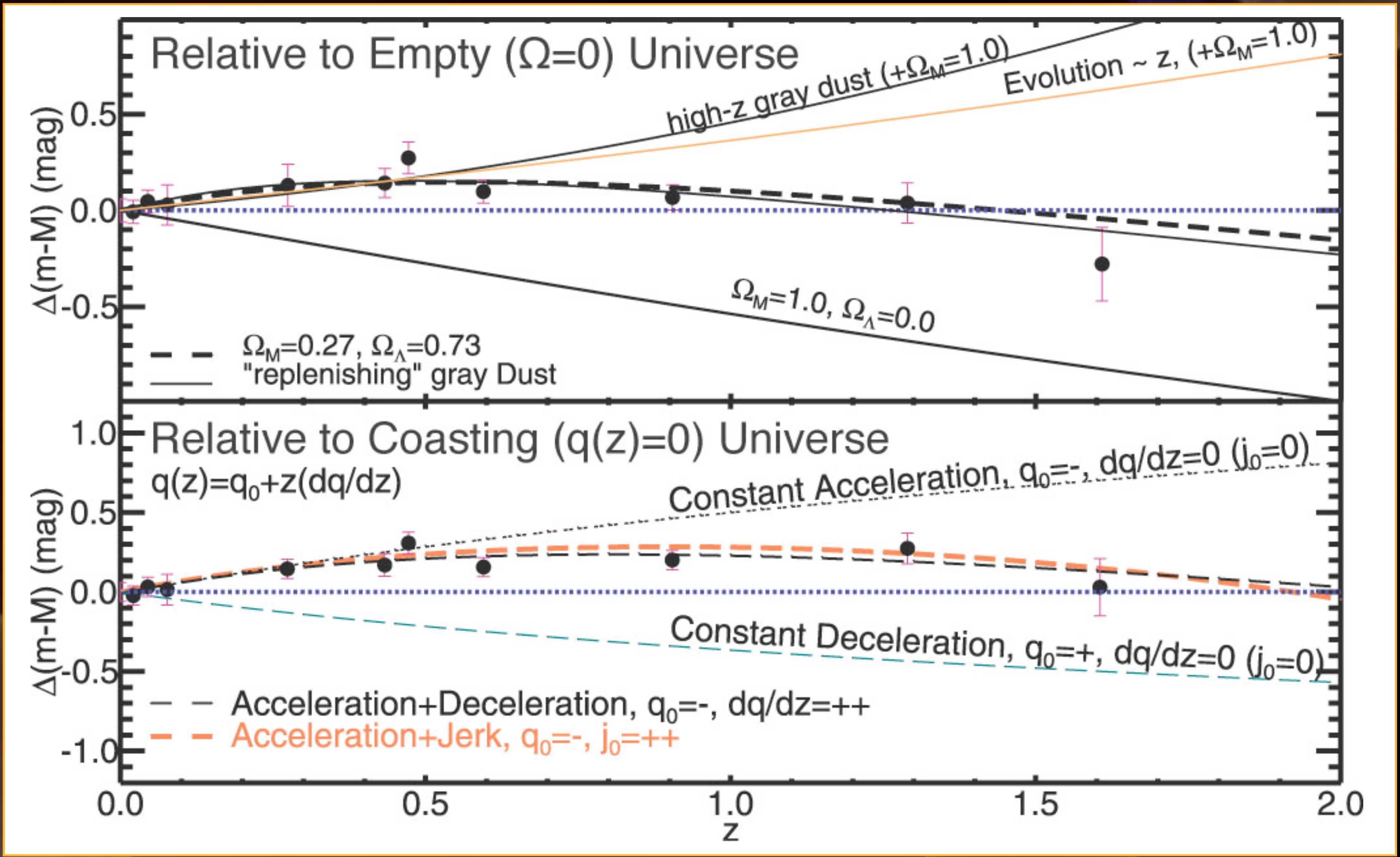
Supernova Hubble Diagram

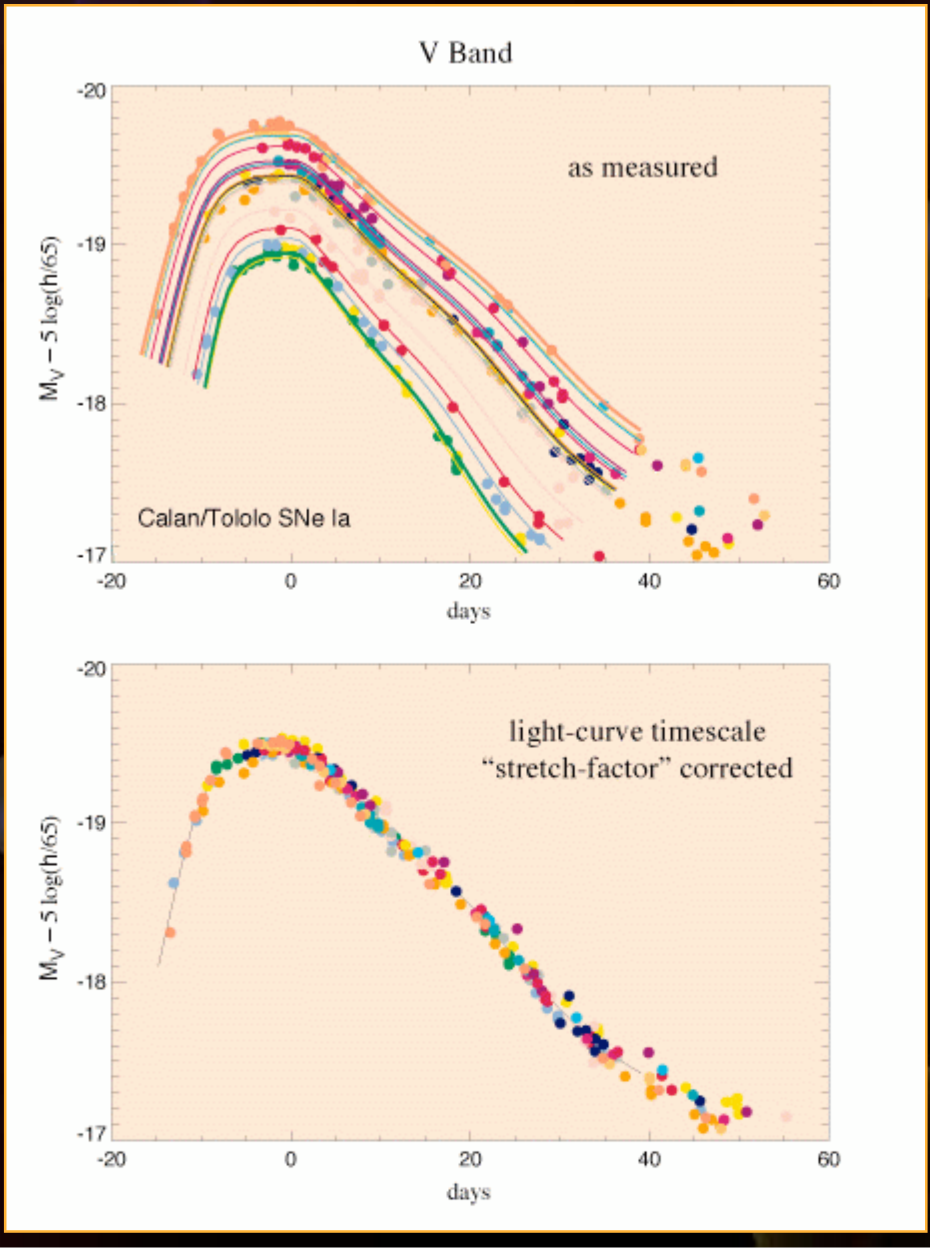
Destiny's primary survey will leverage the **maturity** of the supernova standard candle technique (with data from existing supernova studies) to precisely determine the dark energy equation of state.



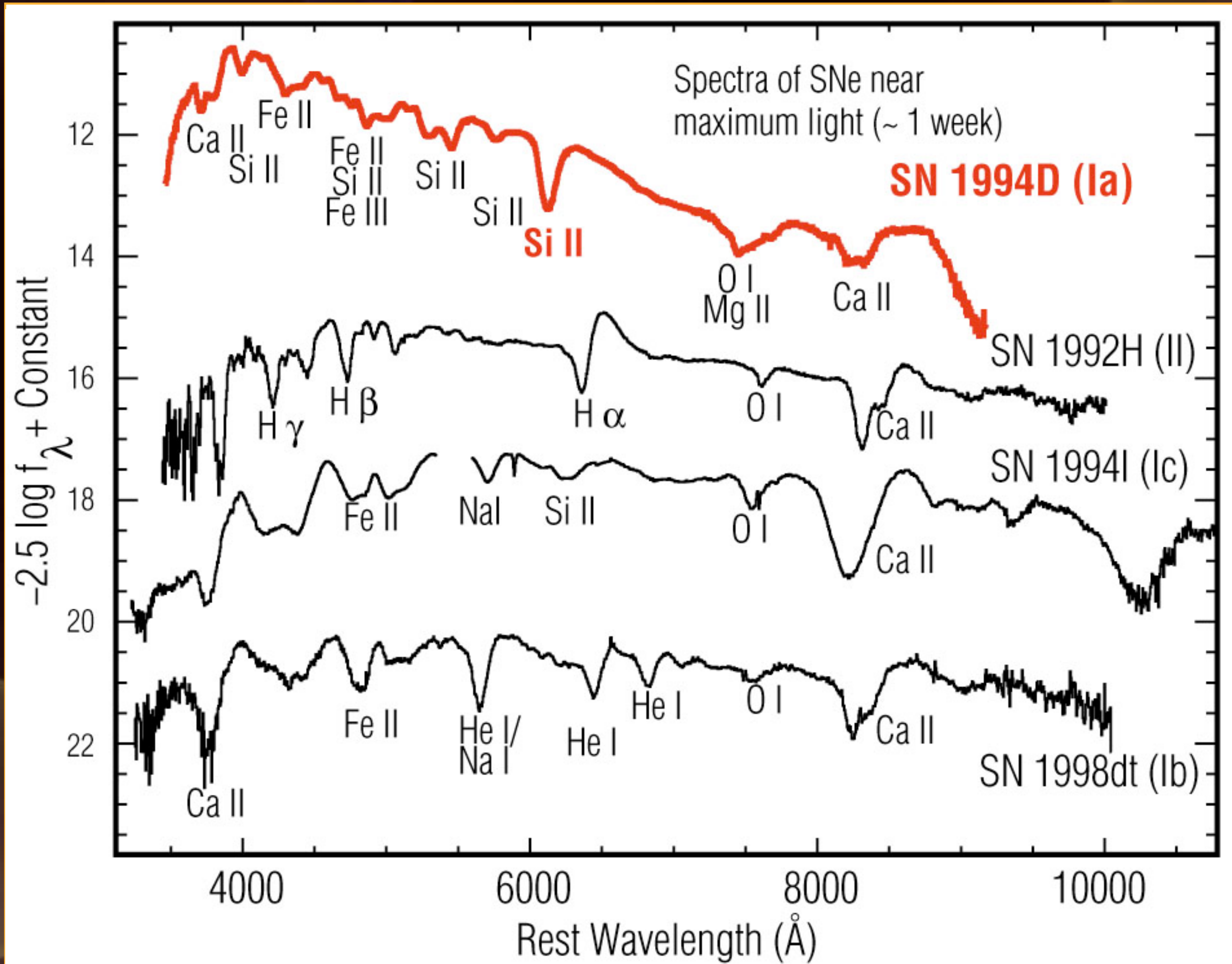
Hubble Diagram (diff.)



SN light curves required for "standard candle" use

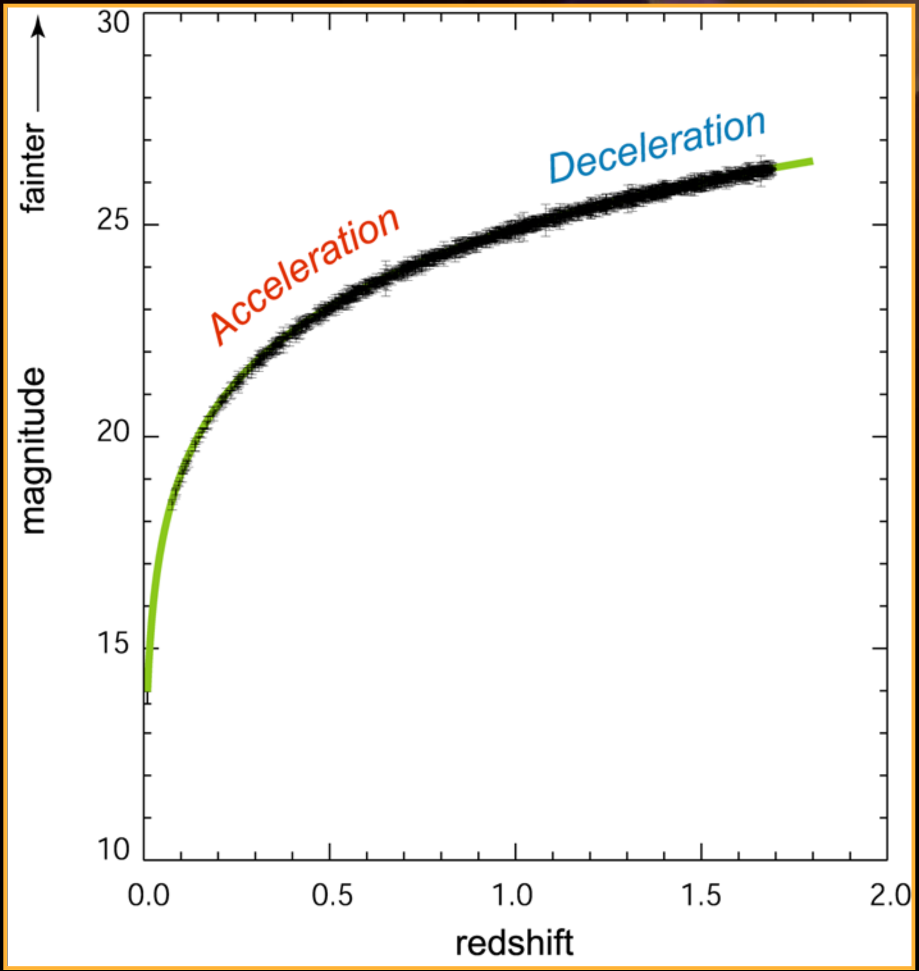


Spectra needed for SN redshifts & classification



Why go to high redshifts?

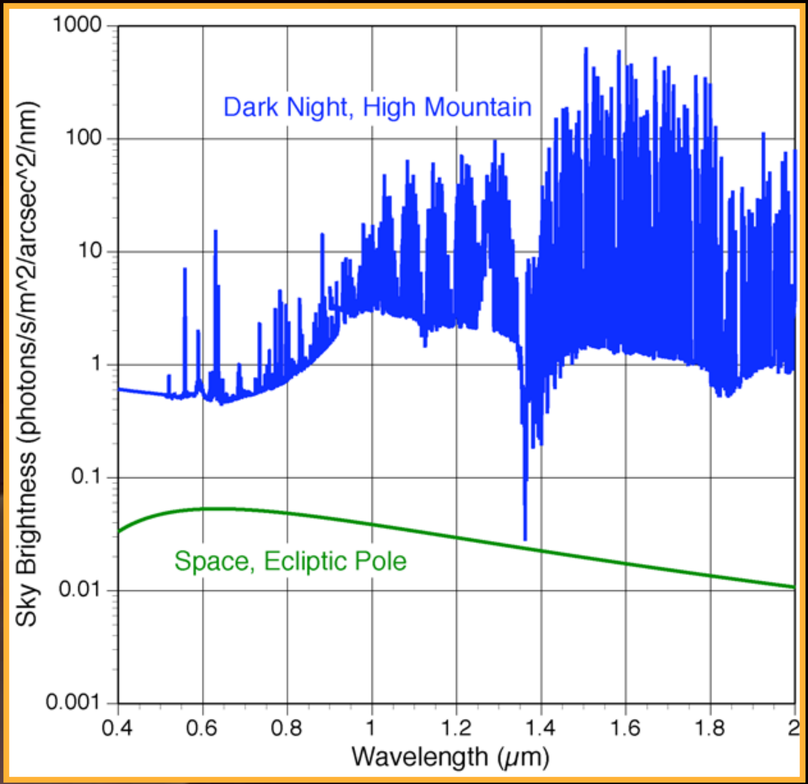
Dark energy has been well detected at $z<0.5$. To determine what it is – and not just that it is – demands measurements at earlier epochs.

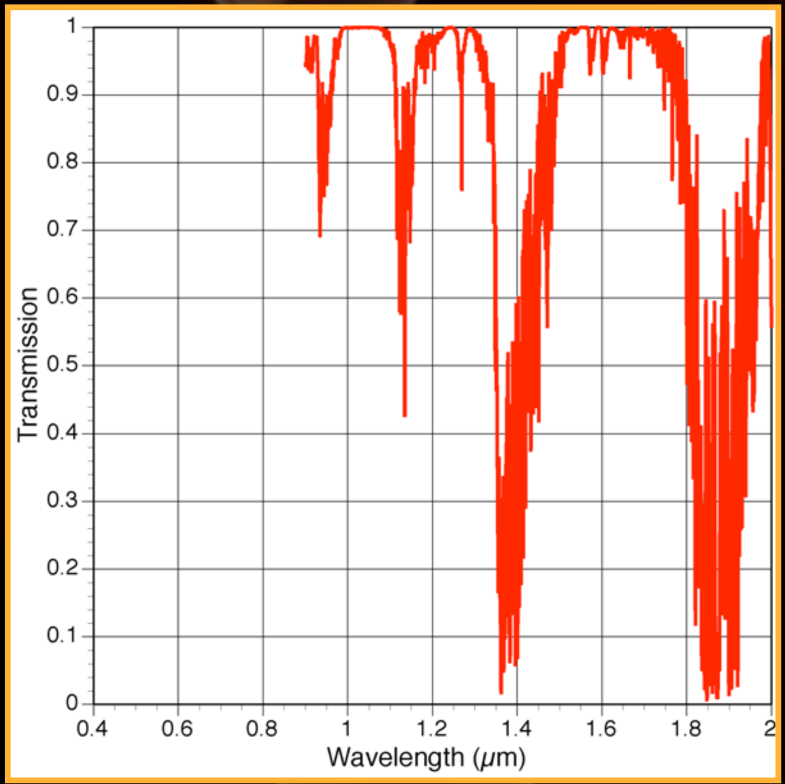


NIR available only in space

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

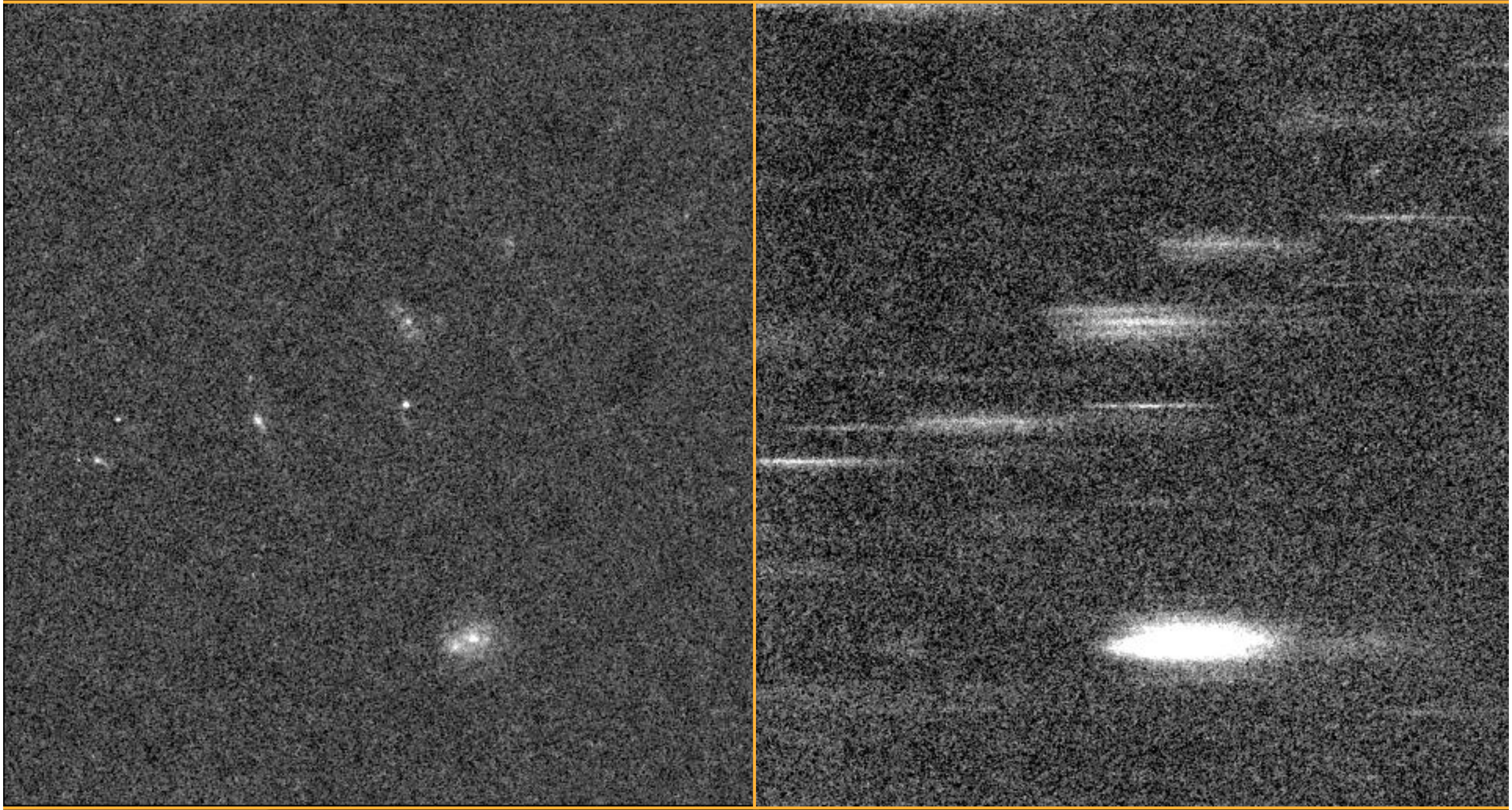
- Sky is very bright in NIR: >100x brighter than in visible
- Sky is not transparent in NIR: absorption due to water is very strong and extremely variable





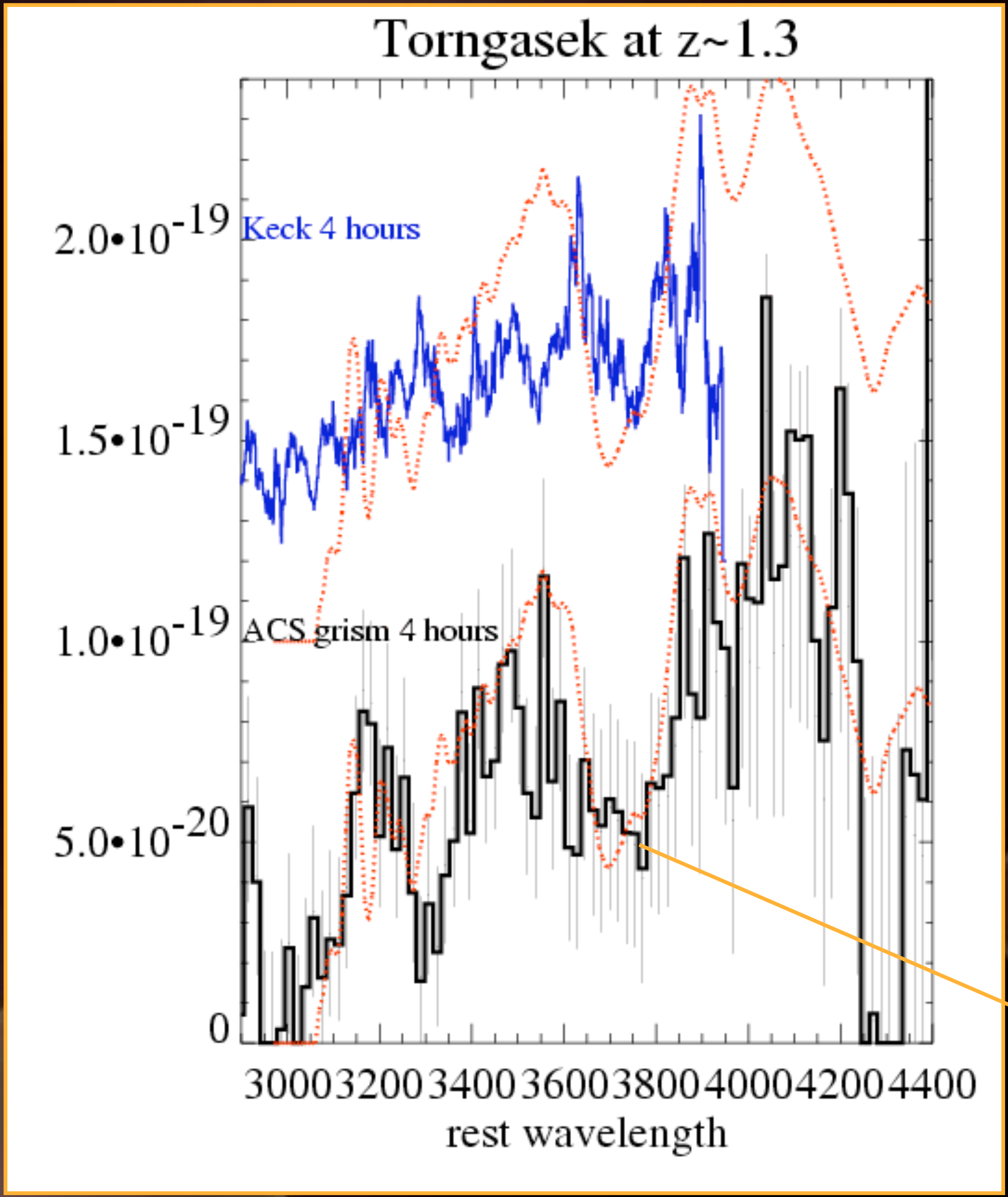
Data from Gemini Observatory & ATRAN: Lord (1992)

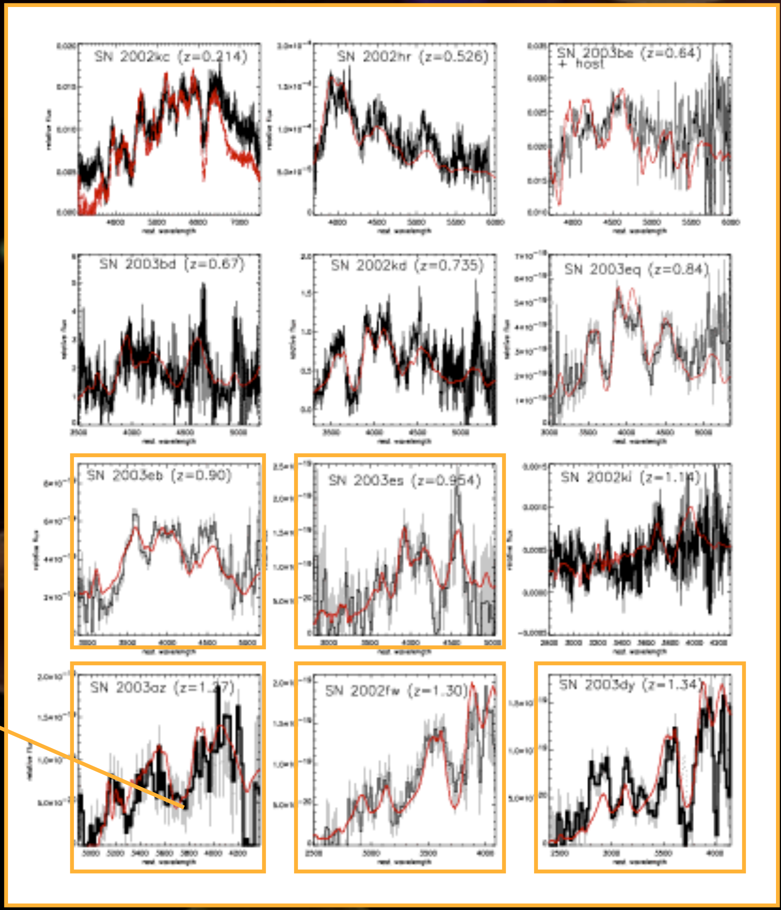
ACS Grism Images of SN2002FW (z = 1.30)



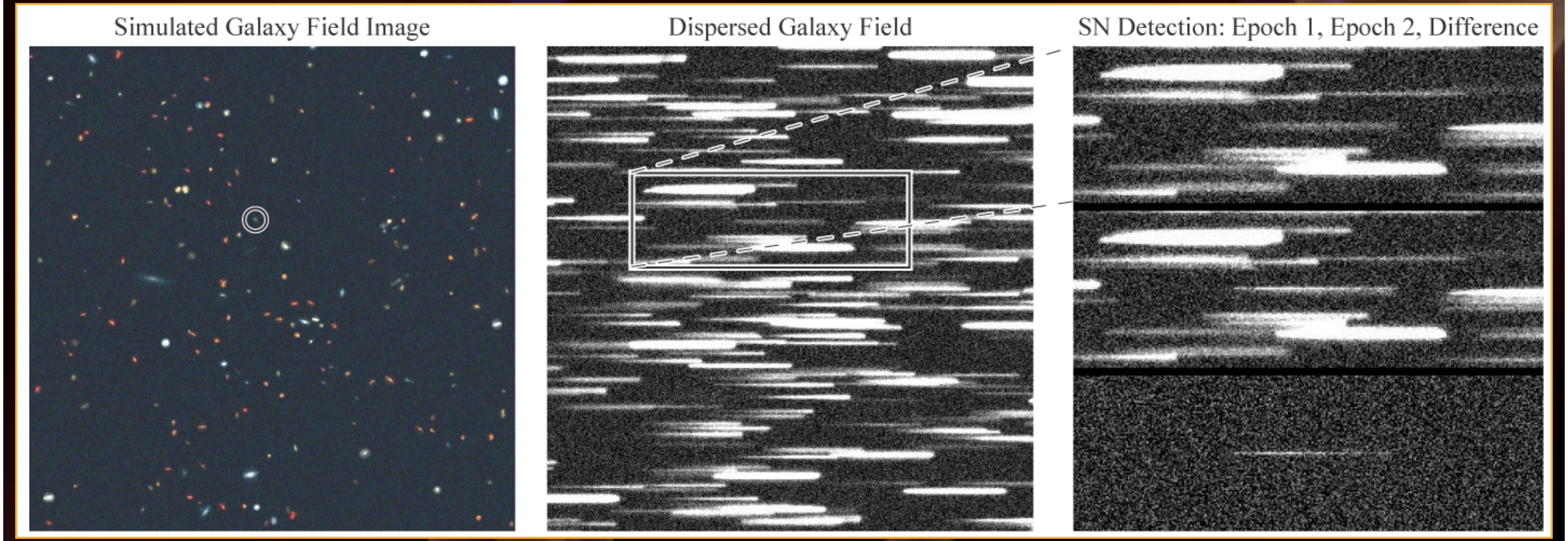
Riess et al. (2004)

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



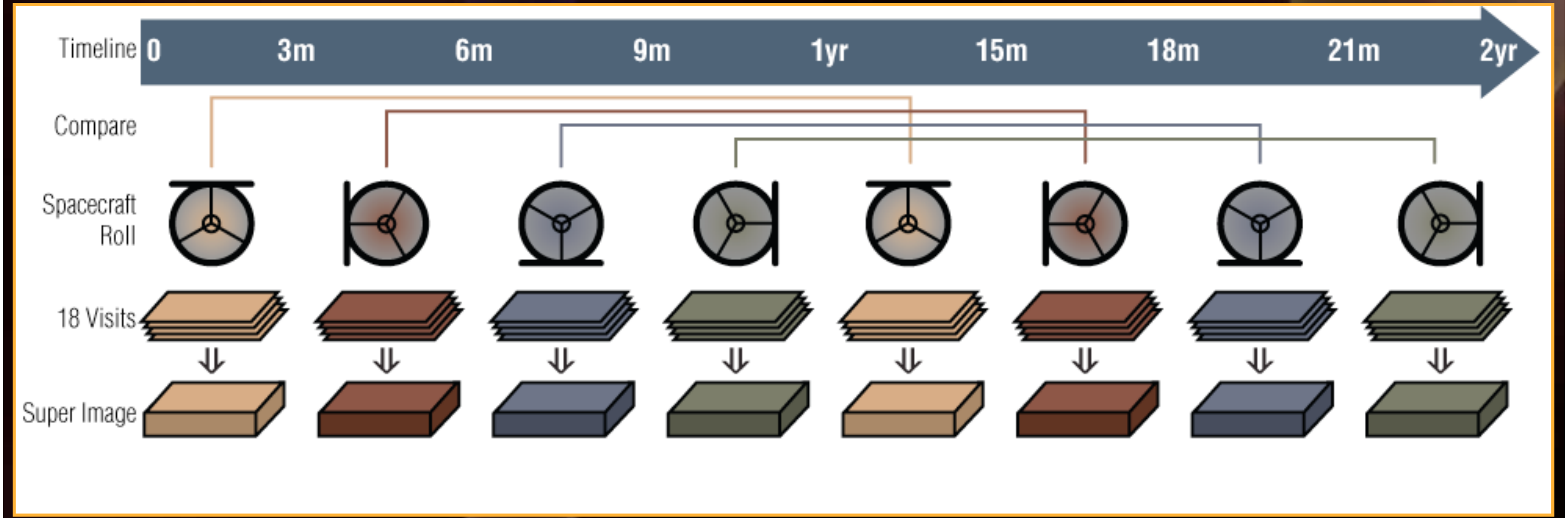


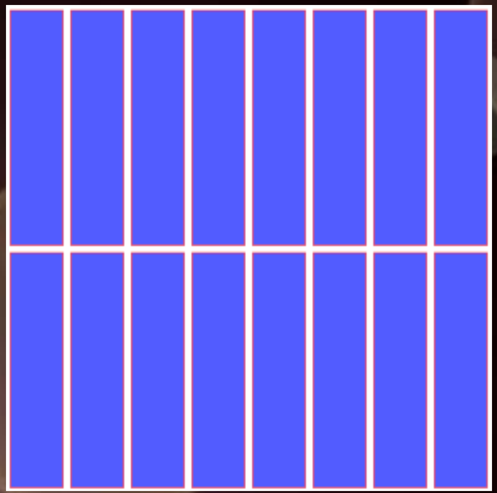
Supernova Observations

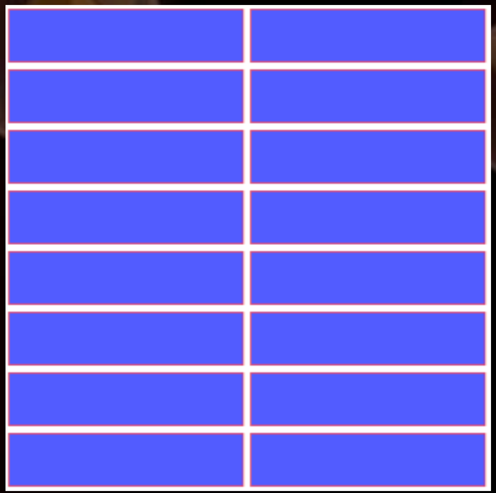


1. Broadband: locate SN & host galaxy
2. Dispersed: spectral time series
3. Difference & extract SN spectrophotometry

Supernovae Survey Schema

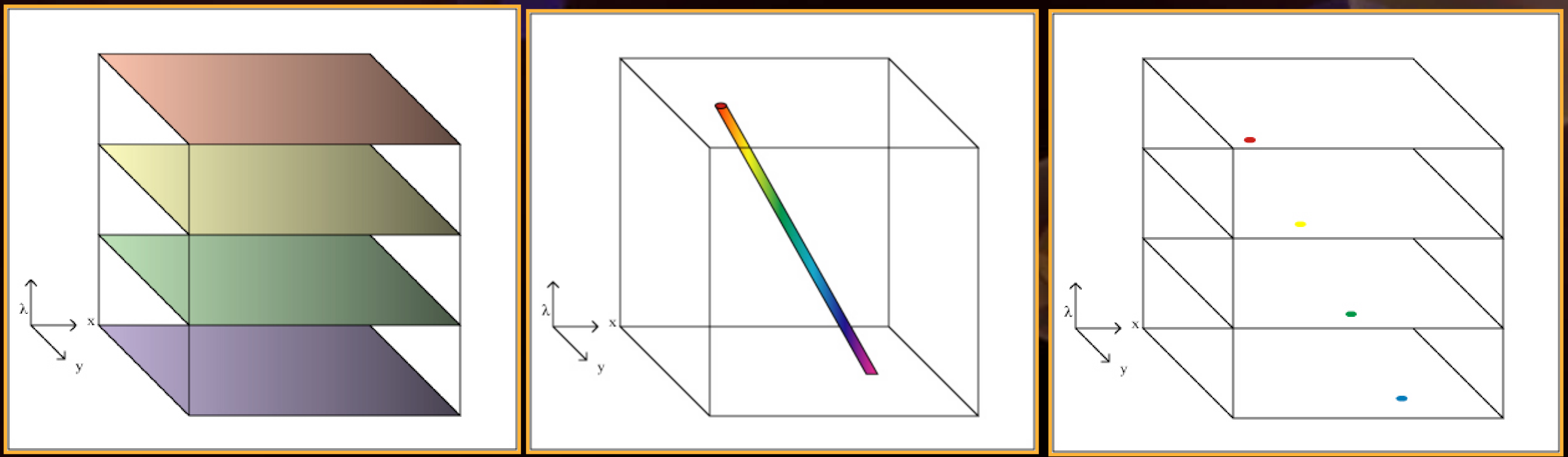






Survey area is a contiguous mosaic of Destiny FOVs.
Orientation rolls by 90° every 3 months.
Dithering will fill in chip gaps and ensure Nyquist sampling.

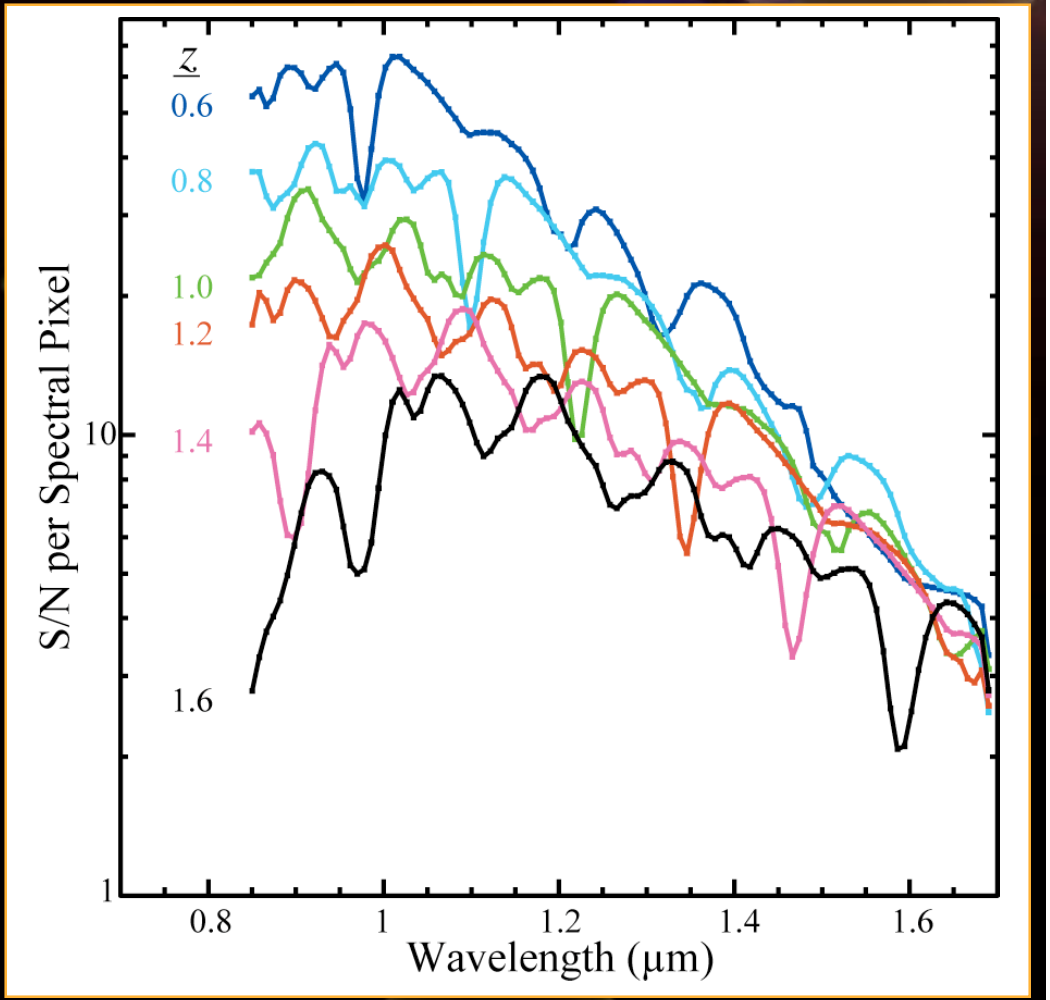
Sn Photometric Calibration



- 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.

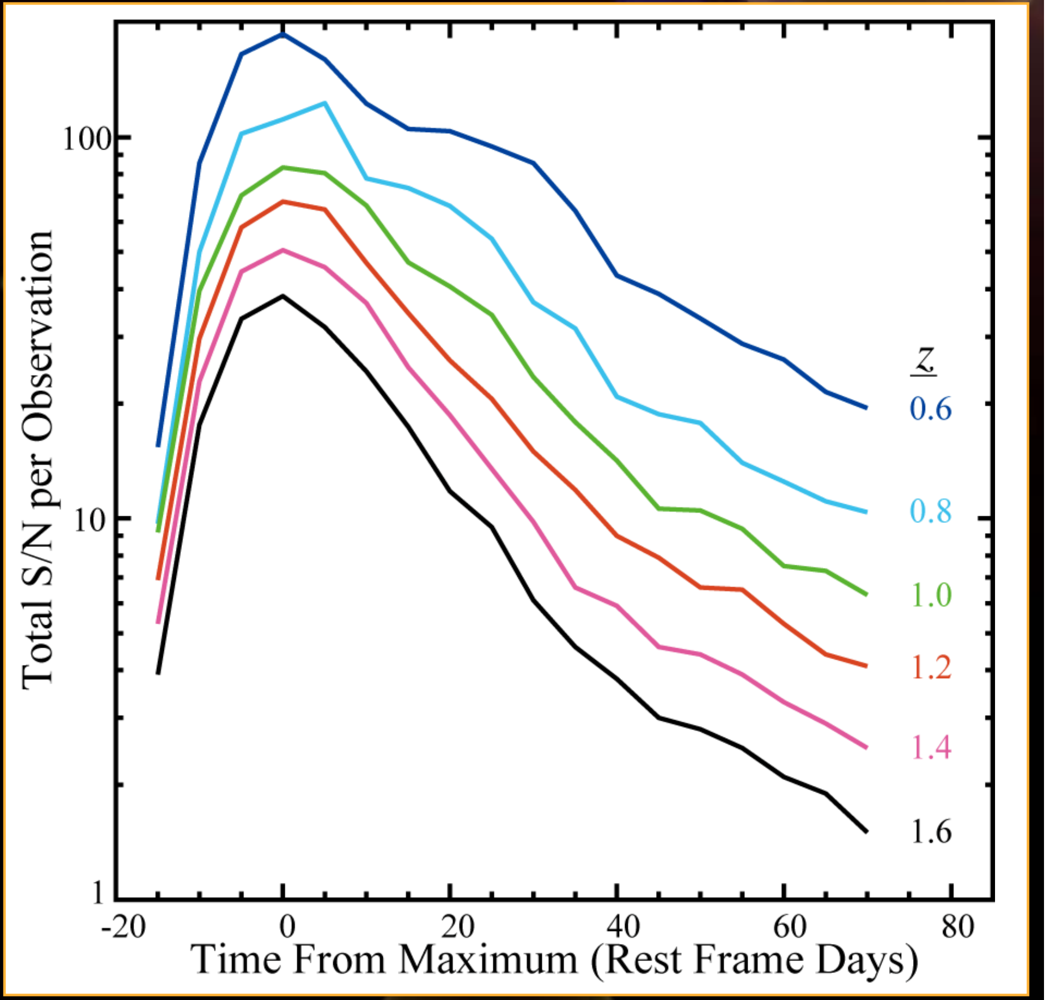
Supernova Spectra

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



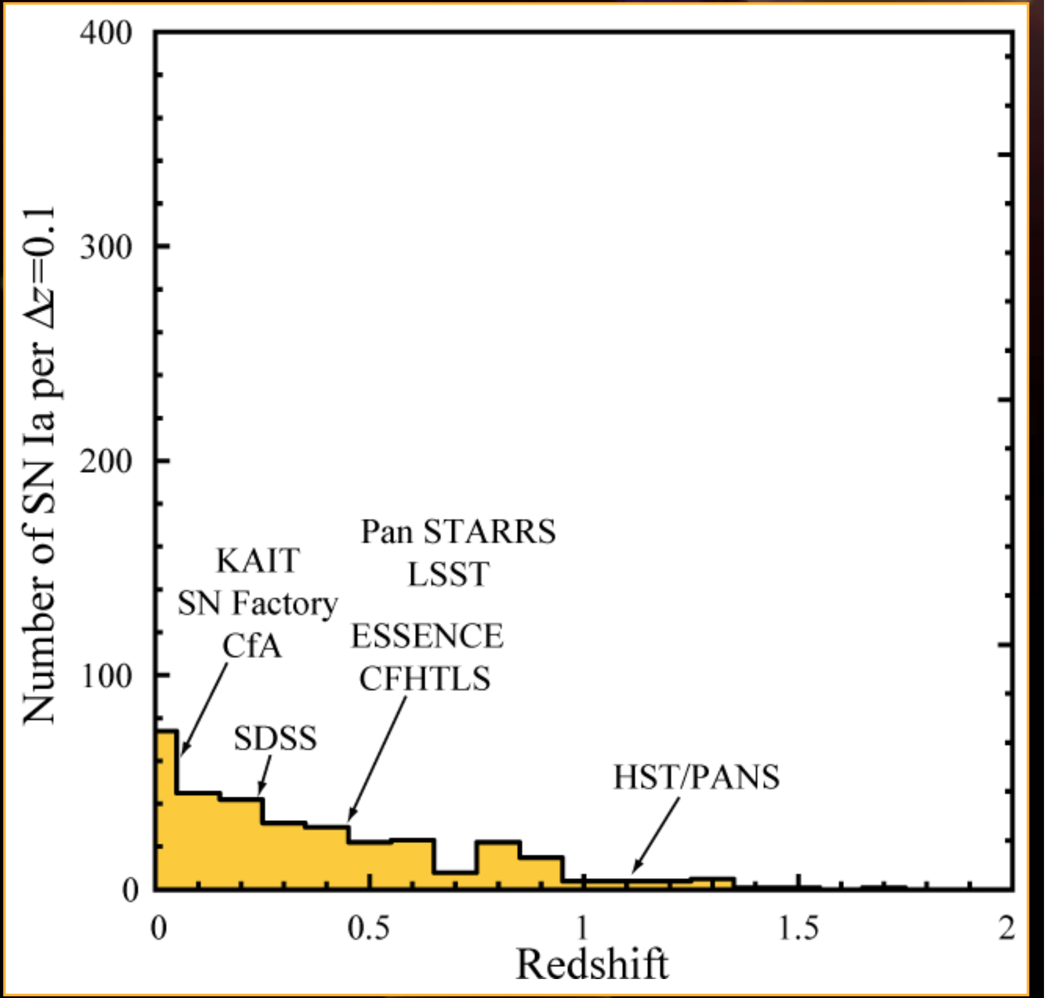
Supernova Light Curves

- Always get photometry around maximum light
- Sample every 5 days
- SN Ia are "most direct & precise approach" to study Dark Energy



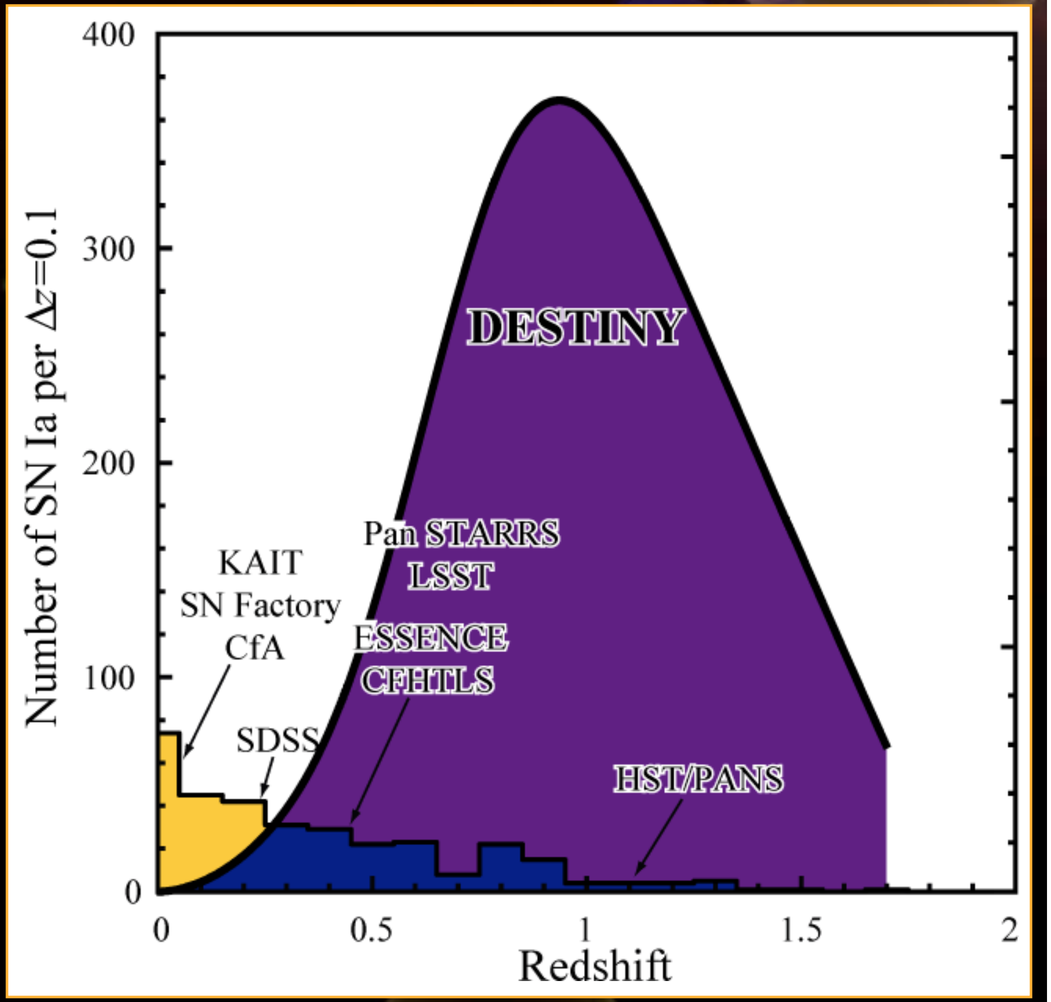
Supernova Survey

- Present day & ongoing surveys find hundreds



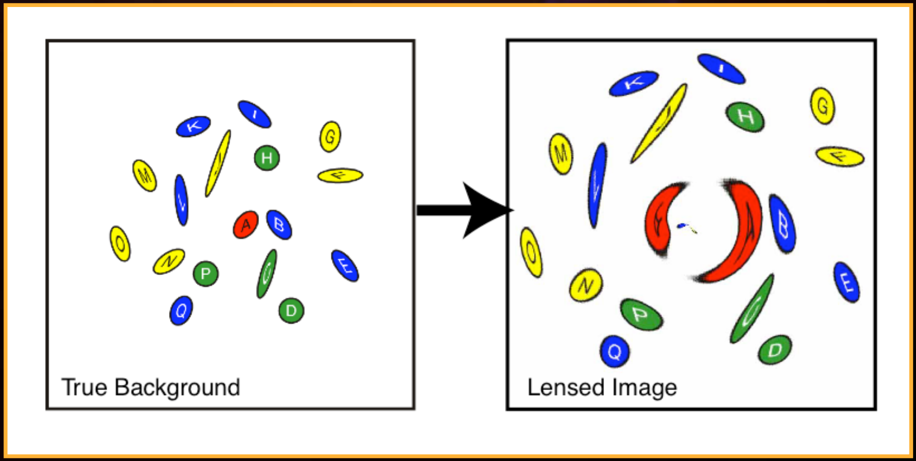
Supernova Survey

- Present day & ongoing surveys find hundreds
- Destiny will find >3000 SN in 2 yrs.
- Most at z~1; requires 3.2 deg^2 survey area
- Destiny does $0.4 < z < 1.7$ - combine with ground over $0 < z < 0.8$
- Goal: 100 SN Ia in each $\Delta z = 0.1$ bin




Weak Lensing

What IS Weak Lensing?

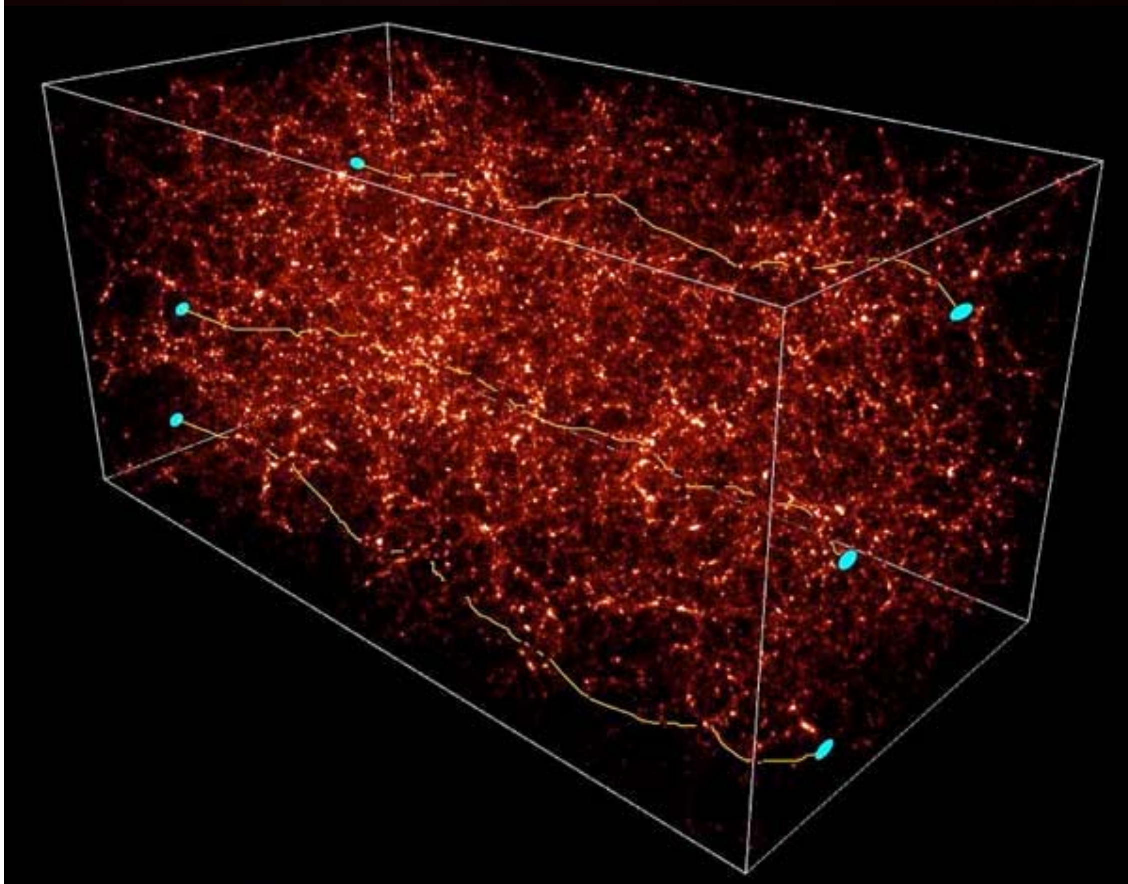


In **weak lensing**, we measure the *shapes* of galaxies.

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:

$w = p/\rho \qquad (w = -1 \text{ for } \Lambda)$

modifies:

- *angular-diameter distance*
- *growth rate of structure*
- *power spectrum on large scales*

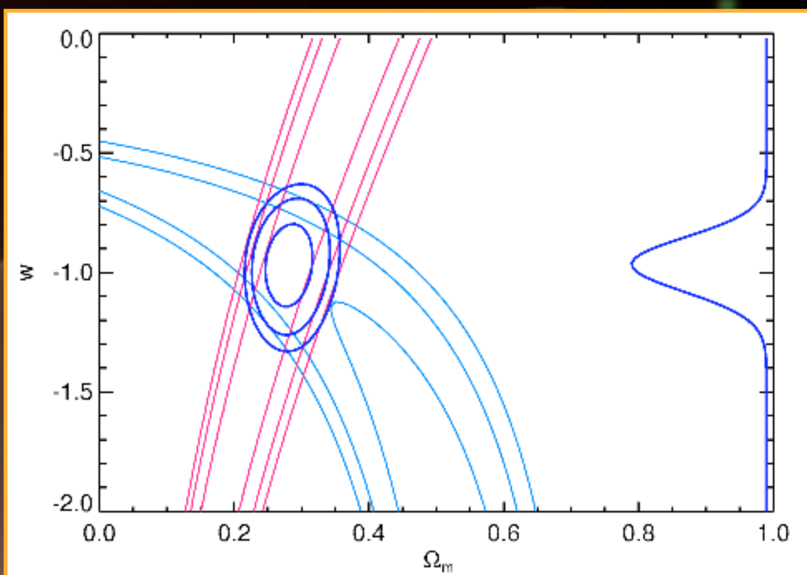
a(t)

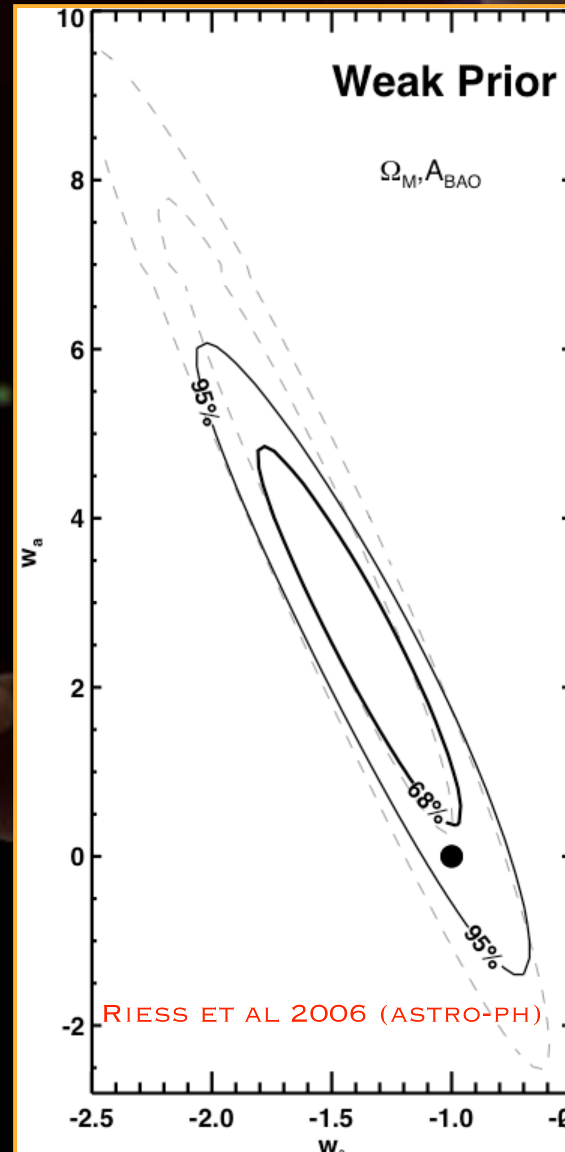
→ *w can be measured from the lensing power spectrum*

Destiny Performance

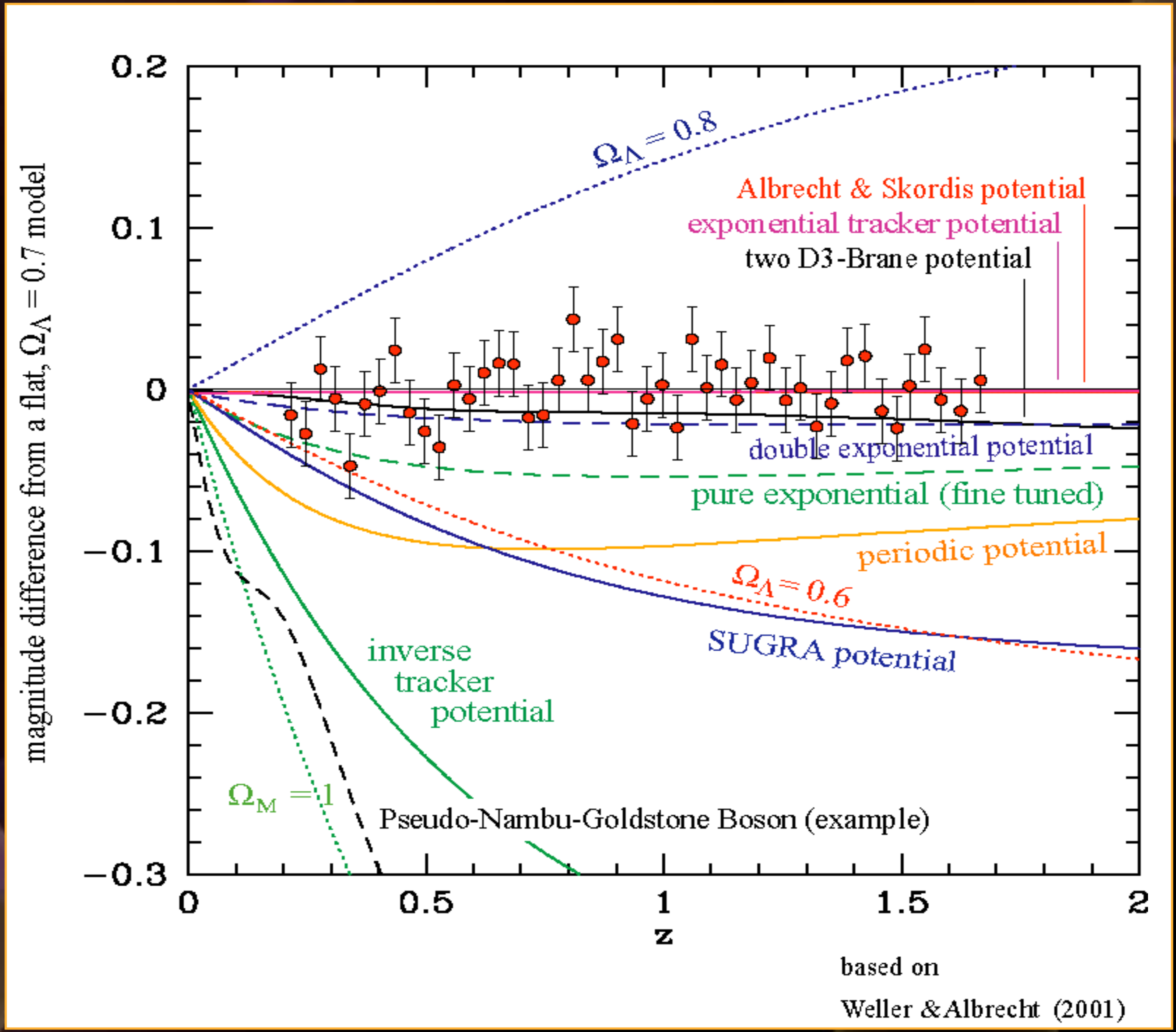
Ongoing Work Continues to Refine DE & Cosmological Parameters

Preliminary results from ESSENCE are Consistent with w = -1



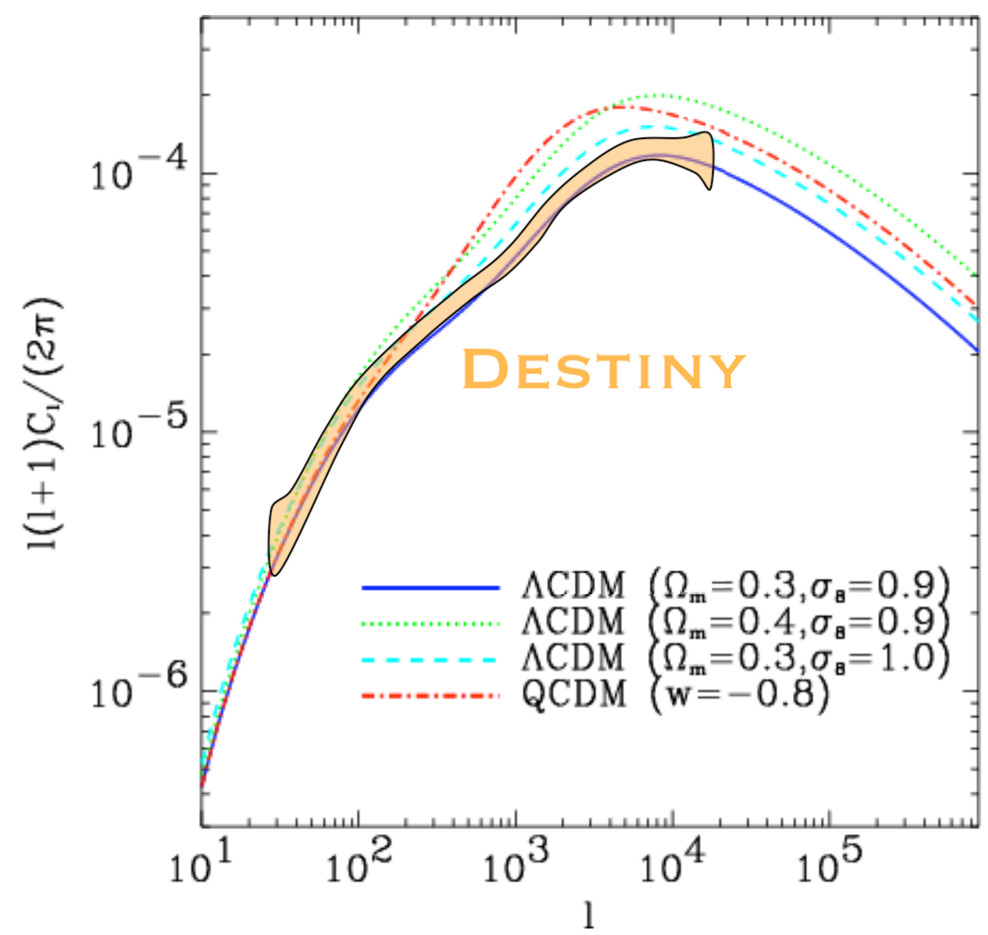


Understanding Dark Energy



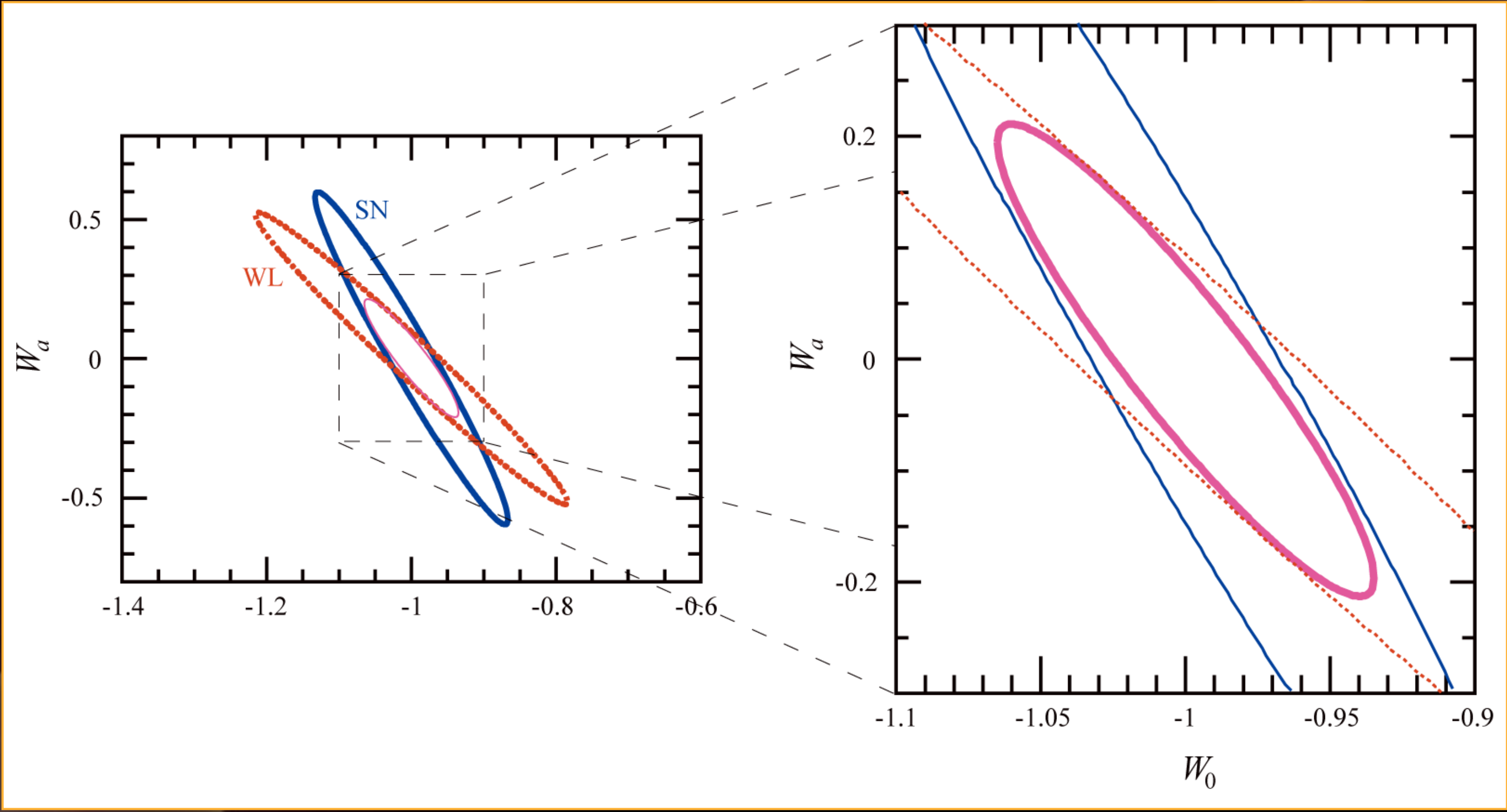
Weak Lensing Measurement

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.



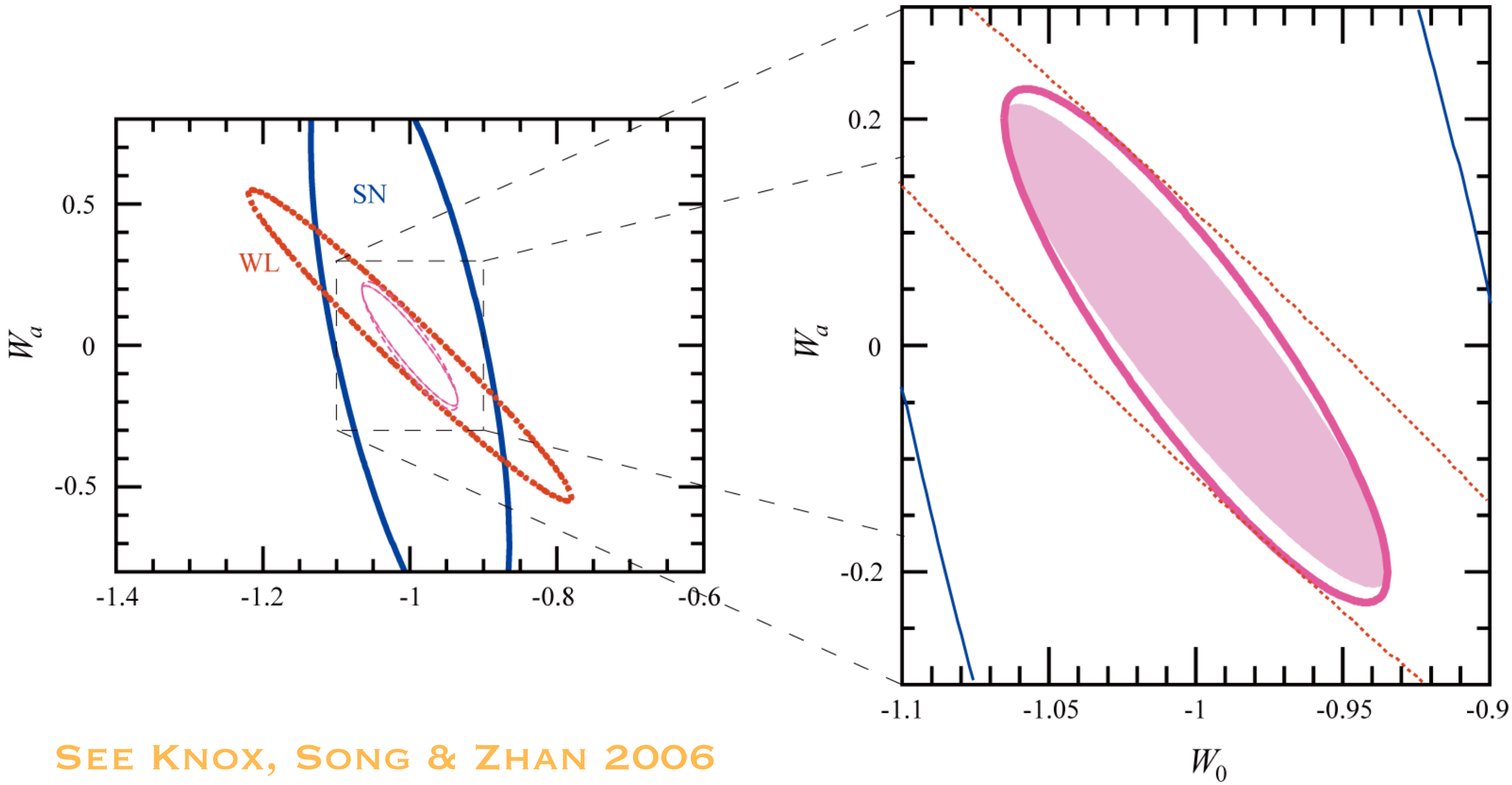
$$C_\ell^{x_a x_b} = \int dz \frac{H(z)}{D_A^2(z)} W_a(z) W_b(z) P^{s_a s_b}(k = \ell / D_A; z)$$

Predicted Survey Results



Assuming a Flat Universe

Predicted Survey Results



See Knox, Song & Zhan 2006

Not Assuming a Flat Universe

Destiny Design

SN Survey requirements Flowdown

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 theequation of state constant term w_o to within 0.05 and its time derivative w_a 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 Δz= 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 Δz~ 0.005.

SN Ia occur at the rate of 1.5x10^{-4} Mpc^{-3} yr^{-1} at z ~1. Repeatedly monitor ~3 sq-degs with ~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 ~1.5 sq-degs 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 –1.65 m

Field of View and Image Scale:

- **Angular Resolution**
  Diffraction-Limited at 1µm to $1.2\lambda/D = 0.15$ arcsecs
- **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 µm

Minimum Wavelength Coverage
850–1700 nm

Implementation

Optics

- 1.65 m monolith PM
- Three-mirror anastigmat 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 µm 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 (1σ), 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.

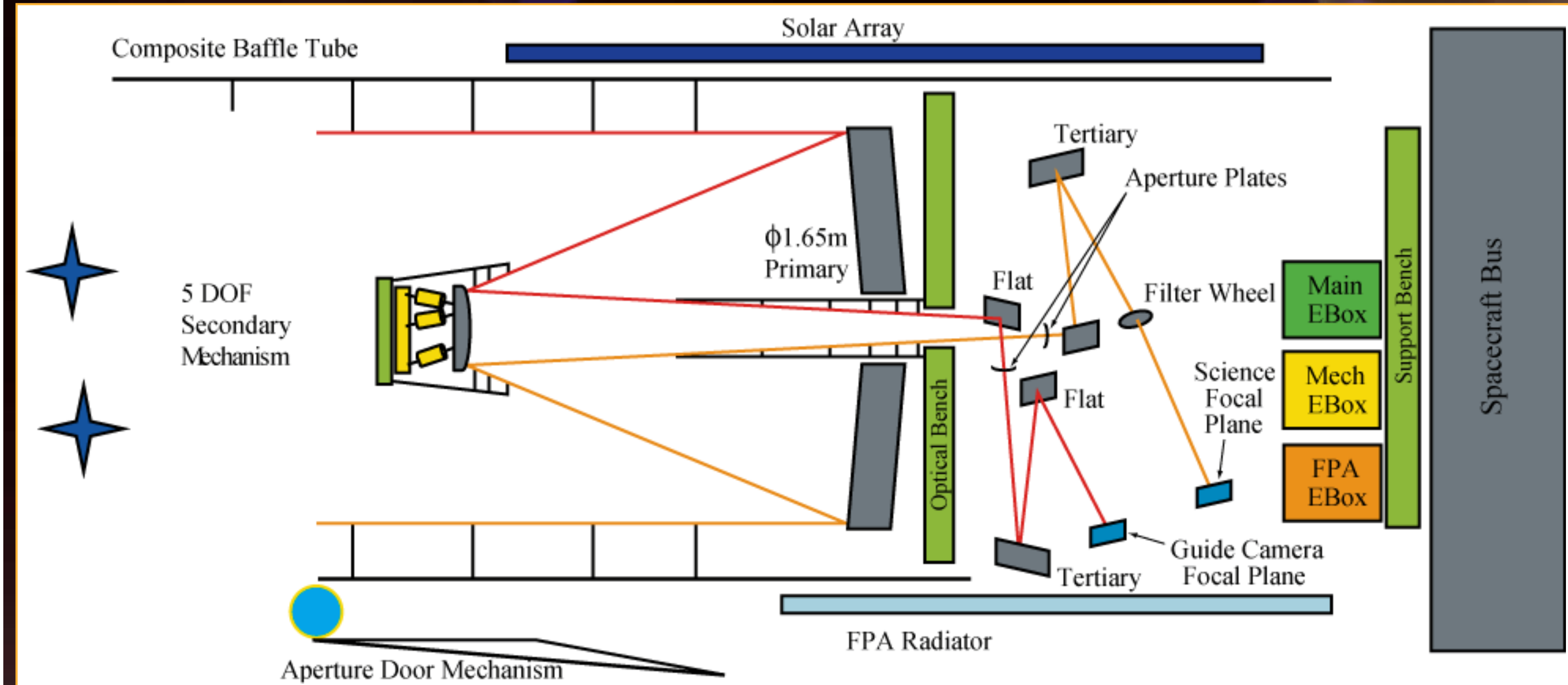
Mission Design / Operations

- 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 deg^2;
  WL: 1000 deg^2
- 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

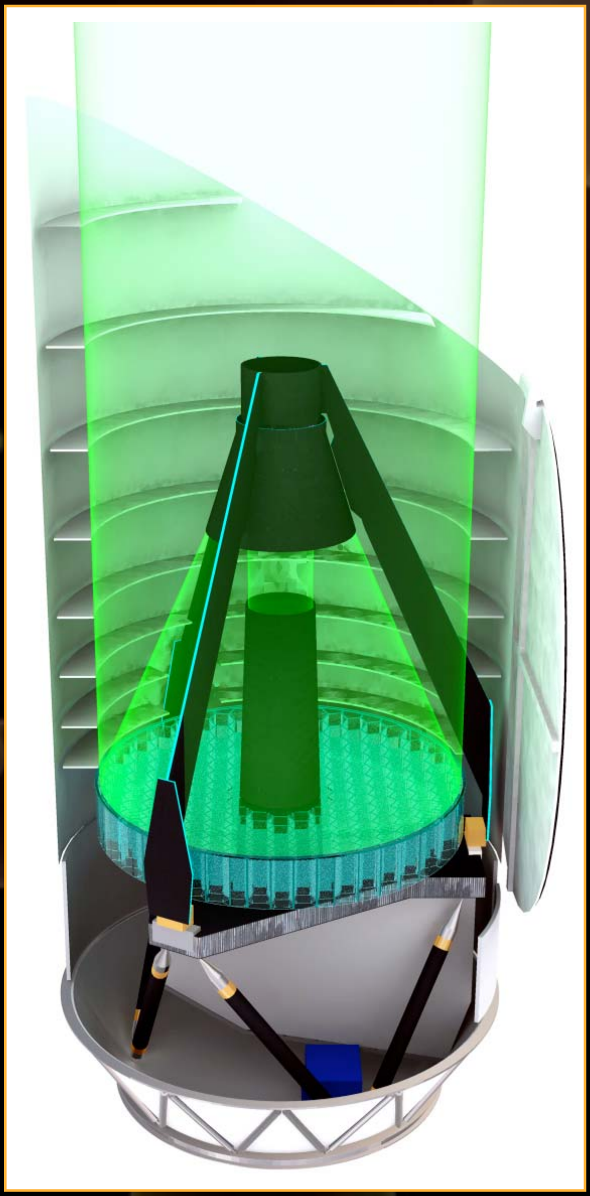
Payload Layout



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

Optical Design

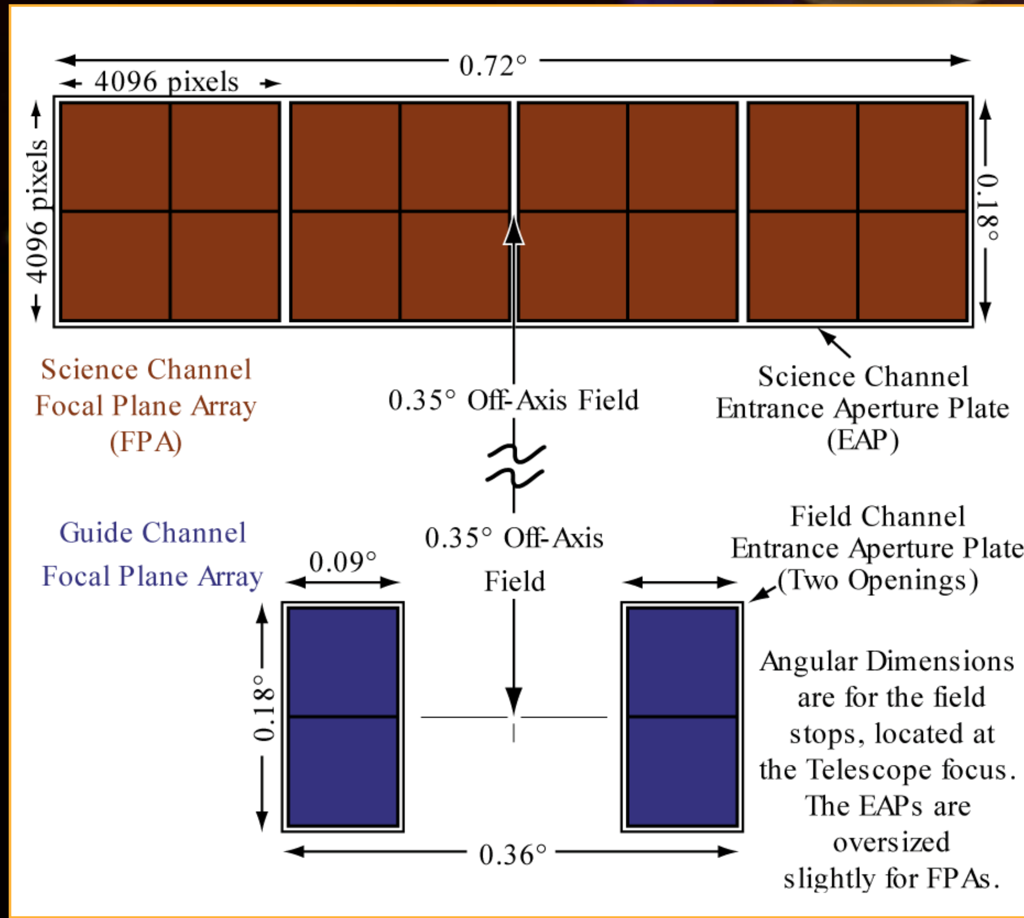
- 1.65m primary, ULE glass
- Three-mirror anastigmat
- Movable secondary
- FOV for surveys is 0.72°x0.18°; well-corrected diameter of 1.15°
- Filter wheel with disperser & broadband filters



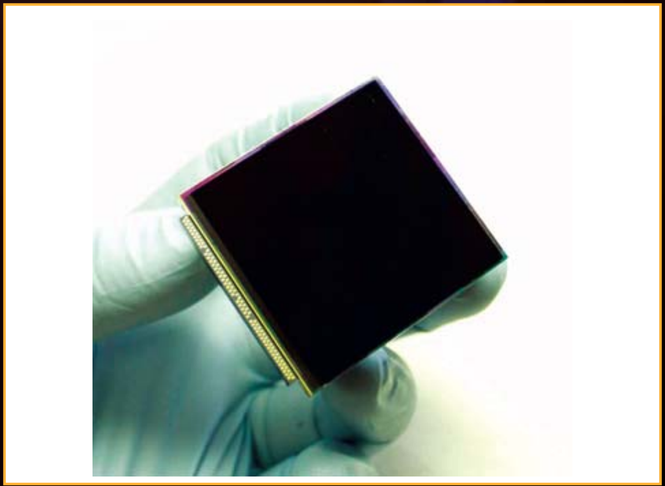
Focal Plane Layout

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

- Guide FPAs:
  2k x 2k arrays,
  2 x 2 sparse mosaic

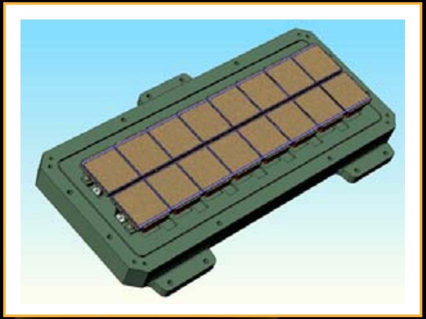


Detector Arrays



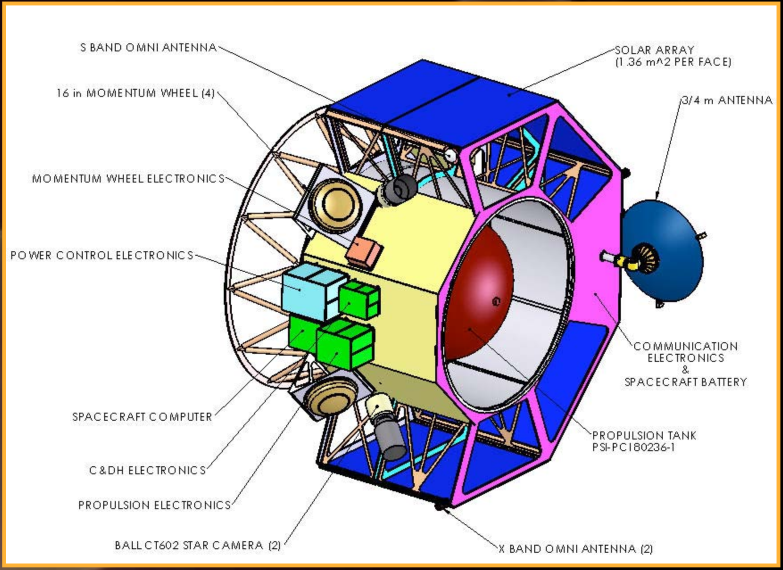
Parameter	Rockwell H2RG	Raytheon VIRGO
I_{dark} (λ_C=1.7μm)	0.1 e^-/s at 145K	0.1 e^-/s at 139K
Read noise, CDS	15 e^- (Loose et al. 2003)	15 e^- (McMurtry et al. 2005)

Existing technology can meet requirements



Mission Parameters

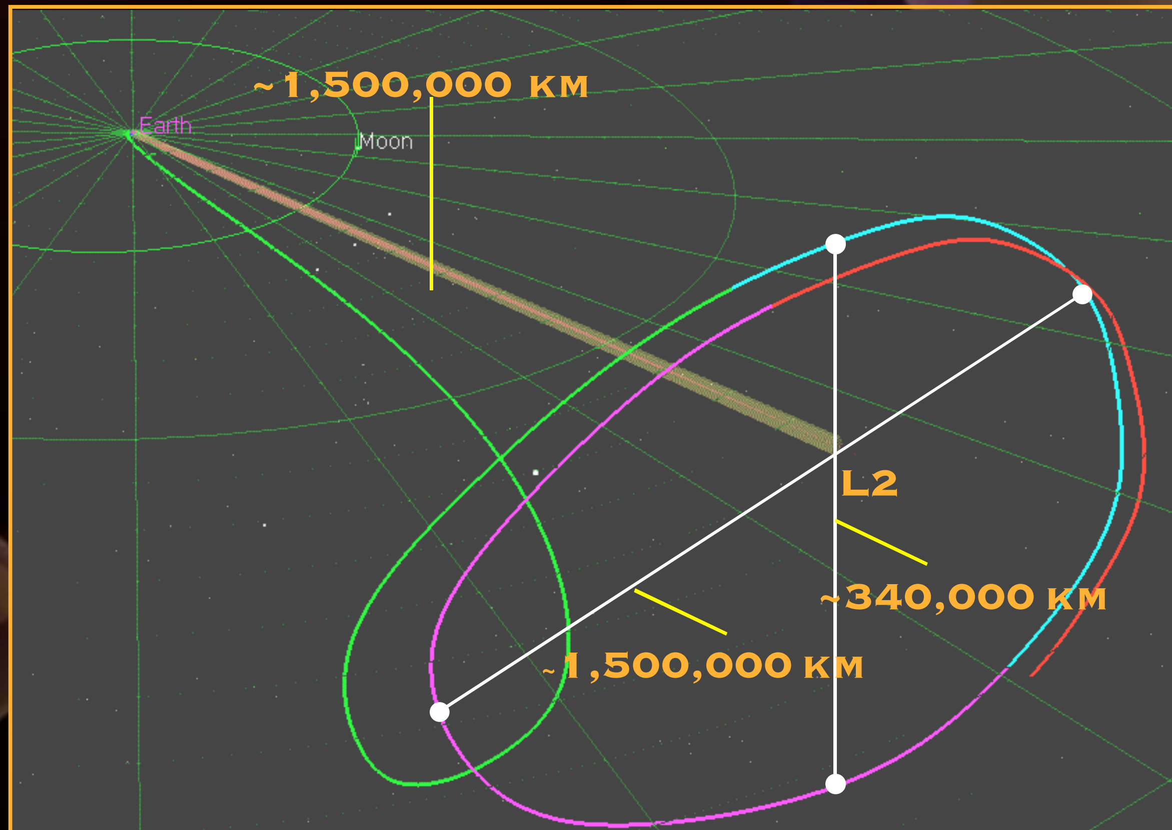
- Mass: 1972 kg (wet)
- Power: 785W
- Size: 4.4m x 2.5m
- Data: ~13 GB/day
- Launch: Atlas V 401
- Location: L2
- Timeline: 2013



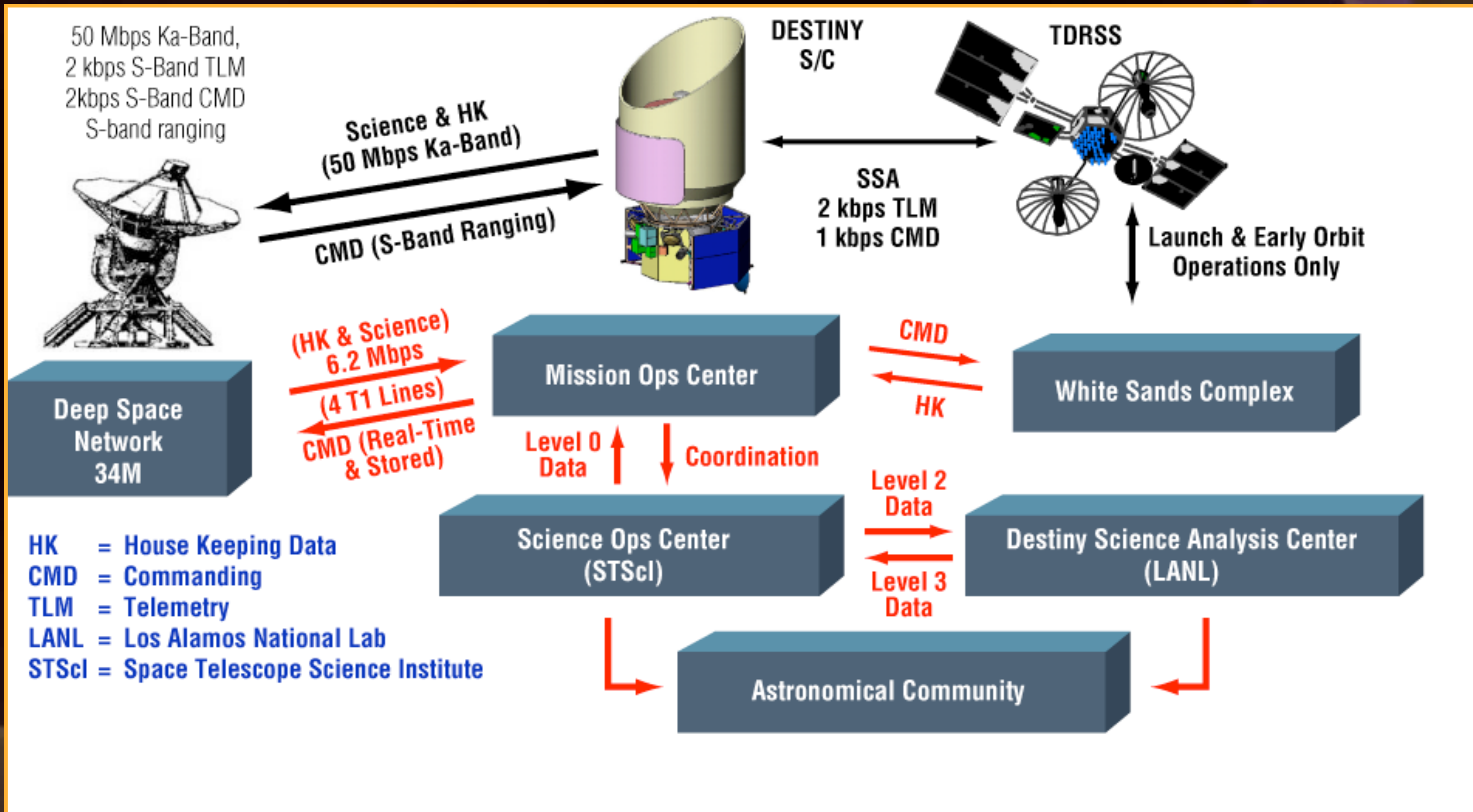
Spacecraft Implementation

- 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



Mission Operations / Data Flow



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