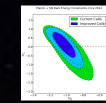
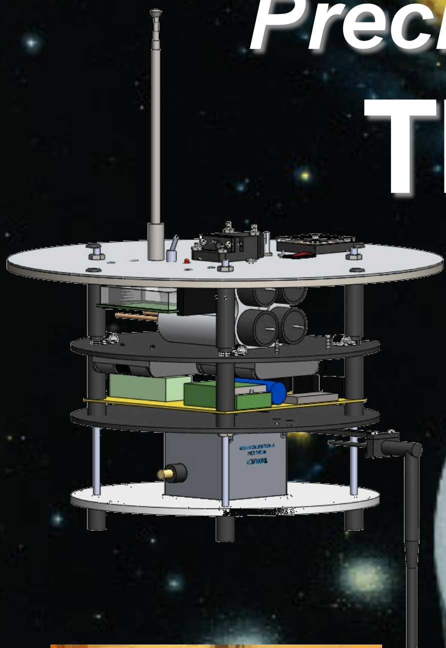
Understanding Dark Energy

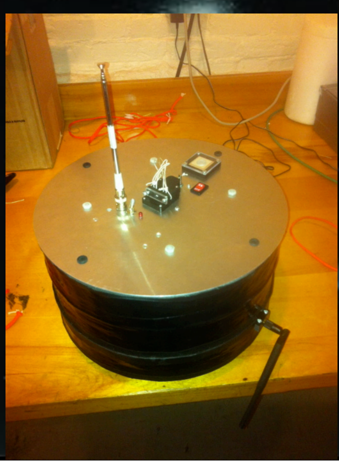


Using New Instrumentation for Precision Photometry Calibration:

The ALTAIR Project



Airborne
Laser for
Telescopic
Atmospheric
Interference
Reduction



Dr. Justin Albert

Univ. of Victoria

Space Expands

Edwin Hubble
1929

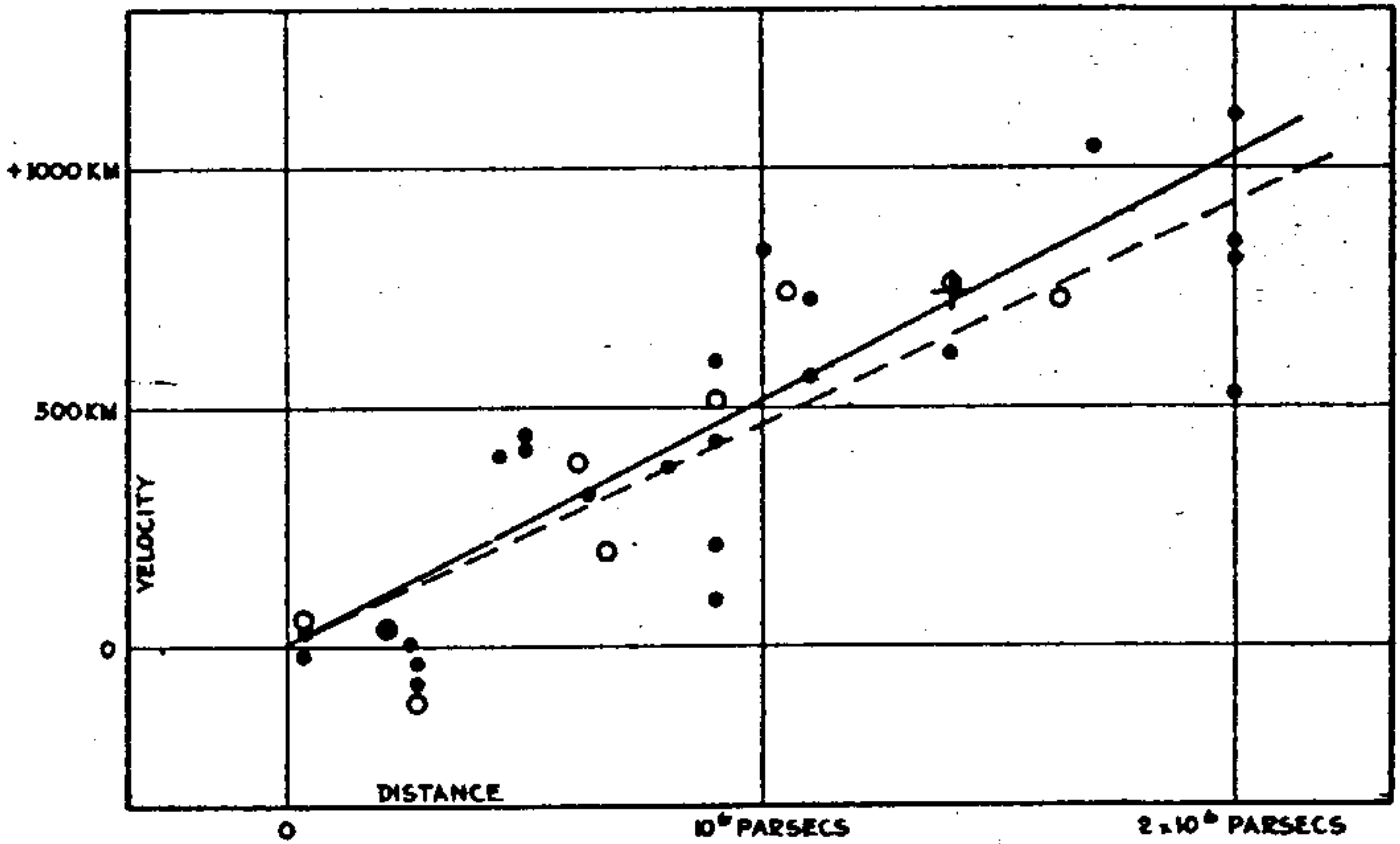
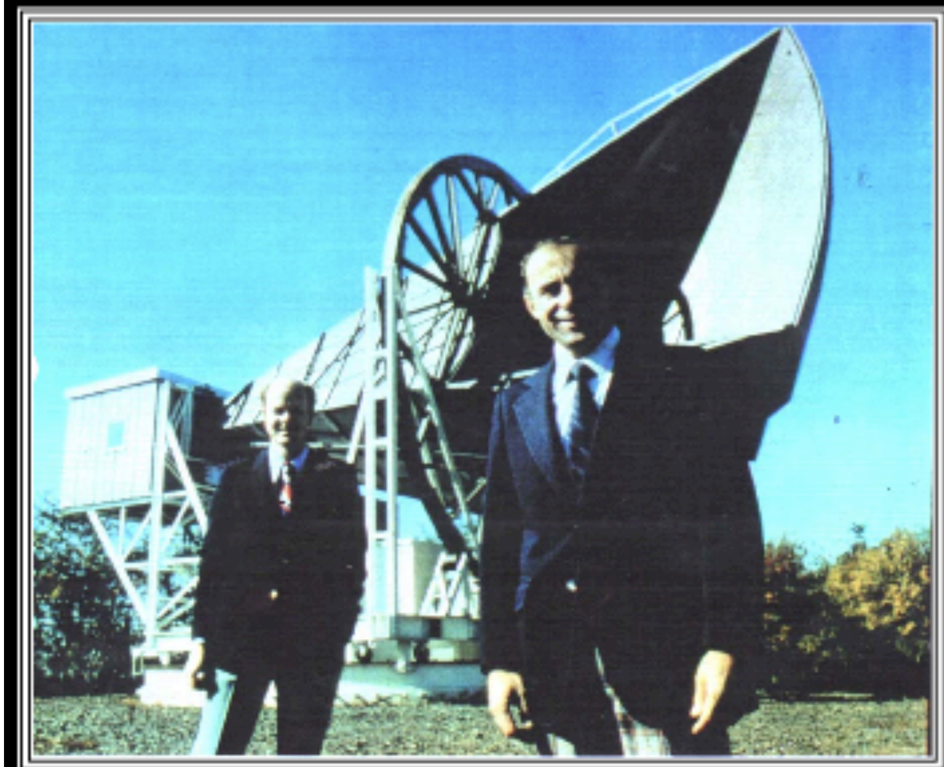

+1000 KM
500 KM
0
VELOCITY
DISTANCE
0
10⁶ PARSECS
2 x 10⁶ PARSECS

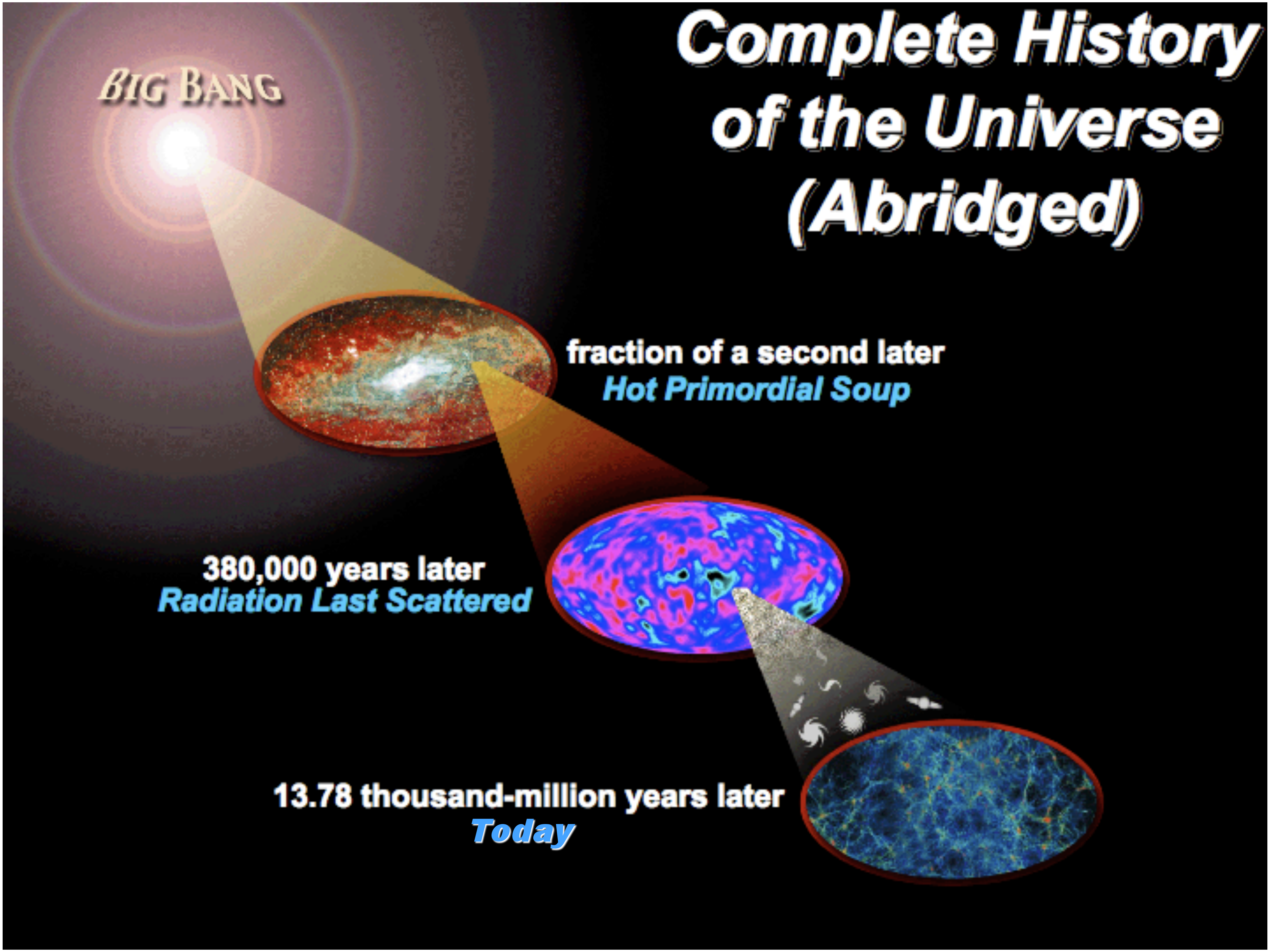
FIGURE 1

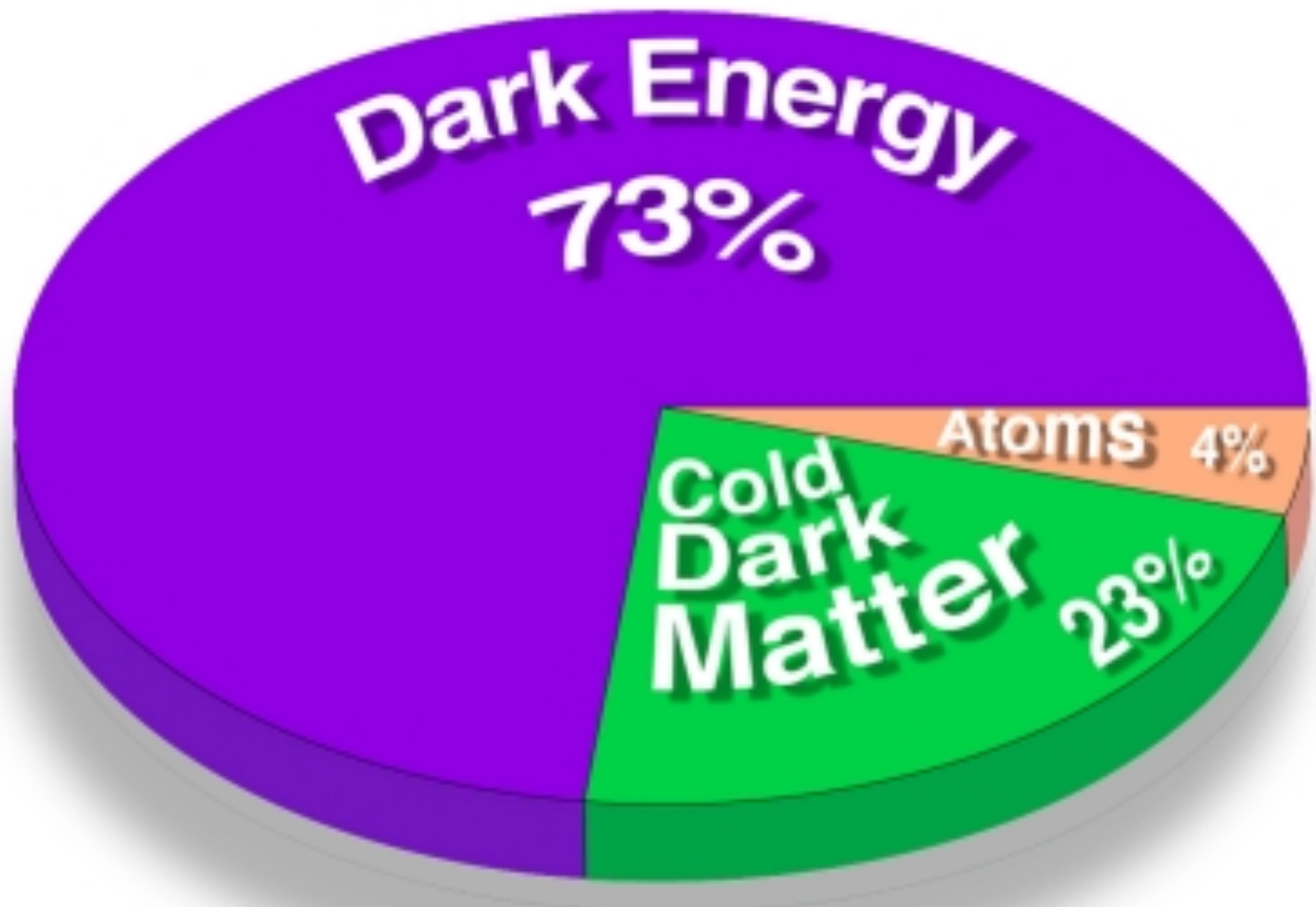
The Universe Is Radiant



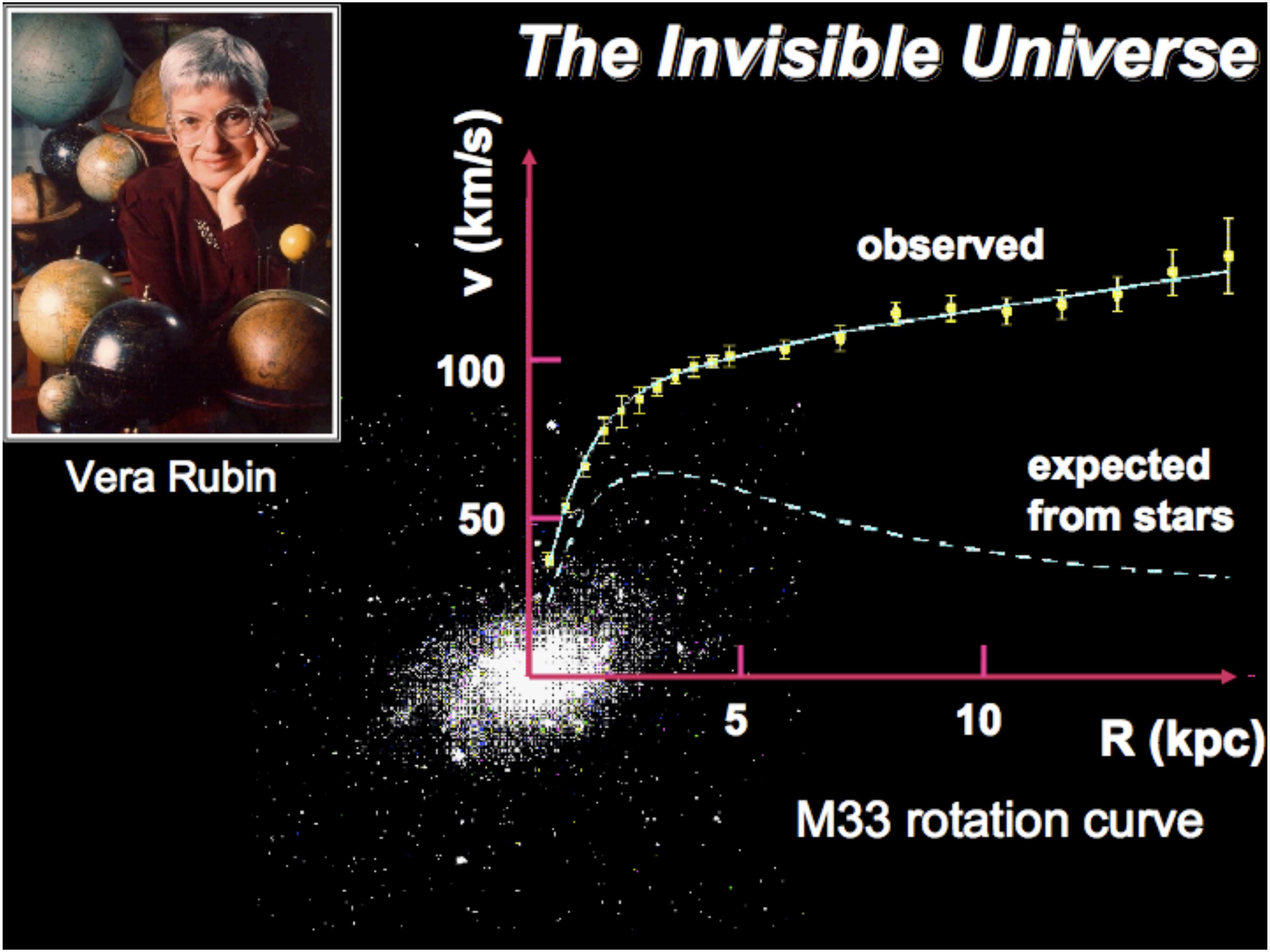
Penzias & Wilson 1965

Temperature of the Universe is 3K (–270C)

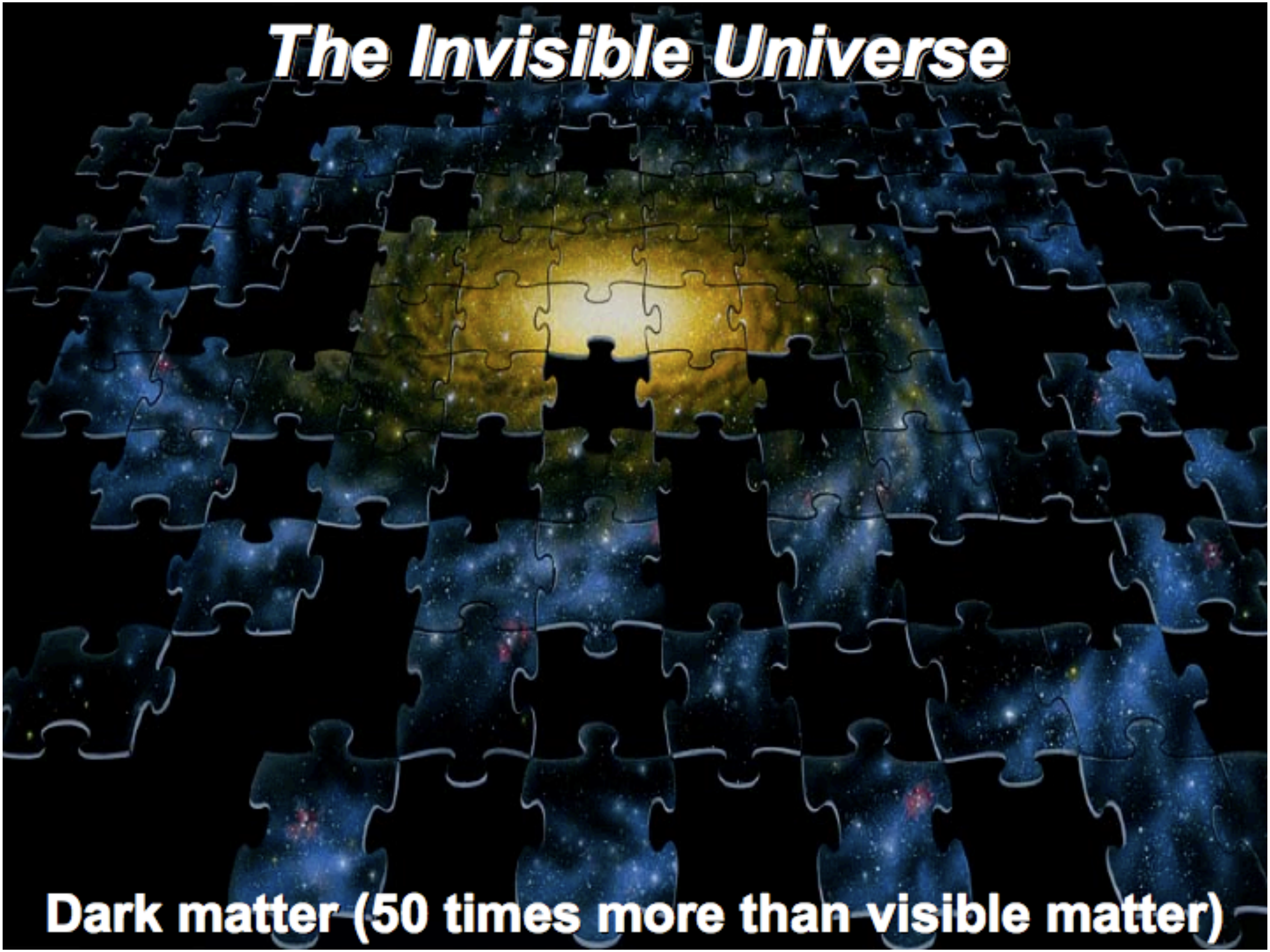

Complete History
of the Universe
(Abridged)
BIG BANG
fraction of a second later
Hot Primordial Soup
380,000 years later
Radiation Last Scattered
13.78 thousand-million years later
Today


Dark Energy
73%
Atoms 4%
Cold
Dark
Matter
23%


The Visible Universe
Spitzer Space Telescope
M81


The Invisible Universe
Vera Rubin
v (km/s)
100
50
observed
expected
from stars
5
10
R (kpc)
M33 rotation curve


The Invisible Universe
Abel 2218 HST

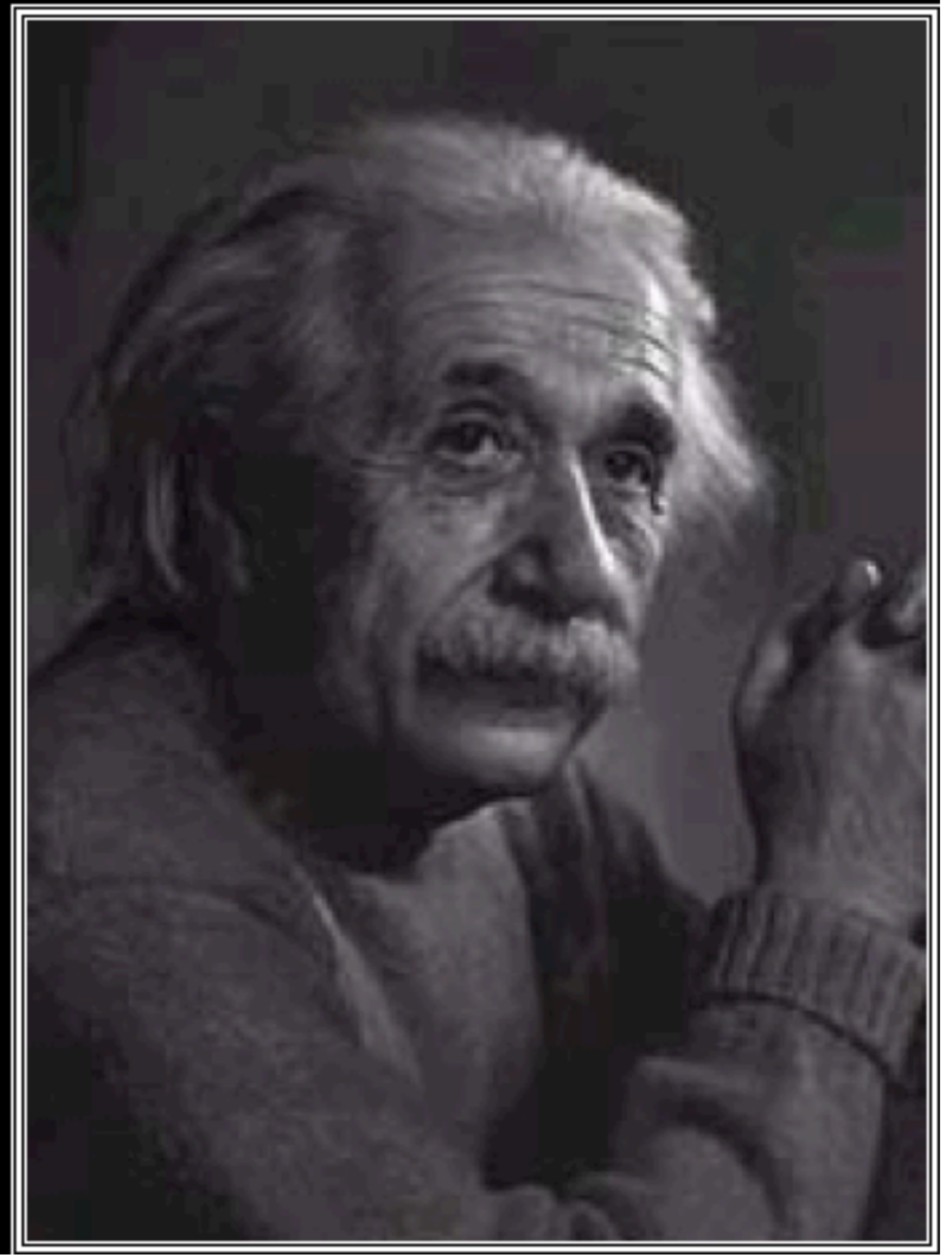

The Invisible Universe
Dark matter (50 times more than visible matter)

Dark Matter?

- Newton's (or Einstein's) law of gravity is wrong
- MACHOS (massive astronomical compact halo objects)
  - planets
  - dwarf stars (white, red, brown)
  - black holes
- WIMPS (weakly interacting massive particles)
  - a new type of particle relic from the big bang

Yet More To The Dark Side

Dark Energy



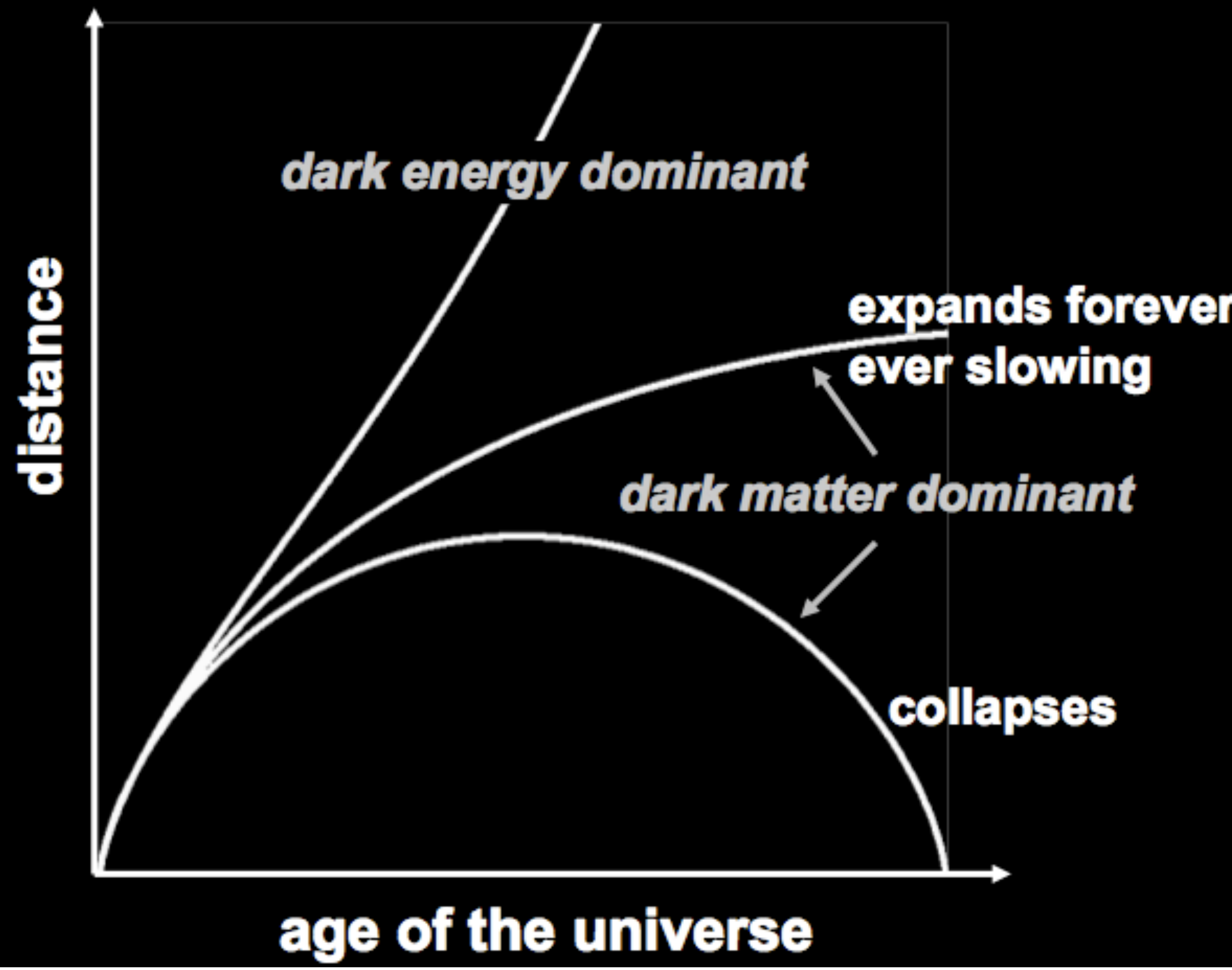
1917 Einstein proposed cosmological constant.

1929 Hubble discovered expansion of the Universe.

1934 Einstein called it "my biggest blunder."

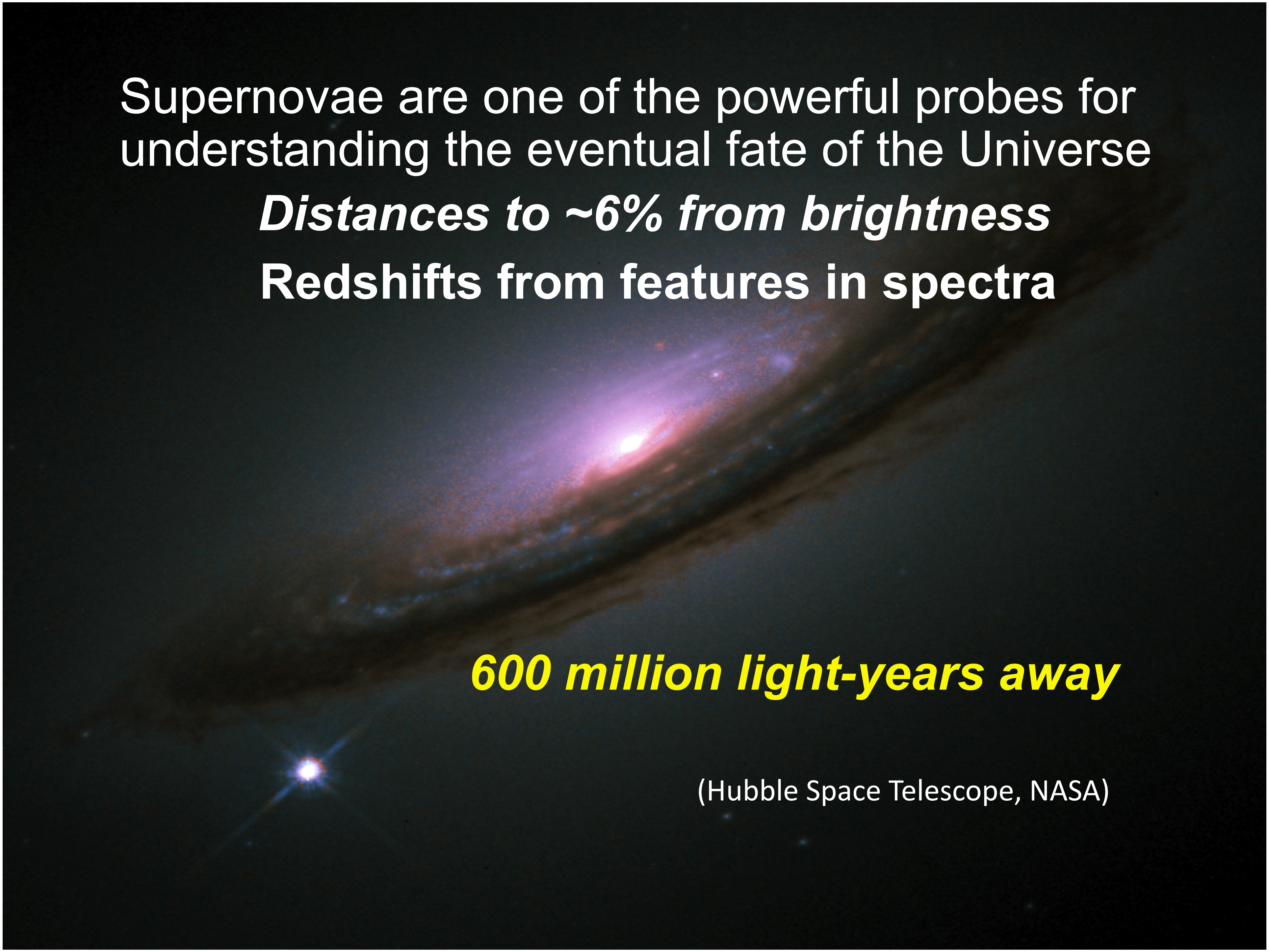
1998 Astronomers found evidence for it.

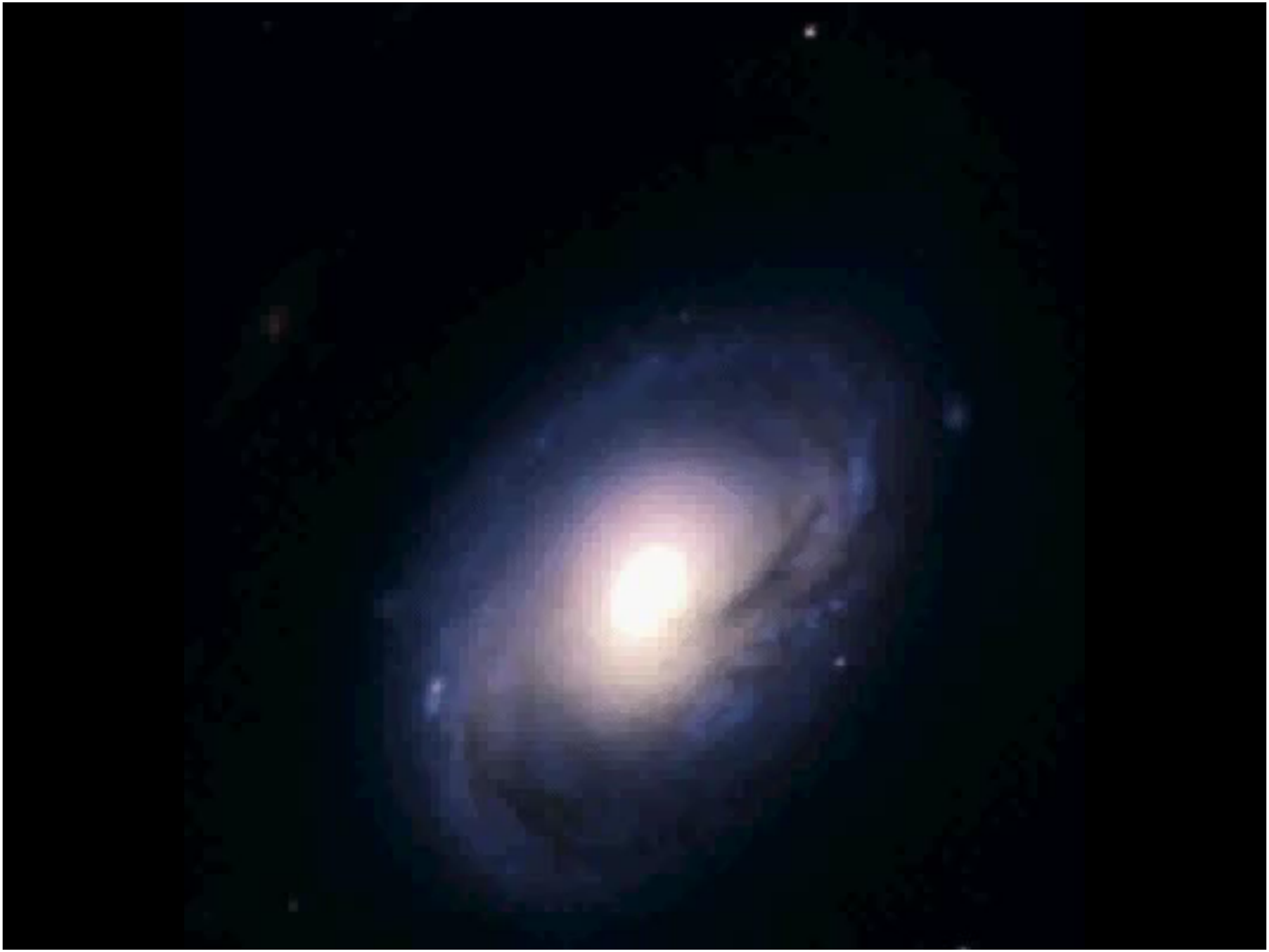
The Dark Side of the Universe



Unbearable Lightness of Nothing

10^{-30} grams per cc


Supernovae are one of the powerful probes for understanding the eventual fate of the Universe
Distances to ~6% from brightness
Redshifts from features in spectra
600 million light-years away
(Hubble Space Telescope, NASA)



Cosmic Arithmetic

General Relativity, isotropy, and homogeneity require that (in the relevant units)

$$\boxed{\Omega_{geometry} + \Omega_{matter\&radiation} + \Omega_{\Lambda} = 1}$$

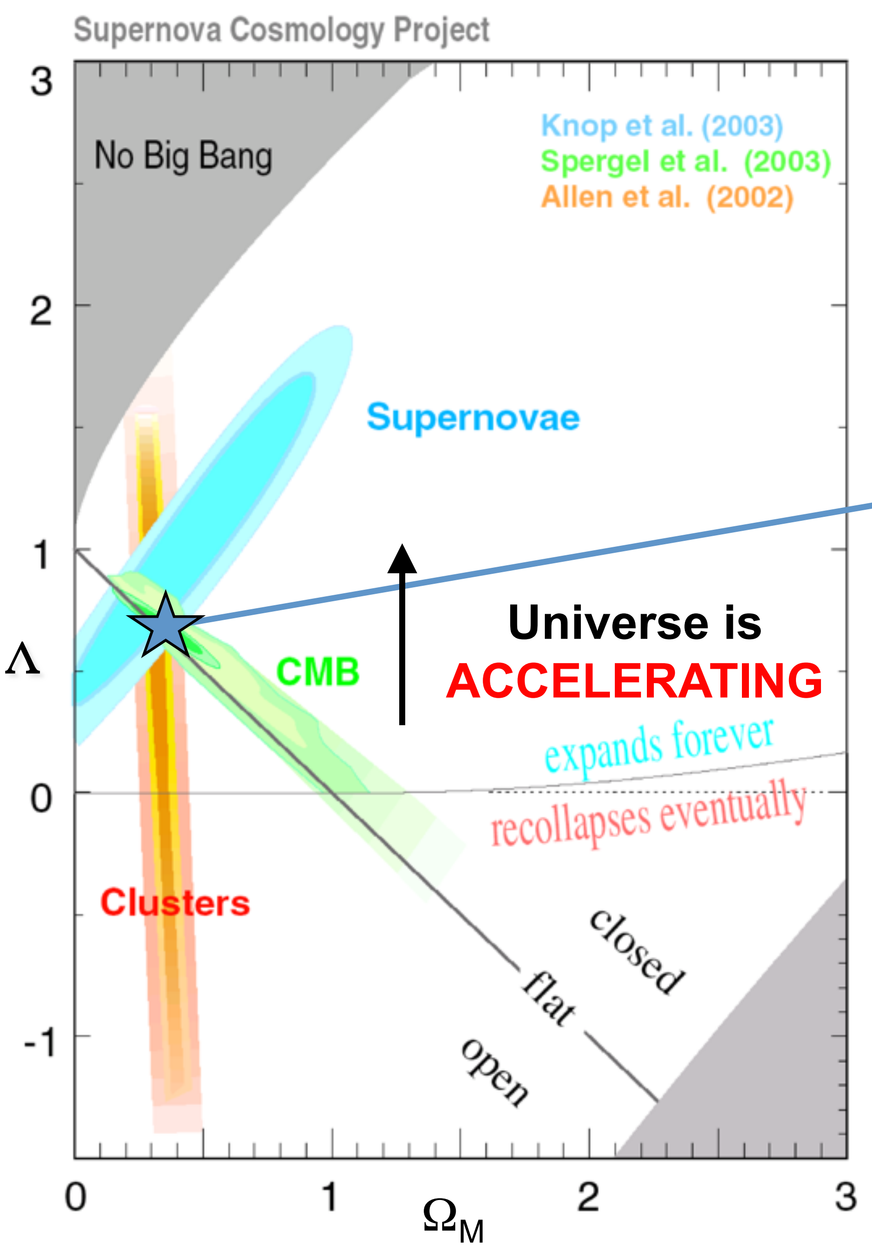
If the underlying geometry is flat ($\Omega_{geom} = 0$), & if $\Omega_{m\&r} < 1$ then Ω_{Λ} ("cosmological constant term") *must* be non-zero.

Cosmic microwave background (CMB) measurements demonstrate the geometry is flat, $\Omega_{geometry} = 0$.

Mass inventories fall short of $\Omega_{matter\&radiation} = 1$

($\Omega_{matter} \approx 0.3$, and the radiation contribution is tiny)

Insufficient mass to halt the expansion…



"Best Fit"
at
$\Omega_{mass} \sim 0.3$
$\Omega_{\Lambda} \sim 0.7$

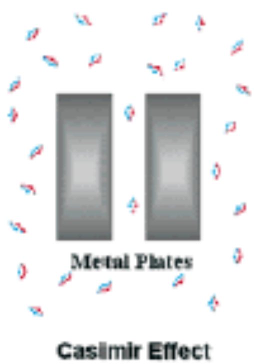
Rate of expansion is increasing…

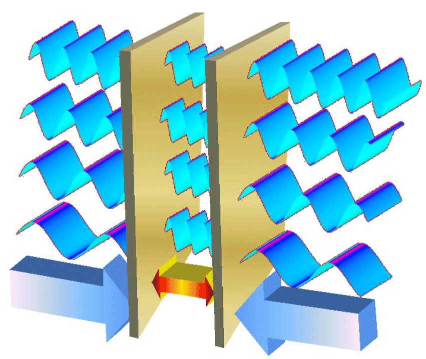
What does this mean?

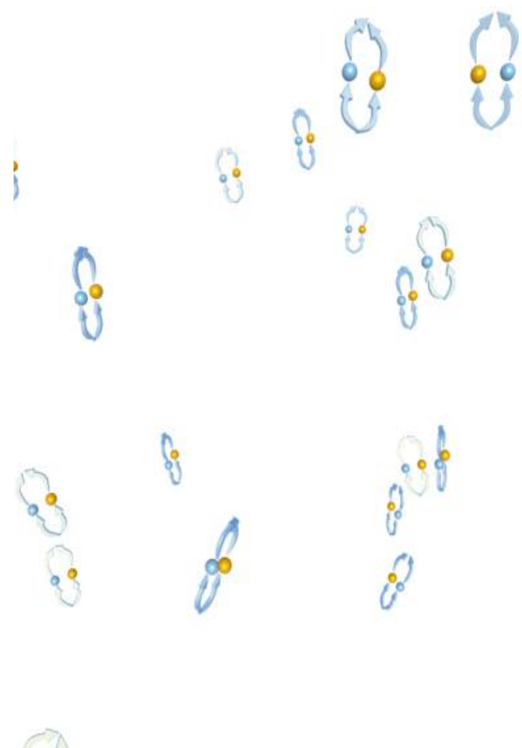
A Perplexing Result

- Expansion of Universe is *accelerating*!(?)
- Implies something new: "Dark Energy"
- Regions of empty space *repel* each other!
  - ? "Cosmological constant"…

    Einstein's greatest blunder?
  - ? **What's going on in the vacuum?**

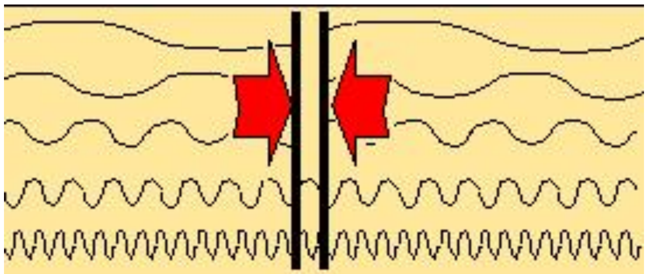


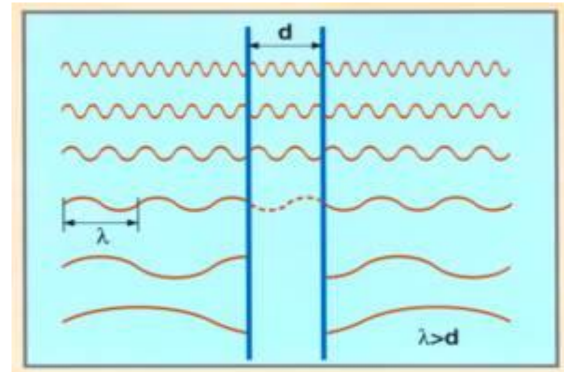




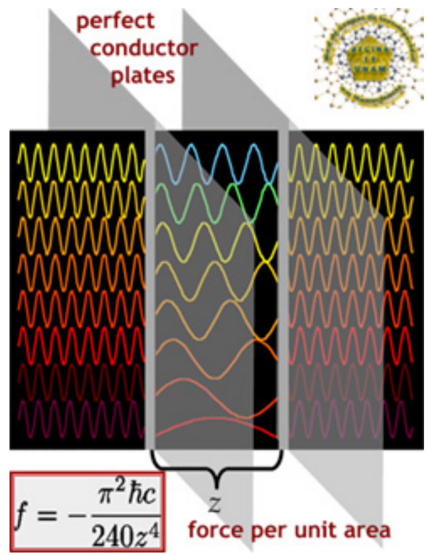
Vacuum Energy and the Casimir Effect

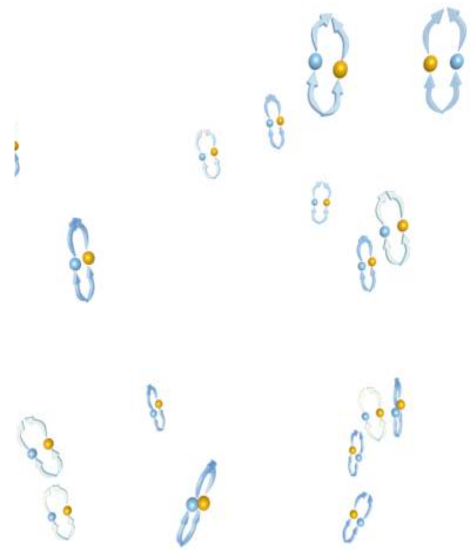
- Vacuum energy is **real** -- we can *see* it:





- Predicted in 1948
by H.B.G. Casimir

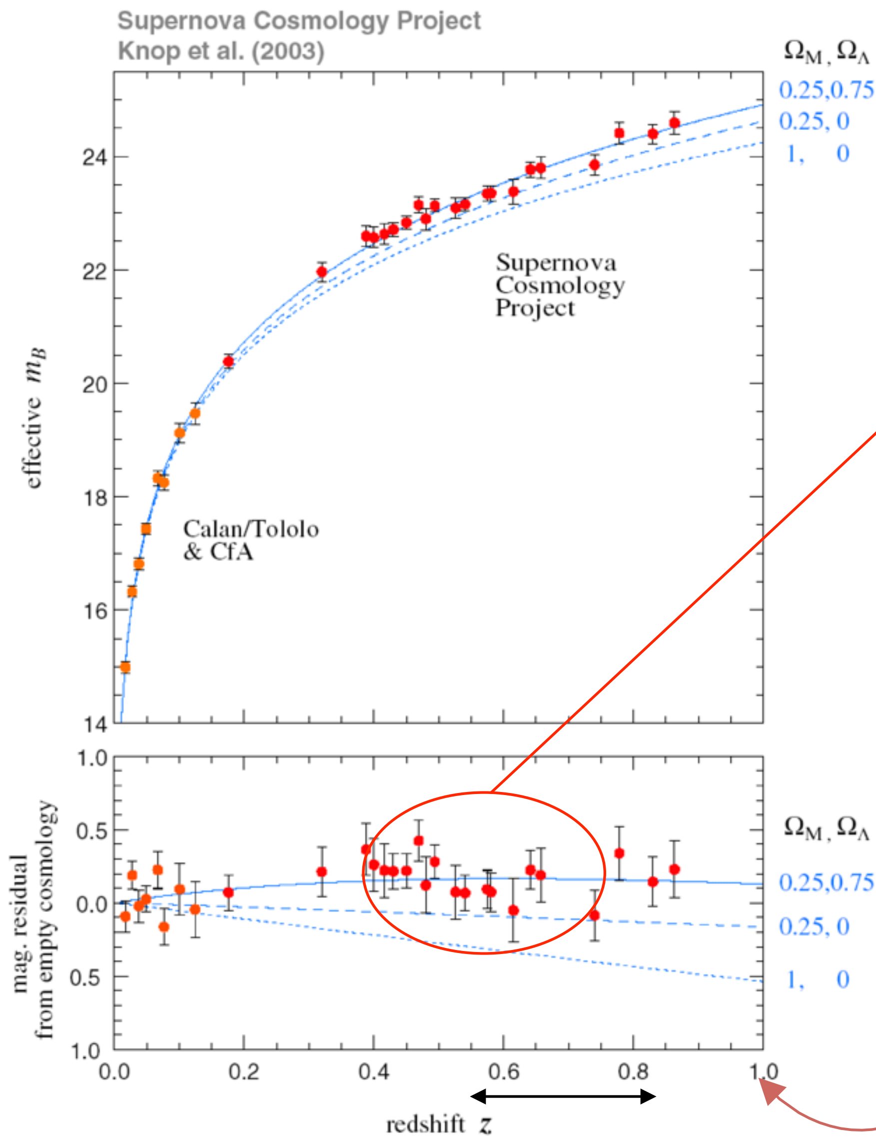




- Since measured to
better than 5% precision

- **So -- since vacuum fluctuations are real, why isn't dark energy *enormous* (*10^{120} times larger*)???**

Limitations on our Knowledge of Dark Energy



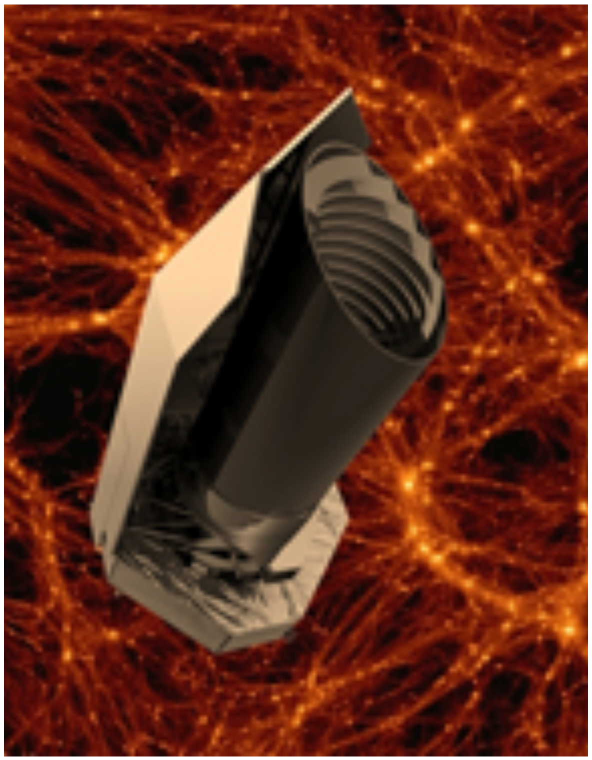
→ Calibration of, and corrections to, brightness measurements are a significant source of uncertainty in measured cosmological parameters.

➢ Unless we improve calibration standards (for flux as a function of color) to < 1%, this will be a limiting systematic uncertainty for upcoming projects …

7.7 billion light-years from Earth

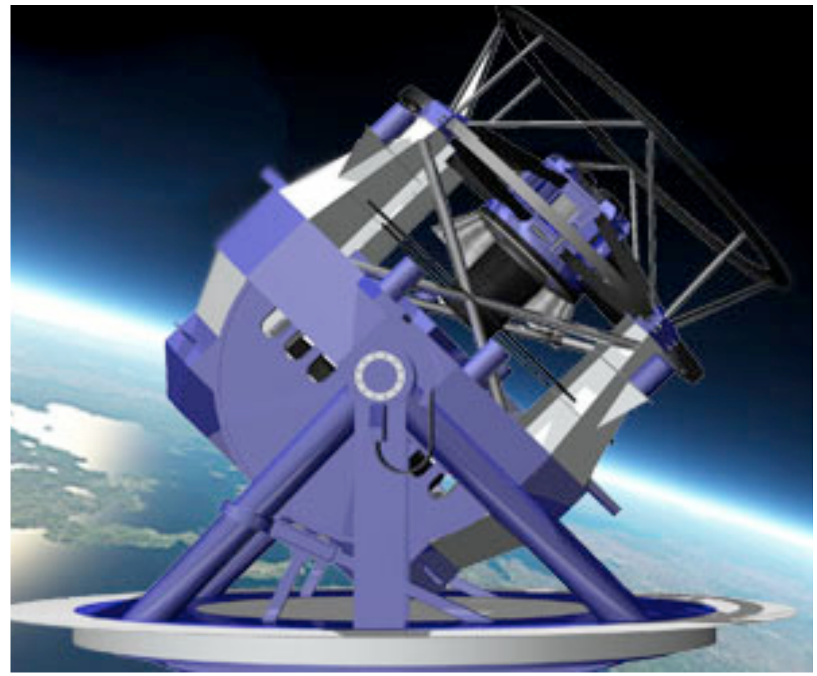
Understanding the Acceleration of the Universe

EUCLID



Launch date ~2020

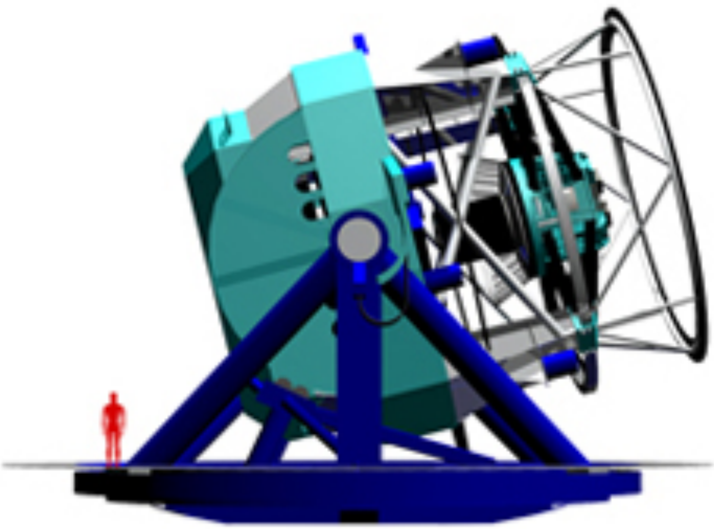
LSST
Large Synoptic Survey Telescope



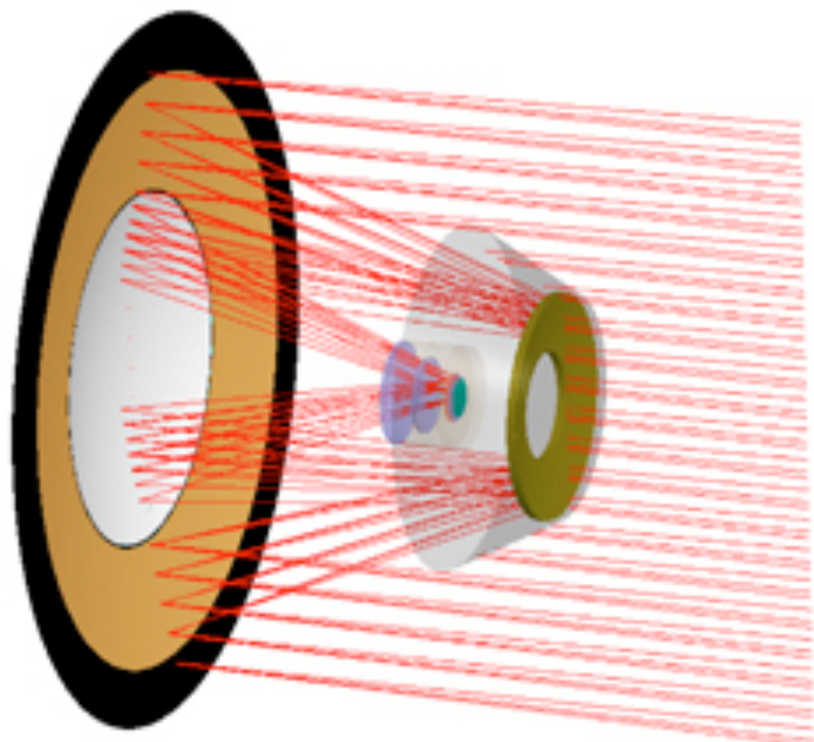
First data ~2019

… and others

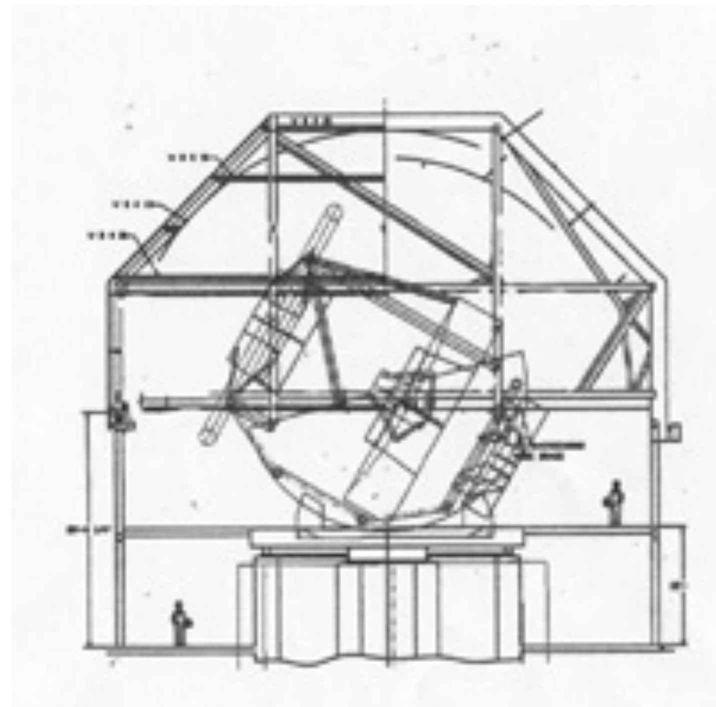
The Large Synoptic Survey Telescope (LSST)



- 8.4 m aperture
- Survey: 20,000 sq. degrees
- 9.6 sq. degree field-of-view
- 6 filters from 320nm to 1060nm
- Site: Cerro Pachon, Chile

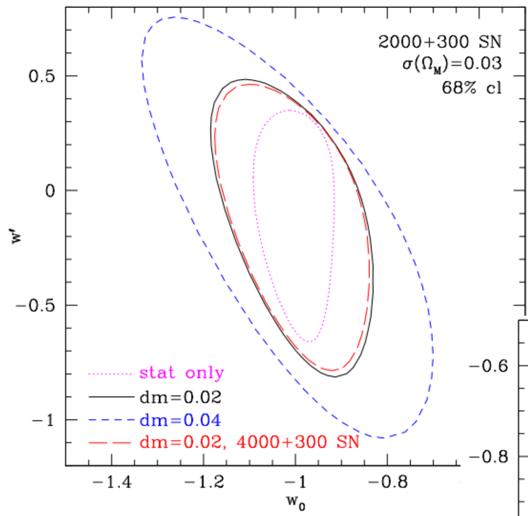


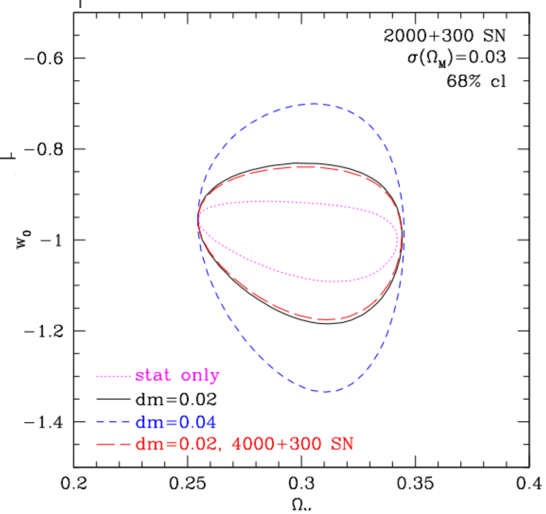
The Large Synoptic Survey Telescope (LSST)



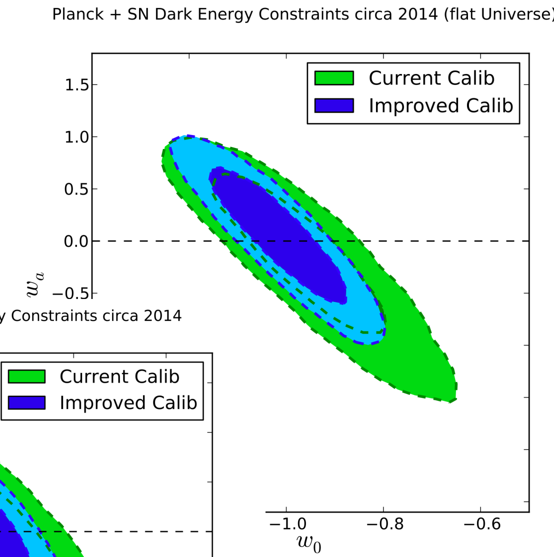
Systematic Uncertainties Dominate Both Present & Future Dark Energy Measurements

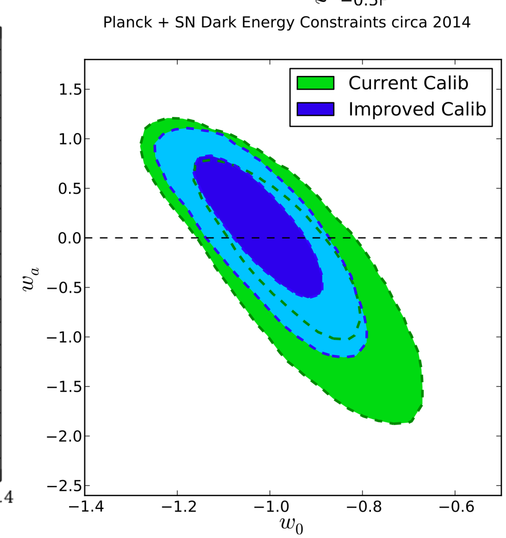
Kim, Linder, Miquel, & Mostek (MNRAS, 2004):





Conley (2011):

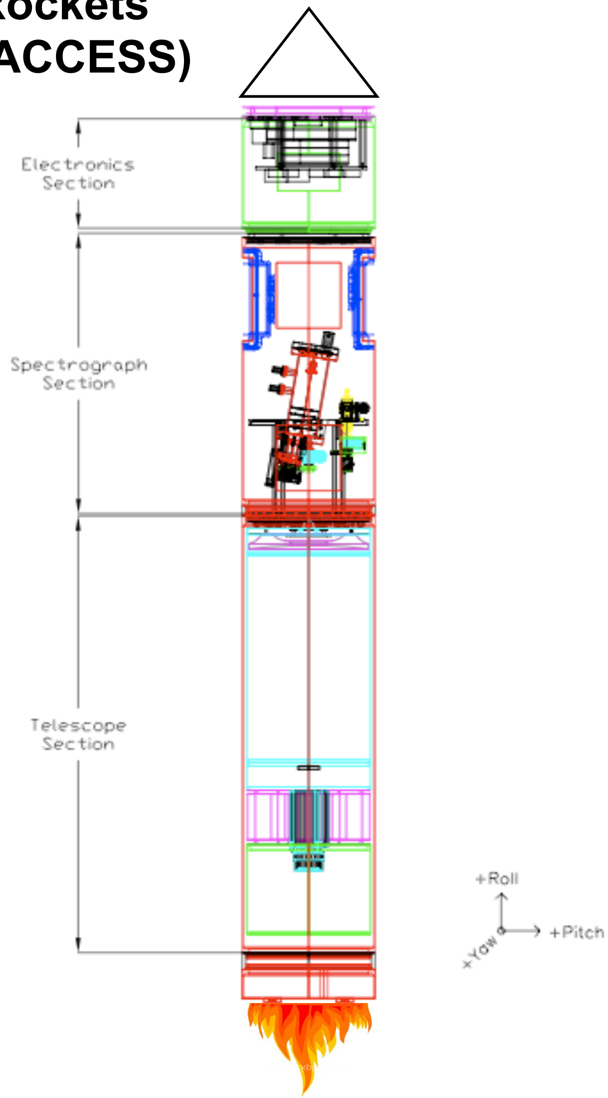




- *2%* uncertainties in photometry fundamentally limit measurements of w_a to **> ±0.40** and w_0 (when w_a is floated) to **> ±0.12**.
- Future SNIa surveys nearly useless for cosmology without significant photometry improvement.

Improving Fundamental Calibration

Rockets (ACCESS)



Not Easy

Need to get above the ATMOSPHERE

Another possibility: Balloons

But even after you very carefully calibrate them, stars are VARIABLE (majority on the > 1% scale).

Wouldn't it be nice to just have a (man-made) source up there … ?

Our Collaboration

Funding graciously provided by:

Justin Albert, Karun Thanjavur, Spencer Bialek, James Hartwick
Univ. of Victoria

Arnold Gaertner, Jeff Lundeen
NRC-INMS

NRC Institute for National Measurement Standards

Matt Dobbs, James Forbes, Khoi Nam, Nate Long
McGill

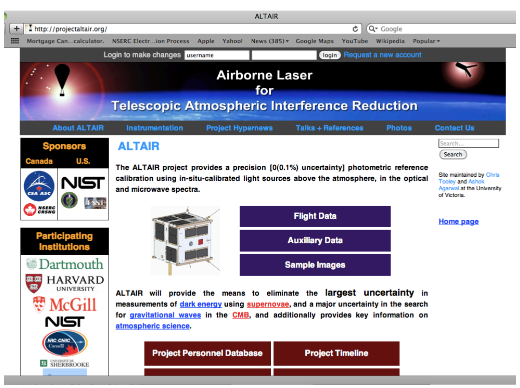
Keith Vanderlinde, Ray Carlberg
Toronto

Christopher Stubbs, Peter Doherty, William High, Isaac Shivvers
Harvard

Keith Lykke, Steven Brown, Claire Cramer, John Woodward
NIST

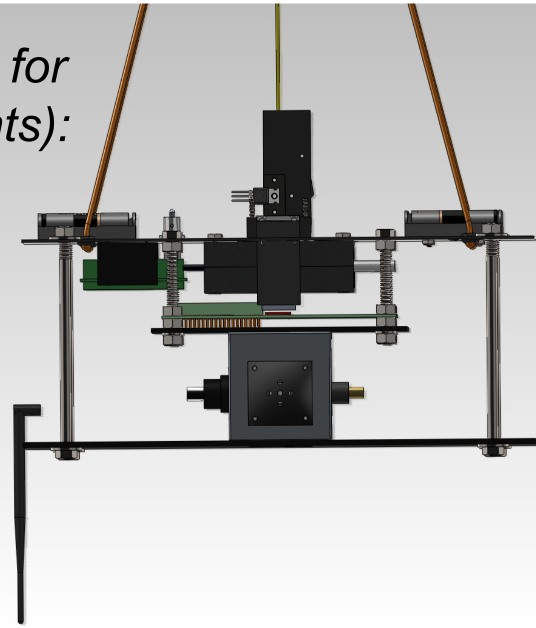
Yorke Brown, Max Fagin, Will Voigt, Nina Maksimova
Dartmouth

http://projectaltair.org

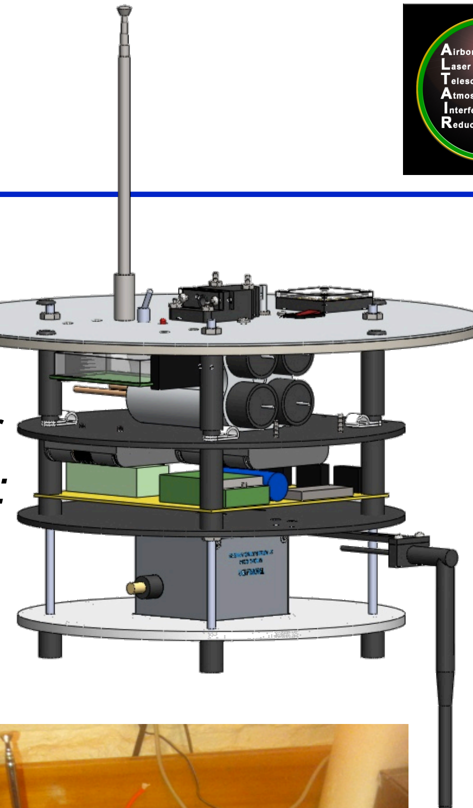


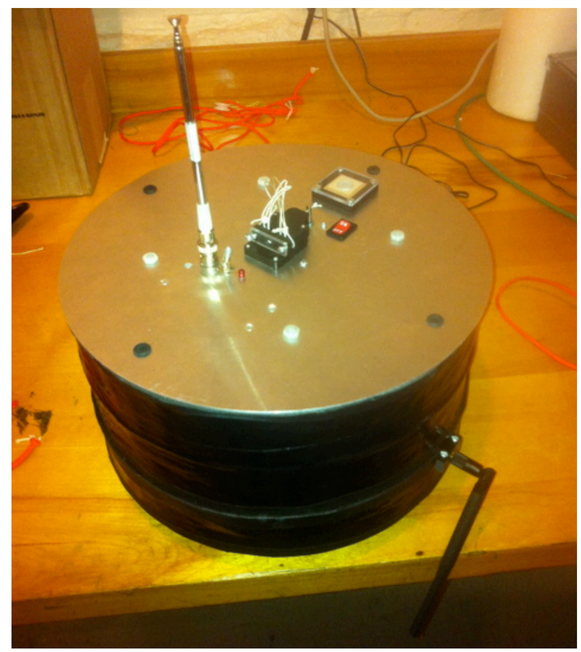
Our Payload

***v.1** (used for 2011 flights):*



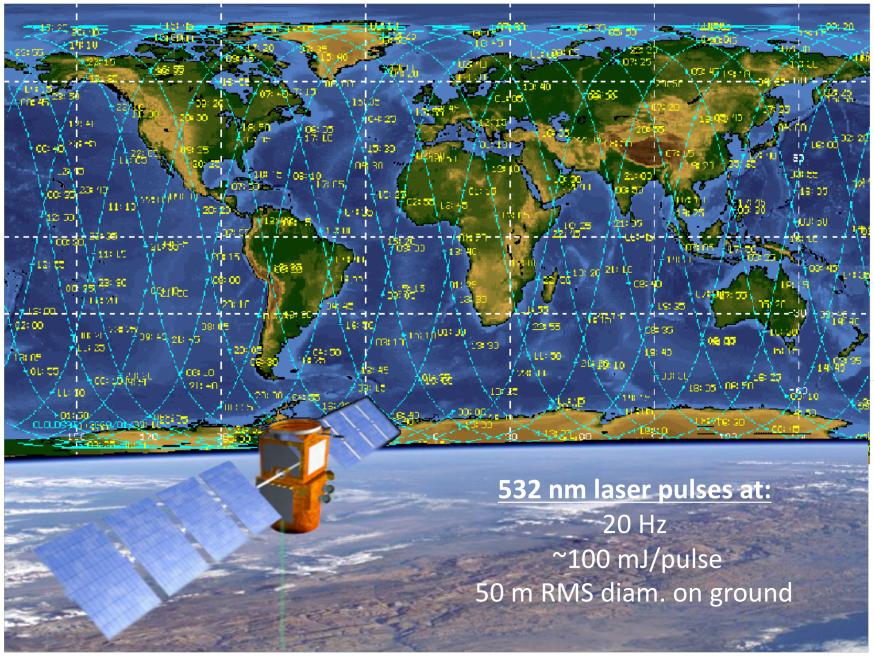
***v.2** (used for 2012 flights):*



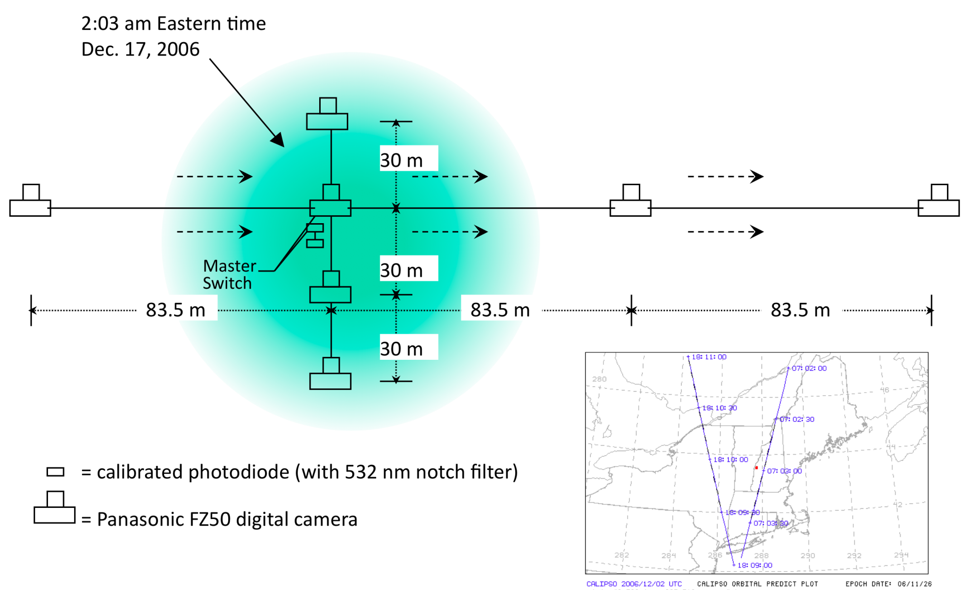


Payload Design

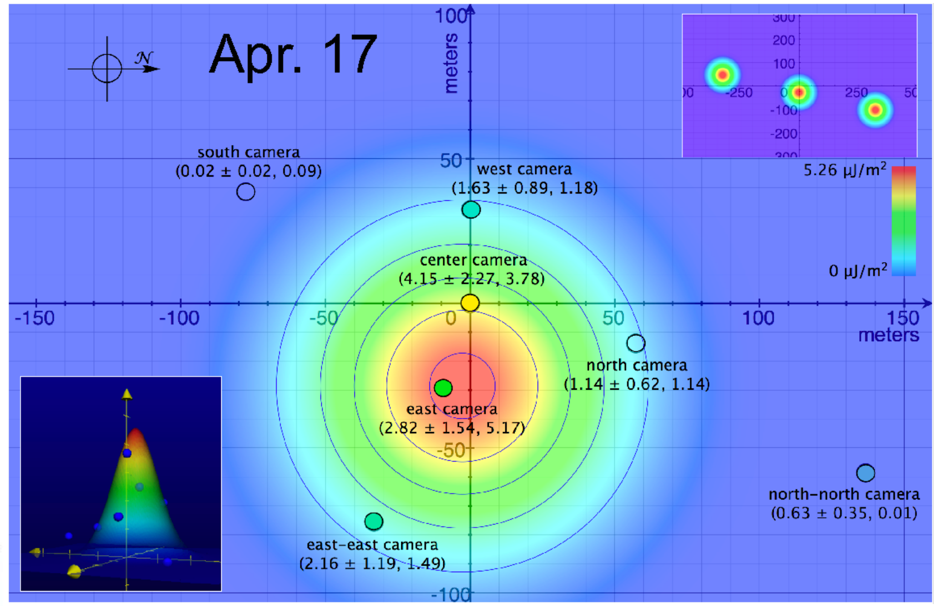
Some “Pre-History,” & How we Got Here



Setup for Calibrated CALIPSO Observations

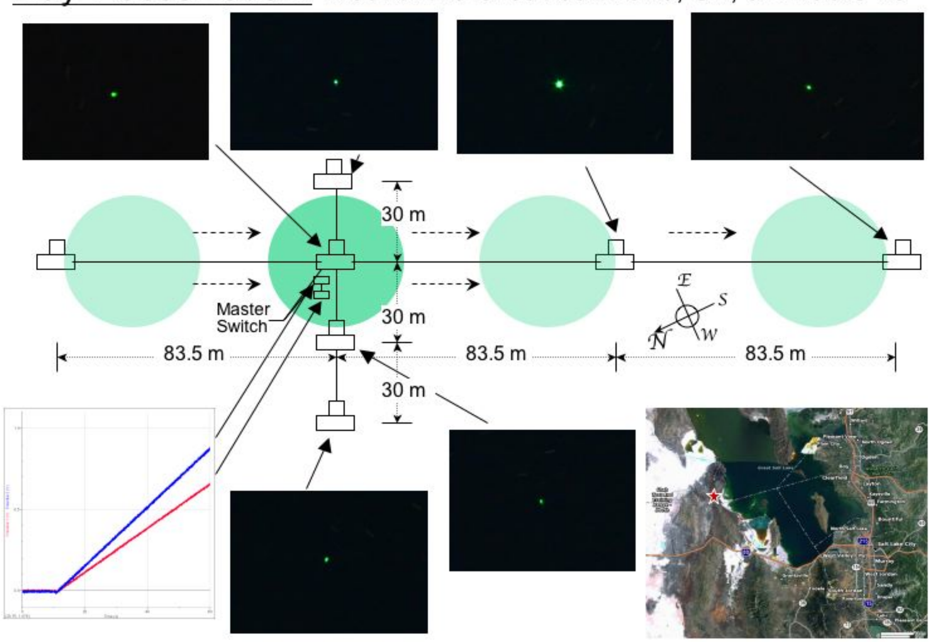


Some "Pre-History," & How we Got Here

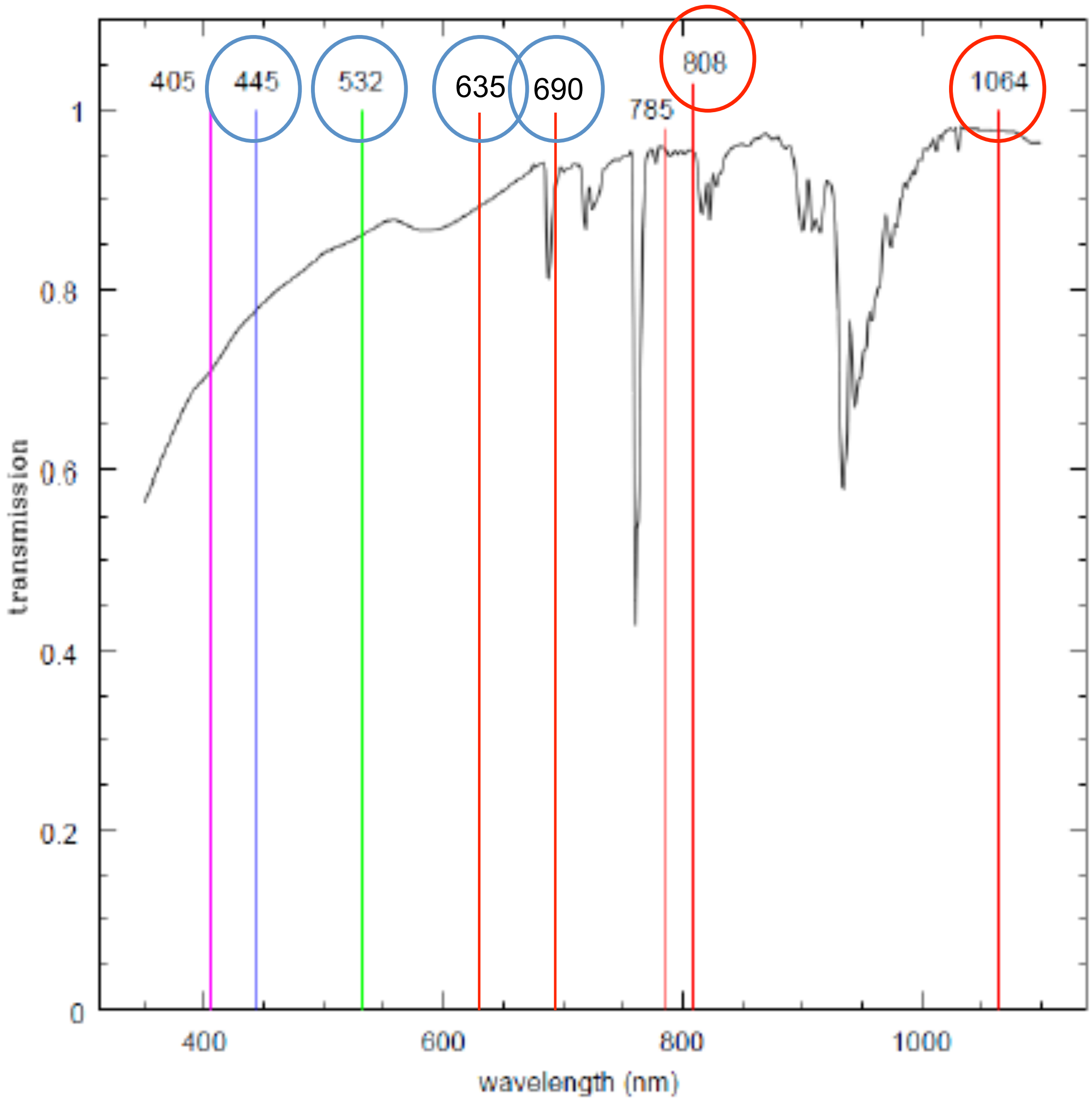


Astronomical Journal 143, 8 (2011)

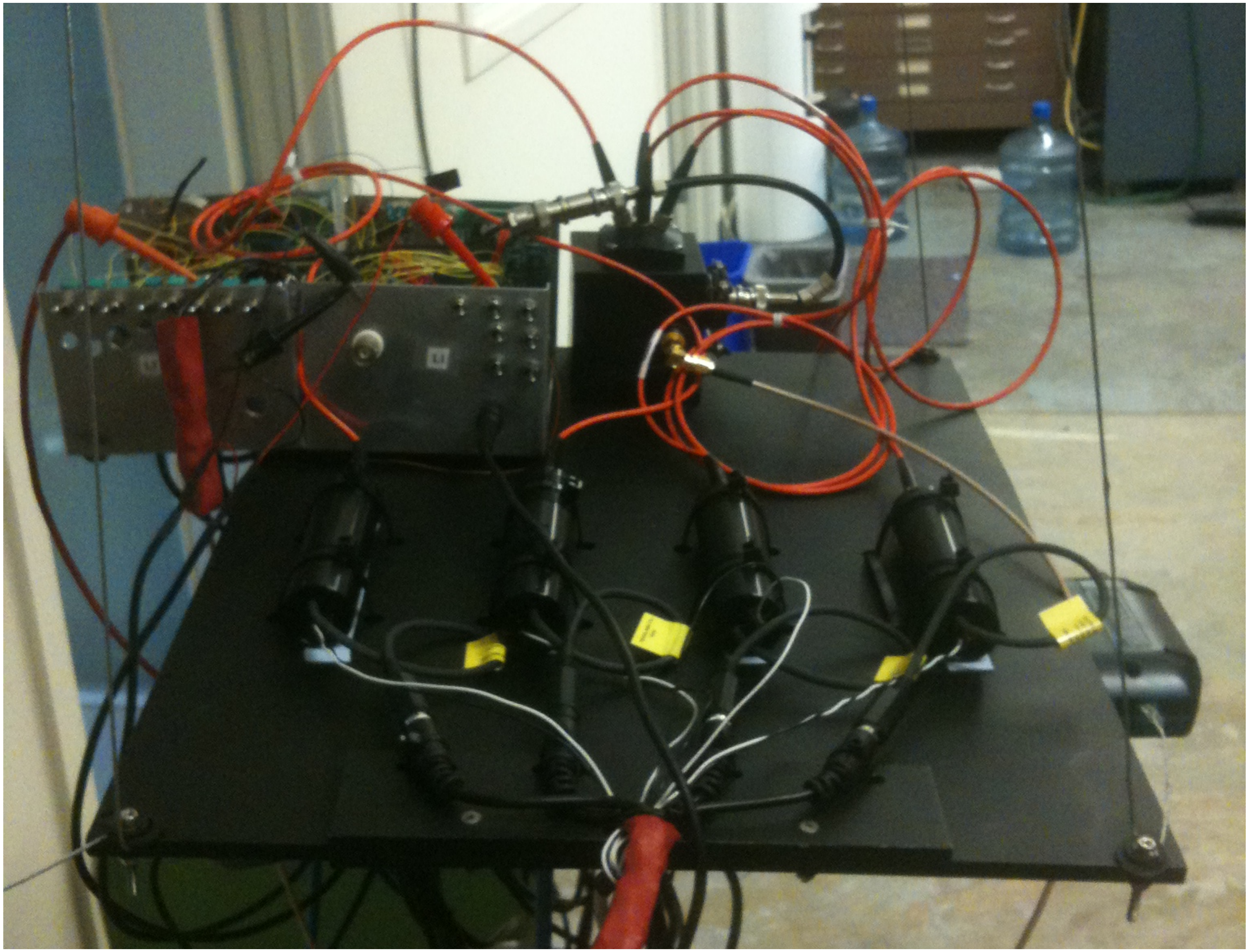
May 1 observation: west of the Great Salt Lake, UT, 9:44:50 UTC



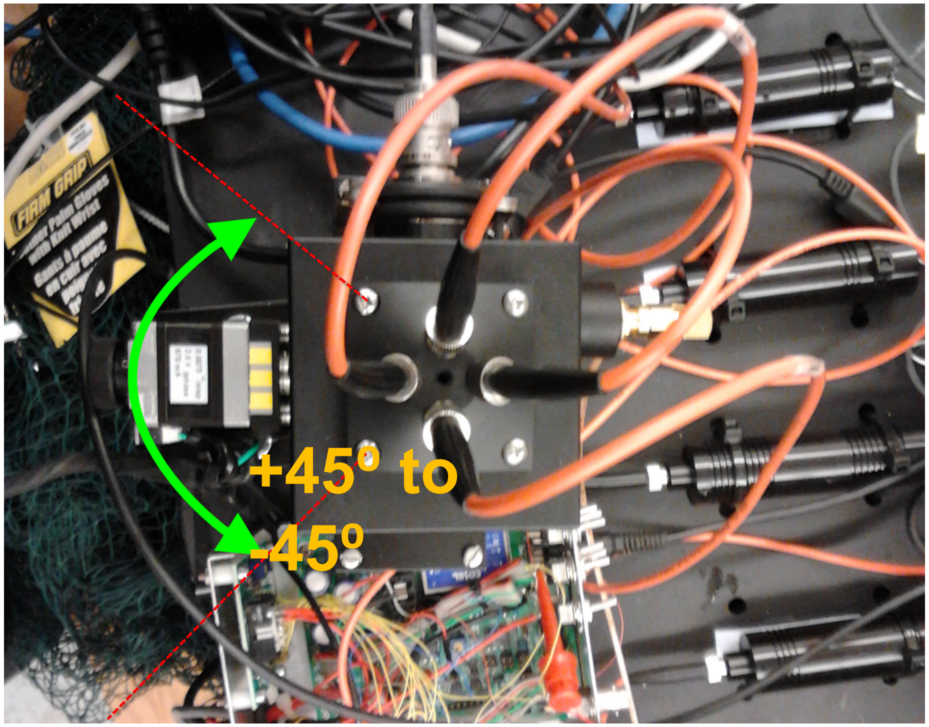
Optical Source Lines

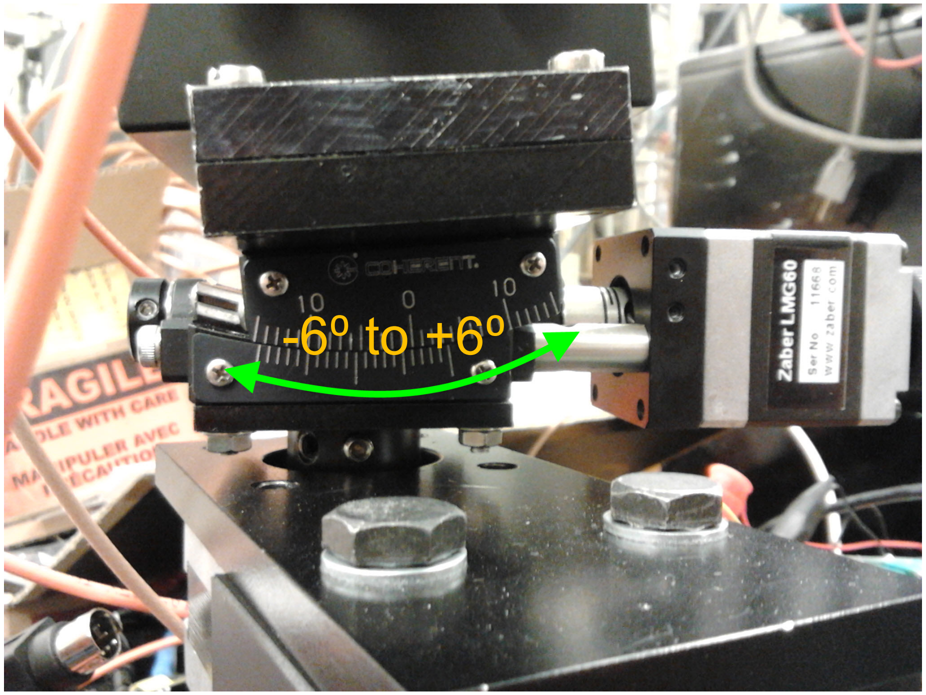


Optical Payload Test Platform



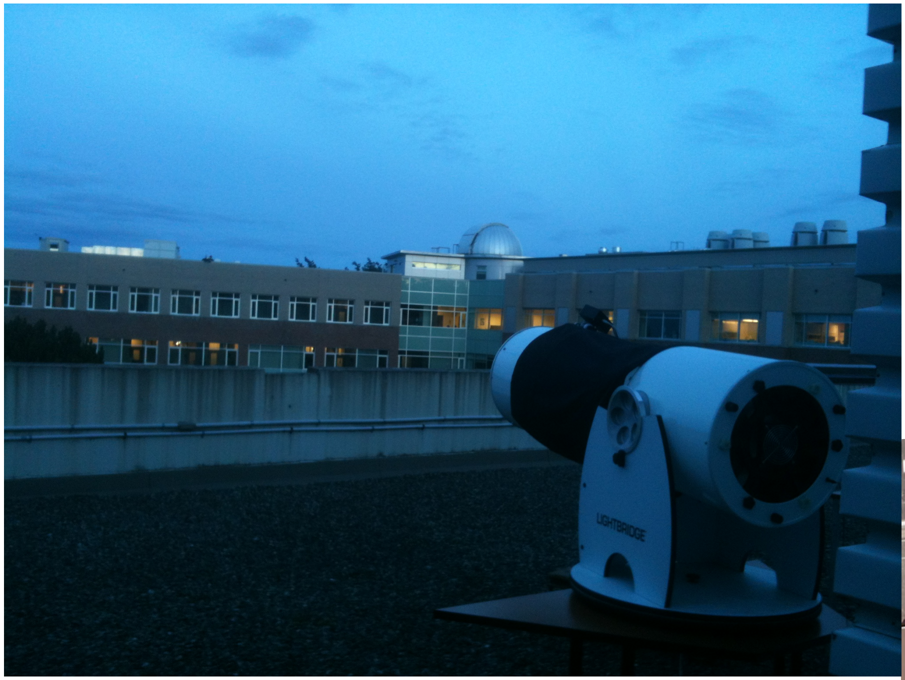
Testing the Optical Payload

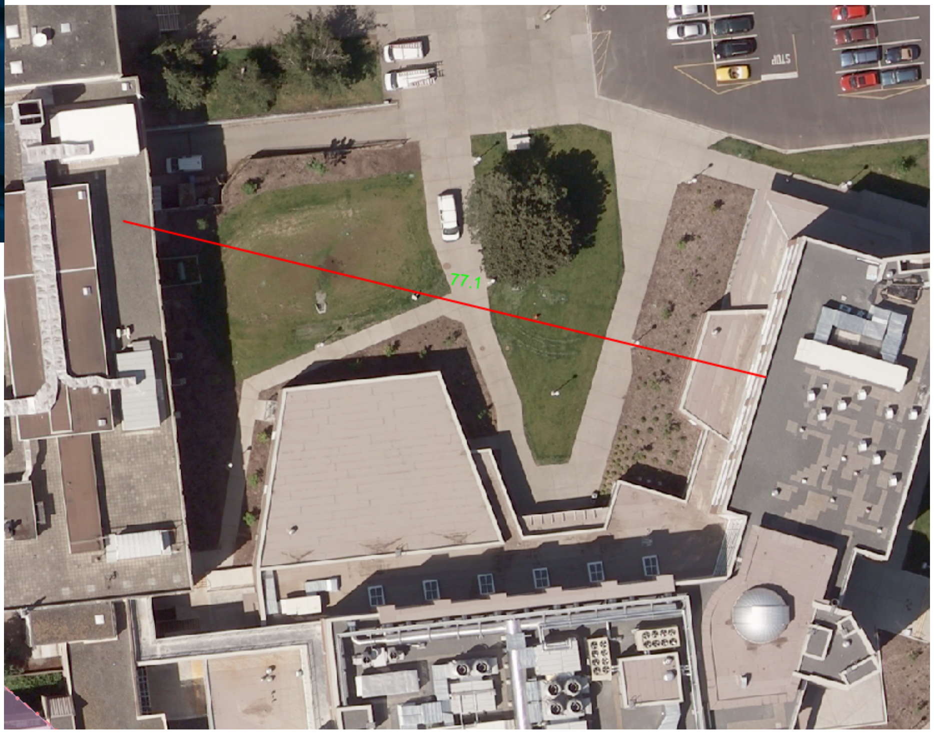




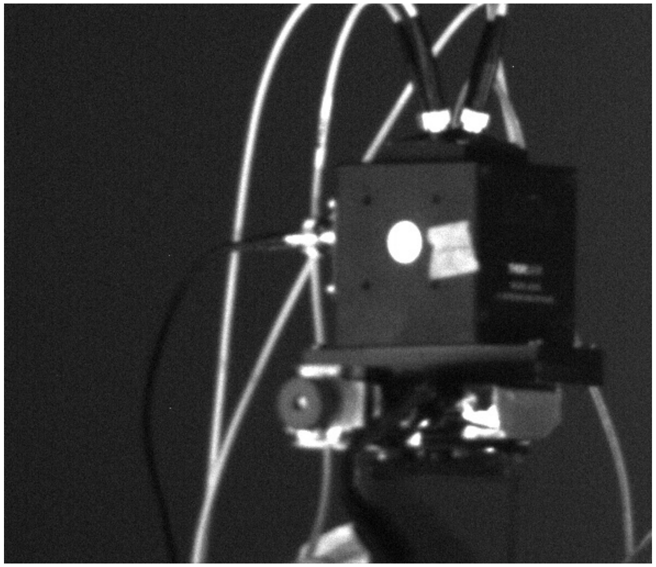
Testing the Optical Payload

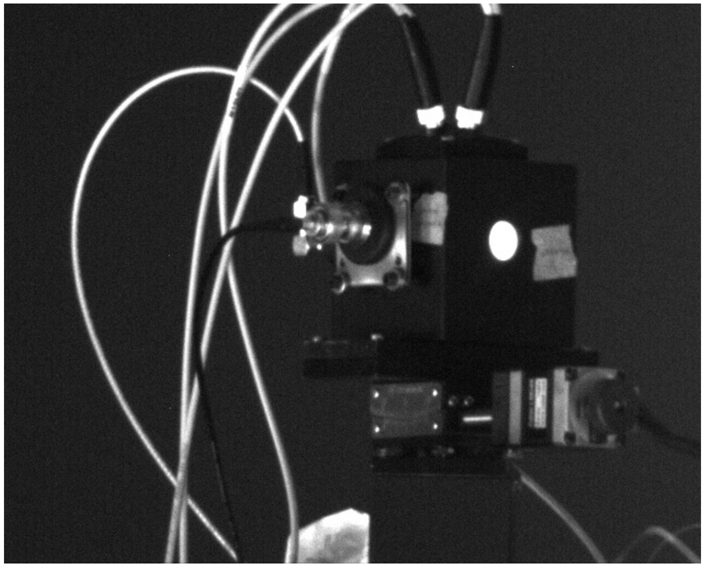
Testing the Optical Payload

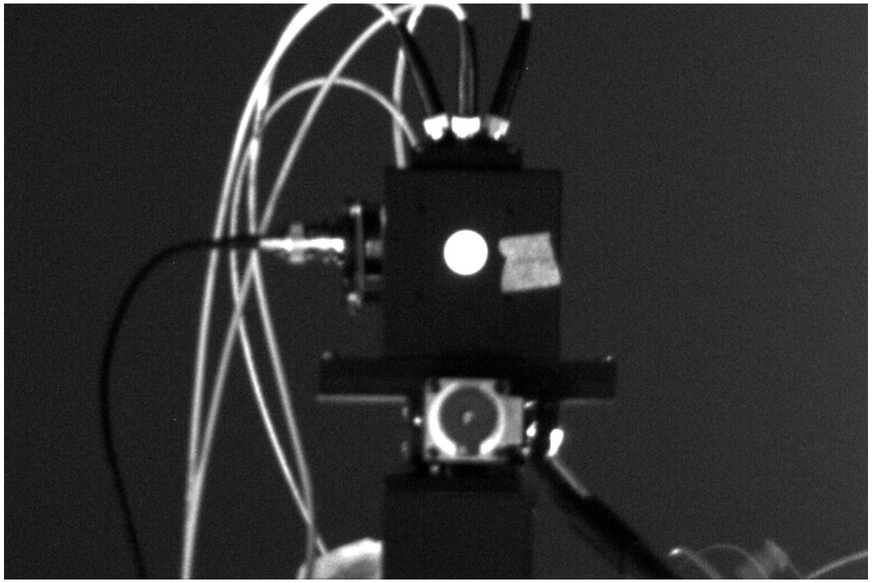




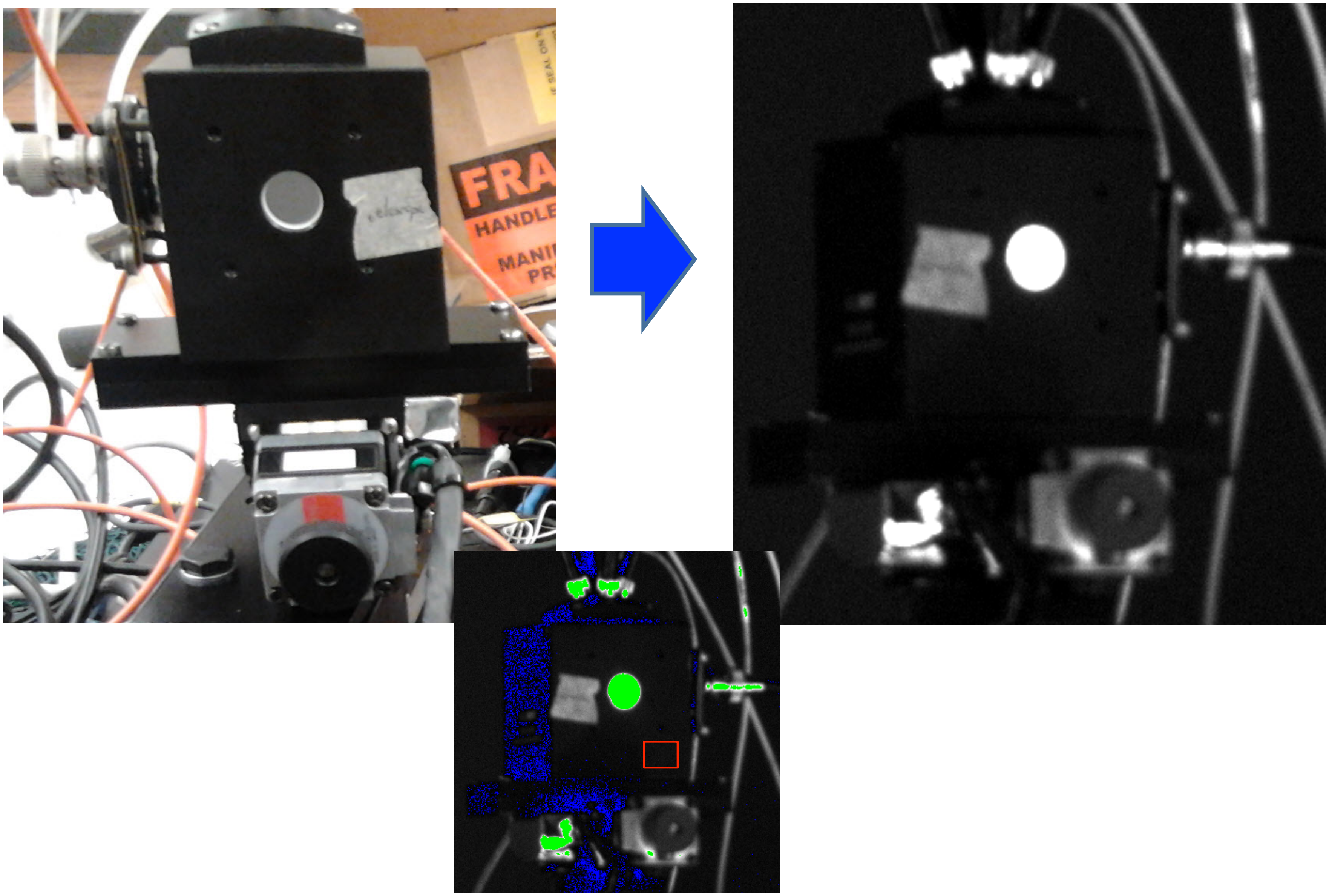
Some Near-Field (80 m) Images





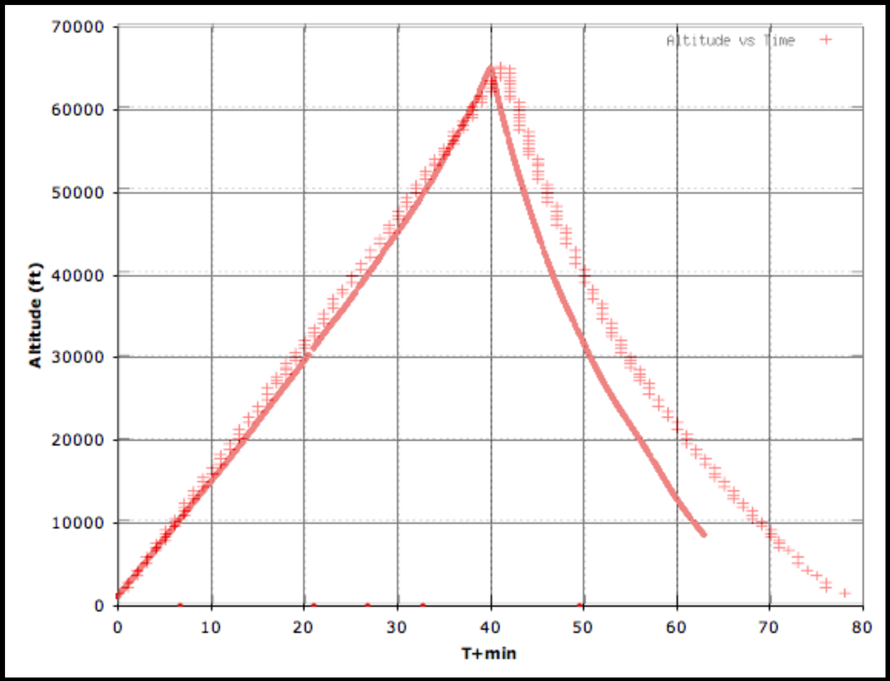


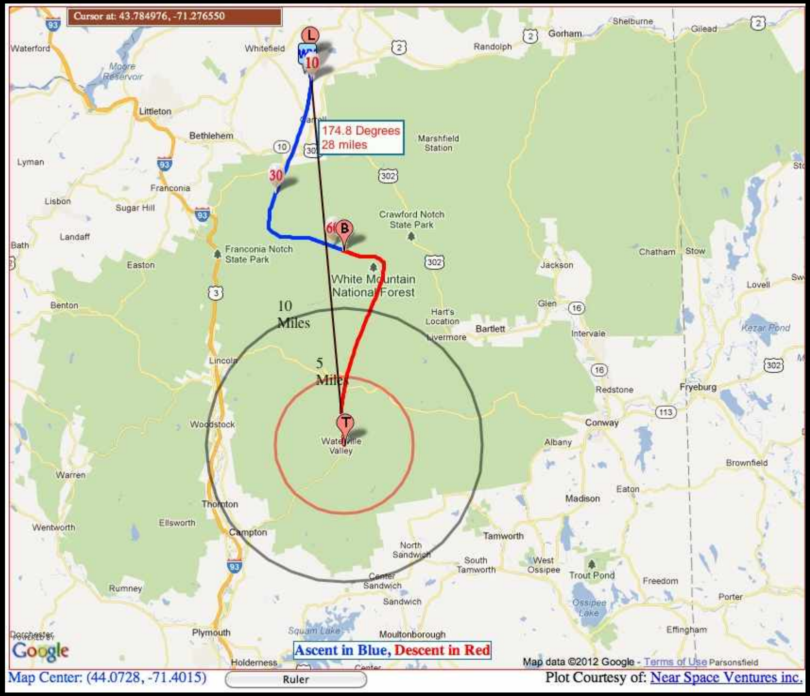
Photometry



Demonstration Flight: ALTAIR 2
04/13/2012

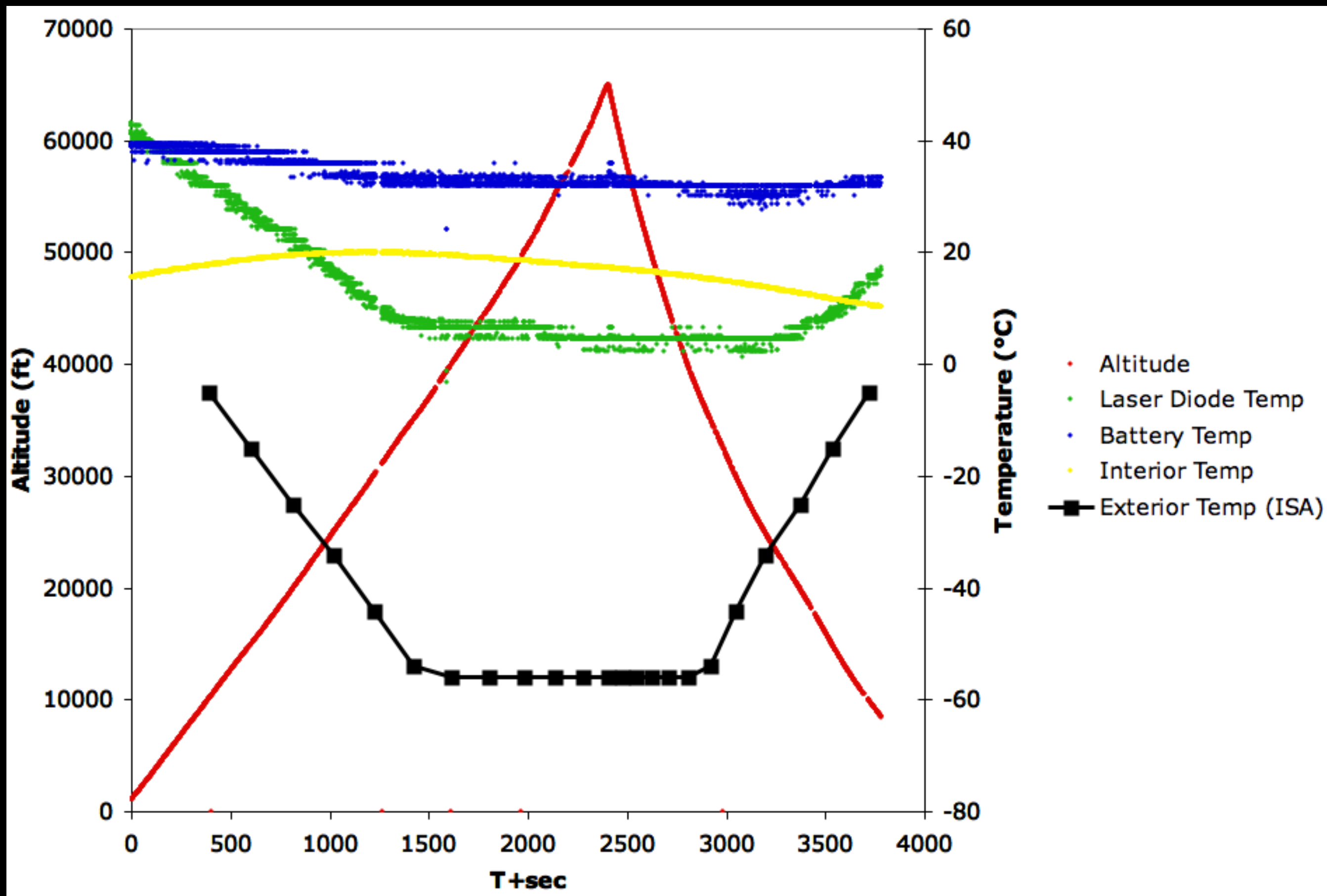
ALTAIR 2 Results
04/13/2012





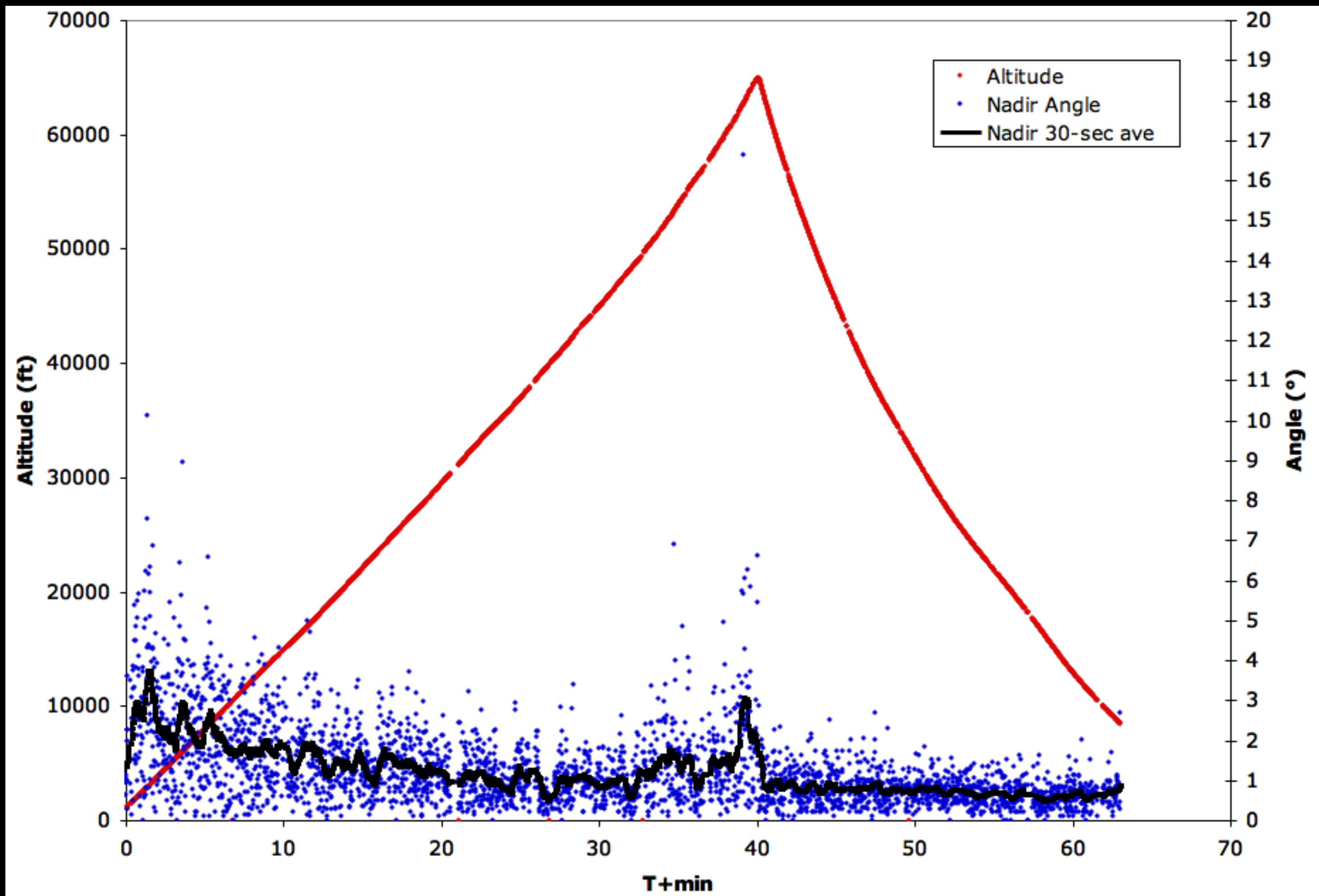
Demonstrated: Ability to control flight profile

ALTAIR 2 Results
04/13/2012



Demonstrated: Ability to maintain payload at normal temperatures

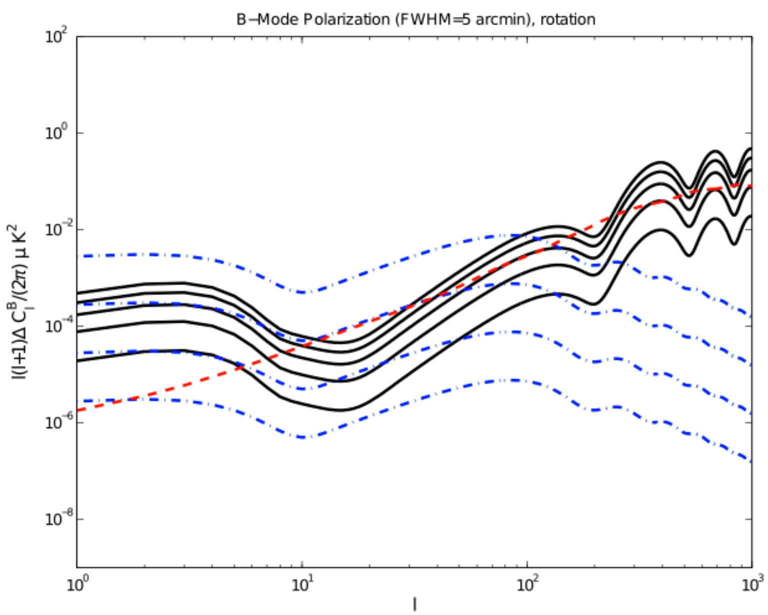
ALTAIR 2 Results
04/13/2012



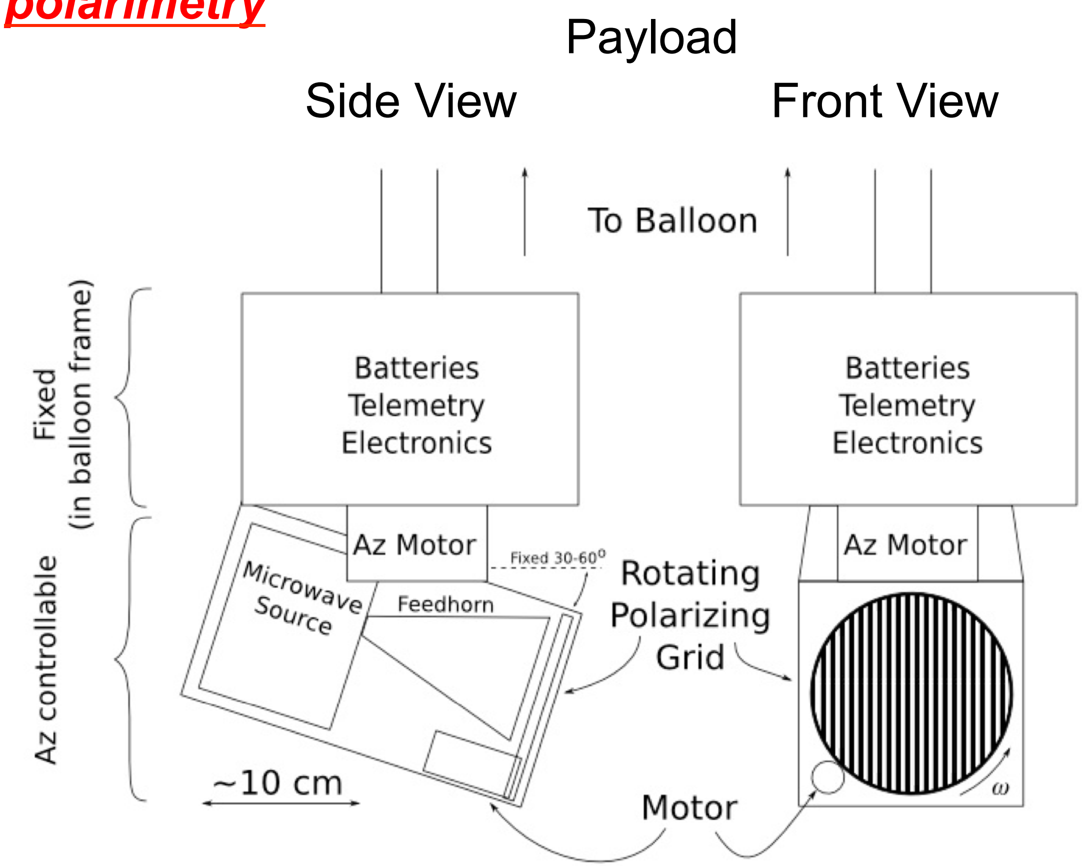
Demonstrated: Measure payload's real time attitude

A Microwave Source …

Calibrate ***polarimetry***



Angular power spectrum of false CMB B-mode signals generated by errors in polarization sensitivity angles (from Shimon et al, PRD 77, 083003)



McGill University
(Matt Dobbs & Keith Vanderlinde)

Our Schedule & Plans

- Our next flight: New Hampshire night flight this early spring – test observing strategy.

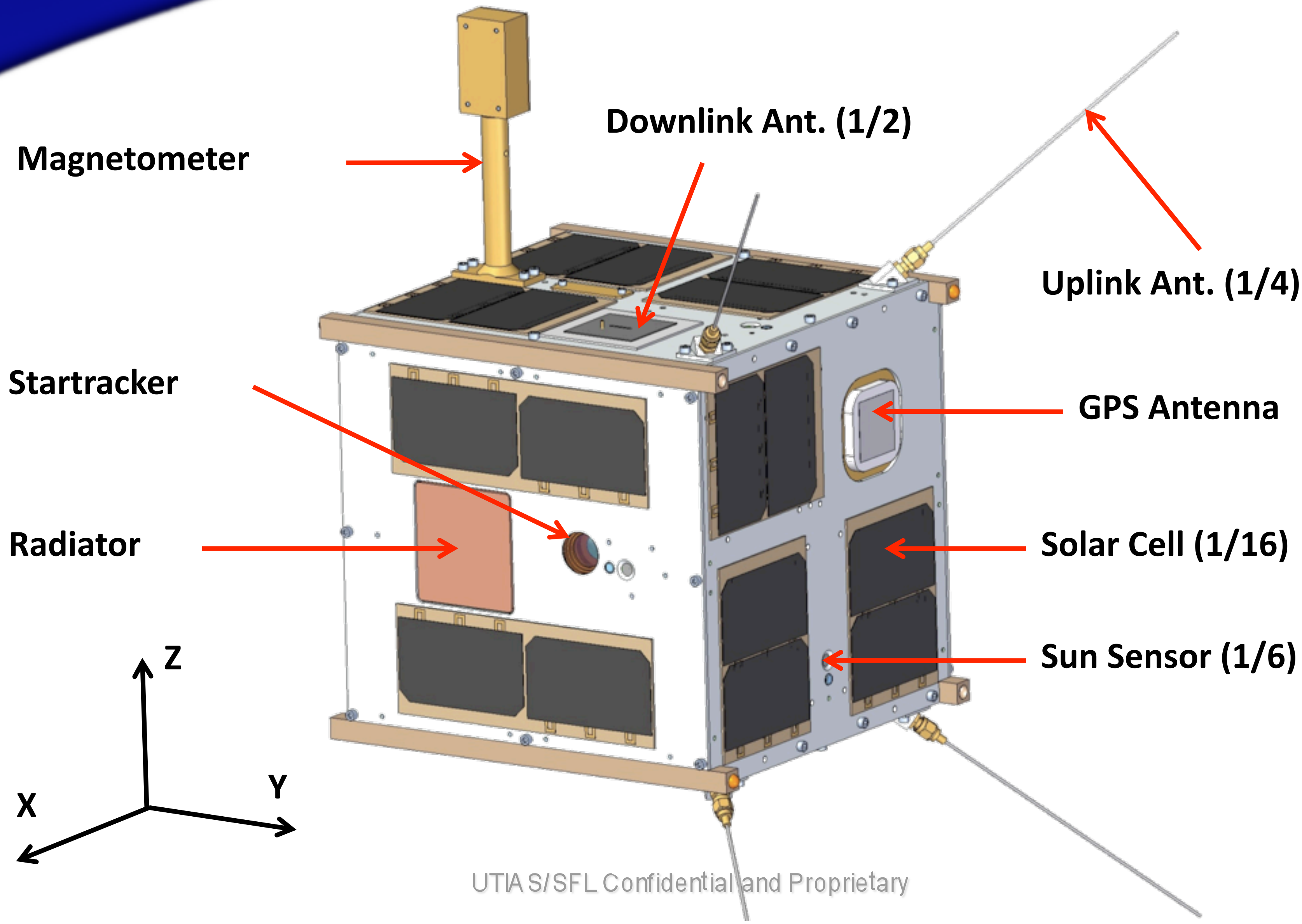
- Following that, flights over Mt. Hopkins (Arizona) NIST facility this spring.

- Additional Canadian flights: over HIA/DAO and Mont Megantic. Initial tests of microwave payload in early 2014.

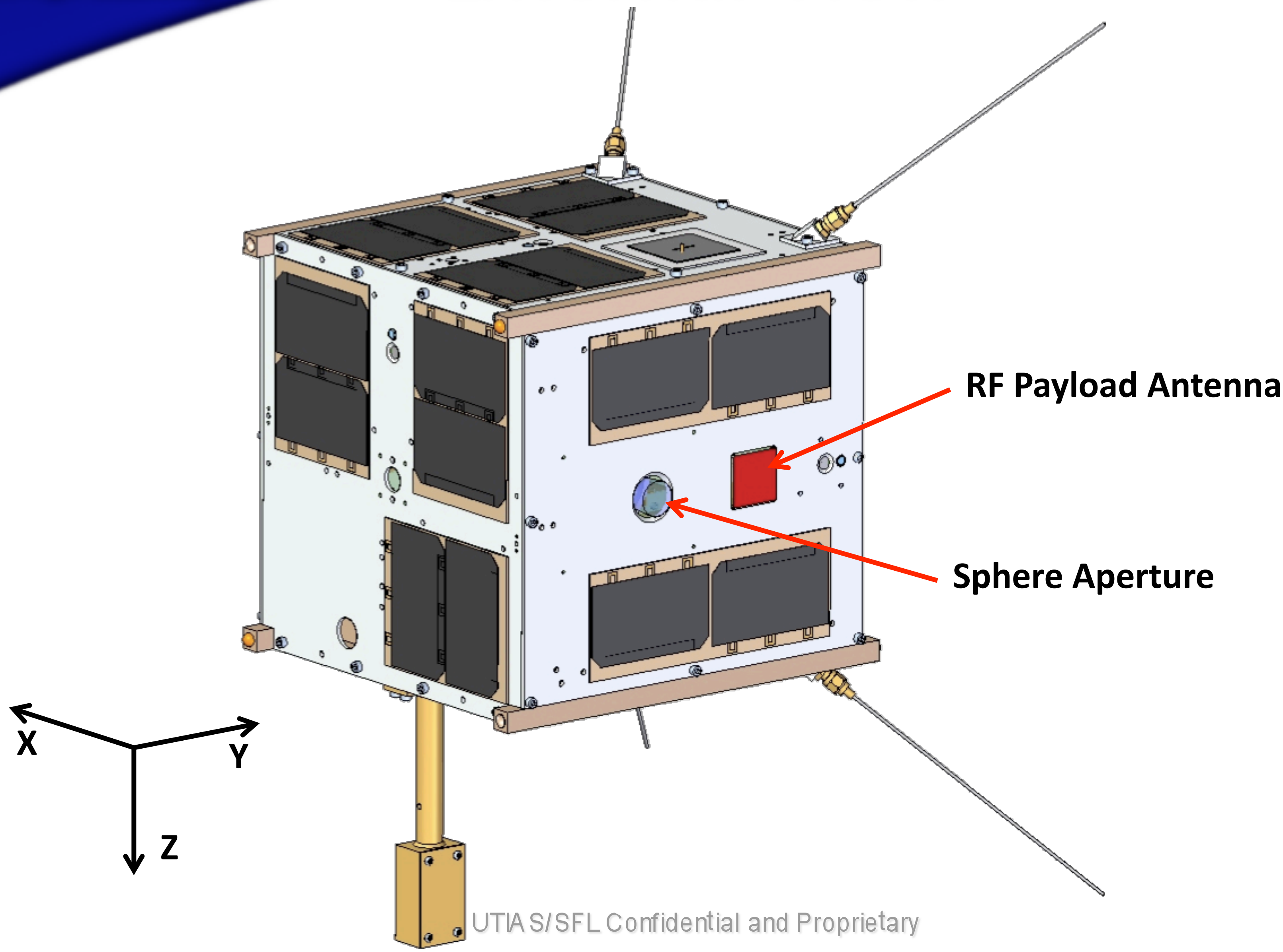
- Optical payload: work toward flights in Chile (and Hawaii) in 2014 and beyond.

- Microwave payload: flights over South Pole (SPT-Pol) and Cerro Chajnantor.

External View



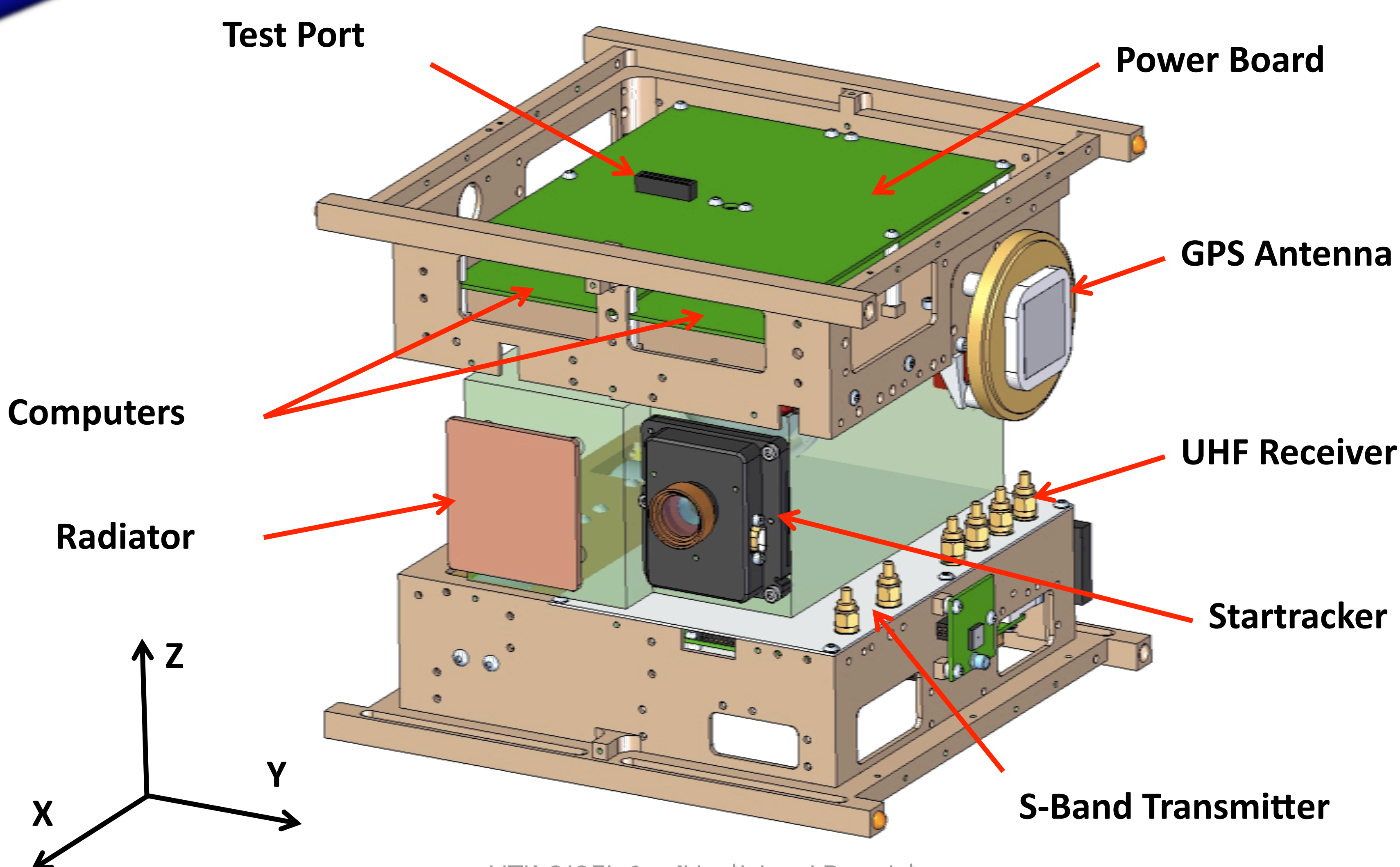
External View



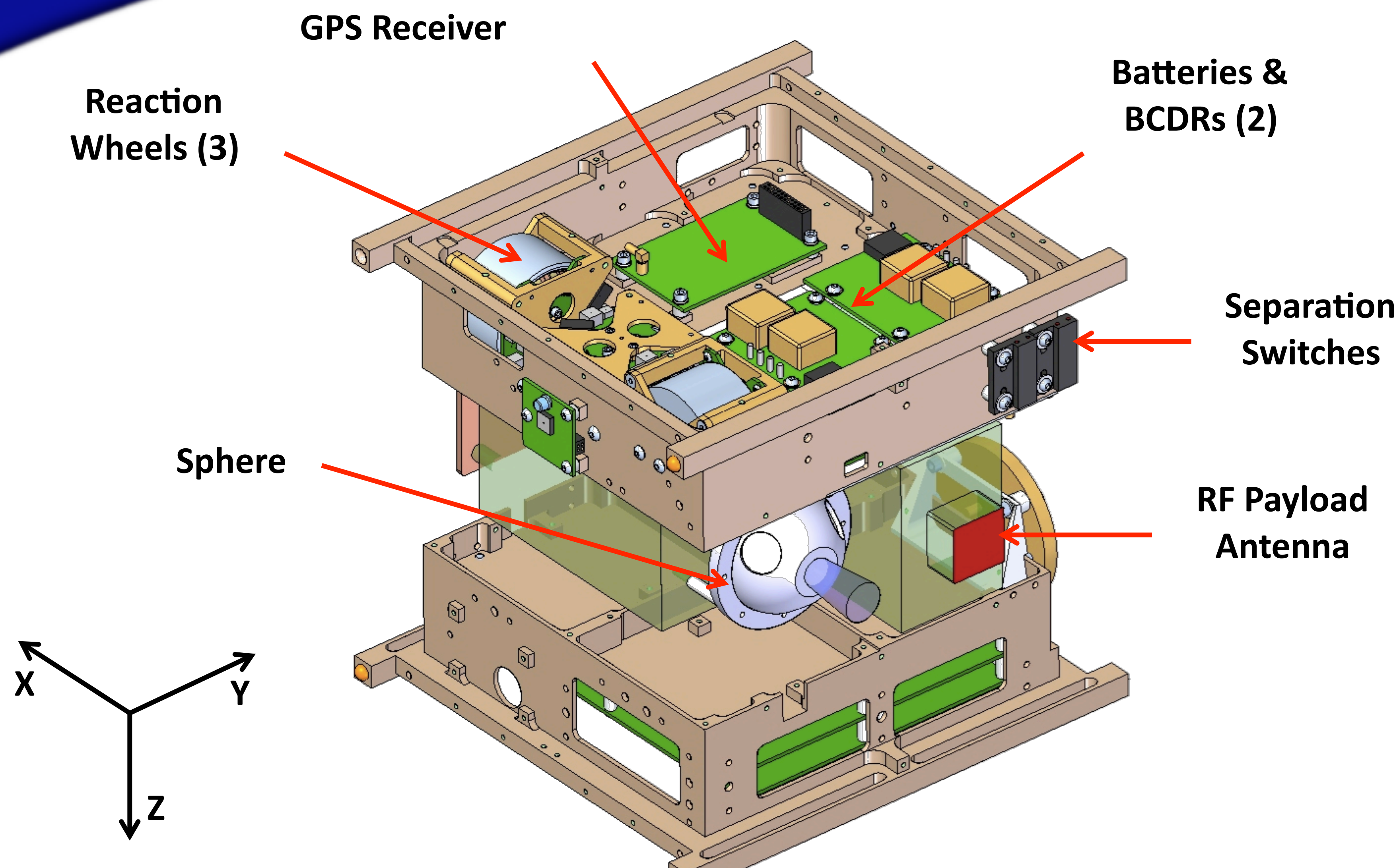
UTIAS SFL Space Flight Laboratory

Building Canada's Future In Space

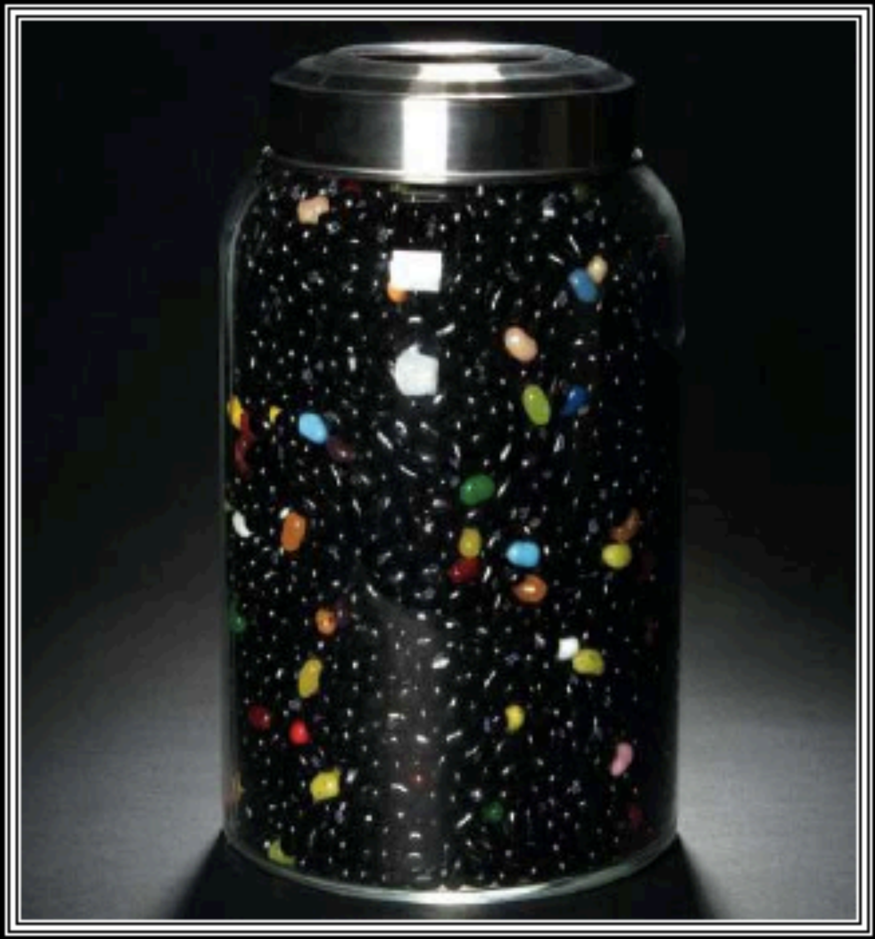
Internal View



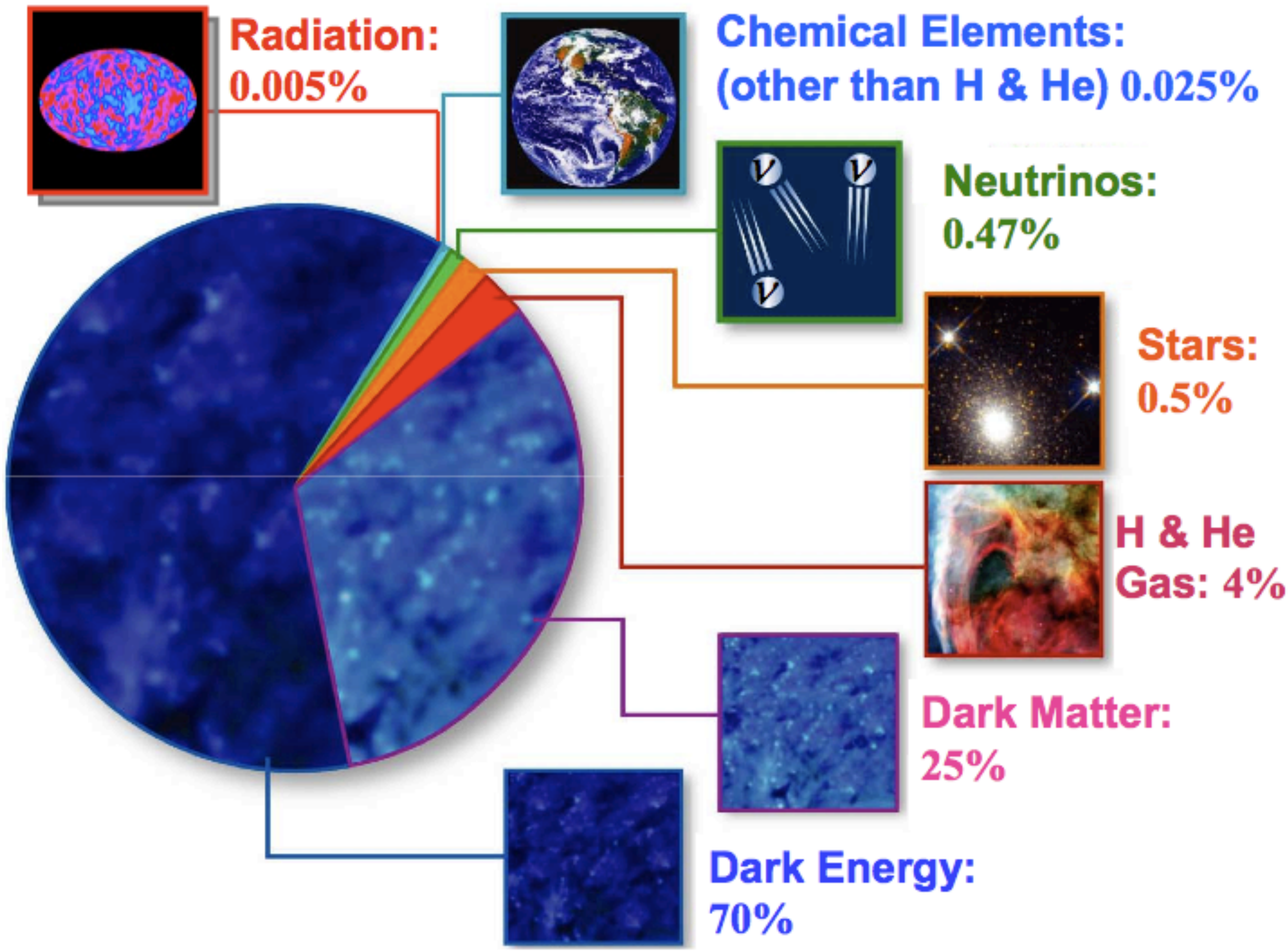
Internal View



The Dark Side of the Universe



95% of the Universe Is Dark!



Radiation:
0.005%
Chemical Elements:
(other than H & He) 0.025%
Neutrinos:
0.47%
Stars:
0.5%
H & He
Gas: 4%
Dark Matter:
25%
Dark Energy:
70%

Conclusions

- **Man-made sources are, in principle, able to reach up to two orders of magnitude better photometric calibration precision than any natural light sources.**
  1) Can ***take them into the lab before and after use***, unlike stars.
  2) Can ***monitor them in-situ***, in real time.
  3) Can be used to ***calibrate white dwarfs*** (and the Moon) very precisely, and on a detector-based standards scale.
  4) Small balloons are ***inexpensive***.
  5) Your ***choice of spectrum*** & color on demand (including microwave! etc.), ***brightness***, … ***location*** in the sky, time of night (or day), …
- **AJ 143, 8 (2011), arXiv:1101.5214 (astro-ph).**
- **This is a core program for LSST: will be the primary photometry calibration method for LSST SNIa observations.**

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.

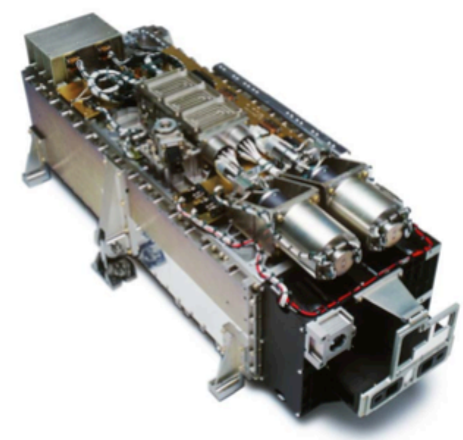
– T. S. Eliot

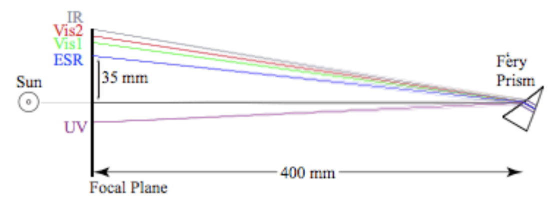
The More Distant Future: Wild Ideas

- We will achieve O(0.1%) calibration with simple NIST-calibrated photodiodes.
- Beyond that, an in-situ radiometer could achieve O(0.01%) or better …

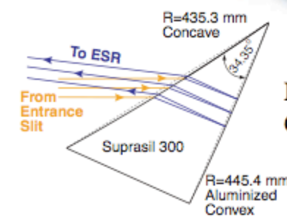
Spectral Irradiance Monitor SIM

- **Measure 2 absolute solar irradiance spectra per day**
- **High measurement accuracy**
  - **Goal of 300 ppm ($\pm 1\sigma$)**
  - **Achieving about 2%**
- **High measurement precision**
  - **SNR ≈500 @ 300 nm**
  - **SNR ≈ 20000 @ 800 nm**
- **High wavelength accuracy**
  - **1.3 μm knowledge in the focal plane**
  - **(or $\delta\lambda/\lambda$ < 150 ppm)**
- **In-flight re-calibration**
  - **Prism transmission calibration**
  - **Duty cycling 2 independent spectrometers**





Instrument Ray Trace



Fèry Prism Geometry

- **Provide Total Solar Irradiance (TSI) measurements**
  - **Flight history:**
    - SORCE: January 25, 2003 to 2008
    - GLORY: 2008 -2013
    - NPOESS: 2013….
  - **Extend the long-term TSI record.**
    - How does the Sun's output vary and what is its impact on terrestrial climate?
    - Address long-term climate change and natural variability
- **Measurement Requirements**
  - **Performance**
    - Accuracy — 300 ppm (0.5 W/m^2) (1 σ)
    - Stability — 10 ppm/yr (1 σ)
    - Noise — 10 ppm (1 σ)
  - **Report four 6-hourly averages and one daily average TSI measurement per day (Level 3 data products)**