Complexity, Ambiguity, and Risk:
The Gravity Probe B Launch Decision

NASA Case Study

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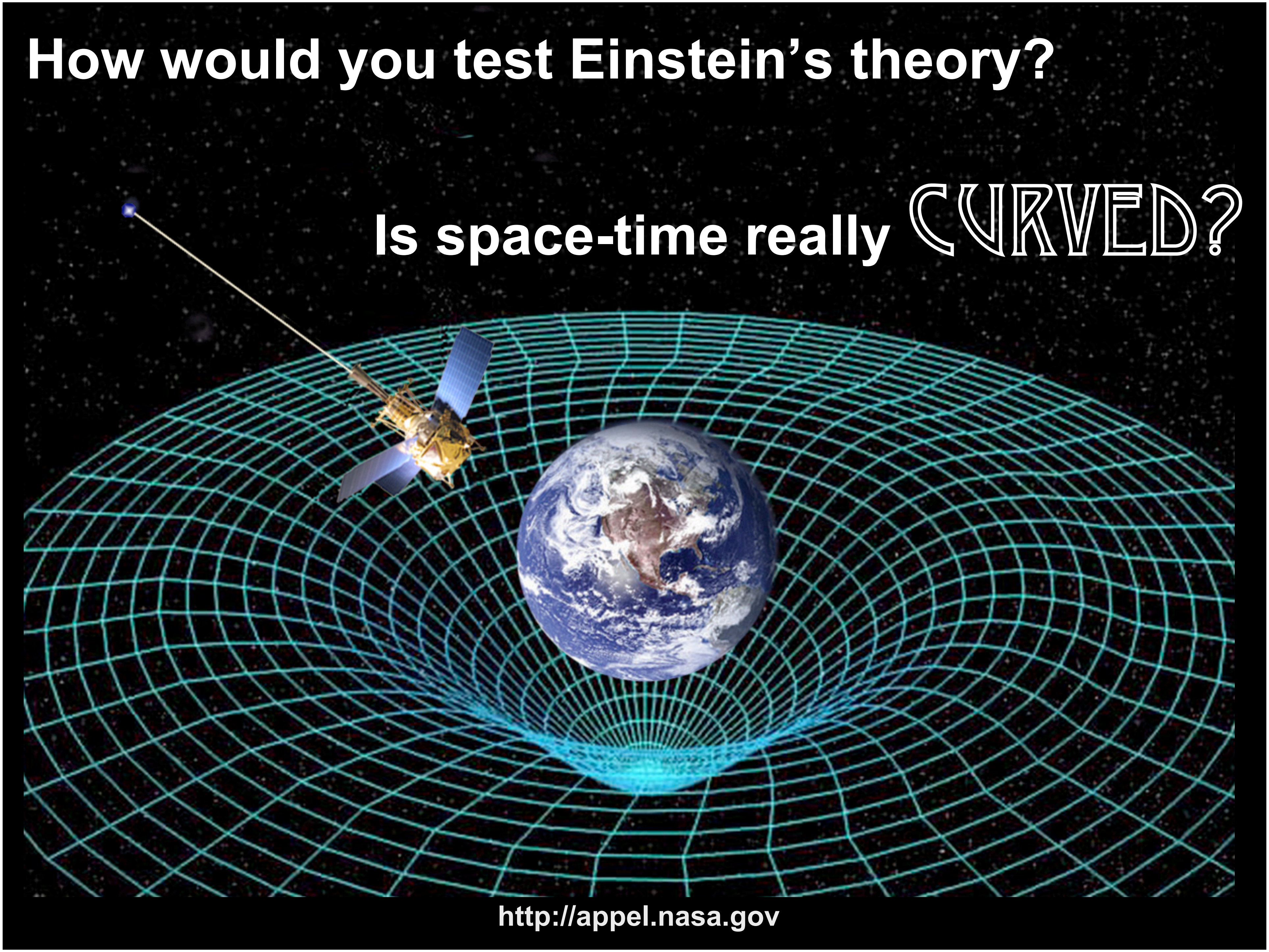
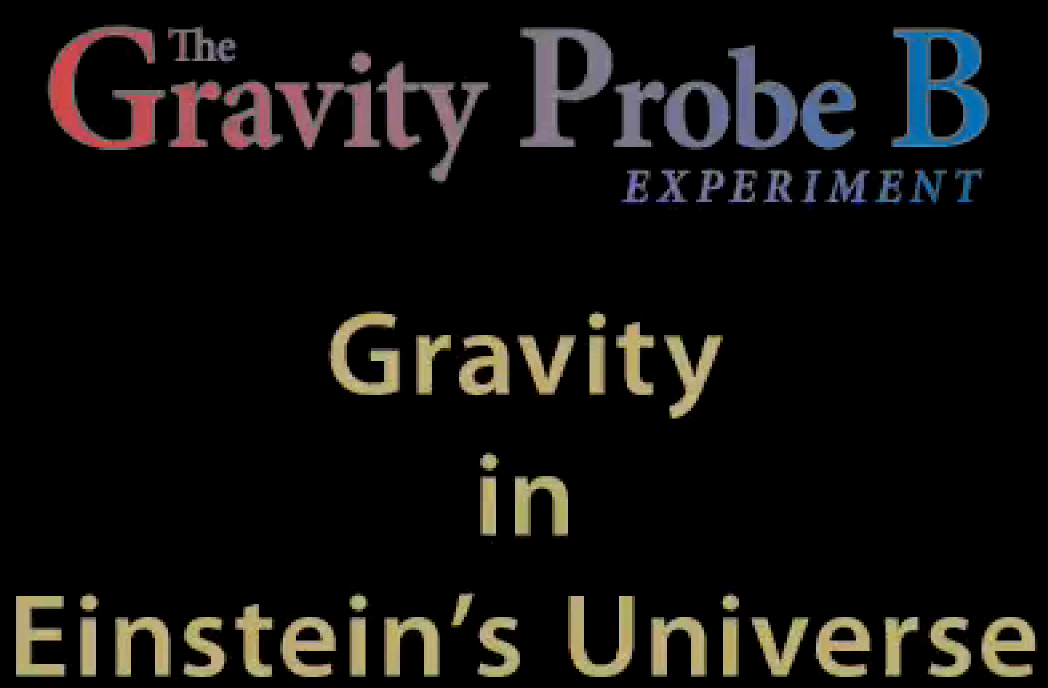
http://appel.nasa.gov


How would you test Einstein's theory?
Is space-time really CURVED?
http://appel.nasa.gov



(credit: Stanford University)

(Click to play in Flash)

The Gravity Probe B Mission - A Long Journey to Space

- Longest-running mission in NASA history -- began in 1963
- Lifelong work of Dr. Francis Everitt, Stanford University
- Cancelled **7** times -- funding restored each time

GP-B spacecraft

The Gravity Probe B EXPERIMENT

A “Simple” Experiment

(credit: Stanford University)

(Click to play in Flash)

GP-B in Context: the Complex Project Environment

	Complex Project-Based Organization	*Functional Organization*
Problems	**Novel**	Routine
Technology	**New/invented**	Improved/more efficient
Team	**Global, multidisciplinary**	Local, homogeneous
Cost	**Life cycle**	Unit
Schedule	**Project completion**	Productivity rate
Customer	**Involved at inception**	Involved at point of sale
Survival skill	**Adaptation**	Control/stability

Discussion point: does this model describe GP-B?

Defining Project Complexity at NASA

PROGRAMMATIC

Budget

- Congressional appropriations
- Changing agency constraints and priorities

Contractual

federal regulations

Schedule

- Launch windows
- Science/operational requirements

Sustained commitment

- Administration
- Congress
- Public
- Partners - academia, international, industry

TECHNICAL

Interfaces/systems engineering

Technological readiness

One-of-a-kind systems

Harsh environment

Software

Long operational lifetimes

Unique test facilities & eqpt.

High performance requirements

It has to work the first time

http://appel.nasa.gov

(adapted from Vern Weyers, 2006)

Technical Complexity: Zero Room for Error

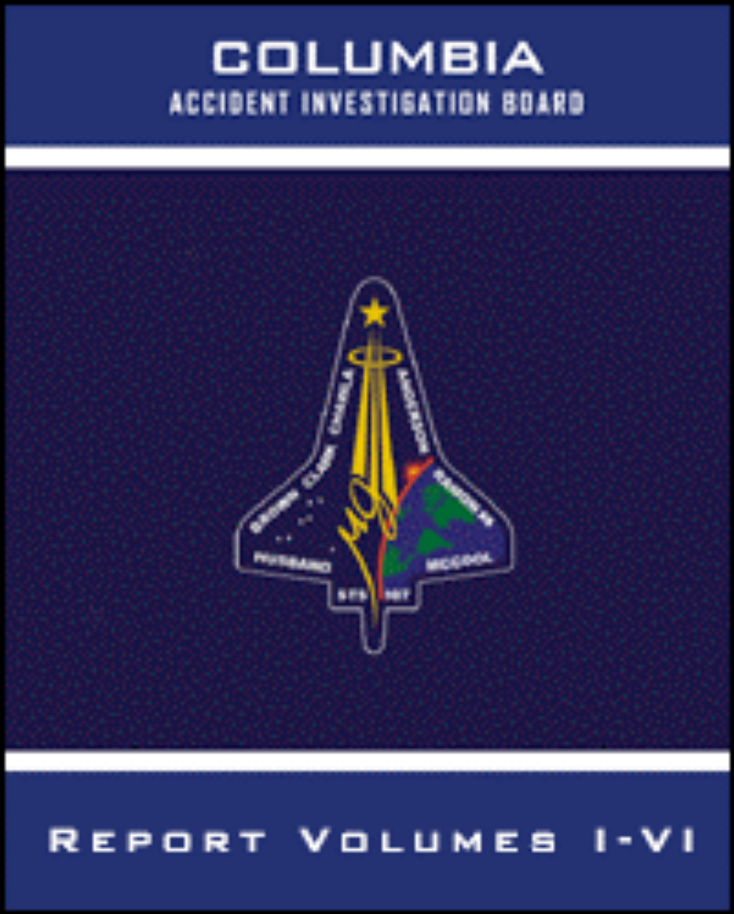
- Highly complex technology development
- "The entire spacecraft *was* the instrument."

GP-B gyros - most perfect spherical objects produced

Organizational Complexity

Stanford University	NASA	Lockheed Martin
Program management*; technology development; home Institution of Principal Investigator	Program management; final go / no-go launch authority	Construction of space vehicle and hardware; systems engineering support

Organizational Context at NASA in 2003



"NASA's current organization…has not demonstrated the characteristics of a learning organization."

Columbia Accident Investigation Board Report

Discussion point: how does organizational context shape decision-making?

July 2003

- ✓ Spacecraft arrives at Vandenberg Air Force Base (California) for final integration with launch vehicle and testing
- ✓ Launch scheduled for December 6

September 2003

- Dewar filled with liquid helium to achieve temperature close to absolute zero - process took three weeks
- Once filled, precise temperature had to be maintained
- In the event of a problem, process would have to be reversed

GP-B “Thermos bottle” dewar

October 2003: Testing Anomaly

- ✓ Experimental Control Unit (ECU), which houses several electronic components, creates “noise” when powered on that could corrupt scientific data readout
- ✓ Fault tree analysis points to ECU power supply

Experimental Control Unit (ECU)

Risk of Taking ECU off Spacecraft for Repair

Technical risks:

✓Have to remove and re-install:
- ✓All four solar arrays (extremely touch-sensitive)
- ✓ Numerous thermal blankets
- ✓ Electronics boxes

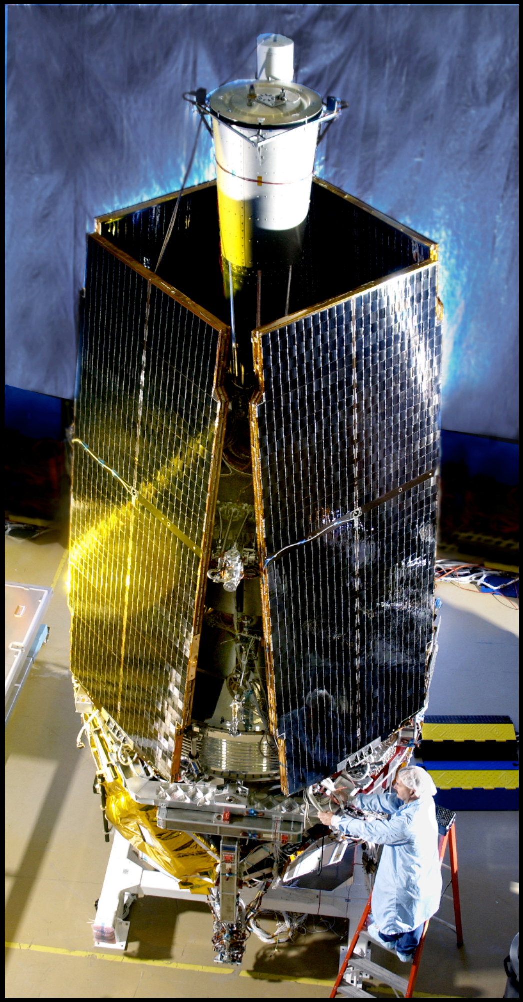
✓ Have to drain and refill dewar

Schedule impact:

✓ Original installments took three months

Cost:

✓ Estimated additional $20 million

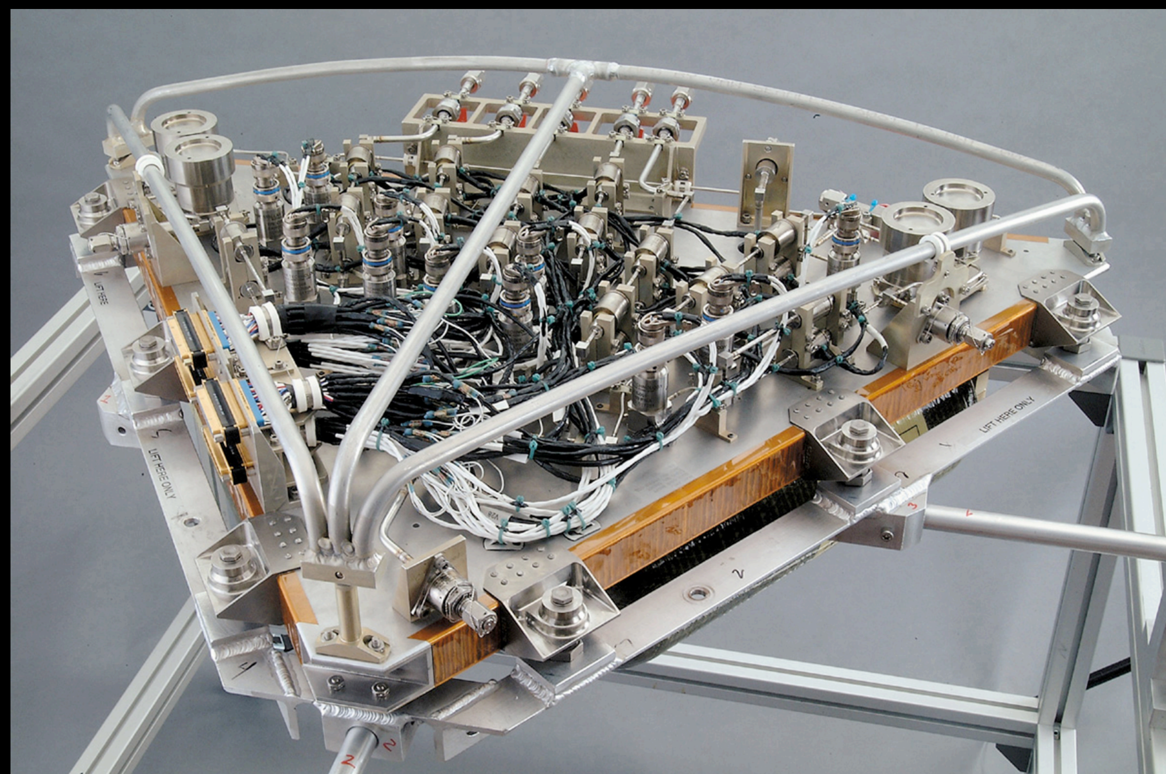


Solar arrays

Risk of Leaving ECU on Spacecraft As Is

✓ May not turn on and initialize science experiment

Mission Failure



Gas Management Assembly

Point of View #1

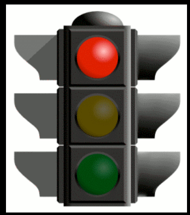
"I was fairly comfortable that the ECU would work on orbit for the length of time (necessary)."

"I was confident that it would spin up the gyros, I was confident that we could succeed through the mission, and so I pushed hard that we should go ahead and fly."

"You run a risk anytime you take a box off, peer into it, and reintegrate it on the launch pad."

- Gaylord Green, Program Manager, Stanford University

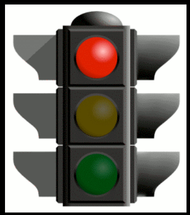
Point of View #2



“You couldn’t initialize the experiment without the ECU working. It only needed to work for a few months, but it did need to work. If the ECU failed initially when it got up on orbit, we wouldn’t have been able to initialize the science experiment and the whole mission would have been a failure.”

- Bill Reeve, Gravity Probe B Program Manager for Lockheed Martin

Point of View #3



"My chief worry was ECU reliability; the system had to function during the checkout phase of the mission or the mission would fail."

"Experience with other DC-to-DC converters (power supplies) of this type in other boxes showed them to be quite fragile when operated improperly."

- Bill Bencze, Electronics Manager, Stanford University

You Are the Program Manager

- What are the risks of removing the ECU?
  - Technical
  - Programmatic: schedule and cost
- What are the risks of not removing the box?
- What would *you* do?

What Happened?

The NASA Program Manager decided to pull the ECU.

What Did They Find?

"When we pulled the box, we actually found three other problems in the design."

- Bill Bencze, Electronics Manager, Stanford University

"I asked for an independent audit of all the circuits in the box, and I brought in electronics experts from around the country to come and have a review of every single circuit in the box. And I think they found 20-some issues."

- Bill Reeve, Gravity Probe B Program Manager for Lockheed Martin


April 20, 2004
NASA
GP-B

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