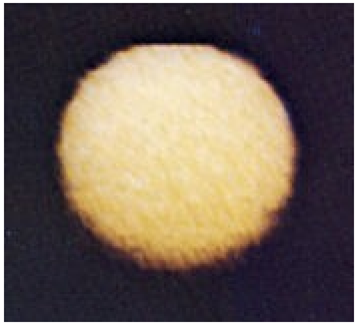
The Pioneer Anomaly (J-club 8/6/2012)

Mission: asteroid belt, Jupiter + Saturn (and their moons)

Pioneer 10 (1972)

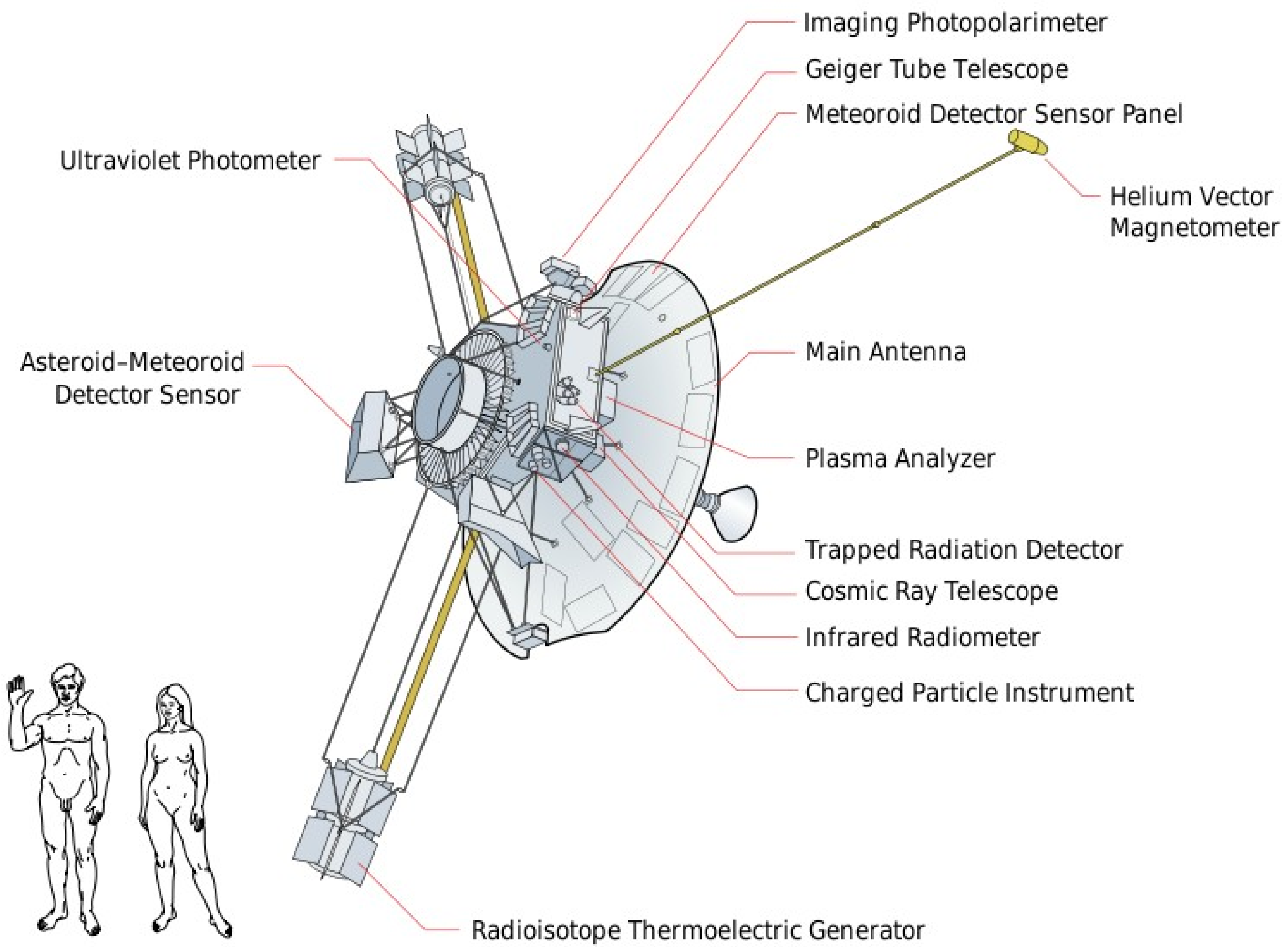
Ganymene (Jupiter's moon)

Pioneer 11 (1973)



Titan (Saturn's moon)

Pioneer 11 (1973)



Mission status

http://nssdc.gsfc.nasa.gov/nmc/

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Headquarters, Washington Feb. 25, 2003
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RELEASE: 03-082

PIONEER 10 SPACECRAFT SENDS LAST SIGNAL

After more than 30 years, it appears the venerable Pioneer 10 spacecraft has sent its last signal to Earth. Pioneer's last, very weak signal was received on Jan. 22, 2003.

NASA engineers report Pioneer 10's radioisotope power source has decayed, and it may not have enough power to send additional transmissions to Earth. NASA's Deep Space Network (DSN) did not detect a signal during the last contact attempt Feb. 7, 2003. The previous three contacts, including the Jan. 22 signal, were very faint with no telemetry received. The last time a Pioneer 10 contact returned telemetry data was April 27, 2002. NASA has no additional contact attempts planned for Pioneer 10.

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RELEASE: 95-163

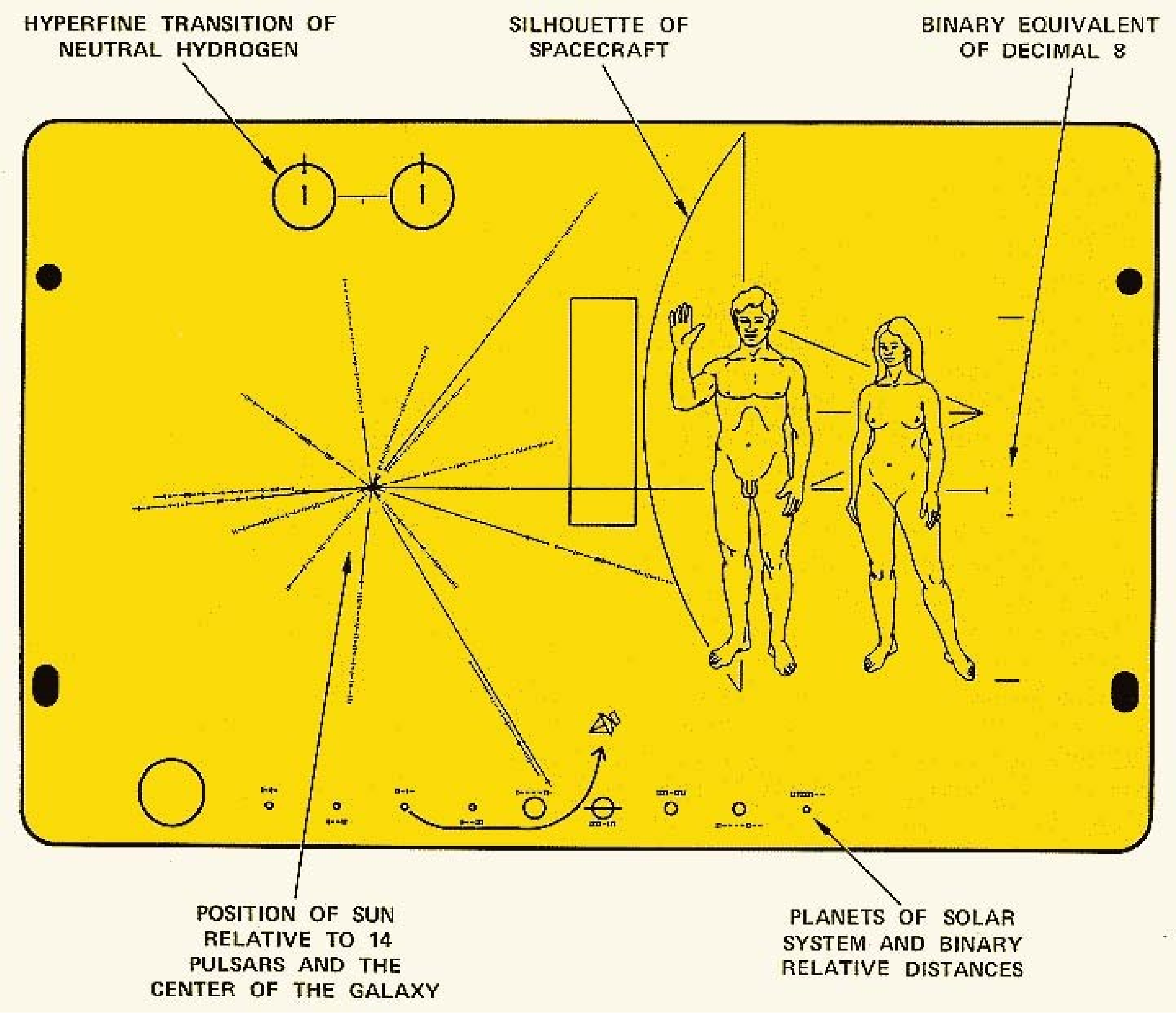
PIONEER 11 TO END OPERATIONS AFTER EPIC CAREER

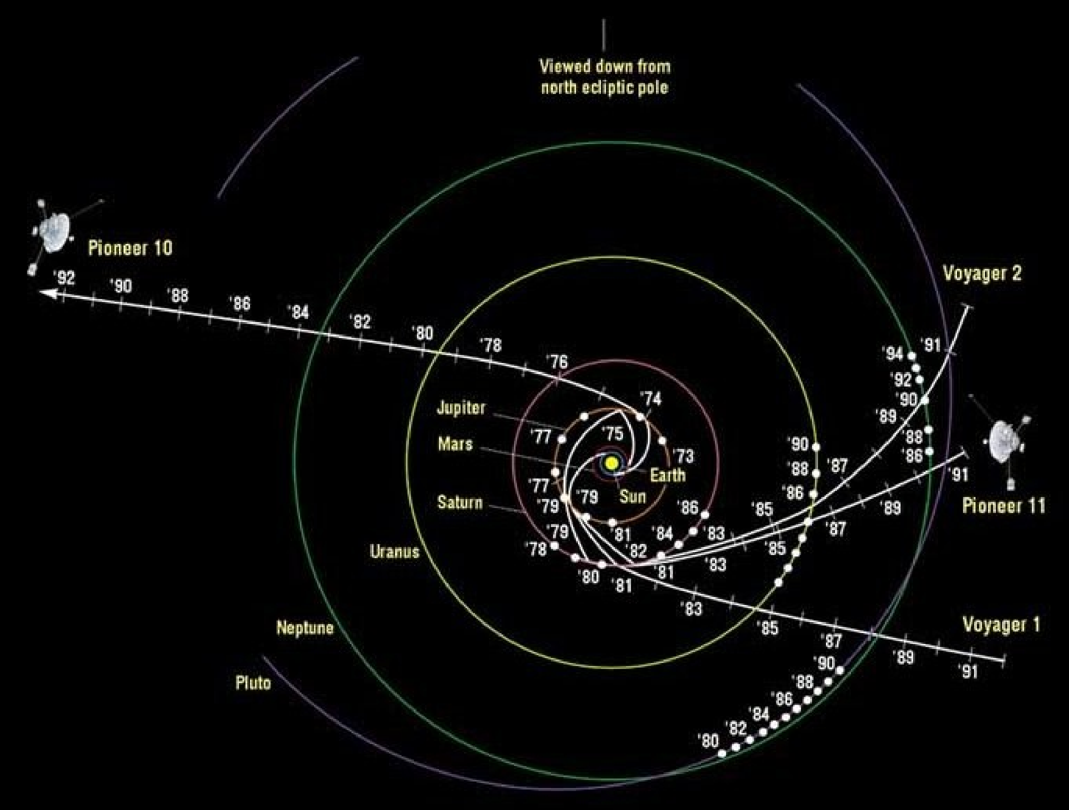
After nearly 22 years of exploration out to the farthest reaches of the Solar System, one of the most durable and productive space missions in history will come to a close.

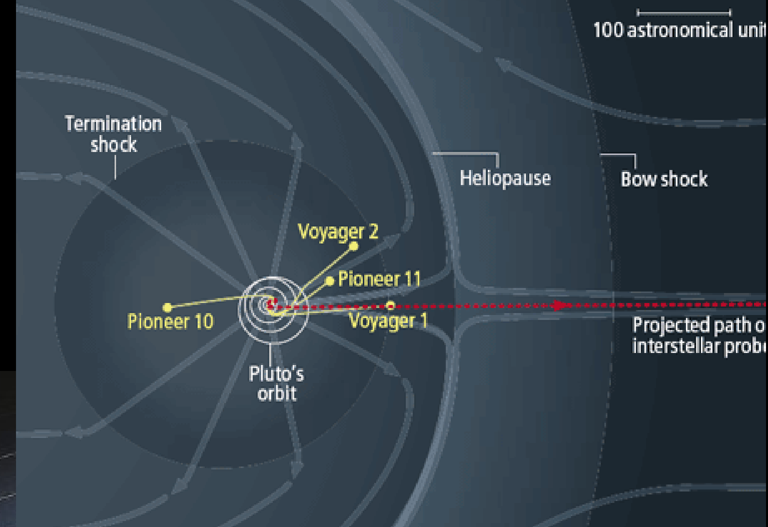
Now beyond the orbit of Pluto and more than four billion miles from Earth, NASA's unmanned Pioneer 11 spacecraft is heading out into interstellar space. Because the spacecraft's power is too low to operate its instruments and transmit data, on September 30 NASA will cease daily communications with the spacecraft. At that distance, faint signals from Pioneer 11 traveling at the speed of light take over six hours to reach Earth.

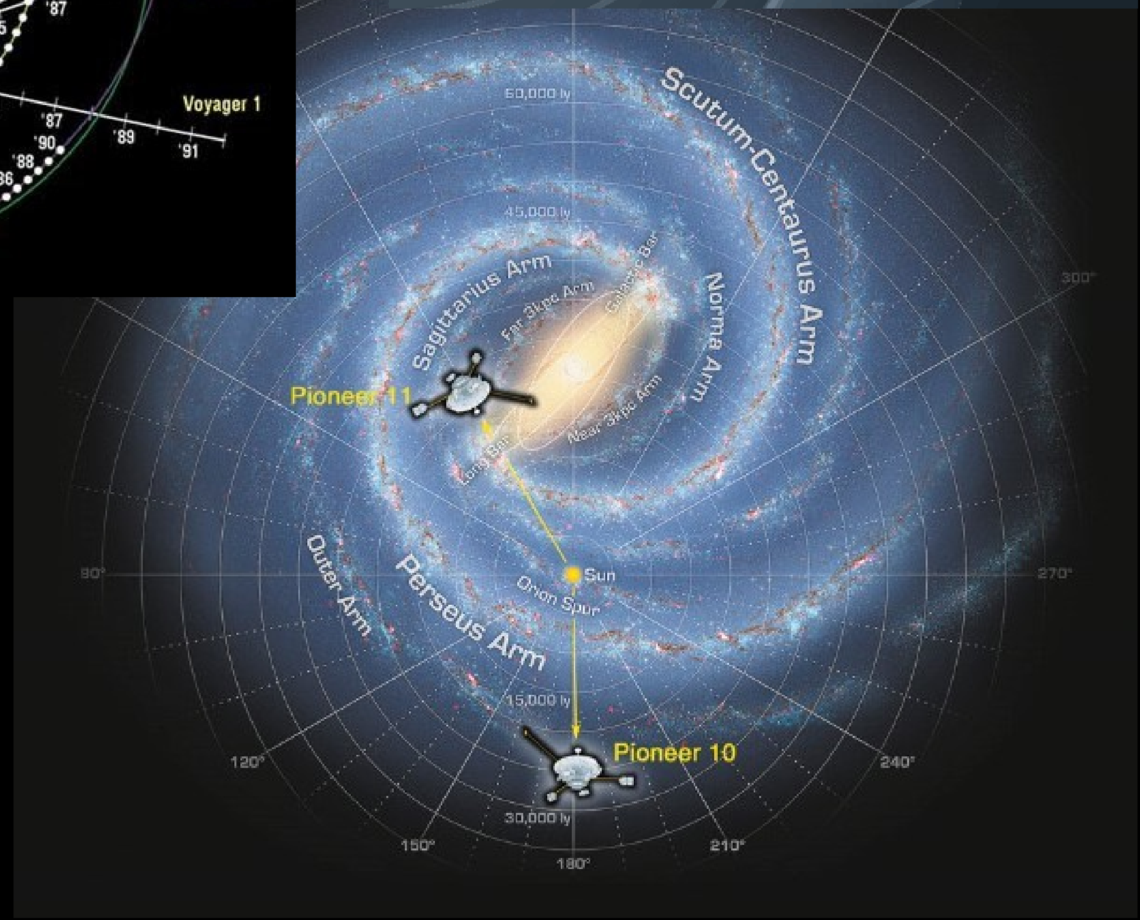
The spacecraft will continue speeding out into interstellar space toward the center of the Milky Way, taking an engraved gold plaque bearing a message about Earth to other civilizations which it may encounter. Pioneer 11 will pass near the star Lambda Aquila in almost four million years.

Pioneer 11


HYPERFINE TRANSITION OF NEUTRAL HYDROGEN
SILHOUETTE OF SPACECRAFT
BINARY EQUIVALENT OF DECIMAL 8
POSITION OF SUN RELATIVE TO 14 PULSARS AND THE CENTER OF THE GALAXY
PLANETS OF SOLAR SYSTEM AND BINARY RELATIVE DISTANCES


Viewed down from
north ecliptic pole
Pioneer 10
Voyager 2
Pioneer 11
Voyager 1
Jupiter
Mars
Earth
Sun
Saturn
Uranus
Neptune
Pluto


100 astronomical unit
Termination
shock
Heliopause
Bow shock
Voyager 2
Pioneer 11
Pioneer 10
Voyager 1
Pluto's
orbit
Projected path o
interstellar prob


Scutum-Centaurus Arm
Sagittarius Arm
Far 3kpc Arm
Galactic Bar
Norma Arm
Near 3kpc Arm
Long Bar
Pioneer 11
Sun
Orion Spur
Perseus Arm
Outer Arm
Pioneer 10
60,000 ly
45,000 ly
15,000 ly
30,000 ly
90°
120°
150°
180°
210°
240°
270°
300°

Anomalous acceleration first note circa 1980

arXiv:1107.2886

We considered three models for the anomalous acceleration — constant, linear and exponential — all applied along the nominal Earth-spacecraft line. The constant model has one parameter, a_P, representing a constant modeling error. The linear model,

$$a_P(t) = a_P(t_0) + (t - t_0)\dot{a}_P \tag{1}$$

contains a jerk term, $\dot{a}_P$. The exponential model,

$$a_P(t) = a_P(t_0)e^{-\beta(t-t_0)\ln 2} \tag{2}$$

decays with half life β^{-1}. This last model is physically motivated by a potential relation to the on-board power generators, which radioactively decay. The epoch is t_0 =January 1, 1972.

The rationale for an exponential model (2) is based on the possibility that the acceleration may be due to thermal recoil forces generated on-board. Due to degradation of the RTG thermocouples and changes in the thermal louver system [4], the resulting thermal recoil force could have a half-life significantly shorter than the 87.74 year half-life of the ^{238}Pu fuel [8], with 27 years being in the acceptable range.

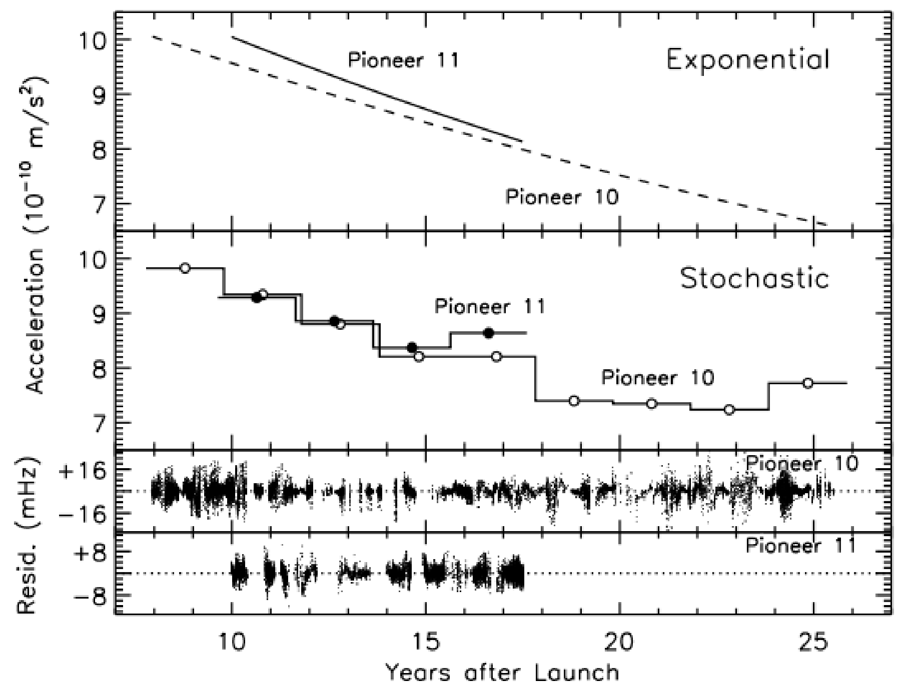


FIG. 1: *Top panel*: Estimates of the anomalous acceleration of Pioneer 10 (dashed line) and Pioneer 11 (solid line) using an exponential model. *Second panel*: Stochastic acceleration estimates for Pioneer 10 (open circles) and Pioneer 11 (filled circles), shown as step functions. *Bottom two panels*: Doppler residuals of the stochastic acceleration model. Note the difference in vertical scale for Pioneer 10 vs. Pioneer 11.

=> inconsistent with Newtonian gravity!

New physics origin?

- More than 200 papers (models?)
  - a path based speed loss driven by the externalisation of aggregate non-inertial QM energy
  - Chameleon effect
  - An Expanding Locally Anisotropic metric
  - Conformal Cosmology
  - General relativity with variable speed of light
  - Gravity in Brans-Dicke Theory with Born-Infeld Scalar Field
  - The Clifford Space Geometry
  - A rotating Gödel universe

=> New mission proposed...

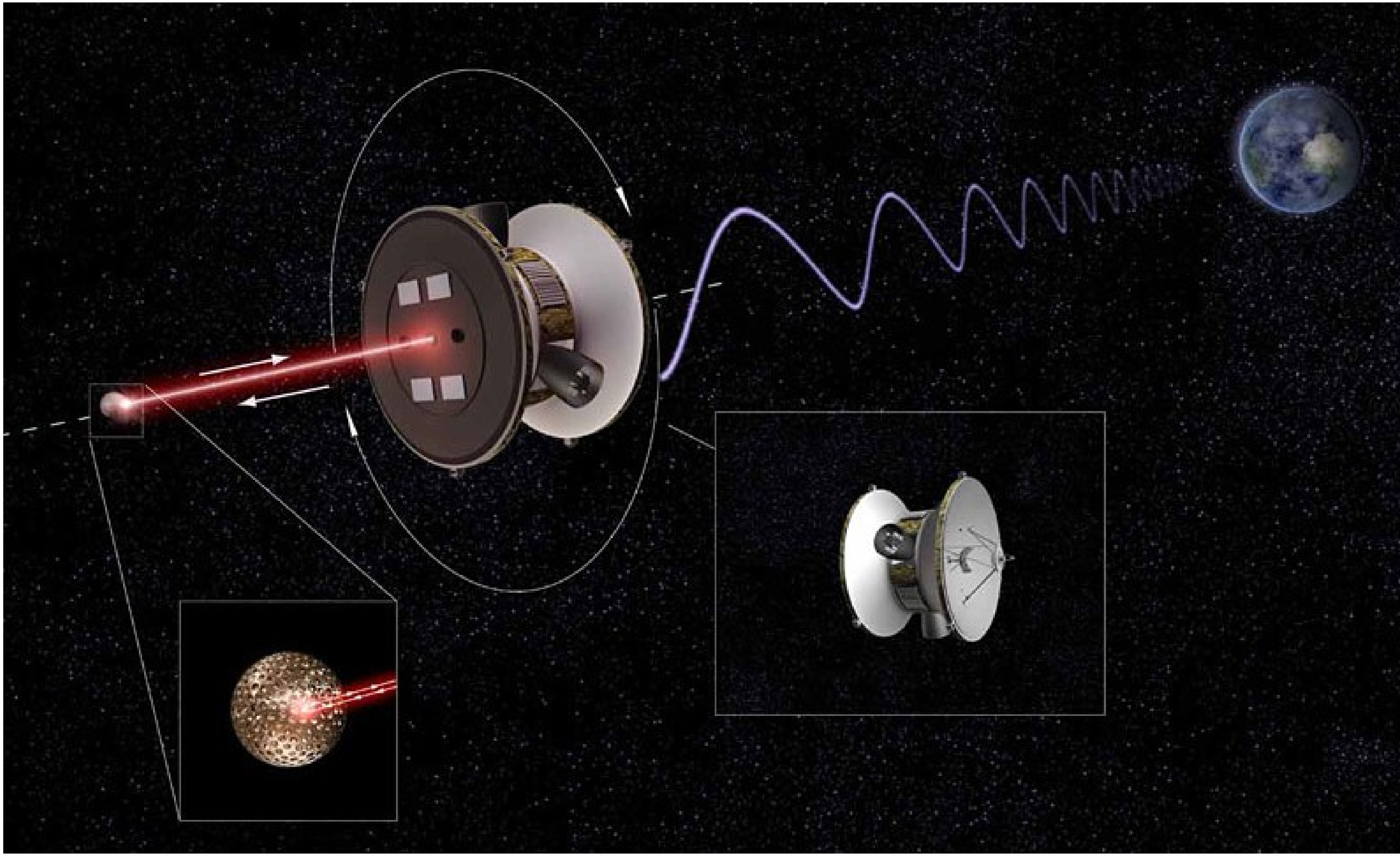


Figure 6.1: A drawing for the measurement concept chosen of the Deep Space Gravity Probe (from [106], drawing courtesy of Alexandre D. Szames). The formation-flying approach relies on actively controlled spacecraft and a set of passive test-masses. The main objective is to accurately determine the heliocentric motion of the test-mass by utilizing the 2-step tracking needed for common-mode noise rejection purposes. The trajectory of the spacecraft will be determined using standard methods of radiometric tracking, while the motion of the test mass relative to the spacecraft will be established by laser ranging technology. The test mass is at an environmentally quiet distance from the craft, ≥ 250 m. With occasional maneuvers to maintain formation, the concept establishes a flexible craft to test mass formation.

Thermal origin: the end of the story?

ArXiv:1107.2886 & 1204.2507

Finite-element thermal model (from blueprints)

A comprehensive finite-element (FE) thermal model (Fig. 1) of the Pioneer 10 and 11 spacecraft was constructed at the Jet Propulsion Laboratory (JPL) in collaboration with the Applied Sciences Laboratory (ASL). The geometric and thermal models of the spacecraft were constructed using the SINDA/3D thermal modeling software [15]. While the software provides the capability to build a numerical model directly from CAD drawing files, no such files exist for a spacecraft designed 40 years ago. For this reason, the model was built in a more tedious manner by specifying the coordinates of the vertices of each modeled spacecraft surface, using available blueprints and recovered project documentation. The spacecraft geometric model was built with a Monte Carlo based radiation analyzer (TSS) to calculate the radiative exchange factors using infrared emittance values for modeled surfaces specified within it. The model incorporated approximately 3,300 surface elements, 3,700 nodes, and 8,700 linear conductors. The spacecraft thermal-mechanical configuration is simulated by a network of thermal capacitance, conductive couplings, and radiative exchange factors between all surfaces and to deep space.

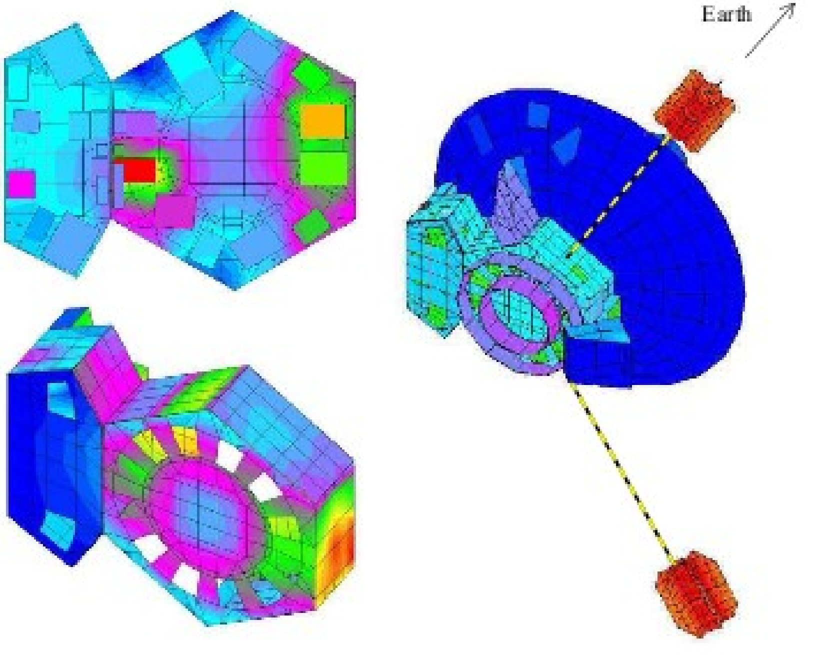


FIG. 1: Illustrative representation of the thermal model of the Pioneer 10 spacecraft evaluated at 40 AU. Top left: spacecraft body interior (temperature range: blue -16° C, red $+10^\circ$ C); Bottom left: spacecraft exterior (blue -155° C, red -108° C); Right: entire spacecraft (blue -213° C, red $+136^\circ$ C). Unmodeled struts that connect the RTGs to the spacecraft body are indicated with yellow-black dashed lines.

TABLE II: Error budget for the Pioneer 10 thermal model; the contributions shown in percentages, relative to a_P.

Description	Error
Other sources	$< 0.1\%$
Quantization error in telemetry data	2.2%
11 1-W radioisotope heater units	2.2%
Discrepancy in TWT telemetry	2.5%
Inaccuracy of geometric model[a]	5.0%
Modeling of instrument openings[b]	5.0%
Subtotal:	**8.1%**
RTG surface degradation	25.0%
TOTAL:	**26.3%**

[a]Assuming a fore-aft positional uncertainty of 2.5 cm.
[b]Heat escaping through instrument openings is ill-documented.

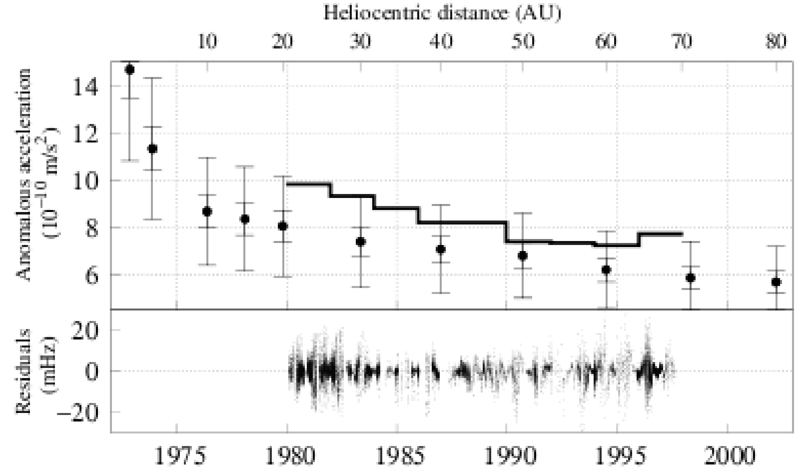


FIG. 3: Comparison of the thermally-induced and anomalous accelerations for Pioneer 10. The estimated thermal acceleration is shown with error bars. The stochastic acceleration estimate from [8] appears as a step function. For reference, the Doppler residuals of the stochastic acceleration are also shown in the bottom panel. Inner and outer error bars correspond to the subtotal and total shown in Table II.

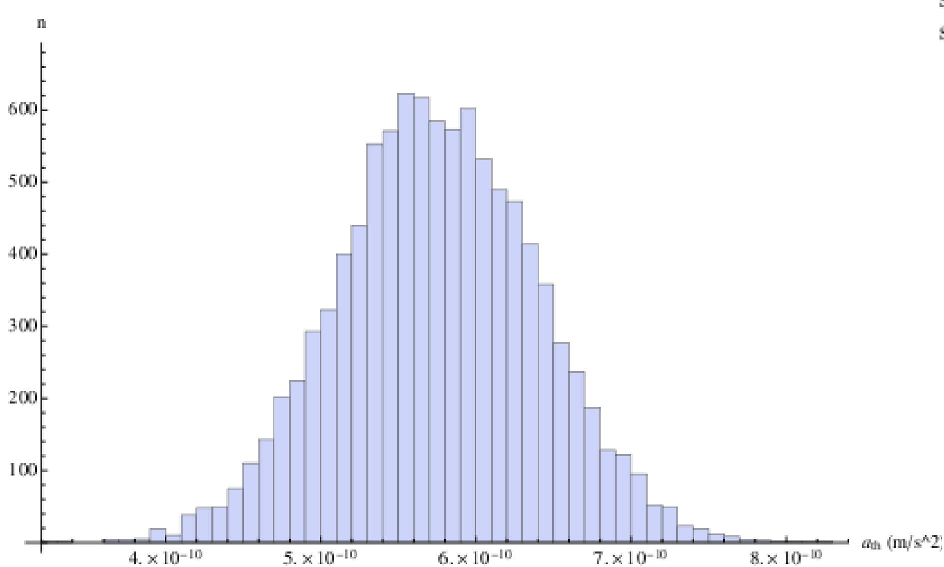
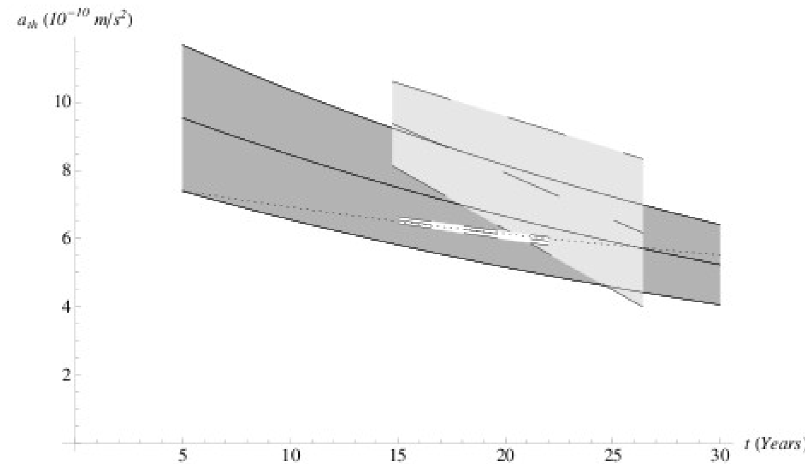


Figure 5: Histogram for the distribution resulting from the Monte Carlo simulation with 10000 iterations for the thermal acceleration of the spacecraft at $t = 26$ years after launch.



Time evolution of the thermal acceleration on the Pioneer spacecraft. The dotted line is the time extrapolation of the static analysis of the thermal acceleration and the dark grey area correspond to a 95% probability for the thermal acceleration in the time evolution analysis. Light grey area is based on results from the data analysis in Refs. [5] and [3], respectively.