AAS 02-042

American Astronautical Society

Credibility of GP-B's Gyroscopic Test of General Relativity (0.2 milliarcseconds per year)

Daniel DeBra, Bradford Parkinson, George Keiser, Francis Everitt, Sasha Buchman

Gravity Probe-B, Stanford University

25th ANNUAL AAS GUIDANCE AND CONTROL CONFERENCE

February 6-10, 2002
Breckenridge, Colorado

Sponsored by
Rocky Mountain Section

American Astronautical Society
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AAS Publications Office, P.O. Box 28130 - San Diego, California 92198

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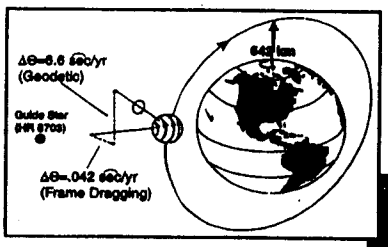
The Relativity Mission Concept
(Invented in 1959)



$$\vec{\Omega}=\left(\gamma+\frac{1}{2}\right)\frac{GM}{c^2R^3}(\vec{R}\times\vec{V})+\left(\gamma+1+\frac{\alpha_1}{4}\right)\frac{GI}{2c^2R^3}\left[\frac{3\vec{R}}{R^2}(\vec{R}\cdot\vec{R})-\vec{R}\right]$$

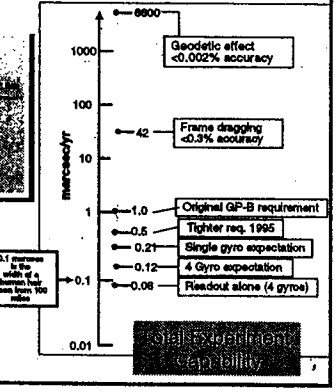
[redacted]

[redacted]

[redacted]

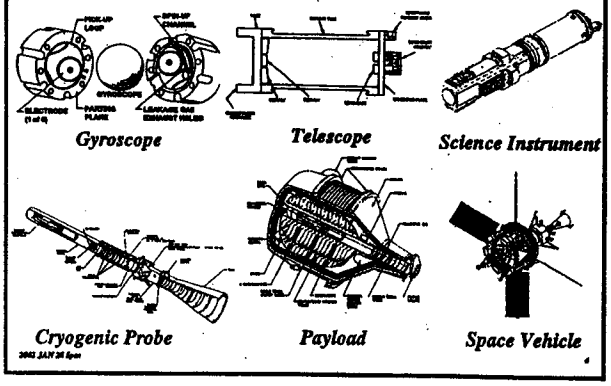
GP-B Performance

[redacted]



[redacted]

Main GP-B Systems

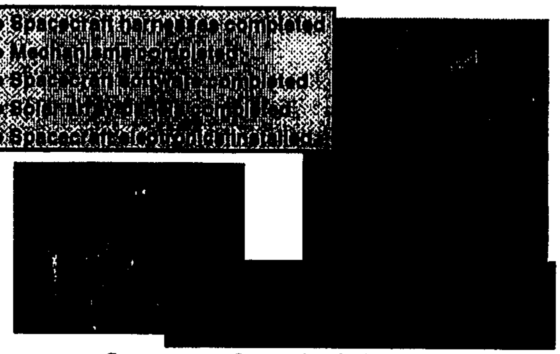


[redacted]

- Electrostatically suspended quartz gyroscopes with He gas spin-up (< 0.3 marcsec/yr drift)
- Telescope with cryogenic photo detector readout pointed at guide star HR 8703 (IM PEG) (<0.1 marcsec measurement, < 10 marcsec/√Hz pointing)
- Drag free satellite in 642 km polar orbit, rolling about line of sight by star ($<10^{-11}$ g, 5 mHz roll-rate)
- Cryogenic experiment 2 K superfluid helium (>16 month lifetime)
- London moment based readout with dc SQUID amplifiers (resolve 1 milliarcsecond in 10 hours)
- Superconducting magnetic shielding ($< 5\times10^{-7}$ G, $>10^{12}$ total ac attenuation)

Spacecraft Complete

- Spacecraft harness[illegible]completed
- Mechanisms [illegible]
- Spacecraft [illegible] completed
- Solar Arrays [illegible]
- Spacecraft [illegible] installed



Current status: Integration & Testing with Payload

[illegible]

- Error Analysis – dominant terms
- Simulation/verification
- Calibration of the guide star
- Calibration of telescope with aberration of starlight
- Measurement of "known quantities"
  - Bending of starlight
  - Parallax of guide star
- Deliberate, on-orbit stimulation of errors

Conceptual Approach

Minimize Newtonian Drift on Conventional Spherical Gyroscopes

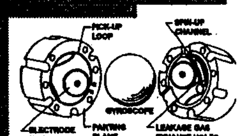
GYROSCOPE [illegible]

READOUT [illegible]

Gyroscopes

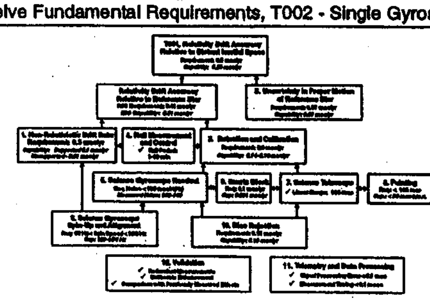
Gyro-only drift: < 0.02 marcsec/yr (non-supported gyro)
<0.09 marcsec/yr (supported gyro)

[illegible]



GP-B Error Tree
(Analysis [illegible])

Twelve Fundamental Requirements, T002 - Single Gyroscope

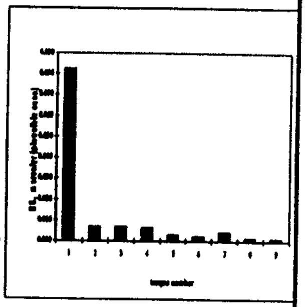


GEODETIC EFFECT: TOP NINE CLASSICAL DRIFT TERMS
(INCLUDES ALL TERMS > 0.001 MILLIARCSEC/YEAR)

A. SUPPORT-DEPENDENT TORQUES FROM TEMPERATURE VARIATIONS OF SUSPENSION ELECTRONICS AT SPACECRAFT ROLL-RATE (1,6,7,8,9)
- [illegible]

B. SUPPORT-DEPENDENT TORQUES FROM NON-TEMPERATURE-DEPENDENT MISALIGNMENTS/ MISCENTERING (3,4,5)
- [illegible]

C. SUPPORT-INDEPENDENT TORQUE (2)
- 2: London moment coupling to local magnetic shield – gyro axis misaligned with line of sight to star



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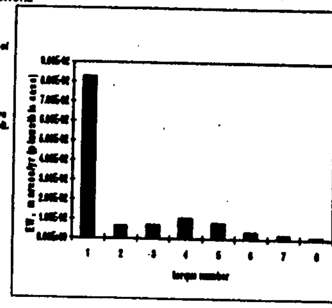
FRAME-DRAGGING EFFECT: TOP EIGHT CLASSICAL DRIFT TERMS
(INCLUDES ALL TERMS > 0.001 MILLIARCSEC/YEAR)

A. SUPPORT-DEPENDENT TORQUES FROM TEMPERATURE VARIATIONS OF SUSPENSION ELECTRONICS AT SPACECRAFT ROLL-RATE (1,5,7,8)
- [illegible]

B. SUPPORT-DEPENDENT TORQUES FROM NON-TEMPERATURE-DEPENDENT EFFECTS (3,4,6)
- [illegible]

C. SUPPORT-INDEPENDENT TORQUE (2)
- 2: London moment coupling to local magnetic shield – gyro axis misaligned with line of sight to star



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How can Gyro Drift be < 10^{-11} deg/hr ?

[illegible]

And: all fundamental parameters have been exhaustively ground calibrated

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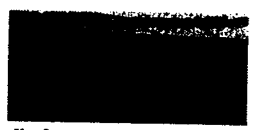
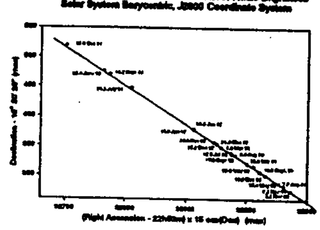
GP-B Guide Star HR 8703 (IM PEG)



Very Large Array, Socorro, New Mexico

- Optical and radio star
- Magnitude m_v = 5.69
- DE = 16.84 deg (close to equator)
- Proper motion calibrated by SAO using VLBI
- Expected accuracy by 2004 ~0.09 marcsec/yr



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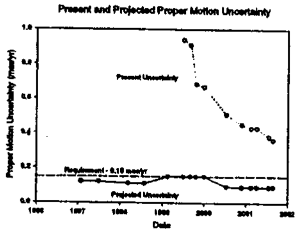
VLBI Measurements of Proper Motion of Guide Star by Harvard-Smithsonian Center for Astrophysics and York University

Each open circle represents the standard error of the proper motion at the estimated midpoint of the mission (1 September 2003) computed from position results available up to the date corresponding to the open circle.

Each filled circle represents the projected standard error of the proper motion at the midpoint of the mission (as that midpoint error was estimated at the date corresponding to the filled circle) computed from results then available plus an additional 4 VLBI position measurements per year through the estimated end of the mission (April 2004).



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Cosmic radiation effects on gyroscopes
(20 g/cm² Al equivalent shielding)

CHARGING
- Charging rate ≤ 10^{-19} A
- Max. allowed charge ≤ 2×10^{-11} C
- SOLUTION UV photoemission charge control Force modulation charge measurement

HEATING
- Heating rate ≤ 1 nW
- Max. allowed heating ≤ 2 nW
- SOLUTION None needed. Quartz heat capacity sufficient.

TORQUES
- Radiation torque << 10^{-19} N-m
- Max. allowed torque ≤ 5×10^{-18} N-m
- SOLUTION None needed

FLUX MOTION IN GYROSCOPE COATING
- Flux jumps ≤ 5/year (≤ 0.1 μm)
- Max. allowed ≤ 100/year (≤ 0.1 μm)
- SOLUTION None needed

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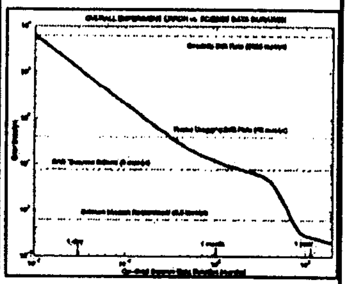
GP-B Mission Timeline

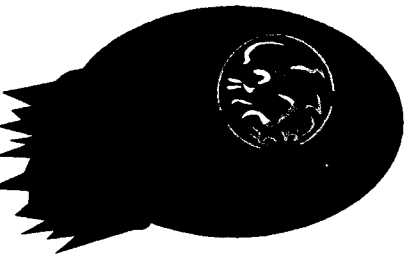


GP-B *Gyro Data* is Credible if:

Comparison with GR is credible if:

- Orbit positioning accuracy is consistent with calculation of GR effects (use three techniques)
- GI is known to 10^{-4} (believed to be 10^{-5})
- GM is known to 10^{-6} (believed to be [illegible])

In Summary



Analytical Engineering

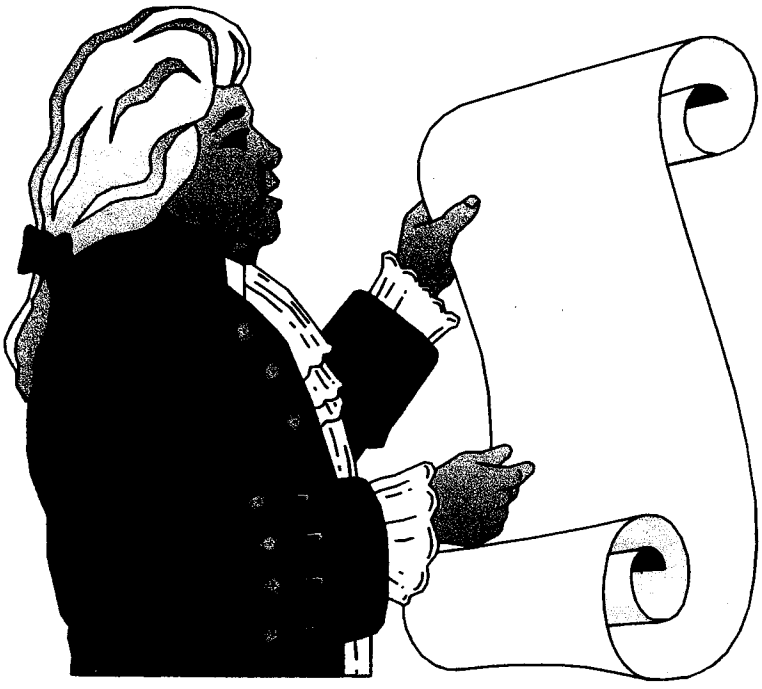
Presents the 5th Annual

Procrustian Prize

2002 Winner:

Profs. Daniel B. DeBra & Bradford W. Parkinson

"Gravity Probe B"



"There's no rule requiring you to squeeze all your results into your title"

Date: Fri, 15 Feb 2002 11:56:08 -0800
To: Noriko Low <lowno@relgyro.stanford.edu>
From: Ken Bower <bower@relgyro.stanford.edu>
Subject: Re: 2002 Procrustian Prize to Prof DeBra & Parkinson

Noriko,

Could it be the Proc_r_ustian Prize they received? (Procrustes was character in Greek mythology who invited travellers to stay in his bed and then modified their legs to fit it.)

Ken

> Dave Sonnabend of Analytical Engineering presented the 5th Annual **PROCUSTIAN PRIZE** to Profs DeBra and Parkinson for their storyboard presentation at the AAS Breckenridge 25th G&C Conference (which Dr. Debra co-founded). "There's no rule requiring you to squeeze all your results into your title" Their title: Credibility of GP-Bís Gyroscopic Test of General Relativity (0.2 milliarcseconds per year) *Daniel DeBra, Bradford Parkinson, George Keiser, Francis Everitt, Sasha Buchman Gravity Probe-B, Stanford University* Certificate is on display in my cubicle. I understand the presentation went very well. They did not come back with any copies. Thanks Noriko Noriko Low Executive Assistant GPB/HEPL Stanford University Stanford, CA 94305-4085 lowno@relgyro.stanford.edu 650-725-7429 650-725-9167 fax **********