GP-B Experiment Error: A Work in Progress

B. Muhlfelder, G.M. Keiser, and J. Turneaure

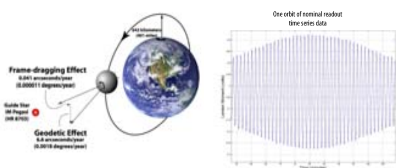
Overview

Experiment error status: 1σ limit: 100 marcsec/yr

Pre-launch expectation: Three main error sources
- Torque induced gyro drift ~ 0.1 marcsec/yr
  - Gyro mass & shape tightly controlled
  - Support force minimized with drag free
    - Magnetic forces, gas damping controlled
- Gyro readout errors ~ 0.1 marcsec/yr
  - dc SQUIDs to reduce stochastic error
  - Thermal & magnetic control to limit systematics
- Guide star proper motion error ~ 0.1 marcsec/yr
  - SAO VLBI provides precision measurements

Total pre-launch error: ≤ 0.5 marcsec/yr

Experiment Concept



Post-launch Findings

Most systems met pre-launch plan:
- Gyro shape, mass properties < ground limit
- Gyro position stability met spec
- Drag free control system worked properly
- SQUID sensor met spec (3 out of 4 systems)
- Telescope readout met spec
- Data timing accuracy to 0.002 seconds
- Roll phase uncertainty met spec
- Magnetic fields met spec (achieved 3 μG)
- Minimal gyro gas damping: $\tau_{gyro\ spindown}$ ~ 26,400 yr
- Orbit determination met spec

Gyroscope

SQUID

Above give error ≤ 0.5 marcsec/yr

Telescope

Two requirements were not met:
- Gyro torques
- Gyro readout EMI effects

Quantifying the Error

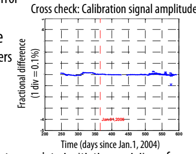
Sensitivity Analysis
- Intentionally degrade data for one parameter
- Perform full mission analysis with degraded data
- Compare degraded relativity result to original
- Difference provides experiment error for parameter

Gyro to gyro consistency
- Consistency increases confidence in result
- Combining consistent results decreases error

Internal cross checks build confidence
- Stability of measured reference parameters

Error tree to track/organize effort

Cross check: Calibration signal amplitude



Definition: The residual relativity uncertainty associated with the modeling of a systematic effect is the systematic error of that effect.

Gyro Torques (I)

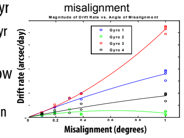
Misalignment torque: Torque proportional to angle subtended by SV roll axis and gyro spin axis

Cause: Interaction of patch fields on rotor and casing

Induced drift rate ~0.1 to 1.0 arcsec/yr

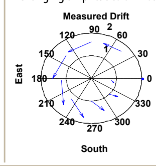
Require > 99 % removal for 10^{-3} arcsec/yr

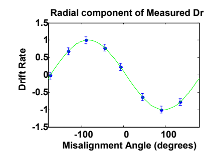
Measured drift rate vs. misalignment



Misalignment torque: direction is know
- Mitigation: phase sensitive detection
- measure relativity in orthogonal direction

Error in resulting mitigated drift:
- Uncertainty in torque direction: gives 4 marcsec/yr
- Changing amplitudes of misalignment, torque coefficient





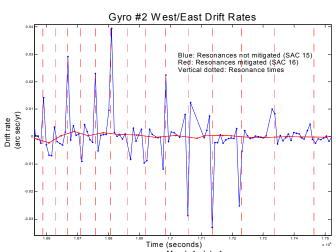
Current Limits on Experiment Error

Error Source	Current Error (marcsec/yr)	Mitigation
Current error including resonance observation	100	Improved modeling
EMI effects	5	Data grading & noise removal
Misalignment patch-effect torque	4 *	Improved misalign-ment model
Polhode frequency error (Cg)	2.5	Trapped flux mapping.
Roll phase uncertainty	< 1	None required
Other known torques	< 1	None required
Telescope nonlinearity	< 1	None required
Time tagging uncertainty	< 1	None required
SQUID thermal sensitivity	< 1	None required
SRE circuit issues (multi)	< 1	None required
Guide star proper motion	< 1	None required

* contribution from misalignment uncertainty only

Gyro Torques (II)

Resonance-correlated observation
- Cause may be related to patch effect fields
- Observation present when $f_{roll} = N f_{polhode}$ where N is an integer



Impact on experiment error 100 marcsec/yr

Error obtained by performing sensitivity tests when the resonance width is varied
- Some of above error may be due to data selection process

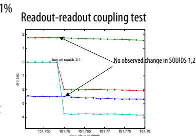
Non-roll averaged patch torque

Other torques: Support dependent & indep. < 1 marcsec/yr

Gyroscope Readout

Investigated the following effects:
- Space vehicle EMI
  - Turned off offending EMI emmitter
    - Prior to turn off gives 5 marcsec/yr error impact
- Polhode frequency sensitivity
  - Determined polhode frequency to ~ 0.01%
  - Gives 2.5 marcsec/yr error impact
- Readout to readout coupling
  - Gyro-gyro coupling < 0.04%
  - Gives < 1 marcsec/yr error impact
- Thermal sensitivity
  - 1-2 % of data removed to mitigate effect
- Preferred A/D codes
  - Effect < 1 code out in 16 bit converter
- Dynamic range
  - No science data limited by system dynamic range

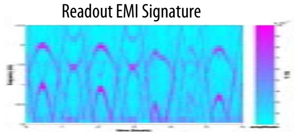
Readout-readout coupling test



Also evaluated:
- Signal aliasing, open loop gain limitations, gyro position sensitivity

Current readout impact on experiment error ~ 5 marcsec/yr

Readout EMI Signature

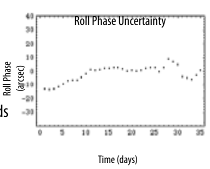


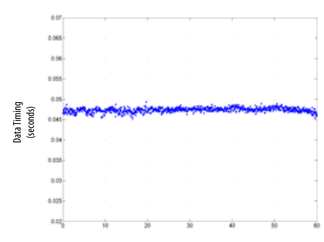
Telescope, Roll Phase, Timing

Telescope: Provides vehicle inertial pointing information
- Telescope uncertainty causes relativity error
  - 0.5 % scale factor uncertainty
  - 3 % nonlinear term uncertainty
- Impact on error < 1 marcsec/yr

Roll phase: Known to < 10 arcsec
- Impact on error < 1 marcsec/yr

Timing: known to < 0.002 seconds
- Impact on error < 1 marcsec/yr





Next Steps

Driving Down Experiment Error
- Improved resonance and non-roll averaged torque modeling
- More complete removal of EMI from data
- Update misalignment analysis
- Continue investigation of systematic effects

Use flux mapping to reduce scale factor error and increase integration durations

Pre-launch single integration of t duration mission

$\delta\Omega_{single}$ proportional to $t^{-3/2}$

Current status: N sub-mission length integrations

$\delta\Omega_{multiple}$ proportional to $N\ \delta\Omega_{single}$

Confident of significant reduction in experiment error from current 50-100 marcsec/yr value

W. W. Hansen Experimental Physics Laboratory • Stanford University, Stanford, CA 94305-4085 • http://einstein.stanford.edu

This research supported by NASA on contract NAS8-39225